MANAGEMENT AND CONTROL OF MANUFACTURING PROCESSES

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Introduction

Reliability parameters in a production process depend on occurrence of disturbances that cause changes in a basic schedule. The basic schedule becomes unrealizable after the disturbances have appeared. Any event which is possible to forecast should be planned in the basic schedule. The more changes in the basic schedule are the lower robustness of the schedule is [10]. Cost of reorganization of the production schedule increases and time is wasted.

A method for elaborating the robust basic schedule is searched. Analysis of historical data of a machine failures frequency, a number of the machine failures and data acquisition for forecasting a future time of the machine failure are essential for elaborating the robust schedule. In the literature the machine failure and repair are described by: mean time between the machine failures and mean time of repair [5].

In literature there are two most common ways for data acquisition for a parameter value forecasting. The first one uses a fuzzy logic to estimate stochastic parameters and calculate probability of its appearance. The example of using the fuzzy logic to estimate the parameters of a time of a material deficiency and a time of the material deliver is in [4]. The second one uses theory of probability to forecast a value of the parameter under the constrain that a trend based on historical value of the parameter is possible to notice. An example of using normal, exponential, triangular distributions for both failure and repair times is in [5].

In the paper the time of the machine failure is forecasted using the probability theory. Following measures used to describe failure of the machine are computed: Mean Time Between Failures (MTBF), Mean Time To First Failure (MTTFF), the probability of occurrence at least one failure in a time period. The frequency of the machine failure is described by Weibull distribution as it describes changing probability of failure with time [7]. Time of the machine‘s repair is described by exponential distribution as it has been assumed that the repair time does not depend on time of previous repairing works of the machine [7].

Basing on literature review the paper is the answer for the need of searching for methods of Weibull characteristics estimating. The problems of complementarities and reliability of historical data appear. The goal is to find a method that gives reliable values of Weibull characteristics that are basic to reach the robust schedule.

A production scheduling model of failures

A production scheduling model of failures is considered in that successive failure-free times are supposed to have Weibull distributions and are followed by exponentially distributed times of repairs. It is assumed that parameters of these distributions, in general, change with time. Basing on information about the number of failures and failure-free times in a number of periods of the same duration in the past predictions of the reliability characteristics are searched.

Let us consider a classical model of failures in that successive periods of reliable work of a production system are followed by times of repair. Such the system, firstly, is observed on m successive time periods

$$[0,T),[T,2T),\dots,[(m-1)T,mT) \tag{1}$$

of the same durations, for which the information about numbers of detected failures or failure-free times is known. The prediction of system behavior is being built for the next period $[mT,(m+1)T)$. We assume that failure-free times $X_{i,1},\dots,X_{i,N_i}$ in the ith period $[(i-1)T,iT),\ i=1,\dots,m+1$ have Weibull distribution with PDF (=probability density function) $f_i(\cdot)$ of the form

$$f_i(t)=\begin{cases}\lambda_i p_i t^{p_i-1}\exp\left(-\lambda_i t^{p_i}\right), & t>0,\\ 0, & t\le 0,\end{cases} \tag{2}$$

where $p_i>0,\ \lambda_i>0,$ thus parameters of the distribution depend on the number of period and are the same in each period separately. Here N_i denotes a random number of failures detected in $[(i-1)T,iT)$. As it is well known [7]:

$$EX_{i,k}=\left(\frac{1}{\lambda_i}\right)^{1/p_i}\Gamma\left(\frac{1}{p_i}+1\right), \tag{3}$$

$$EX_{i,k}^2=\left(\frac{1}{\lambda_i}\right)^{2/p_i}\Gamma\left(\frac{2}{p_i}+1\right), \tag{4}$$

where:
$k = 1,...,N_i$,
$EX_{i,k}$ - mean value of $X_{i,k}$,
$EX_{i,k}^2$ - second moment of $X_{i,k}$.

At the end of reliable work period $X_{i,k}$, as the failure occurs, a repair time $Y_{i,k}$ begins immediately and so on. Repair times $Y_{i,1},...,Y_{i,N_i}$ for $i = 1,...,m+1$ are supposed to be exponentially distributed with PDFs $g_i(\cdot)$ of the form:

$$g_i(t) = \begin{cases} \alpha_i \exp(-\alpha_i t), & t > 0, \\ 0, & t \le 0, \end{cases} \tag{5}$$

As it is well known [7]:

$$EY_{i,k} = \frac{1}{\alpha_i}, \tag{6}$$

$$D^2 Y_{i,k} = \alpha_i^{-2}, \tag{7}$$

where:
$\alpha_i > 0$ is known for $i = 1,...,m+1$,
$EY_{i,k}$ - the mean value of $Y_{i,k}$,
$D^2 Y_{i,k}$ - the second moment of $Y_{i,k}$.

We take certain simplifying assumption that each new period of the form $[(i-1)T, iT)$, starts with the beginning of reliable work $X_{i,1}$, in other words we “delete” the residual repair time Y_{i-1,N_i} in the *i*th period $[(i-1)T, iT)$. Thus, we can write

$$\sum_{k=1}^{N_i} Z_{i,k} = \sum_{k=1}^{N_i} \left(X_{i,k} + Y_{i,k} \right) \approx T, \quad i = 1,...,m+1. \tag{8}$$

Random variables $X_{i,k}$, $Y_{i,k}$, for $i=1,...,m+1$ and $k=1,...,N_i$ are supposed to be totally independent. So, the evolution of the system can be observed on successive cycles $Z_{i,k}=X_{i,k}+Y_{i,k}$, $i=1,...,m+1$, $k=1,...,N_i$ which are independent random variables with PDFs defined as follows:

$$h_i(t)=\int_0^t f_i(t-y)g_i(y)dy=\int_0^t g_i(t-y)f_i(y)dy= \\ =\alpha_i\lambda_i p_i e^{-\alpha_i t}\int_0^t y^{p_i-1}e^{\alpha_i y-\lambda_i y^{p_i}}dy,\ \ t>0 \tag{9}$$

and DFs (=distribution functions) of the form

$$H_i(t)=\int_0^t h_i(y)dy=\alpha_i\lambda_i p_i\int_0^t e^{-\alpha_i y}\int_0^y x^{p_i-1}e^{\alpha_i x-\lambda_i x^{p_i}}dxdy,\ \ t>0\,. \tag{10}$$

Maximum likelihood approach

This approach is based on the assumption that numbers and durations of successive error-free periods have been measured and are known. Suppose that in each of intervals $[0,T),[T,2T),...,[(m-1)T,mT)$ we have given sample values of random variables $X_{i,k}$, $k=1,...,N_i$ for any $i=1,...,m$, where n_i is the observed value of N_i, so we have the following observations:

$$(x_{1,1},\ \ x_{1,2},\ ...,x_{1,n_1}),...,(x_{m,1},\ \ x_{m,2},\ ...,x_{m,n_m}). \tag{11}$$

Consider firstly the interval $[0,T)$. Since $x_{1,1}$, $x_{1,2}$, ..., x_{1,n_1} are i.i.d. (independent and identically distributed) random variables we can apply the Maximum Likelihood Principle to estimate unknown parameters λ_1, p_1 of Weibull distribution. Define the likelihood function as follows:

$$L(\lambda_1,p_1|x_{1,1},\ \ x_{1,2}\ ...,x_{1,n_1})=\prod_{k=1}^{n_1}f_1(x_{1,k})=\prod_{k=1}^{n_1}\lambda_1 p_1 x_{1,k}^{p_1-1}e^{-\lambda_1 x_{1,k}^{p_1}}\,. \tag{12}$$

Logarithming (12) and differentiating on variables λ_1 and p_1 we obtain the following system of normal equations:

$$\frac{\partial \ln L}{\partial \lambda_1} = \frac{n_1}{\lambda_1} - \sum_{k=1}^{n_1} x_{1,k}^{p_1} = 0,$$
$$\frac{\partial \ln L}{\partial p_1} = \frac{n_1}{p_1} + \sum_{k=1}^{n_1} \ln x_{1,k} - \lambda_1 \sum_{k=1}^{n_1} x_{1,k}^{p_1} \ln x_{1,k} = 0. \tag{13}$$

Eliminating parameter λ_1 from these two equations we get the following condition for p_1:

$$\frac{n_1}{\sum_{k=1}^{n_1} x_{1,k}^{p_1}} = \frac{1}{\sum_{k=1}^{n_1} x_{1,k}^{p_1} \ln x_{1,k}} \left(\frac{n_1}{p_1} + \sum_{k=1}^{n_1} \ln x_{1,k} \right), \tag{14}$$

and hence we get

$$n \sum_{k=1}^{n_1} x_{1,k}^{p_1} \ln x_{1,k} - \left(\frac{n_1}{p_1} + \sum_{k=1}^{n_1} \ln x_{1,k} \right) \sum_{k=1}^{n_1} x_{1,k}^{p_1} = 0. \tag{15}$$

Now, having $\hat{p}_1$, we find the Maximum Likelihood estimator for λ_1 just from the first equation in (13):

$$\hat{\lambda}_1 = \frac{n_1}{\sum_{k=1}^{n_1} x_{1k}^{\hat{p}_1}}. \tag{16}$$

The problem of estimation parameters of Weibull distribution was investigated in [3] where, among others, the problem of estimation in the case where not all values $x_{1,k}$, $k = 1,\dots,n_i$ are known but e.g. we know $x_{1,1}$, $x_{1,2}$, ..., $x_{1,nd}$ where $d < n_1$ and n_1 is known. Such an estimation is also significant from the practical point of view: a permanent observation is often difficult to execute or is expensive.

After finding estimators $\hat{p}_1,\dots,\hat{p}_m$ and $\hat{\lambda}_1,\dots,\hat{\lambda}_m$ we can extrapolate values $\hat{p}_{m+1}$ and $\hat{\lambda}_{m+1}$ for the period $[mT,(m+1)T)$ for which we have no observation, using the regression method.

Empirical moments approach

Suppose that we have given sample values $x_{1,1}$, $x_{1,2}$, $\dots, x_{1,n_1}$ for period $[0,T)$ as in the previous section. Introduce sample mean and the second moment as follows:

$$m_1(x_1) = \bar{x}_1 = \frac{1}{n_1}\sum_{k=1}^{n_1} x_{1,k}\ ,\ m_2(x_1) = \frac{1}{n_1}\sum_{k=1}^{n_1} x_{1,k}^2\ . \tag{17}$$

Comparing empirical moments to theoretical ones (see (3)-(4)) we obtain the following system of equations:

$$m_1(x_1) = a_1\Gamma\left(\frac{1}{p_1}+1\right), m_2(x_1) = a_1^2\Gamma\left(\frac{2}{p_1}+1\right) \tag{18}$$

where:

$a_1 = \left(\frac{1}{\lambda_1}\right)^{1/p_1}$. Hence we get

$$\frac{\Gamma^2\left(\frac{1}{p_1}+1\right)}{\Gamma\left(\frac{2}{p_1}+1\right)} = \frac{m_1^2(x_1)}{m_2(x_1)} \tag{19}$$

Of course, the exact value of p_1 is impossible to obtain just from the above equation. We are forced to use one of methods of approximation Gamma function. Different-type approximations can be found e.g. in [1], [2] and [8]. The main problem is that these approximations lead to the implicit equation for p. Here we use the classical method of Stirling series which leads to the following result (see e.g. [8]):

$$\Gamma(x+1) \approx x^{x+\frac{1}{2}} e^{-x} e^{\frac{1}{2}\ln 2\pi},\ \ x \to \infty . \tag{20}$$

Using such an approximation makes it necessary to impose restrictions for p_1: p_1 should be small to make $\frac{1}{p_1}$ sufficiently large. So, assuming that $p_1 << 1$, from (19) we obtain

$$\frac{\left[\left(\frac{1}{p_1}\right)^{\frac{1}{p_1}+\frac{1}{2}} e^{-\frac{1}{p_1}+\frac{1}{2}\ln 2\pi}\right]^2}{\left(\frac{2}{p_1}\right)^{\frac{2}{p_1}+\frac{1}{2}} e^{-\frac{2}{p_1}+\frac{1}{2}\ln 2\pi}} = \frac{1}{\sqrt{2p_1}} \cdot \left(\frac{1}{2}\right)^{\frac{2}{p_1}} \cdot \sqrt{2\pi} = \sqrt{\frac{\pi}{p_1}} \cdot \left(\frac{1}{4}\right)^{\frac{1}{p_1}} = \frac{m_1^2(x_1)}{m_2(x_1)} \cdot \quad (21)$$

Now, observing the behavior of the function $T(x) = \sqrt{\frac{\pi}{x}} \cdot \left(\frac{1}{4}\right)^{\frac{1}{x}}$ for fixed value $T_0 = \frac{m_1^2(x_1)}{m_2(x_1)}$, we can find an approximate value $\hat{p}_1$ of p_1 with the required precision. Having $\hat{p}_1$ we get $\hat{\lambda}_1 = \left[m_1(x_1) \middle/ \Gamma\left(\frac{1}{\hat{p}_1}+1\right)\right]^{-\hat{p}_1}$.

The same procedure we apply in the case of next intervals of type $[iT,(i+1)T)$, $i = 1,\dots,m-1$. Having estimators $\hat{p}_1,\dots,\hat{p}_m$ and $\hat{\lambda}_1,\dots,\hat{\lambda}_m$ we build the predictions $\hat{p}_{m+1}$ and $\hat{\lambda}_{m+1}$ using the regression.

Renewal-theory approach

The last proposed method is based on the renewal theory. Recall that if $\xi_1,\xi_2,\dots$ are nonnegative and independent random variables with the same distribution function *B*(*t*)*;* then the following stochastic process:

$$\nu(t) = \max\left\{ n \in N : \sum_{i=1}^{n} \xi_i < t \right\}, \quad t \geq 0 \qquad (22)$$

is called a *renewal process* generated by random variables $\xi_1,\xi_2,\dots$ with *renewal moments* $t_n = \sum_{i=1}^{n} \xi_i$, $n = 1,2,\dots$.

It is easy to note that the value $\nu(t)$, at fixed moment *t*, is equal to the maximum number of random variables ξ_i which sum does not exceed *t*.

Let us consider time period $[0,T)$ in that a random number N_1 of failures was observed. Since random variables Z_1, Z_2, ...,Z_{N_1} denoting successive work cycles (consisting of failure-free times followed by repair times) are nonnegative and independent and have the same distribution function $H_1(t)$, then they form a renewal process $\nu(t)$ and besides, in particular, $\nu(T)=N_1$.

From the properties of renewal process (see e.g. [6]) follows that the first and the second moments of $\nu(t)$ can be expressed by means of convolutions of distribution function $H_1(t)$. Indeed, we have

$$E\nu(t)=\sum_{n=1}^{\infty} H_1^{n*}(t), \tag{23}$$

$$E\nu^2(t)=2\sum_{n=1}^{\infty} nH_1^{n*}(t)-\sum_{n=1}^{\infty} H_1^{n*}(t), \tag{24}$$

where successive convolutions $H_1^{n*}(t)$ are defined as follows:

$$H_1^{1*}(t)=H_1(t),\ \ H_1^{n*}(t)=\int_0^t H_1^{(n-1)*}(t-y)dH_1(y),\ \ n\geq 2. \tag{25}$$

Introduce Laplace-Stieltjes transforms of appropriate functions in the following way:

$$\Phi_1(s)=\int_0^\infty e^{-st}dE\nu(t)dt,\ \Phi_2(s)=\int_0^\infty e^{-st}dE\nu^2(t)dt,$$

$$\hat{H}_1(s)=\int_0^\infty e^{-st}dH_1(t),\ \mathrm{Re}(s)>0 \tag{26}$$

Since transform of convolution equals product of transforms, then we obtain from (23)

$$\Phi_1(s)=\int_0^\infty e^{-st}d\left(\sum_{n=1}^{\infty} H_1^{n*}(t)\right)=\sum_{n=1}^{\infty}\left(\hat{H}_1(s)\right)^n=\frac{\hat{H}_1(s)}{1-\hat{H}_1(s)} \tag{27}$$

since $\left|\hat{H}_1(s)\right|<1.$

Similarly we can prove that

$$\Phi_2(s)=\frac{\hat{H}_1(s)+\hat{H}_1^2(s)}{\left(1-\hat{H}_1(s)\right)^2} \tag{28}$$

Since $\hat{H}_1(s)$ one can evaluate numerically (as a function of unknown parameters λ_i and p_i, we can invert the right sides of (27) and (28) on argument s (using one of the methods of numerical inversion of Laplace or Laplace-Stieltjes transform). Denote the originals of the right sides in (27) and (28) by $R_1(t, p_1, \lambda_1)$ and $R_2(t, p_1, \lambda_1)$ respectively.

We propose to compare them to the following empirical estimators of $E\nu(t)$ and $E\nu^2(t)$ respectively:

$$n_1,\ \sigma^2+n_1^2 \tag{29}$$

where $\sigma^2=\frac{1}{m}\sum_{i=1}^{m}\left(n_i-\bar{n}\right)^2$ and $n_1, n_2, ..., n_m$ are numbers of failures physically observed in successive periods $[0,T),[T,2T),...,[(m-1)T, mT)$ and $\bar{n}=\frac{1}{m}\sum_{i=1}^{m}n_i$.

From the system of equations

$$n_1=R_1(t, p_1, \lambda_1),\ \sigma^2+n_1^2=R_2(t, p_1, \lambda_1) \tag{30}$$

we estimate unknown parameters λ_i and p_i .

For the next period $[0,T)$ we use the same algorithm for parameters λ_2 and p_2 with n_2 instead of n_1 as the first estimator in (29). Having $(p_1,\lambda_1),...(p_m,\lambda_m)$ we use the classical regression to predict (p_{m+1},λ_{m+1}).

Predictions for reliability characteristics

Let us consider the interval $[(m-1)T, mT)$ for which we found (using one of three methods) estimators $\hat{p}_{m+1}$ and $\hat{\lambda}_{m+1}$ of parameters for Weibull distribution. Below we present formulae for the most important reliability characteristics:

(1) Reliability function $R(t)$, $t \in [mT,(m+1)T)$, that gives the probability that, beginning with moment $t_0 = mT$, the first failure occurs after time t:

$$R(t) = P\{X_{m+1,1} > t\} \\ = \hat{\lambda}_{m+1}\, \hat{p}_{m+1} \int_t^{\infty} u^{\hat{p}_{m+1}-1} \exp\left(-\hat{\lambda}_{m+1}\, u^{\hat{p}_{m+1}}\right) du, \quad t > 0. \tag{31}$$

(2) Mean Time To First Failure (MTTFF):

$$MTTFF = R(t)dt \\ = \hat{\lambda}_{m+1}\, \hat{p}_{m+1} \int_0^{\infty}\int_t^{\infty} u^{\hat{p}_{m+1}-1} \exp\left(-\hat{\lambda}_{m+1}\, u^{\hat{p}_{m+1}}\right) du dt. \tag{32}$$

(3) Mean Time Between Failures (MTBF):

$$MTBF = E\{X_{m+1,1} + Y_{m+1,1}\} = \left(\frac{1}{\hat{\lambda}_{m+1}}\right)^{1/\hat{p}_{m+1}} \Gamma\left(\frac{1}{\hat{p}_{m+1}} + 1\right) + \left(\frac{1}{\alpha_{m+1}}\right). \tag{33}$$

(4) Probability P that in the interval $[f, g] \in [mT,(m+1)T)$ there occurs at least one failure:

$$P = P\{f \le X_{m+1,1} \le g\} \\ = \hat{\lambda}_{m+1}\, \hat{p}_{m+1} \int_f^{g} u^{\hat{p}_{m+1}-1} \exp\left(-\hat{\lambda}_{m+1}\, u^{\hat{p}_{m+1}}\right) du. \tag{34}$$

Conclusion

In the paper a classical model of failures is considered in that successive failure-free times are supposed to have Weibull distributions and are followed by exponentially distributed times of repairs. It is assumed that parameters of these distributions, in general, change with time. Basing on information about the number of failures and failure-free times in a number of periods of the same duration in the past, three different methods of estimation unknown parameters of the model are proposed. In these approaches Maximum Likelihood Principle, empirical moments and renewal function are used respectively. Next, predictions of the most important reliability characteristics are found using classical regression technique. In the article theoretical description of the reliability characteristics are given, in the second article a model of a production system is described and numerical examples are attached.

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Estimation of reliability characteristics in a production scheduling model with time-changing parameters – first part, theory

Abstract

In the paper a classical model of failures is considered in that successive failure-free times are supposed to have Weibull distributions and are followed by exponentially distributed times of repairs. It is assumed that parameters of these distributions, in general, change with time. Basing on information about the number of failures and failure-free times in a number of periods of the same duration in the past, three different methods of estimation unknown parameters of the model are proposed. In these approaches Maximum Likelihood Principle, empirical moments and renewal function are used respectively. Next, predictions of the most important reliability characteristics are found using classical regression technique. In the article theoretical description of the reliability characteristics are given, in the second article numerical examples are attached.

Keywords: Predictive scheduling, Maximum Likelihood Principle; Mean Time Between Failures (MTBF); Mean Time To First Failure (MTTFF); reliability function; renewal function; Weibull distribution.

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Estimation of reliability characteristics in a production scheduling model with time-changing parameters – second part, numerical example

Introduction

The problem is to generate the workable, proactive baseline schedule based on knowledge acquired from historical data about frequency of a machine work disturbances. The paper is continuation of the first part where three different methods of estimation of unknown parameters of Weibull distribution are presented: Maximum Likelihood Principle, empirical moments and renewal function [2]. Next, predictions of the most important reliability characteristics are found using classical regression technique.

In the paper a model of a production system is presented and numerical examples of using two methods (Maximum Likelihood Principle, empirical moments) of estimation unknown parameters of Weibull distribution are given. Because the renewal theory approach is to much time consuming we are not able to make the calculation.

The predictive schedule can be generated using Earliest Finishing Time of the Operation Rule (ETFR) and The Flexibility Priority Rule (FPR) to assign an operation to a machine [1]. Because the computer aiding predictive scheduling system has been not operated jet, we propose the Enerprise Dynamics (ED) system to generate the predictive schedule. In the ED system jobs are scheduled according to priority rules such as: FIFO, LIFO, Random, Sort by label ascending (for example job with lowest duration time), Sort by label descending, user can predefine which location in a queue has a new job. The ED system generates predictive schedules for data introduced by a decision maker. For each machine the decision maker can define Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR) using various distributions but there is no possibility to adjust the distribution to the data and to estimate its parameters. Therefore in the paper we propose three methods for estimation of unknown parameters of Weibull distribution used for the machine breaking time prediction in the model. Having input data - MTTF of the machine one can generate the predictive schedule using ED system.

Problem formulation

Problem is stated as follows: V operations, $v=1,2,...,V$ have to be executed on W machines, $w=1,2,...,W$. $A_{w},_{v}$ denotes *v*th operation time executed on *w*th machine, $a_{w},_{v}$ are predefined in the Matrix of Operation Time $MOT=[a_{w},_{v}]$. Such the system, firstly, is observed on *m* successive time periods

$$[0,T),[T,2T),...,[(m-1)T,mT) \tag{1}$$

of the same durations, for which the information about numbers of detected failures or failure-free times is known. It is assumed, that during a scheduling horizon $[(m-1)T,mT)$ uncertain disruptions have occurred. After the machine B_w has been broken repair works are done.

The predictive schedule is generated for a production shop for a next time period $[mT,(m+1)T)$. In order to generate the predictive schedule information about time of *w*th machine failure in scheduling horizon $[mT,(m+1)T)$ is needed. The information about numbers of failures $N_{i,w}$ and failure-free times $X_{i,w,1},...,X_{i,w,N_{i,w}}$ detected in the *i*th scheduling period $[(i-1)T,iT)$, $i=1,...,m$ for *w*th machine are given. It is assumed that failure-free times $X_{i,w,1},...,X_{i,w,N_{i,w}}$ have Weibull distribution. Repair times $Y_{i,w,1},...,Y_{i,w,N_{i,w}}$ for $i=1,...,m+1$, for wth machine are supposed to be exponentially distributed with mean $\dfrac{1}{\alpha_{i,w}}$ being predefined. After having the parameter $\alpha_{i,w}$ the average values $EY_{i,w,k}$ of repair time for *i*th scheduling period $i=1,...,m$, for wth machine is computed.

The goal is to answer the questions:

- what is the probability that, beginning with moment $t_0=mT$, the first failure of *w*th machine occurs after time t

$$R_w(t)=P_w\{X_{m+1,w,1}>t\}, \tag{2}$$

- what is the Mean Time To First Failure ($MTTFF_w$) for *w*th machine:

$$MTTFF_w=R_w(t)dt, \tag{3}$$

- what is the Mean Time Between Failures ($MTBF_w$) for *w*th machine:

$$MTBF_w = E\left\{X_{m+1,w,1} + Y_{m+1,w,1}\right\}, \tag{4}$$

- what is a probability P_w that in the interval $[f,g] \in [mT,(m+1)T)$ there occurs at least one failure of *w*th machine:

$$P = P_w\left\{f \le X_{m+1,w,1} \le g\right\}, \tag{5}$$

and to generate the predictive schedule for the next time period $[mT,(m+1)T)$ basing on an assumption that the information about numbers of failures $N_{i,w}$ and failure-free times $X_{i,w,1},\ldots,X_{i,w,N_{i,w}}$ in the *i*th period $[(i-1)T,iT)$, $i=1,\ldots,m+1$ for *w*th machine are given. Predictions of the reliability characteristics are found using classical regression technique. Predictive scheduling can consist in placing time window and in the schedule at time $\left[MTBF_w - Y_{m+1,1}, MTBF_w + Y_{m+1,1}\right]$ [1]. In the paper the predictive schedule is generated using ED system having the values of parameters of Weibull distribution.

Numerical example

Let us consider the production shop of $W=3$ machines and $V=1$ product. Butch size of the product is unlimited. The operation times are defined in MOT, where first row describes the route of the process and second describes operations' times:

$$MOT = \begin{bmatrix} 3,2,1 \\ 10,5,4 \end{bmatrix}. \tag{6}$$

It is assumed that there are $m=5$ successive time periods of the same durations, for which the information about numbers of detected failures and failure-free times $X_{i,3,1},\ldots,X_{i,3,N_{i,3}}$ of machine $w=3$ in the *i*th period $[(i-1)T,iT)$, $i=1,\ldots,5$ are presented in Table I.

After the failure of *w*th machine occurs, a repair time $Y_{i,w,k}$ begins immediately in *k*th sub-period of *i*th period. Repair times $Y_{i,w,1},\ldots,Y_{i,w,N_{i,w}}$ for $i=1,\ldots,m+1$ for *w*th machine have exponential distribution. The parameter of the exponential distribution $\alpha_{i,3}$ and the average values of repair time $EY_{i,3}$ for the *i*th scheduling period $[(i-1)T,iT)$, $i=1,\ldots,5$, for 3[rd] machine are presented in Table. II.

TABLE I. The failure-free times of 3rd machine in the *i*th period

i	$N_{i,w}$	$x_{i,3,1}$	$x_{i,3,2}$	$x_{i,3,3}$	$x_{i,3,4}$	$x_{i,3,5}$	$x_{i,3,6}$	$x_{i,3,7}$	$x_{i,3,8}$	$x_{i,3,9}$	$x_{i,3,10}$
1	10	6,0	5,5	8,0	5,6	6,0	4,5	6,7	8,0	6,0	8,0
2	10	7,0	5,5	6,0	7,0	6,5	5,6	5,0	8,0	7,0	5,6
3	9	8,0	6,3	5,0	6,4	5,0	6,8	7,0	5,8	6,0	
4	10	6,1	6,2	5,0	8,0	6,4	6,0	7,0	7,0	5,6	6,8
5	9	8,0	6,0	5,7	7,0	6,4	6,3	8,0	7,6	8,2	

TABLE II. $\alpha_{i,3}$ and $EY_{i,3}$ of repair time for *i*th scheduling period

i	1	2	3	4	5
$\alpha_{i,3}$	2,06	3	2,09	2,03	3,1
$EY_{i,3}$	0,49	0,33	0,48	0,49	0,32

The average value of repair time $EY_{6,3}$ for the 6th scheduling period for *3rd* machine is estimated using linear regression and equals to 3.76.
We assume that failure-free times $X_{i,3,1},\dots,X_{i,3,N_{i,3}}$ of 3rd machine in the *i*th period $[(i-1)T, iT),\ i=1,\dots,6$ have Weibull distribution. In order to predict the production system behavior in the next scheduling period $[mT,(m+1)T)$ one has to model the behavior of the production system in the *i*th period $[(i-1)T, iT),\ i=1,\dots,5$. Basing on information about numbers of detected failures and failure-free times $X_{i,3,1},\dots,X_{i,3,N_{i,3}}$ of 3rd machine in the *i*th period $[(i-1)T, iT),\ i=1,\dots,5$ parameters of Weibull distribution $p_{i,3}>0,\ \lambda_{i,3}>0$ are estimated using two methods:

- Maximum likelihood approach
- Empirical moments approach.

Maximum likelihood approach

The observation of numbers and durations of successive error-free periods $X_{i,w,1},\dots,X_{i,w,N_{i,w}}$ are presented in Table 1. For each interval $[(i-1)T, iT),\ i=1,\dots,m$, for *w*th machine $p_{i,w}$ is searched that the condition (7) is true.

$$n_{i,w}\sum_{k=1}^{n_{i,w}} x_{i,w,k}^{p_{i,w}} \ln x_{i,w,k} - \left(\frac{n_{i,w}}{p_{i,w}} + \sum_{k=1}^{n_{i,w}} \ln x_{i,w,k}\right)\sum_{k=1}^{n_{i,w}} x_{i,w,k}^{p_{i,w}} = 0, \qquad (7)$$

For example, for the fourth interval $[3T,4T)$ for 3rd machine the condition (7) equals 0 if $\hat{p}_{i,3}=8{,}47$. $\hat{p}_{i,3}$ for *i*th successive time period $[(i-1)T,iT),\ i=1,...,5$ are presented in Tab. III.

TABLE III. Values $\hat{p}_{i,3}$ and $\lambda_{i,3}$ for *i*th scheduling horizon and for 3rd machine

i	Left side of condition (7)	$\hat{p}_{i,3}$	$\lambda_{i,3}$
1	2,30E-05	6,18	6,39E-06
2	0,0001	7,65	4,72E-07
3	1,19E-06	7,34	9,13E-07
4	0	8,47	9,34E-08
5	0,00075	9,13	1,12E-08

The Maximum Likelihood estimator $\lambda_{i,w}$ for the *i*th period $[(i-1)T,iT),\ i=1,...,m$ and for *w*th machine is counted from equation (8):

$$\hat{\lambda}_{i,w}=\frac{n_{i,w}}{\sum_{k=1}^{n_{i,w}} x_{i,w,k}^{\hat{p}_{i,w}}}. \tag{8}$$

Values $\lambda_{i,3}$ for the *i*th period $[(i-1)T,iT),\ i=1,...,5$ and for 3rd machine are presented in Tab. III.

After finding estimators $\hat{p}_{1,w},...,\hat{p}_{m,w}$ and $\hat{\lambda}_{1,w},...,\hat{\lambda}_{m,w}$ we extrapolate values $\hat{p}_{m+1,w}$ and $\hat{\lambda}_{m+1,w}$ for the next scheduling horizon using the regression method. $\hat{p}_{6,3}=9{,}69$ (Fig. I) and $\hat{\lambda}_{6,3}=3{,}75\cdot 10^{-9}$ (Fig. II) for 6th scheduling horizon $[5T,6T)$ for 3rd machine.

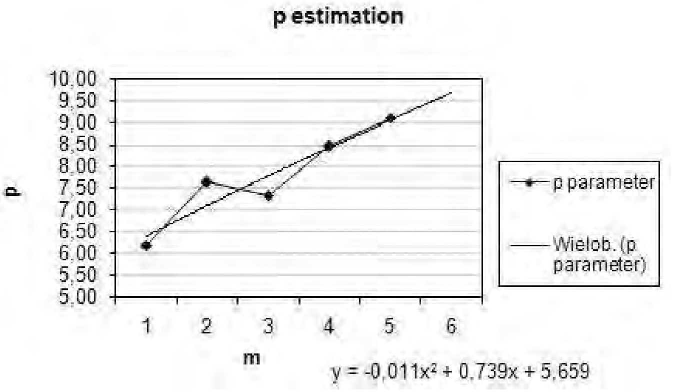


FIGURE. I. The extrapolation of value $\hat{p}_{6,3}$

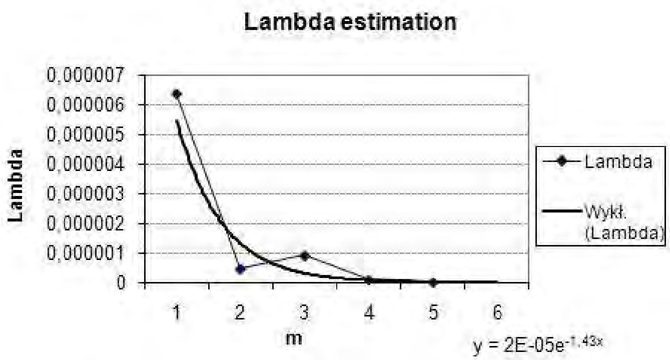


FIGURE. II. The extrapolation of value $\hat{\lambda}_{6,3}$

Empirical moments approach

In this example sample values $x_{i,w,1}$, $x_{i,w,2}$, ..., $x_{i,w,n_{1,w}}$ for each scheduling horizon $[(i-1)T, iT)$, $i=1,...,5$, for 3rd machine are the same as in the previous section.

The sample mean and the second moment are counted for each scheduling horizon $[(i-1)T, iT)$, $i=1,...,m$ and for *w*th machine:

$$m_{I,i,w}(x_{i,w}) = \bar{x}_{i,w} = \frac{1}{n_{i,w}} \sum_{k=1}^{n_{i,w}} x_{i,w,k} \ , \ m_{II,i,w}(x_{i,w}) = \frac{1}{n_{i,w}} \sum_{k=1}^{n_{i,w}} x_{i,w,k}^2 \ . \tag{9}$$

$m_{I,i,3}(x_{i,3})$ and $m_{II,i,3}(x_{i,3})$ for each scheduling horizon $[(i-1)T, iT)$, $i=1,...,5$, for 3rd machine are presented in Table IV.

Observing the behavior of the function $T_{i,w}\left(\frac{1}{p_{i,w}}\right)=\sqrt{\frac{\pi}{p_{i,w}}}\cdot\left(\frac{1}{4}\right)^{\frac{1}{p_{i,w}}}$ for fixed value $T_{0,i,w}=\frac{m_{I,i,w}^2\left(x_{i,w}\right)}{m_{II,i,w}\left(x_{i,w}\right)}$, we find an approximate value $\hat{p}_{i,w}$ of $p_{i,w}$.

$T_{0,i,3}, T_{i,3}\left(\frac{1}{p_{i,3}}\right)$ and the approximate value $\hat{p}_{i,3}$ for each scheduling horizon $[(i-1)T, iT),\ i=1,\ldots,5$, for 3rd machine are presented in Table IV.

TABLE IV. Mean and the second moment, functions and parameters for each scheduling horizon and for 3rd machine

i	$m_{I,i,3}(x_{i,3})$	$m_{II,i,3}(x_{i,3})$	$T_{0,i,3}$	$T_{i,3}\left(\frac{1}{p_{i,3}}\right)$	$\hat{p}_{i,3}$	$\hat{\lambda}_{i,3}$
1	6,43	42,68	0,969	0,646	2,735	0,0026
2	6,32	40,72	0,981	0,645	2,910	0,0018
3	6,26	39,95	0,980	0,645	2,910	0,0019
4	6,41	41,72	0,985	0,645	2,910	0,0017
5	7,02	50,13	0,984	0,646	2,837	0,0016

Having $\hat{p}_{i,w}$ we count $\hat{\lambda}_{i,w}=\left[m_{I,i,w}\left(x_{i,w}\right)\Big/\Gamma\left(\frac{1}{\hat{p}_{i,w}}+1\right)\right]^{-\hat{p}_{i,w}}$. $\hat{\lambda}_{i,3}$ for each scheduling horizon $[(i-1)T, iT),\ i=1,\ldots,5$, for 3rd machine are presented in Table IV.

After finding estimators $\hat{p}_{1,w},\ldots,\hat{p}_{m,w}$ and $\hat{\lambda}_{1,w},\ldots,\hat{\lambda}_{m,w}$ we extrapolate values $\hat{p}_{m+1,w}$ and $\hat{\lambda}_{m+1,w}$ for the next scheduling horizon using the linear regression method $\hat{p}_{6,3}=2{,}919$ (Fig. III) and for $\hat{\lambda}_{6,3}=0{,}002$ (Fig. IV) for 6th scheduling horizon $[5T, 6T)$ for 3rd machine.

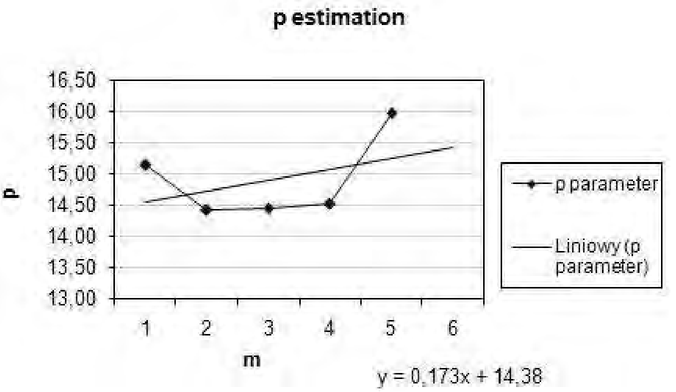


FIGURE. III. The extrapolation of value $\hat{p}_{6,3}$

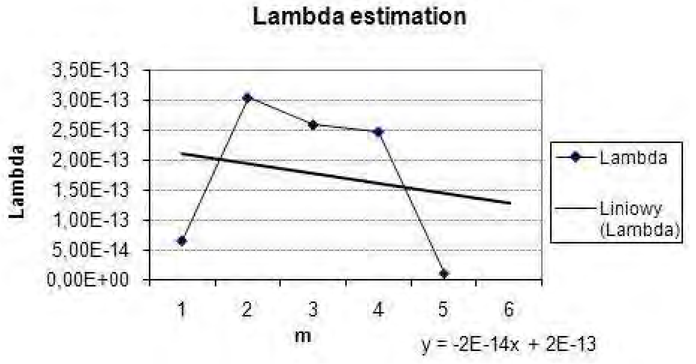


FIGURE. IV. The extrapolation of value $\hat{\lambda}_{6,3}$

The empirical moments approach can be used only for $p_{i,w} << 1$ and, $\hat{p}_{6,3} >> 1$ for each scheduling horizon $[(i-1)T, iT),\ i = 1,\ldots,5$ for 3rd machine taking into consideration sample values given in Table I. The empirical moments approach can be used only for system with long times between machine failures. This is the reason of differences between values of $\hat{p}_{6,3}$ and $\hat{\lambda}_{6,3}$ reached using Maximum likelihood and Empirical moments approach.

Following question appears: why the value of shape parameter $\hat{p}_{6,3}$ is very big and value of scale parameter $\hat{\lambda}_{6,3}$ is very small? $\hat{p}_{6,3} = 6{,}96$ and $\hat{\lambda}_{6,3} = 3{,}75 \cdot 10^{-9}$ using Maximum likelihood approach. One reason can be that input data are not generated by a real production system, and predefined failure frequency of the machine is too high. Another reason can be that the input data should be adjusted to a distribution and in the paper the Weibull distribution was predefined to describe the failure time parameter. The answer for the given question will be the goal of further research.

For predictions for reliability characteristics firs we use $\hat{p}_{6,3} = 2{,}919$ and $\hat{\lambda}_{6,3} = 0{,}002$ reached with application of Empirical moments approach.

Predictions for reliability characteristics

Let us consider the production shop of $W = 3$ machines and $V = 1$ production process. The operation times are defined in MOT (6). Basing on information about numbers of detected failures and failure-free times $X_{i,3,1},\ldots,X_{i,3,N_{i,3}}$ of machine $w = 3$ in the ith period $[(i-1)T, iT)$, $i = 1,\ldots,5$ presented in Table I, parameters for Weibull distribution $\hat{p}_6$ and $\hat{\lambda}_6$ for 6th period has been estimated. $\hat{p}_{6,3} = 2{,}919$ and $\hat{\lambda}_{6,3} = 0{,}002$ using the empirical moments approach. Having values of Weibull parameters we computed:

- the probability that the 3rd machine will be working by 5 unit of time is very small (Fig. V), $R_w(5) = P_w\{X_{6,3,1} > 5\} = 0.032$.
- the MTTFF$_3$ for *3*rd machine $MTTFF_3 = 0.346$,
- the MTBF$_3$ for *3*rd machine $MTBF_3 = 0.266$,
- the probability P_w that in the interval $[5,10]$ there occurs at least one failure of *3*rd machine $P_3 = 0.028$

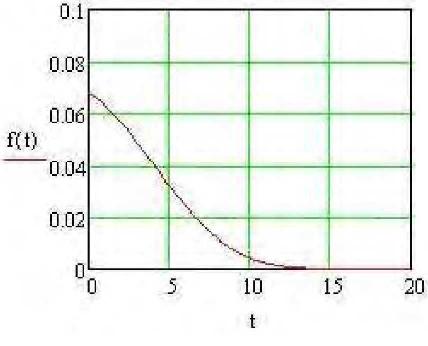


FIGURE V. The probability of the first failure of 3rd machine

Having $\hat{p}_{6,3} = 6{,}96$ and $\hat{\lambda}_{6,3} = 3{,}75 \cdot 10^{-9}$, estimated using Maximum likelihood approach, the same value of $MTBF_3 = 0.266$ is reached. Predictive scheduling consists in placing time window in the schedule at time $\lfloor MTBF_3, MTBF_3 + Y_{m+1,3} \rfloor$ the time period $[mT, (m+1)T)$.

Having the values of $MTBF_3$ parameter for Weibull distribution we generate the predictive schedule using the ED system. The production model is presented in Figure VI.

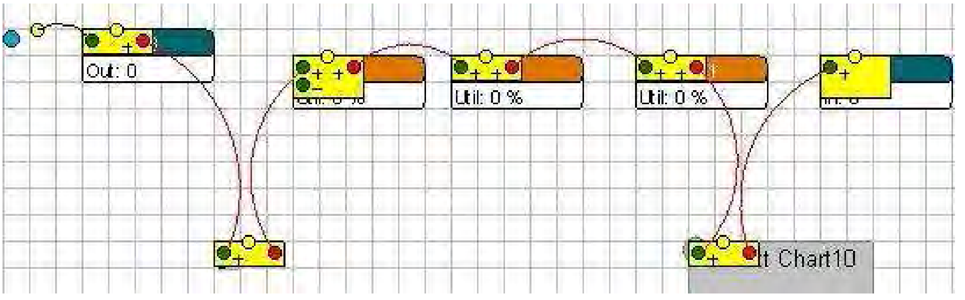
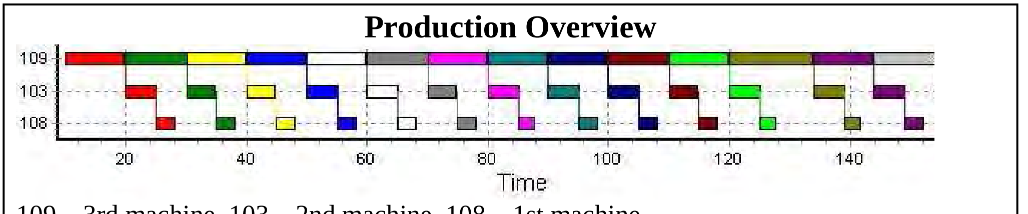


FIGURE VI. The production system modeled in ED system

Let us assume that the time unit for $MTBF_3$ parameter is a shift equals to 8 hours. The $MTBF_3$ for 3rd machine $MTBF_3 = 0.266 \cdot 8h = 2.128h = 127.68 \min$. Let us assume that a time unit for $MTTR_3$ is the minute. $MTTR_3 = 3.76 \min$ as the average value of repair time $EY_{6,3}$ for the 6th scheduling period for *3rd* machine equals to 3.76.

For the production process described by MOT (6) and $MTBF_3 = 127.68 \min$ and $MTTR_3 = 3.76 \min$ the predictive Gantt chart (Fig. VII) is generated. The duration of the fist operation of 12th product takes 13.76 minutes



109 – 3rd machine, 103 – 2nd machine, 108 – 1st machine

in stead of 10.

FIGURE VII. The Gantt chart with failure of *3rd* machine

Conclusion

In the paper the numerical example for the production model with failures is presented where successive failure-free times are supposed to have Weibull distributions and are followed by exponentially distributed times of repairs. Basing on information about the number of failures and failure-free times in a number of periods of the same duration in the past, methods of estimation unknown parameters of the model: Maximum likelihood and Empirical moments approaches were applied. Having values of parameters: MTTF and MTTR, the predictive schedule is generated using ED system.

During the research question about correctness of values of the shape parameter and the scale parameter of Weibull distribution appears. Therefore the subject of further research is the application of methods used for adjusting input data to a distribution.

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2. W. Kempa, I. Wosik, B. Skołud Estimation of reliability characteristics in a production scheduling model with time-changing parameters – first part, theory

Estimation of reliability characteristics in a production scheduling model with time-changing parameters – second part, numerical example

Abstract

In the paper the numerical example for the production model with failures is presented where successive failure-free times are supposed to have Weibull distributions and are followed by exponentially distributed times of repairs. Methods of estimation unknown parameters of the production model: Maximum likelihood and Empirical moments approaches are applied. Having values of parameters: MTTF and MTTR, the predictive schedule is generated using ED system.

Keywords: Predictive scheduling, Maximum Likelihood Principle; Mean Time Between Failures (MTBF); Mean Time To First Failure (MTTFF); reliability function; Weibull distribution.

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ANNA BORATYŃSKA-SALA

Forecasting of technical system evolution using TRIZ methodology

Introduction

The progress of civilization results from the growing human requirements to the world around. If a description of the existing phenomenon informs about the "undesired effects", then we can treat it as "innovative situation with undesired effects". The characteristic feature is the progress in defining "undesired effects". The solution satisfying us 20 years ago, now could be not acceptable. So, it can be stated that the civilization progress means the continuous improvement of technical systems to make them more ideal. Now it is time to explain the meaning of "ideality" in the TRIZ (Theory of Inventive Problem Solving). H .S. Altszuller defined the ideality as the features of the system "which does not exist, but its function is being executed". This a little controversial definition seems to be too much abstractive. The real techniques convict us, that even complete realization of such system is possible. This is very good illustrated by the problem of mixing fodder for cattle. Usually, first the seeds are sowed, cultivated, then various plants are harvested and mixed in the fodder mixer. Different fodder components can be also sown on parallel plots and collected together using the harvester running across these plots. In this way, the container of the harvester will store already mixed fodder. So, there is no fodder mixed, but its function is executed. It is possible to give more examples of this type. Generally speaking, "ideal technical system" is a targeted model of the solution, although it is not always possible to realize it.

Despite the great variety of technical systems, there is one common feature. The process of the development toward the ideality has all characteristic development phases, similarly like biological systems. Altszuller formulated the general outline of the laws of technical system evolution and named them as LTSE (Laws of Technical System Evolution).

Below there is a short listing of these laws together with comments.

The laws are grouped into three blocks, conventionally called as: "statics" (laws 1-3), "kinematics" (4-7), "dynamics" (8,9).

Laws of development of technical systems	Section
1.Law of part of system completeness	Static
2. Law of "energy conductivity" of the system	
3. Law of coordination (harmonization) of rhythms of parts of the system	
4. Law of increasing the degree of ideality of the system	Kinematics
5. Law of non-uniform evolution of sub-systems	
6. Law of transition to a super-system (higher-level system)	
7. Law magnify degree dynamisation of system	
8. Transition from macro to micro level	Dynamics
9. Law of increasing Su-Field interactions	

Picture 1. Laws of development of Technical Systems

The relationship between these groups and the model of "birth, development and death" can be noticed, represented in the graphical form as the s-curve. In the other words, it is the curve of the live of technical systems, used by H. S. Altszuller to illustrate the evolution processes in techniques. The "statics" law relates to the period of the appearance and forming of technical systems (TS), "kinematic" laws relates to the period of the development and blooming, while the "dynamic" laws are related to the end of the development period of TS and transition to the newer system.

Laws of Technical System Evolution

The development process of TS results both from the conscious human actions as well as form objective laws of nature. If the human acts in line with the objective laws of nature, then the development of TS is objective and runs with these laws. These laws can be learn and used for the purpose of the development of TS. This statement forms the base for the theory of technical system evolution (TTSE).

Each scientific theory only reflects (with different degree of details) the multiformity, complexity and contradictions of the real evolution processes. In such approach, the cognition process is infinite and the occurrence of the new ideas, hypothesis and conclusions is the natural element of the theory being developed. Nevertheless, the logics and pragmatics of the evolution of real systems are the main factors limiting the logical and theoretical structures, which necessitates the verification of all opinions and hypothesis.

The system laws are divided into four groups:

- **structural laws of shaping** formulating the conditions for the development of structures,
- **functioning laws** explaining the conditions for the appearance and the evolution of constraints and organizations,
- **evolution laws** revealing the forces and mechanisms fueling the system transformations through the definition and solving of contradictions,
- **laws of cooperation** with other systems, subsystems, higher-level systems and external environment.

The laws of Technical Systems evolution are significant, durable and repetitive relation between system components and the external environment in the evolution processes, i.e. during transition from one state to another to increase the useful functions.

These laws are discovered during the analysis of large sets of facts (inventions described in the patent databases, history of evolution of techniques). Nevertheless, the laws in the techniques acts as energetic force and we can be never sure that the analyzed set of facts (representing fragment of human activity) revealed the ultimate, not random and significant system bases.

Because of this, the laws are revealed using the subsequent approximations: selection of "sure" inventions (technical solutions), disclosure of rules for solving the technical contradictions, separation of groups of rules and physical, chemical and geometrical effects, and at the end the standard steps in the technical system evolution. It is not possible to exclude the subjective factors (style, approach, individual estimations, lack of quantities criteria) on all stages of research works. The ideality is the only, enough general, criteria of qualities estimation of the progress in the development of any technical system.

The most important role of ideality of Technical Systems can be observed in all TRIZ mechanisms, and this law describes the most general trends in the evolution of techniques. In fact, all remaining laws are the exemplifications of this main law in the different phases of the TS evolution.

In his pioneering work of 1975, Altshuller subdivided all laws of technical systems evolution into 3 categories:

- Statics - describes criteria of viability of newly created technical systems.
- Kinematics - defines how technical systems evolve regardless of conditions.
- Dynamics - defines how technical systems evolve under specific conditions.

STATIC LAWS

1.Law of part of system completeness

This first law describes the minimum required to have a viable system. It is also the only law necessary for the birth of a new system.
Any technical system appears as a result of a synthesis of several parts into a single whole. In order to be viable, the main components of this technical system have to be present and perform a minimal working efficiency.
The main characteristics of a system are the following: Systems are composed of parts, elements, they have a structure; Systems are designed for specific reasons (objectives), they fulfil useful functions.
Parts of systems are interconnected, they are designed and linked in a structured way in space and time. Every system possesses in its whole a particular property additionally from the sum of the properties of its constituent elements

Any working system must have four parts:

- the engine which generate energy from external resources
- the transmission brings the energy to the working unit
- the working unit (working organ) that is in contact with the object
- and the control element (organ of steering).

The engine generates the needed energy, the transmission guides this energy to the working unit, which ensures contact with outside world (processed object), and the control element makes the system adaptable.
In order to be complete, a TS (Technical System) should have an engine, a transmission, an operation subsystem (or tool) and a control subsystem. For the TS to be controllable, at least one of its parts must be controllable. Each parts must be present, and perform its function. Looking a technical system in this way allows to identify if the system is complete and efficient. The working unit, which is in contact with the object, is the last transformation of energy.

The Main Useful Function (MUF)
A function describes the ability of a technical system to deliver a requested property in defined conditions. To be able to define it, we must answer either one or the other of these questions:

- What does the system do? (for existing ones)
- What should the system do? (for non existent systems or systems in the synthesis phase

It is the why the system exists, and must be written as a sentence with:

- The subject is the system
- The verb is the action
- The object is ... the object

Another very important point is to use very simple language. Typically, a six years children should be able to understand the MUF for example: For a car, we can formulate this sentence: "The car transports the passenger", where The system is the car; The action is to transport; The object is the passenger. With this MUF, lets analyse the object decomposition.
The working unit is in contact with the object. In this case, the seat can be considered as the working unit. The transmission is the structure that maintain the seat in the car the engine is the wheel, or can be the surface between road and the wheel. This case shows that we have to define precisely the scope of the study. By doing that we reduce or increase the field of the study I we just wants to study a new seat. we can define a more precise MUF, as "the seats supports the passenger",...

2. Law of “energy conductivity” of the system

As every technical system is a transformer of energy, this energy should circulate freely and efficiently through its four main parts (engine, transmission, working element and control element). The transfer of energy can be by substance, field, or substance-field. Every Technical System is an energy converter. In order to have a working Technical System, at least one of its subsystems should be capable of conducting energy. For a subsystem to be controllable, it is necessary that energy flows between this subsystem and the control subsystem
The energy flow must pass through all of its main components. This law is a law of increasing efficiency. First of all, a system must be conform to the first law. After that, a system must optimize the flow of energy through its components.
The goal of this law is to maximize the ratio between transmitted energy and consumed energy. Conclusion: to make a part of the system controllable, it is necessary to provide power conductivity between the given part and the control unit

3. Law of coordination (harmonization) of rhythms of parts of the system

The frequencies of vibration, or the periodicity of parts and movements of the system should be in synchronization with each other. The subsystems of a TS should have compatible rhythms of operation. In order for a system to maximize its performance, all of its main components must be coordinated or not coordinated. It is a law of harmonization of the tool to the object for example Ergonomic seat: the seat is harmonized to the body, Inflating shoe.

4. Law of increasing the degree of ideality of the system

The ideality of a system is a qualitative ratio between all desirable benefits of the system and its cost or other harmful effects. When trying to decide how to improve a given invention, one naturally would attempt to increase ideality, either to increase beneficial features or else to decrease cost or reduce harmful effects. The Ideal Final Result would have all the benefits at zero cost. That cannot be achieved; the law states, however, that successive versions of a technical design usually increase ideality. Ideality = Benefits / (Cost + Harm)
The development of Technical System happens according to the increase in the degree of ideality. A TS weight, volume and area tends to zero, but its capability to deliver the main function is not diminished.
During its evolution, the technical systems tends to improve the ratio between the system performance and the expenses required to perform this performance
Main directions:

- Improvement of the system performance without additionnal expenditures
- Decreasing the expenditures without performance decreasing
- Transition to the supersystem.

This law is always true. It is a perpetual design direction. It must be considered as a concept, an ultimate goal.
Some linked concepts:
Ideal machine: There is no machine, but the required action is performed
Ideal process: There are no energy expenses and no time expenses, but the required action is performed
Ideal substance: There is no substance, but the function is performed

5. Law of non-uniform evolution of sub-systems

A technical system encompasses different parts, which will evolve differently, leading to the new technical and physical contradictions. The development of a Technical System subsystems is uneven. The more complex the TS, the more uneven the development of its parts tends to be.
Components of technical systems evolve irregularly.
The more complex the system, the more irregularities we will get. These irregularities leads to the birth of new contradictions preventing its evolution

6. Law of transition to a super-system (higher-level system)

When a system exhausts the possibilities of further significant improvement, it's included in a super-system as one of its parts. As a result new development of the system become possible. When a TS reaches its limit of development, it becomes a part (subsystem) of another TS.
During its evolution, technical systems merge to constitute bi and poly-systems. In the future, the system pursue its evolution as a part of the super-system for example Printer + scanner device, Cell phone + PDA

7. Law magnify degree dynamisation of system

The law of increasing the degree of dynamics includes the following sub-laws:

- A law of transition of a system structure from macro- to microlevel.
- The law of increase of degree of substance-field interactions.
- The law of increase of information concentration.

In order to improve their performance, rigid systems should become more dynamic. By dynamic we intend: evolve to more flexible and rapidly changing structures, adaptable to changes of working conditions and requirements of the environment.

DYNAMIC LAWS

8. Transition from macro to micro level

The development of working organs proceeds at first on a macro and then a micro level. The transition from macro to micro level is one of the main (if not the main) tendency of the development of modern technical systems. Therefore in studying the solution of inventive problems, special attention should be paid to examining the "macro to micro transition" and the physical effects which have brought this transition about.
Development of operation subsystems (tools) proceeds first on the macrolevel and then on the microlevel.
The law of transition of a system structure from macro- to microlevel includes the following sub-laws:

- **Changes of a scale,**
- **Changes of linking,**
- **Transition to more complex and energy-saturated forms.**

Evolution of the « tool » element within a given system, begins on the macro level and tends toward the micro-level. This evolution is brought about by the advantages of using properties of dispersed materials and particles of physical fields. The evolution is always from macro-level to micro-level. This law makes the object jumping from its S-curve to the next S-curve by technological jump for example: Mechanical cutting → Water jet → Laser.

9. Law of increasing Su-Field interactions

Non Su-Field systems evolve to Su-Field systems. Within the class of Su-Field systems, the fields evolve from mechanical fields to electro-magnetic fields. The dispersion of substances in the Su-Fields increases. The number of links in the F-fields increases, and the responsiveness of the whole system tends to increase.
Development of TS proceeds in the direction of the increasing involvement of Su-Fields.
In order to improve their performance, systems should become more controllable. By controllable we intend to follow elementary rules expressed in the Inventive Standards.

How appear Technical systems?

The emerging need is satisfied initially using simple su-field: product is processed using the tools and the human power. During the operation of the first su-field, some drawbacks and additional needs to increase the useful function, remove the human participation, connect new useful function of Technical System, remove the harmful functions, etc. appear. All these needs are satisfied by the additional Technical System sub-systems, which also generates some "unwanted effects". All modern and complex systems have the roots in the stone, club and wheel. It is also understandable that is it not possible to continuously increase the complexity. On the certain level of development, the restrictions (physical, economic and ecologic) appear and limit the evolution of TS into "ideal substance".

The evolution laws in the modern TRIZ undergone several important changes and complements. It is quite obvious as the classical TRIZ laws were formulated 25 – 40 years ago. Now, using the laws of TS evolution, procedures and tools were created to help the practical works.

Summary

There are general laws in the nature, as the law of conservation of energy. This law can not be violated, but there are also other laws: imposed by the society, government, civil codes, and others. Unlike the laws of nature, these laws can be violated. The (LTSE) laws can be also violated. Nobody can force a company launching a production to comply with these laws, however, their violation decreases the production characteristics. It is easy to imagine, for example, the violation of the law for electric conductivity. In this case, part of the electric energy will be lost, which lowers the device efficiency, induces additional costs, etc.

The laws of TS evolution based on the objective and rational assumptions, forming the bases of TRIZ, illustrate the evolution of Technical System, without the influence of the commerce, advertisements and marketing actions. Although TRIS is also useful at such assumptions, its main goals is the rational ideality.

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Prognozowanie rozwoju techniki w oparciu o metodykę TRIZ

Streszczenie

W artykule przedstawiono dziewięć praw Rozwoju Systemów Technicznych. Są to: Prawo kompletności części systemu, Prawo energetycznej przewodności systemu, Prawo uzgodnienia rytmu części systemu, Prawo podnoszenia stopnia idealizacji TS, Prawo nierównomiernego rozwoju części systemu, Prawo przechodzenia do nadsystemu, Prawo powiększania stopnia dynamiczności systemu, Prawo przechodzenia z makropoziomu na mikropoziom, Prawo powiększenia stopnia wepolowości.

Słowa Kluczowe: TRIZ, Techniczny System, Prawa Rozwoju Technicznych Systemów;

Forecasting of technical system evolution using TRIZ methodology

The paper presents nine laws of Technical System Evolution. These are: Law of completeness of system parts, Law of system energy conductivity, Law of coordination of system parts, Law of increasing the degree of ideality of the system, Law of non-uniform evolution of system parts, Law of transition to higher-level system, Law of increasing the system dynamics, Law of transition from macro to micro level, Law of increasing Su-Field interactions. This laws were formulated by H. S. Altszuller in the nineteen seventies of the last century and now must by substantially changed and complemented.

Key words: TRIZ, Technical System, Laws of Technical System Evolution

Prognozowanie rozwoju techniki w oparciu o metodykę TRIZ

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MICHAŁ SOBIEPAŃSKI

Modern 8-bit microcontrollers in automation and control of manufacturing processes

Introduction

Modern automation of manufacturing processes, supported by digital controllers and industrial computers expects application of components, which are digital too. They should have communication interfaces and possibilities of collaboration with external analog and digital pieces of whole control system. Present trends in automation indicates the need of small, energy efficient and flexible microcontrollers with build-in support for communication interfaces, common for modern automation systems. Such requirements are fulfilled by many devices, which have 8-bit core but thanks to their advanced structure are very popular in many areas of automation and control. In this article author describes the most important features of modern microcontrollers which make them very interesting tools in automation and control.

1. Reasons for 8-bit microcontrollers popularity

The most important family of microcontrollers was the '51 family. The core of these microcontrollers (CPU) was developed by Intel, and introduced to market in 1980. Fast growing popularity of such devices applied in embedded system caused, that most microcontrollers are still 8-bit devices. Although most of modern 8-bit microcontrollers are now RISC instead of '51 structure devices. The strong position of such devices is the result of view causes:

- the internal architecture of IC's is well known by engineers,
- embedded software developers have wide access to programming tools including free of charge programming tools,
- easy access to hardware support evaluation boards and programmers supported in many operating systems (especially Microsoft Windows and Linux),
- low cost of purchase and short delivery time guaranteed by continuous production or manufacturers inventory.

All of these reasons contribute to keep important role of 8-bit microcontrollers. Of course increasing expectations, mainly from consumer electronics market, caused introducing of modern 16- and 32-bit microcontrollers, especially in such areas where 8-bit resolution is insufficient. Such devices offer higher speeds what in necessary during processing of long numbers, but such speed is often reduced in “bottlenecks” of whole system – data transmission interfaces.

Developing tools for modern microcontrollers are more expensive too. For example evaluation boards equipped with similar peripheral devices (switches, displays etc.) are three, four times more expensive than evaluation boards for 8-bit devices. Summarizing, 8-bit microcontrollers are in the presence, and will be in the future, very attractive for modern projects not only thanks to their still modernized structure, but due to low cost and short developing time of new systems.

2. Short description of RISC 8-bit microcontroller structure

The ATmega microcontrollers manufactured by Atmel Corporation are most popular devices in many industrial, automotive and laboratory applications. This is the result of their versatility resulting from complex internal structure, which consists of many specialized devices. The most important of these are:

- at least three counters/timers (one 16-bit and two 8-bit),
- analog to digital converters (10-bit, often 8-channel, single ended),
- digital do analog converters,
- hardware support for popular communication protocols (RS232C, I2C, CAN, SPI, USB)
- voltage comparators,
- build-in temperature sensors,
- flash memory for program and data.

The presence of such internal devices makes interfacing with external sensors and actuators easy. The data interchanging between processors is simplified too by hardware support especially for SPI and I2C protocols. Devices based on ATmega microcontrollers can interchange data with other computers using RS232C standard, what is very important when the device with microcontroller is an machine interface for personal computer. Figure 1 shows the complex internal structure of sample RISC, 8-bit microcontroller.

3. Electrical aspects of interfacing signals to microcontroller devices

Digital and analog sensors could be connected to microcontroller based device in direct or indirect way. The standard DC voltage in industry is 24V. Microcontrollers operate at voltages up to 5V. That causes difficulties in direct connections of higher voltage devices to microcontroller pins. Application of separating circuits is recommended and simplified by special integrated circuits.

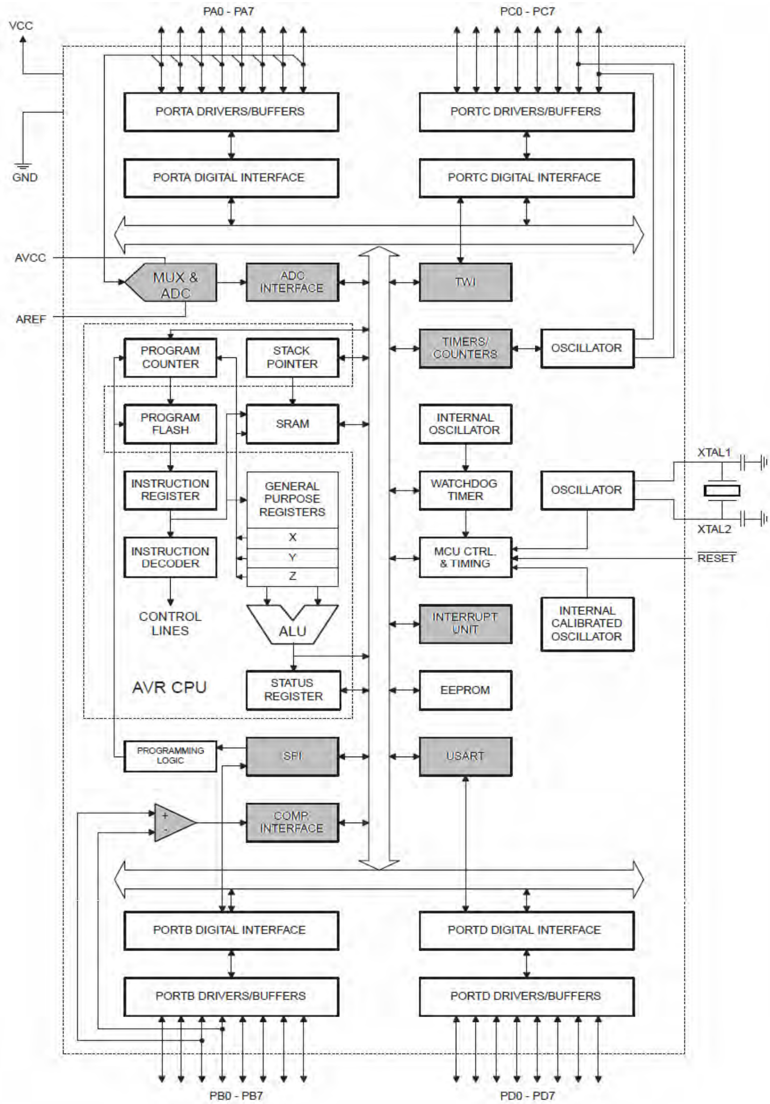

Fig.1. Example structure of modern 8-bit microcontroller – ATmega16 [1] (important devices, useful in automation and control applications are shaded)

Such circuits, called optocouplers, are manufactured as digital and analog devices. Digital devices provide TTL logic compatible signal output. They are commonly used in data transmission between devices operating at different supply voltages. Such devices could be used as isolators for sensors operating at higher voltages than microcontroller. Often used optocoupler is dual channel, 5 Mb/s SFH6731 device [9]. This optocoupler consists of an infrared emitting diode, optically coupled with an integrated photo detector.

The detector incorporates a Schmitt trigger stage for improved noise immunity. Switching time provides data transmission with speed up to 5MBits/s. The presence of Schmitt trigger guaranties explicitness of digital signal at outputs from optocoupler. Digital optocouplers are dedicated for such applications like: industrial control, replace pulse transformers, routine logic interfacing, motion/power control, high speed line receiver, microprocessor system interfaces, computer peripheral interfaces.
Other kind of optocouplers are analog devices. Such devices are ideal for separating signals coming from sensors/switches, interpreted by microcontroller as one-bit signals (signals with values of 1 or 0).

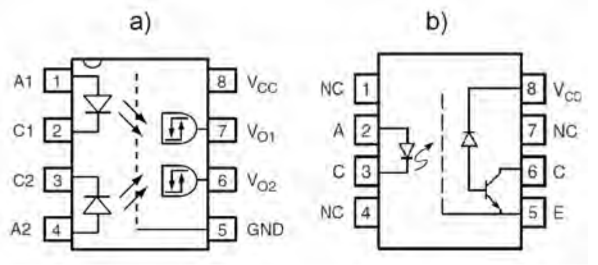

Fig. 2. Operating principle of digital (a) and analog (b) optocouplers [9, 10]

Separating of digital circuit from analog circuit is easy with such devices. They provide true galvanic insulation and high resistance for electrostatic charges.
Both analog and digital optocoupler are absolutely necessary elements of digital controllers. They are responsible for signal conditioning and provide expected immunity of digital circuit for noise and electrostatic damage.

4. Insulating electrically controlled devices from digital circuit

Isolation of digital circuit of controller from controlled external circuits may be done by application of modern solid state relays. They provide coupling between controller circuit and controlled actuators by infrared light. Good example of such devices is the VO14642AT device manufactured by Vishay Corporation [10]. The VO14642AT is high speed SPST normally open solid-state relay in a DIP-6 package. The relays are constructed as a multi-chip hybrid device. Actuation control is via an infrared LED. The output switch is a combination of a photodiode array with MOSFET switches. The relays can be configured for AC/DC or DC only operation (Fig.3). Electrical characteristic of VO14642AT device is very interesting. The current load of switched side is up to 2A DC. Switched voltage could reach maximally 60V DC. Switching time is less than 800us – short enough for typical applications such like driving solenoids of valves. Modern microcontrollers have enough current output for driving LED diode connected directly to their outputs. That makes driving solid state relays directly from microcontroller very easy.

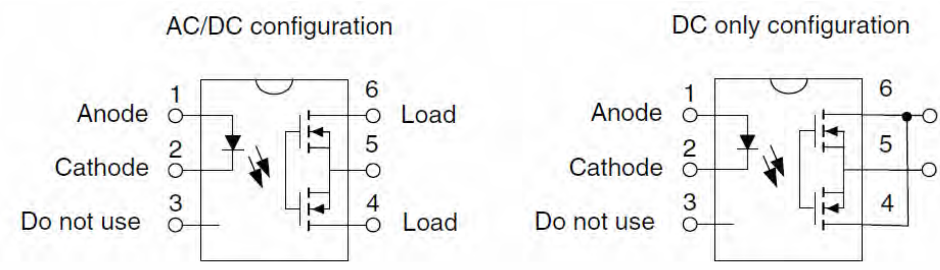

Fig. 3. Configuration of solid state relays for AC or DC switching purposes [10]

5. Controlling of electric motors an solenoids

Some actuators need special additional circuits. Such actuators are for example stepper motors. A stepper motor is a brushless, synchronous electric motor that can divide a full rotation into a large number of steps. The motor rotor position may be controlled precisely without any feedback mechanism. The control of stepper motor is simple switching of its windings in a specific order. This could be done by connection of stepper motor windings to microcontroller pins via Darlington transistors providing expected current amplification. Such solution gives not any control over current in motor windings. This current must be limited by external resistors or by selection of supply voltage for which current does not exceed the permissible value. Such solution is enough for low speed applications. If the situation requires higher speeds the control unit should include at least two additional integrated circuits: digital driver dedicated for stepper motor motion control and H-bridge circuit. The L297 device is good example of special driver, which can drive L298 H-bridge device. Thanks to voltage comparator included in L297 device the windings current is controlled and supply of winding is switched off when current exceeds value set as the maximal one. Current monitoring allows increase supply voltage and achieving high rotation speeds. H-bridge circuit is useful for control of ordinary DC motor too. Rotation direction is controlled digitally by TTL signals coming from microprocessor (microcontroller) or other logic device. By application of pulse width modulation code (PWM) the rotation velocity may be controlled in full range. One L298 device is enough for control of one stepper motor or two DC motors.

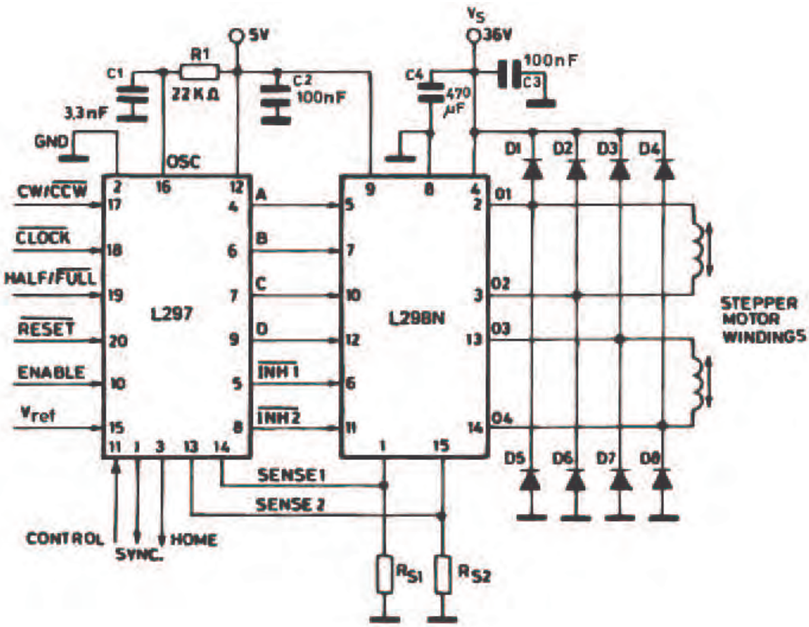

Fig. 4. Stepper motor controller with current control circuit (L297) [7] connected to H-bridge integrated circuit (L298) [8]

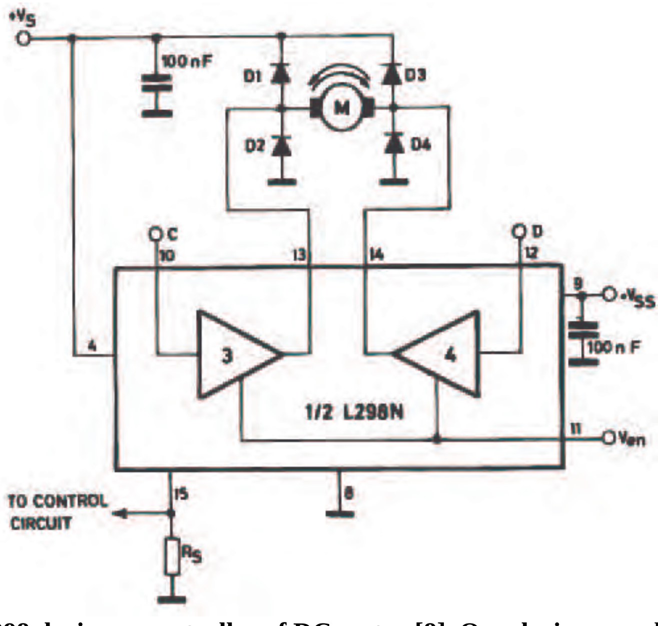

Fig. 5. L298 device as controller of DC motor [8]. One device may drive two independent motors

6. Support for quadrature, incremental encoders

Some features of microcontrollers make them very interesting devices especially, when high frequency signals should be registered-processed. Internal counters and timers are very flexible due to wide possibilities of their configuration. For counters/timers most important features from automation point of view are:

- prescalers – counting may be done with frequency divider based on internal prescaler (possible prescaler settings are 8, 64, 256 and 1024),
- interrupt generation (when timer overflow flag is set and interrupts are enabled, interrupt signal is executed),
- signal source selecting (counter may count internal clock - timer mode, or external clock signals – counter mode),
- PWM signal generation (necessary during control of DC devices - motors).

Possibility of counting external signals helps in interfacing encoders, but additionally instantaneous velocity may be calculated with help of interrupt mechanism. Almost all industrial quadrature encoders have two channels of square signal shifted by half of its period, and one channel of signal with frequency equal to rotation frequency. If interrupts are enabled, and signal from channel A of encoder is connected to external interrupt signal pin of microcontroller, an interrupt occurs always, when signal on channel A rises or falls, depending on microcontroller configuration. An appriopriate program procedure, which services the interrupt signal, monitors the state of input pin, where signal from channel B is introduced. Depending on the state of such pin, procedure increments or decrements the value of angular position. Timer may be used additionally for calculating the time period (measured as number of clock impulses) between following interrupt procedure calls. The idea of direction detection with quadrature encoder is illustrated in figure 6.

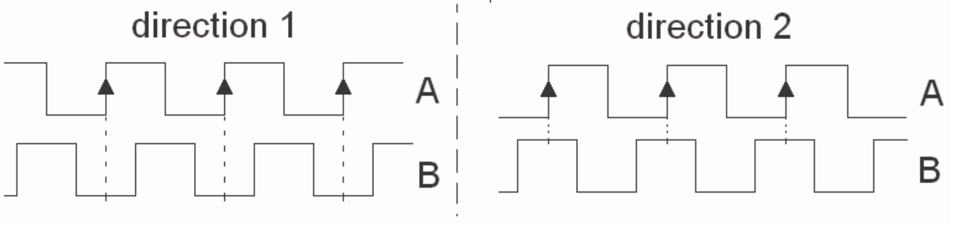

Fig. 6. Determining rotation direction from two signals from quadrature encoder

In first case (direction 1) signal on channel B is always low when signal on channel A rises. If the rotation direction changes, signal on channel B will be high in that moment. Impulses from channel A should invoke interrupt procedure which increments or decrements the counter variable. In such case the counters/timers devices of microcontrollers are not necessary for calculation of actual rotation angle, but during calculations of velocity they are. So, in advanced motion control systems it is necessary to use timers and external interrupt services for control of motors.

7. Measurements of analog voltage signals

Many sensors are sources of analog voltage signals. When signal from sensor has an analog nature it is not necessary to use an additional analog to digital converter. Many microcontrollers are equipped with build-in converters. They operates at resolutions higher than 8 bits.

Good example of popular sensors with voltage output signal are pressure sensors from MPX family [3]. The MPX series piezoresistive transducers are monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. These patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure. Microcontroller equipped with build-in analog to digital converter is ideal for applications where measurement requires conversion followed by some calculations.

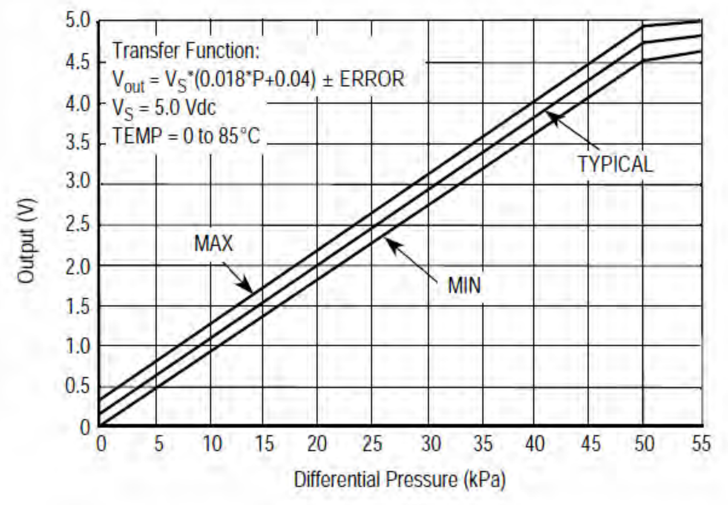

Fig.7. Characteristic of voltage signal from MPX family sensor and its correlation with measured differential pressure [3]

AVR microcontrollers from Atmel corporation are good examples of devices ideal to interfacing MPX sensors. They have build-in 10-bit converters with 8 channel multiplexer. Such converters may operate as single ended or differential channels with programmable gain. Most important features of AVRs build-in converters are [1]:

- 10-bit resolution,
- 0.5 LSB integral non-linearity,
- ±2 LSB absolute accuracy,
- 13 μs- 260 μs conversion time (up to 15 kSPS),
- 8 multiplexed, single ended input channels (7 differential input channels and, 2 differential input channels with optional gain of 10 and 200),
- optional left adjustment for ADC result readout,
- 0 - VCC ADC input voltage range,
- selectable 2.56V ADC reference voltage,
- free running or single conversion mode,
- ADC start conversion by auto triggering on interrupt sources,
- interrupt on ADC conversion complete,
- sleep mode noise canceller.

The MPX sensor is easy applicable due to its output signal range not exceeds TTL voltage range. In other cases simple voltage divider should be used. There are more sensors with voltage signal output. For humidity measurements one can use HIH-3610 series sensor manufactured by Honeywell [4]. This sensor has TTL range output signal with linear correlation to relative humidity.

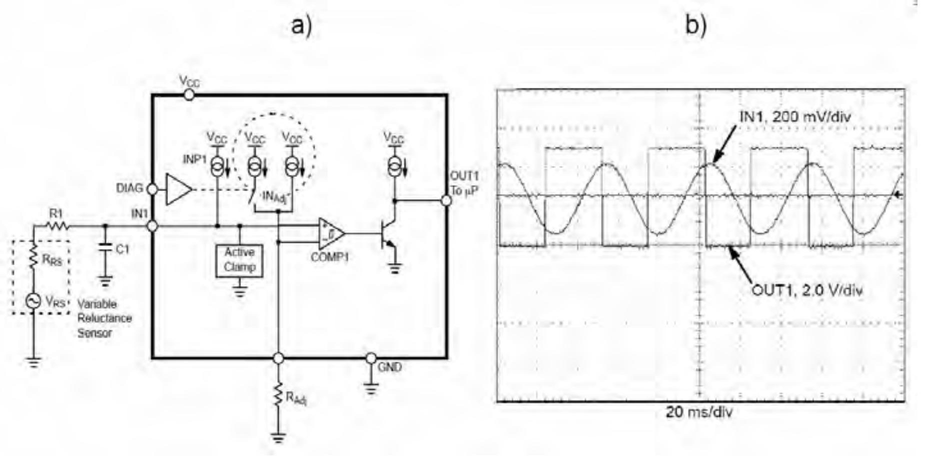

Fig. 8. Interface for variable reluctance sensors NCV1124. Application diagram (a) and signal trace fitted in TTL voltage range (b)

Sensors for temperature measurement with operating range width enough for most applications are TC1046 devices from Microchip Technology Inc. Temperature range for these devices is -40°C to 125°C. The correlation between temperature and output voltage is linear [5]. Some special sensors need special circuits for signal conditioning before introducing to microprocessor circuit. Variable reluctance sensors used for shaft speed-position recognition needs such special circuits. Figure 8 present the idea of circuit used for transforming variable reluctance sensor signal to TTL signal.

8. Data interchange in control systems consisting of multiple microcontrollers/intelligent sensors

When number of sensors in system is greater than number of build-in converter channels the wide range of sensors with I2C (TWI) or other communication interface may be used. Unfortunately the number of connected devices is limited mainly by range of accessible addresses. The worst situation concerns the RS232C interface, where only two devices may interchange data. Four often used data transfer buses are compared on figure 9.

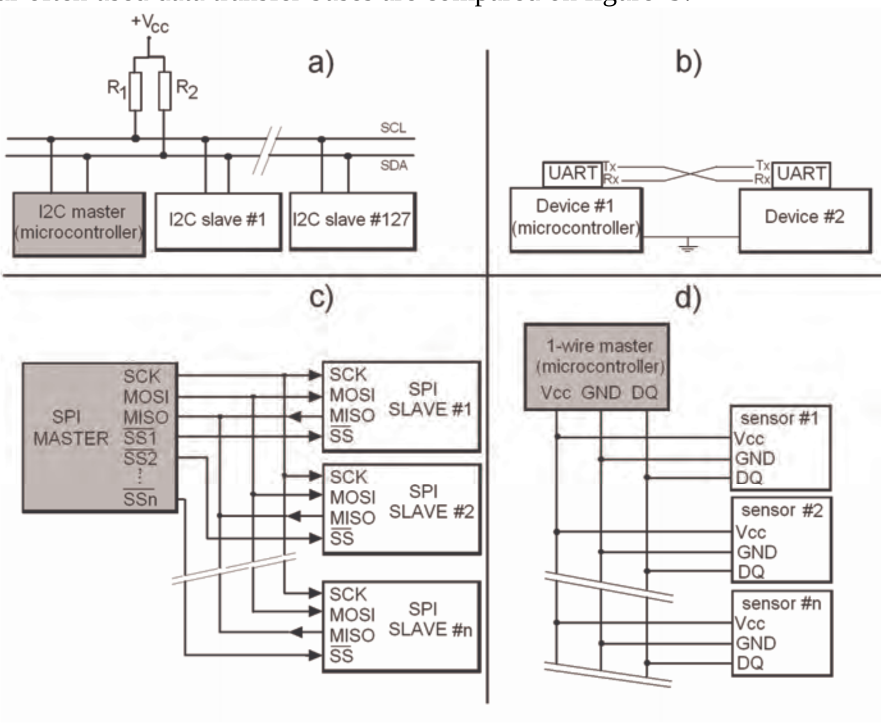

Fig. 9. Four most often used interfaces for data transfer in embedded systems: a- I2C (TWI) bus, b- RS232, c- serial peripheral interface (SPI), d- 1-wire interface for Maxim/Dallas devices

The serial interface in RS232C standard requires only three wires to establish bi-directional data transfer. For systems working at different supply voltages special circuits are necessary to provide compliance with the EIA232 standard. Such additional circuits (for example MAX232) may not be necessary if devices are close enough, and supply voltages for both are the same. The RS232C interface has strong hardware support in almost all microcontrollers and is easy for program implementation, but data transfer is possible only between two devices. Such restrictions are absent in other popular buses, but in these cases the software plays a greater role. One-wire bus developed by Dallas Semiconductors is dedicated to data interchange between one master unit and many slaves. Typical slave unit is well known precision temperature sensor DS1820. The data transfer speeds are lower than in other serial protocols. Big advantage of 1-wire bus is opportunity to reducing wires to one – data wire. Other role plays SPI bus. It is very popular in devices where memory cards are used for storing data. All MMC and SD memory cards may be accessed with SPI interface. The only limitations for number of slaves is the number of free pins in master unit, because all slaves are activated by low signal at their SS line. Most flexible of above interfaces is I2C interface, which requires only two pins in all devices connected to the bus. Other popular communication protocols like for example CAN widely used in automotive industry, are strongly supported by 8-bit microcontrollers too. Many solutions may be easy adopted for new requirements by selecting appropriate microcontroller. For example substituting of ATmega128 by AT90CAN128 gives possibility to introduce CAN bus communication without need of designing new PCB boards, because the AT90CAN128 is functionally pin compatible with Atmega128 [2]. Other communication protocols (including custom ones) are easy to realize by rather software than hardware implementation.

Some commercially available actuators have control interfaces supported by build-in controllers based on microcontrollers. For example VM114 micro actuator-driver is one channel, low voltage bi-directional motor driver with I2C interface [6]. Recently application of actuators with embedded controllers becomes very popular. Such devices reduces wiring problems thanks to simple interfacing with the main system controller by communication bus. Sample drives based on stepper motors but equipped with build-in controllers are presented on figure 10.

9. Conclusions

Modern 8-bit microcontrollers have many features typical for modern devices. They seems to be still attractive but not as main controllers. Their place in modern automation and control applications is rather in distributed systems as communication interfaces between controller and actuator. On the other hand their build-in devices allow for building small control systems equipped with sensors and actuators, in number limited by number of accessible pins.

Fig. 10. Drives consist of stepper motors equipped with controller, where microcontrollers are used to provide RS232C control interface [11]

Summarizing, the eight-bit microcontrollers play an important role in modern issues of automation and control. This is the result of still carried modernization of their internal structure by introducing new build-in devices providing support for new issues. Simple interfacing of intelligent sensors and actuators is a strong side of these devices.

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Modern 8-bit microcontrollers in automation and control of manufacturing processes

Abstract

The author presents some practical aspects of introducing eight-bit microcontrollers in to modern automation and control systems. Interfacing of typical actuators electrically controlled by insulating circuits is presented. The application of sensors with digital and analog nature of output signal is discussed too. Author demonstrated the usefulness of microcontrollers in control systems based on information interchange, where microcontrollers are best devices providing support for many communication protocols. Summarize, author indicates the eight-bit microcontrollers as very universal and easy in application devices.

Nowoczesne mikrokontrolery ośmiobitowe w automatyzacji i sterowaniu procesami wytwarzania

Autor przedstawia niektóre praktyczne aspekty wprowadzania ośmiobitowych mikrokontrolerów do nowoczesnych systemów sterowania i automatyzacji. W artykule omówione zostały podstawowe zagadnienia związane z podłączaniem do mikrokontrolerów typowych elektrycznych członów wykonawczych i czujników, zarówno cyfrowych jak i analogowych. Autor zwraca szczególną uwagę na zastosowanie mikrokontrolerów jako interfejsów wymiany informacji, ze względu na wsparcie sprzętowe od strony urządzeń wewnętrznych mikrokontrolerów, ułatwiających realizację sterowania opartego o wymianę informacji.

GRZEGORZ KŁOSOWSKI[1], Ph.D.

A fuzzy approach for works transport orders in discrete manufacturing systems

Introduction

Artificial intelligence applications in manufacturing systems control are quite popular. Particularly, fuzzy logic is often used in many kinds of decision support systems [1, 4, 5, 6, 7, 10]. Considering a single workstation in terms of its collaboration with the transportation system we can assume that the workstation should give a signal that it needs the transportation service in appropriate moment. The important questionconcerns thedesired kind of service in given moment: pick-up and/or deliver (P&D). The next question is:when the workstation should place an order for P&D service. In case of the flexible manufacturing systems (FMS) where the conveyors are used the answer is relatively easy to predict[8]. But in manufacturing systems equipped with works transport based on automated guided vehicles (AGV) or others free means of transport prediction of due times for P&D transport services is a challenge [9].

One of the possible solutions is thefuzzy logic controlleradoption [2, 3]. Fig. 1 presents a model of the Fuzzy Inference System (FIS) equipped with FLC. We make an assumption that each workstation has three sensors that give the pieces of information regarding progress of the current part processing, lag time of last pick-up service and the risk level. Those pieces of information are directed to FIS controller which transform them into two outputs: pick-up or delivery orders.

The FLC inputs are as follows:

- Progress: range from 0 to 100%. It reflects the progress of the part that is currentlymachined in given workstation,
- Pick-up-time: range from 0 to 100%. The time progress that passed from the last lot (transportation unit) completion. It equals 100% when the time reaches the lot processing time.
- Risk: range from 0 to 1. The formulas are shown in Equations (1) and (2)

There arethe following outputs:

- DELIVERY: range from -1 to 1. It reflects the delivery urgency. If the value is positive the need of delivery service is reported. The urgency of service is proportional to the output value.

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- PICK-UP: range from -1 to 1. It reflects the pick-up urgency. It works similarly to Delivery output.

FLC together with its immediate environment make up Fuzzy Inference System (FIS). The general design of FIS controller presented in Fig. 1 is the same for both cases of FLCs presented in this paper.

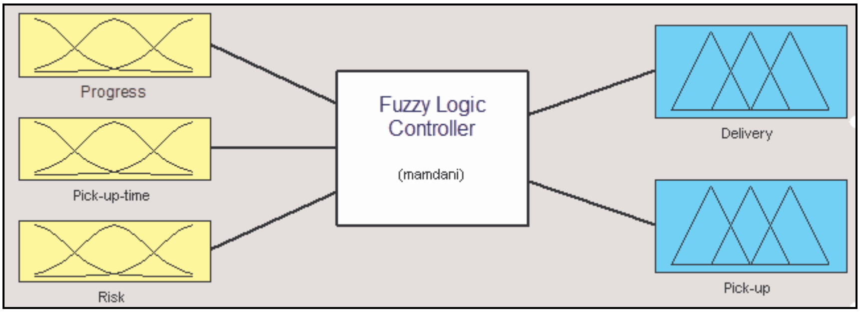

Fig. 1. Fuzzy Inference System (FIS)

Risk calculation ways

As it was mentioned above one of the input values of FIS controller is the Risk. Two ways of the Risk calculation were proposed. First formula (1) considers the number of parts remaining before processing with the current lot l_p at the time of delivery and the number of parts in the lot p_t.

$$R_{lin} = 1 - \frac{l_p}{2p_t}$$

$$R(l_p, p_t) = \begin{cases} 0 & R < 0 \\ R & 0 \le R \le 1 \\ 1 & R > 1 \end{cases} \tag{1}$$

where: R – delivery risk

l_p – the number of parts remaining to be processing with the current lot at the time of delivery

p_t – number of parts in the lot

The graphics interpretation of formula (1) is shown in Fig. 2. The formula is rather simply and it has linear “threshold” character.

Another way of Risk calculation is presented in formula (2). There are two main differences in comparison to the previous one. First of all the formula (2) is exponential. The second difference is p_t parameter omission. Like previous one the formula (2) was designed experimentally. Especially exponential denominator “4” was important because of its impact on the shape of the curve (Fig. 2). The graphics interpretation of formula (1) is shown in Fig. 2. The smaller denominator causes the dipper deflection of the curve. It reproduces the dynamics of Risk change in relation to the number of parts remaining before processing with the current lot at the time of delivery.

$$R_{\exp(l_p)} = e^{-l_p/4} l_p \geq 0 \tag{2}$$

where: R – delivery risk

l_p – the number of parts remaining to be processing with the current lot at the time of delivery

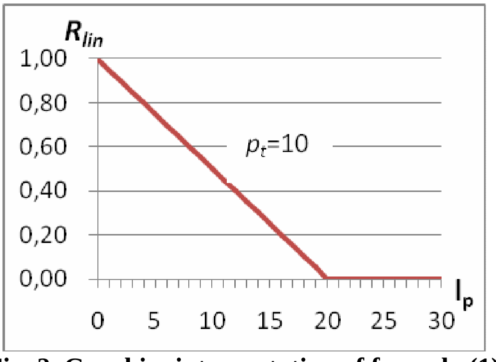

Fig. 2. Graphics interpretation of formula (1)

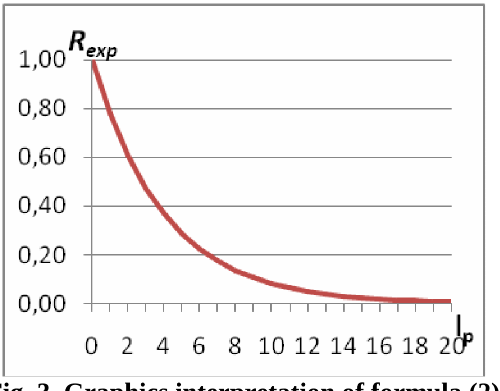

Fig. 3. Graphics interpretation of formula (2)

FIS controllers design

As it was mentioned above two FIS controllers were designed. The first one, let’s call it FIS-LIN (because it works with R_{lin} formula) transform PROGRESS input information according to the membership functions presented in Fig. 4. By the way, exactly the same transformation in the second FIS controller (lets’ call it FIS-EXP because of $R_{\exp}$) was implemented.

The serious differences between FIS-LIN (see Fig. 5) and FIS-EXP (see Fig. 6) starts in the membership functions of PICK-UP-TIME. It can be easily observed that the shapes of plots are different. Another significant difference is an additional membership function in FIS-EXP called “Average”. PICK-UP-TIME input is mostly responsible for pick-up services. Possible lag regarding pick-up can cause excessive stock accumulation. This phenomenon is less dangerous as delivery raw parts delay which can seriously disturbentire production flow.

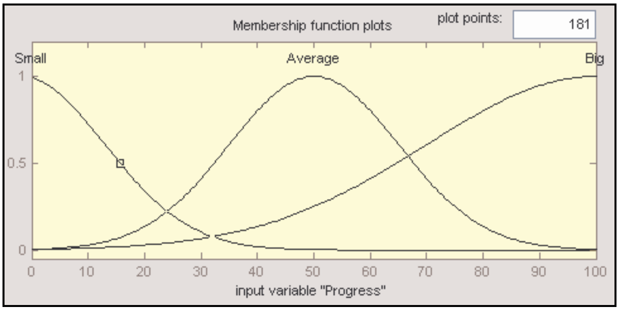

Fig. 4. Membership function plots of PROGRESS input

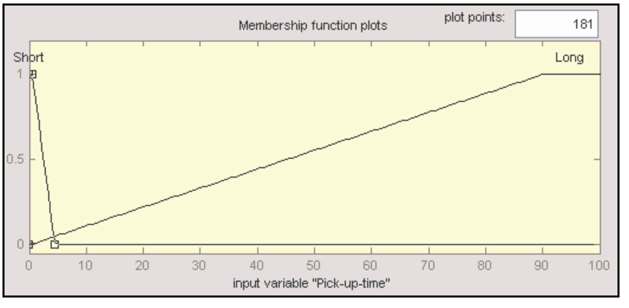

Fig. 5. FIS-LIN: membership function plots of PICK-UP-TIME input

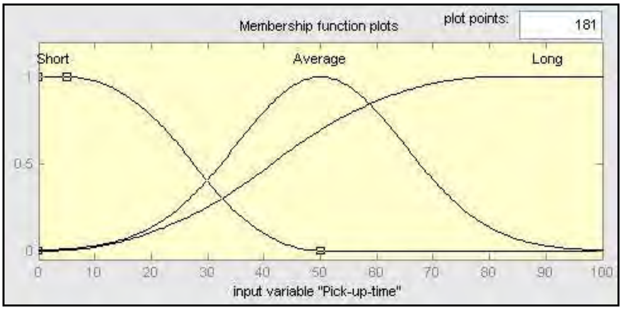

Fig. 6. FIS-EXP: membership function plots of PICK-UP-TIME input

Next input is called RISK. The risk calculation method was described above but this parameter is transformed by membership functions of FIS controllerlater on. The membership function plots of RISK in FIS-LIN are presented in Fig. 7. Fig. 8 showsthe similar values for FIS-EXP.

Finally, the outputs are visible in Fig. 9 and Fig. 10. The differences concern the membership functions. Gaussian functions give more smooth reactions on the tops and bottoms of the curves. It is really difficult to answer the question how it would impact the manufacturing system efficiency. It seems that the good way to select the best courses of membership functions is the computer simulation.The same is true of the membership function for input and output FIS controller. So far, no strict membership function selection methodhaven been developed. Hence the need to seek the best solutions are often based on experts experience and knowledge of researchers.

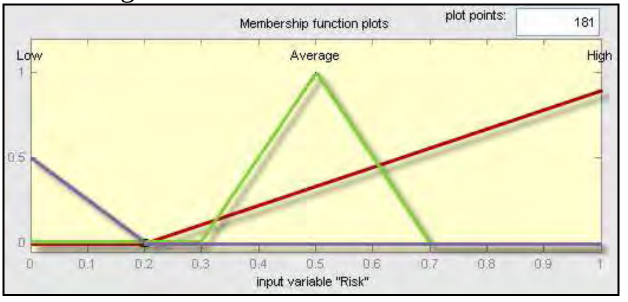

Fig. 7. FIS-LIN: membership function plots of RISK input

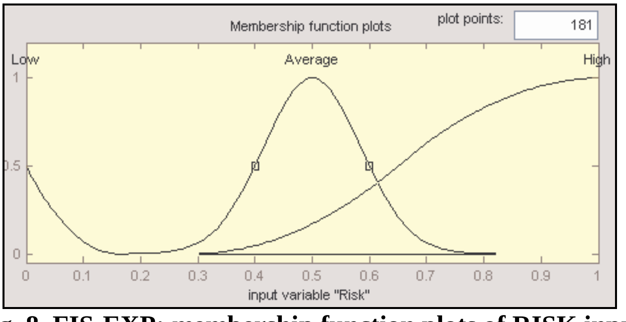

Fig. 8. FIS-EXP: membership function plots of RISK input

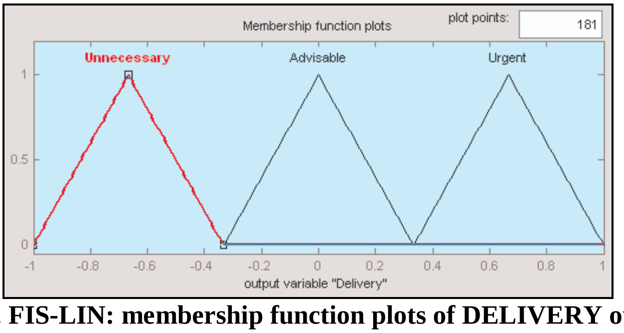

Fig. 9. FIS-LIN: membership function plots of DELIVERY output

All the above-described differences in the controller structurewere designed in order to develop better tools for managing internal transport. Due to the large and indefinite number of variables, it is difficult to develop a mathematical formula describing the dependencies within the manufacturing and transportation systems. For this reason, in many cases it is easier to use methods based on artificial intelligence. An additional argument is an opportunity to test the developed solution by means of computer simulation technologies.

We should be reckoned with the fact that even when using artificial intelligence methods we can fail to develop a universal controller. In practice, this may mean that any manufacturing and transportation systemswill require a separate developed and dedicated controller. However, taking into account the potential benefits (e.g. cost savings, inventory reduction, ensuring of production continuity, etc.), this inconvenience does not seem to be too severe.

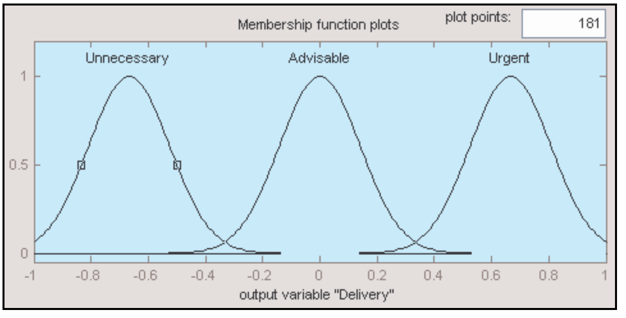

Fig. 10. FIS-EXP: membership function plots of DELIVERY output

Fig. 11 and Fig. 12 present the surface of PICK-UP outputs with respect to two inputs: RISK and PICK-UP-TIME. The shapes of the surfacesdependon not only the membership functions but also on the fuzzification rules (Frames 1 and 2).

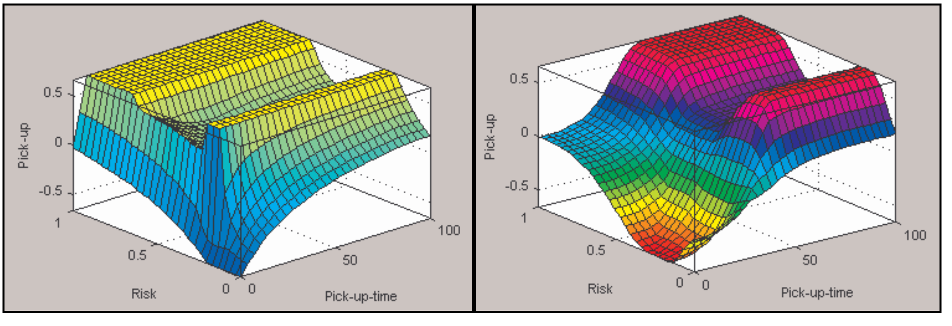

Fig. 11. Membership function plots of PICK-UP output in FIS-LIN (left) and FIS-EXP (right)

Frame 1 presents the set of fuzzification rules that are implemented in the FIS-LIN. There are six rules that consist of the linguistic variables. All of them have*what-if* character. This type of the computer programming language statement is a typical form of software based on fuzzy logic technologies. Because of linguistic form the fuzzification rules are easy to understand for persons who are not very familiar with computer programming. The *Then* word is a point that splits the fuzzy rules into two parts.

Frame 1. Fuzzification rules in FIS-LIN

1. If (Progress is Small) or (Risk is Low) then (Delivery is Unnecessary)
2. If (Progress is Average) or (Risk is Average) then (Delivery is Advisable)
3. If (Progress is Big) or (Risk is High) then (Delivery is Urgent)
4. If (Pick-up-time is Short) or (Risk is Low) then (Pick-up is Unnecessary)
5. If (Pick-up-time is Long) or (Risk is High) then (Pick-up is Urgent)
6. If (Progress is Average) and (Pick-up-time is Long) and (Risk is Average) then (Delivery is Advisable)(Pick-up is Advisable)

The left part tests variables and their properties. The right part consists of the inferences. The typical form of fuzzy rule is as follows: IF *variable* IS *property* THEN *action*.

Frame 2. Fuzzification rules in FIS-EXP

1. If (Progress is Small) or (Risk is Low) then (Delivery is Unnecessary
2. If (Progress is Average) or (Risk is Average) then (Delivery is Advisable)
3. If (Progress is Big) or (Risk is High) then (Delivery is Urgent)
4. If (Pick-up-time is Short) or (Risk is Low) then (Pick-up is Unnecessary)
5. If (Pick-up-time is Long) or (Risk is High) then (Pick-up is Urgent)
6. If (Progress is Average) and (Pick-up-time is Long) and (Risk is Average) then (Delivery is Advisable)(Pick-up is Advisable)
7. If (Pick-up-time is Short) and (Risk is Low) then (Pick-up is Advisable)

FIS-EXP has more rules than FIS-LIN. It was caused by the fact that the risk parameter was calculated without information about the number of parts in the lot (see above variable p_t).

Comparative experiment

In order to compare and evaluate the effectiveness of both FIS controllers two simulation experiments was performed. In each experiment the different FIS controllerwas examined: FIS-LINandFIS-EXP. The object of the simulation was manufacturing system with implemented driver. The manufacturing system consisted of the 20 workstations located on the workshop as it is shown in Fig. 12.

The primary goal was the fuzzy controllers to maintain continuity of work by all workstations. Another objective was to maintain buffer stocks level as low as possible. The final criterion was to fulfill the two previous criteria, with minimal occupancy of the mean of transport. This occupancywas measured by ratio of the duration of the entire simulation (8 hours) to the utilization time of the carrier (i.e. the time when the carrier was in motion).

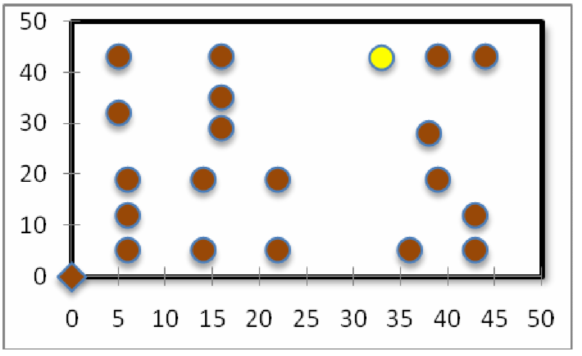

Fig. 12. Topology of the manufacturing system

When the simulation finished the huge set of data was collected. Because of limited space of this paper, only the results taken from one workstation could be presented. The workstation with coordinates (33; 43)was chosen. It is marked yellow in Fig. 12.

The simulation software collected all the data discretized with sampling time in seconds. Fig. 13 and Fig. 14 show the RISK curves during the work shift (8 hours = 28 800 seconds). The horizontal axis represents the simulation time.Let's take a closer look to the risk parameter in FIS-LIN. The risk level (vertical axis) starts from 0,5. It is the initial value of this parameter. The first change took place after about 1000 seconds (about 17 minutes). In that moment the first delivery service happened. This phenomenon can be observed in Figs. 17, 21 and 23, too. The horizontal dotted line shows the mean value of risk parameter. This line starts after the first service occurrence because the includingof the initial (so artificial)value of risk was not our intention.

Fig. 14 shows the same risk parameter but for the FIS-EXP. The different (exponential) formula without p_t (number of parts in the lot) argument caused the different curve. The most significant difference is the fact that in this case the vertical axis values (RISK) are very small. The numbers visible on the vertical axis are multiplied by 10^{-8}.

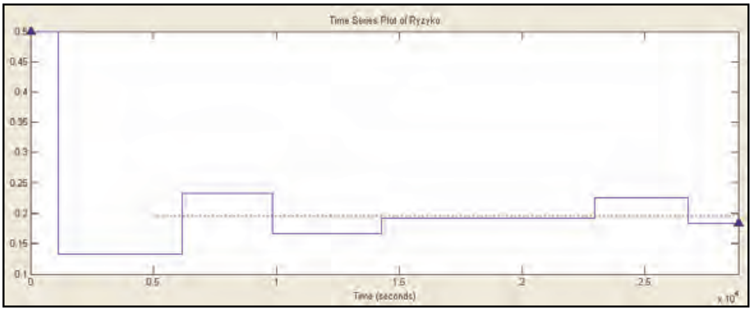

Fig. 13. FIS-LIN: Risk level in workstation No. 2 during simulation

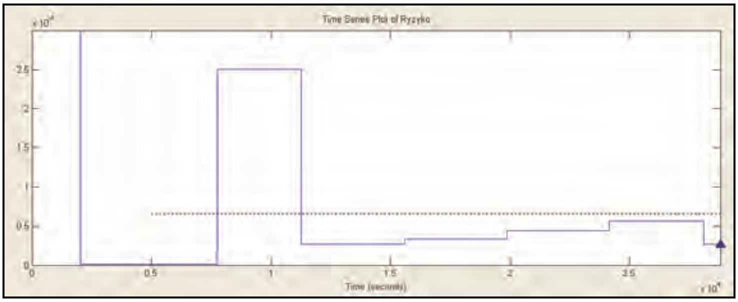

Fig. 14. FIS-EXP: Risk level in workstation No. 2 during simulation

The FIS-EXP controller ordered the first delivery later that FIS-LIN. Yet, the risk level was so low the fuzzy controller was able to keep it stabile during entire time of simulation. We can deductboth ways of risk calculation seemed to be efficient. It can be a premise to draw a conclusion that the fuzzification rules are more important than the risk formulas.

The next pair of figures (Fig. 15 and Fig. 16) presents the stock level in workstation No. 2after processing. Fig. 15 shows that six pick-up operations was completed. Vertical axis shows ne number of waiting parts that should be picked-up. The highest pick of the curve shows the number close to 85. It means that 85 parts were waiting for transport after processing. The mean value (dotted line) indicates slightly below 40 parts.

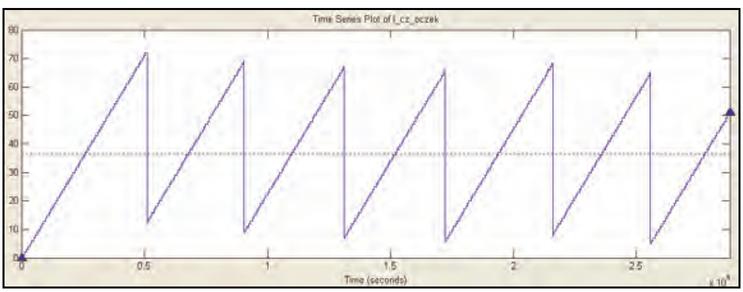

Fig. 15. FIS-LIN: Stock level in workstation No. 2 after processing

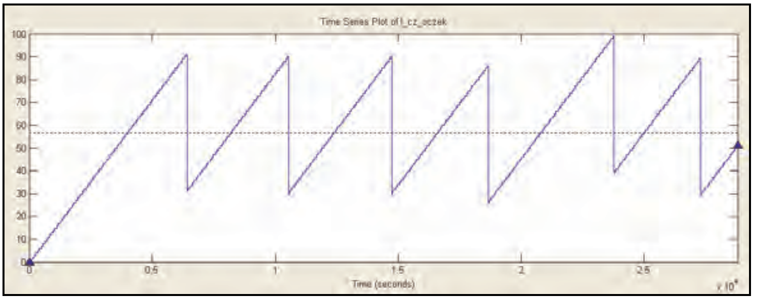

Fig. 16. FIS-EXP: Stock level in workstation No. 2 after processing

Fig. 16 is analogous to Fig. 15 but it is originated from FIS-EXP. At the first look we can see that the mean stock level was significantly more than 50 and the maximum stock level reached 100 parts. Those both values are worse than in the previous case where FIS-LIN controller was discussed. It can prove that the parameter p_t (number of parts in the lot) was important to efficiency and to omit it would bea mistake.

Another pair of figures (Fig. 17 and Fig. 18) are dedicated to stock level in workstation No. 2before processing. This parameter is really important for manufacturing systemefficiency. Vertical axis shows the stock level as a number of pieces. The horizontal axis presents time of simulation. As we previously admit the stock level in relation to the number of parts that are waiting to be processed plays the crucial rule. It is because in case of lack of the parts the workstation would have to stop. In consequence the production flow could be disturbed.

Fig. 17 and Fig. 18 shows that during entire simulationthe workstation No. 2 didn’t stop because of lack of part beforemachining. The proof is the minimum stock level. Fig. 17 in relation to FIS-LIN presents that the minimum stock level was slightly above 30. The mean stock level was almost 70 parts.

This time the better results was obtained from FIS-EXP (Fig. 18). The minimum stock level was 10 parts and the mean stock level was less than 50 parts. Similarly, the maximum stock level of FIS-LIN was more than 100 parts and FIS-EXP was about 90 parts. It proves that FIS-EXP is better solution in this case.

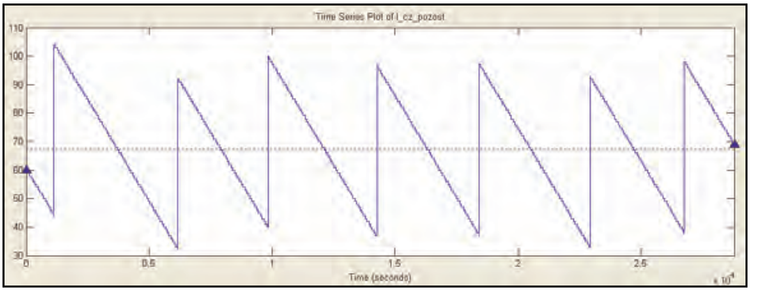

Fig. 17. FIS-LIN: Stock level in workstation No. 2 before processing

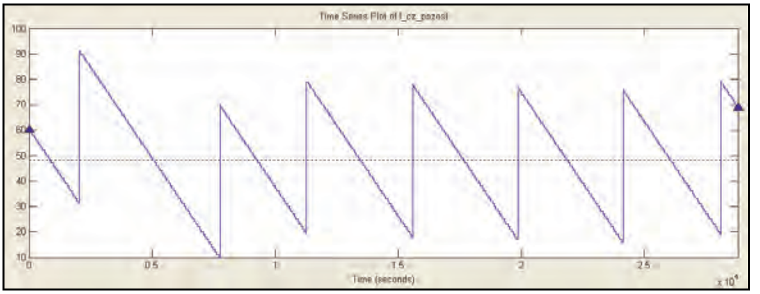

Fig. 18. FIS-EXP: Stock level in workstation No. 2 before processing

Another portion of information is gathered from the outputs of FIS controller. We can make a plot of signals that are generated by the outputs in relation to simulation time. First of all we can analyze the output signal called PICK-UP. The signal is a real number $\langle -1; 1\rangle$. The pick-up order is generated when the signal is positive. Negative signals don't cause any transport activity. Because the signal is a real value it is possible to sort the vector of the many signals collected from a great deal of workstations. It is an additional virtue.

Both plots (Fig. 19 and Fig. 20) show the output PICK-UP values for workstation No. 2. Fig. 19 is dedicated to FIS-LIN and Fig. 20 to FIS-EXP. The vertical axis presents the level of signal and the horizontal axis shows the running time of simulation.

Let's take a closer look at FIS-LIN case (Fig. 19). The six pick-up services was done. The first pick-up service took place after 5000 seconds from the beginning of simulation. Fig. 19 corresponds to Fig. 15 (mentioned above) because both of them presents the similar transportation activity. Fig. 19 shows that the mean level of signal was about -0,3. The maximum and minimum signal levels were 0,7 and -0,7.

The same applies to Fig. 20 and Fig. 16. Those figures are dedicated to FIS-EXP. Both of them shows that the first pick-up service took place about 6500 seconds after the simulation began. It can be noticed that six pick-up services was completed. The global minimum signal level oscillates around -0,65 and the maximum is about 0,17. The mean signal level value is about -0,42. This indicates that most of time of entire simulation any pick-up services were not needed.

The height of plot picks reflect the waiting time for pick-up service. The general rule is: the bigger pick the longer wait. Another interesting observation refers to the width of the picks. It is easily observed that the picks in Fig. 19 are thinner than picks in Fig. 20. It could mean that FIS-EXP activity could cause longer waiting times. Actually, this quick thesis doesn't appear to be truth. The crucial detail we shouldn't forget is a fact that examination of waiting pick-up times of both figures should be lead atthe level of "0" (zero)horizontal line. This detail becomes especially important in Fig. 20. The irregular shape of plot causes significant differences of thickness in various cross-sections of the picks.

The final conclusion is that both figures (Fig. 19 and Fig. 20) give the similar pick-up signals that cause congenial waiting periods for pick-up services.

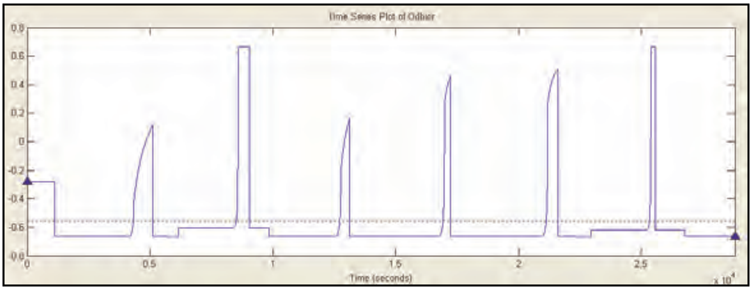

Fig. 19. FIS-LIN: Output PICK-UP values for workstation No. 2

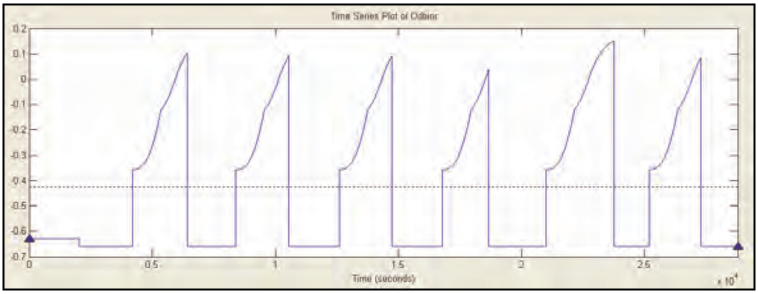

Fig. 20. FIS-EXP: Output PICK-UP values for workstation No. 2

The next pair of plots covers Fig. 21 and Fig. 22. They show the FIS output signal levels for DELIVERY transport service. Just as above the signal is a real number $(-1;1)$. The delivery order is generated when the signal is positive. Negative signals don't cause any transport activity. Both plots (Fig. 21 and Fig. 22) show the output DELIVERY values for workstation No. 2. Fig. 21 is dedicated to FIS-LIN and Fig. 22 to FIS-EXP. The vertical axis presents the level of signal and the horizontal axis shows the running time of simulation.

Let's take a closer look at Fig. 21 (FIS-LIN). Six delivery services was done. The first delivery service took place after 1200 seconds from the beginning of simulation. Fig. 21 corresponds to Fig. 17 (mentioned above) because both of them presents the similar transportation activity. Fig. 21 shows that the mean level of signal was about -0,5. The maximum and minimum signal levels were accordingly 0,1 and -0,66.

The same applies to Fig. 22 and Fig. 18. Those figures are dedicated to FIS-EXP. Both of them shows that the first delivery service took place about 2000 seconds after the simulation began. It can be noticed that seven delivery services was completed. The minimum signal level oscillates around -0,65 and the maximum is about 0,17. The mean signal level value is about -0,42.

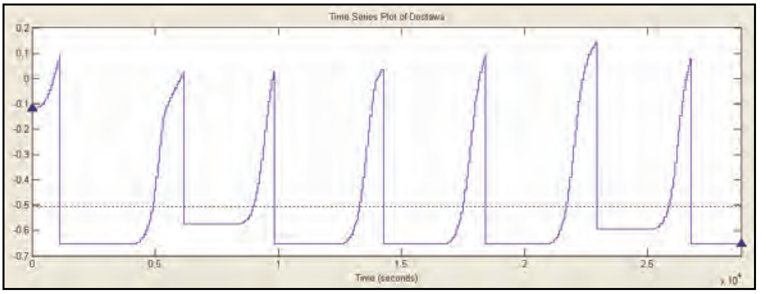

Fig. 21. FIS-LIN: Output DELIVERY values for workstation No. 2

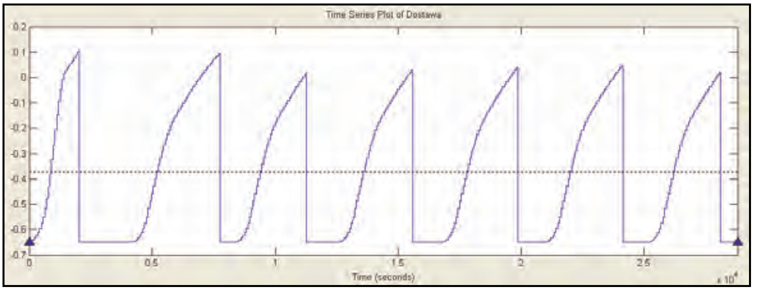

Fig. 22. FIS-EXP: Output DELIVERY values for workstation No. 2

CONCLUSION

In this paper the comparison of two kinds of FIS controllers was conducted. In terms of production system the 8 hour work shift was simulated. The fuzzy controller called FIS-LIN run with linear risk formula (1) and with mostly linear membership functions. The second FIS controller called FIS-EXP run with exponential risk formula (2) and with mostly Gaussian-type membership functions.

As a result of simulation experiments it appeared that both ways of risk calculation seemed to be efficient. It seemsthat more important than risk formulas are the fuzzification rules. The less (desirable) stock level before processing wasobtained from FIS-EXP. It proves that FIS-EXP controllerwas better solution in that case.

Really important and good news was that both FIS controllers didn't cause a production break as a result of lack parts for machining. It is quite possible that fuzzy controllers tuning conducted by membership functions and inputs formulas (e.g. risk parameter) adjusting is suitable for final tuning. The bigger changes in FIS action mode are possible to obtain mostly by profound changes including inputs and outputs.

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Abstract

This paper presents a description of a Fuzzy Logic Controller(FLC) designing way in terms of manufacturing system. The main goal of the FLC is to make right decision in accurate moment regarding pick or deliver (P&D) parts to given workstation. FLC copes with the works transport subsystem to obtain maximum manufacturing efficiency. The main focus of the research is placed on two different FLC modelscomparison. Each FLC is evaluated using computer simulation. The results of both simulation experiments were presented and conclusions were formulated.

Keywords: Fuzzy logic, Transport control, Simulation; Order picking; Production management.

ARKADIUSZ GOLA

Module of Generation of Technological Paths in the Program of Computer Aided Machine-Tools Selection in Casing-class FMS

Introduction

One of the key problems in the area of flexible manufacturing systems (FMS) design remains the issue of design of manufacturing subsystem and especially machine tools selection for designed FMS. This is the first step in the process of system design, which in great majority decides of its effectiveness. Proper (optimal) selection of machine tools subsystem can both considerably reduce investment costs for building and lead to minimization the costs of system exploitation or maximization the level of making use of machines. The purchased machinery stock directly determines the efficiency, automation and flexibility level of the whole FMS, and simultaneously is a start position for designing residual subsystems of flexible manufacturing system [1].

The problem of computer aided machine tools selection, since the late 1980s, has been one of the most important research area in the subject of design and increasing effectiveness of manufacturing systems. The result of provided research works was forming many solutions based among others on integer programming models, diagraph and matrix methods [2], heuristic algorithms, expert systems [3], fuzzy MCDM methods [4], artificial immune systems, genetic algorithms add ant algorithms [5], methods from family of Multi-criteria decision analysis (MCDA) such as: goal programming, analytical net processing (ANP), analytical hierarchy processing (AHP), PROMETHEE, ELECTRE [6], and also methods of random searching [7].

In the article the conception of computer aided casing-class FMS machine tools selection using the authorship program <<OPTSELECT>> was presented. The program was based on the methodology which realizes the selection process using the evolutionary system of multicriteria analysis <ESAW>. In particular the module of generating technological paths which is a part and a parcel of mentioned program, was presented.

1. Algorithm of machine tool selection in casing-class FMS

The <<OPTSELECT>> program of computer aided machine tool selection in casing-class FMS was developed on the base of methodology presented in works [8,9]. The selection process is realized according to the four-stages algorithm presented in fig. 1.

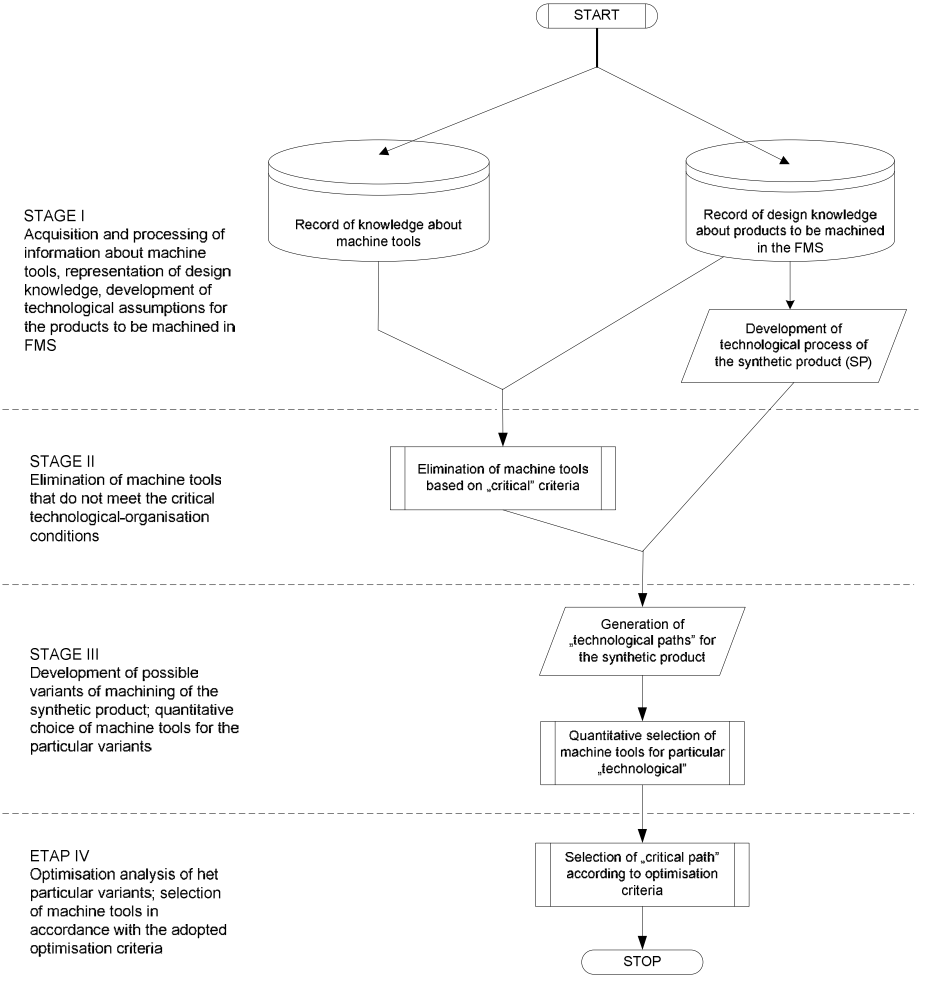


Fig. 1. Main algorithm of the methodology of machine tool selection in casing-class FMS [8,9]

The first step in the process of selection is the preparation of a record of knowledge about all machines tools from among which the choice is to be made $O = \{o_1, o_2, \ldots o_n\} = \{o_i\}$, products to be machined in the FMS being designed W= $\{w_1, w_2, \ldots, w_t\} = \{w_\alpha\}$ and development and saving of technological process of the synthetic product (SP).

In the second stage is realized elimination from the O database of those machine tools that are incapable of producing the parts that are to be machined in the system, based on certain limit criteria ("critical" criteria). In accordance with the adopted assumptions, we should eliminate from the database those machine tools that:

1. Do not meet the limit conditions resulting from the technical parameters of products to be machined in FMS.
2. Do not meet the limitations imposed by the user and/or designer of the flexible manufacturing system.
3. Do not have the design-technological capabilities to perform the machining operations provided for realization within the process of manufacturing.

Those machine tools that „remain" in the database after the stage of elimination constitute of set of machine tools that are taken into consideration at further stages of selection ($X = \{x_1, x_2, \ldots x_m\} = \{x_k\}$).

Obrabiarki spełniające założenia krytyczne zapisywane są w zbiorze maszyn technologicznych $X = \{x_1, x_2, \ldots x_m\} = \{x_k\}$. On the base of X set and the developed technological process of synthetic product the A_{kj} [0-1] matrix of machine tools capabilities is generated. The matrix defines which of the machine tools has the ability to realize specified cut from the technological process of WS.

In the stage three the generation of technological paths and the quantitative selection of machine tools for particular technological paths is realized. Technological paths determines possible ways of going the synthetic product through the system, i.e. following machine tools which realizes following cuts in the technological process of WS. Technological paths and the results of quantitative selection of machine tools which is realized using the method of balancing the burden level of particular machine tools with the manufacturing tasks forms solutions to be analyzed in fourth stage of methodology.

The last step in the process of selection is a choice the best solution using the accepted criteria of evaluation. The optimization criteria (target functions) in presented model are as follows:

1) Minimisation of total costs of machine tools acquisition and operation (per annum) calculated using formula (1):

$$F_1(M_\mu) = \sum_{k=1}^{m} \{L_k[(C_k * a_{ok}) + k_{sk}]\} \rightarrow \min \qquad (1)$$

where: L_k – number of *k* machine tools

C_k – total purchasing price of *k* machine tool,

a_{ok} – annual depreciation rate of *k* machine tool,

k_{sk} – average annual cost of service for *k* machine tool.

2) Minimization of time of machining (throughput time) of synthetic product (exclusive of inter-cut transport and storage operations time) – calculated using formula (2):

$$F_1(M_\mu) = \{[\max(t_{wnk}; t_{wpk}) + t_{1k}] + \sum_{j=2}^{z} \{\lambda * \max(t_{wnk}; t_{wpk}) + [(1-\lambda) * t_{wnk}] + t_{jk}\}\} \rightarrow \min \tag{2}$$

where:

value λ assumes the following values:

$$\lambda = \begin{cases} 0 & \text{, when cut } \delta_j \text{ is realized on the same machine tool as cut } \delta_{j-1} \\ 1 & \text{, when cut } \delta_j \text{ is realized on another machine tool than cut } \delta_{j-1} \end{cases}$$

t_{wnk} – tool change time „from chip to chio" on *k* machine tool,
t_{wpk} – technological palette change time on *k* machine tool,
t_{1k} – unit time of realization of first operations in technological process of synthetic product on *k* machine tool,
t_{jk} – unit time of realization of *j* cut on *k* machine tool.

To solve the task of optimization the Evolutionary System for Multicriteria Analysis <ESAW> was used. The system takes advantage of many different cooperating with each other methods and enables to generate one solution or small set of solutions, optimal in Pareto sense which are not much sensitive for changing the preferences for criteria given by experts.

The result obtained as a consequence of realization the procedure of selection is the solution in form of one or more technological paths with equal vector or vectors which are the result of quantitative selection of machine tools. The same the solution indicates simultaneously the type and number of machine tools, which allow for machining all casing-class products intended to be machined in the system in proper quantity, meet the requires defined by the system's designer and are optimal from the target functions point of view defined as a minimum cost of purchasing and service of machine tools and minimum throughput time for synthetic product in designed flexible manufacturing system.

3. The structure and functions of computer program for casing-class FMS machine-tool subsystem selection

The developed on the base of conception of methodology of casing-class FMS machine-tools selection, presented in point 2, computer program <<OPTSELECT>> has the ability to complex gathering and processing data, in the way which allows to select in optimal way (for defined constraints) machine tools for designed FMS. The structure of the program containing the notation of streams of data flow, was presented in fig. 2.

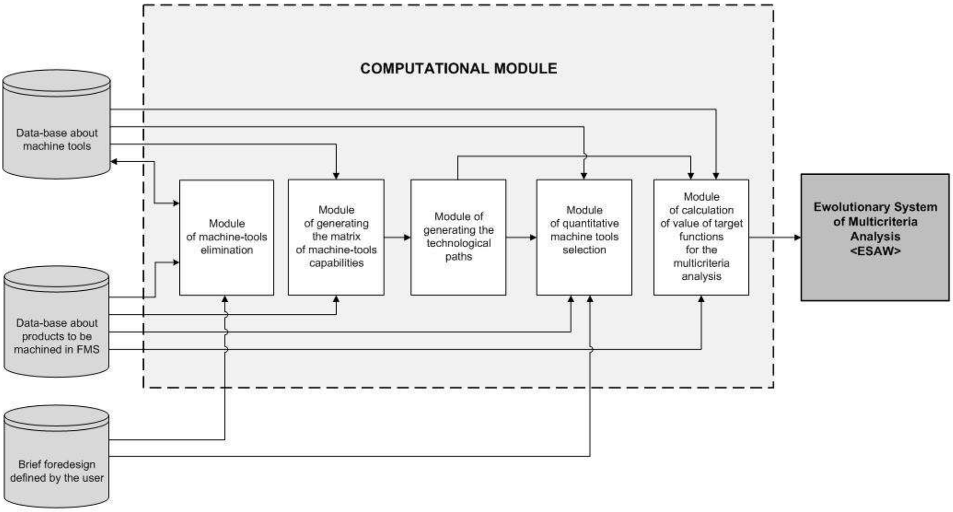


Fig. 2. Structure of the <<OPTSELECT>> computer program

The whole program was developed using the database system MS Access (data-base modules, module of machine tools' elimination, module of generating the matrix of machine tools' capabilities) and the program for engineering analysis MATLAB (module of generating technological paths, module of calculation of value of target functions for the multicriteria analysis). The Evolutionary System of Multicriteria Analysis <ESAW> was programmed in the FORTRAN language and it is an independent module which allows to find the best (suboptimal) solution or solutions from the defined optimization criteria point of view. The data exchange between particular modules is realized by the direct data import.

Taking advantage of the program begins using the main panel of the system's user from which one can enter directly to particular modules of the <<OPTSELECT>> program. The interface of the main panel of the program was presented in fig. 3.

3. The problem of generation of technological paths

One of the key problem in realization of algorithm presented in point 2 is generation of technological paths on the base of generated matrix of machine-tools capabilities (stage III). The issue of the problem boils to developing all possible ways of machining the synthetic product using the machine tools which remained after the elimination process and creates the $X = \{x_1, x_2, \ldots x_m\} = \{x_k\}$ with the constraint of reduction the number of solutions for that with the least number of fix operations in technological process.

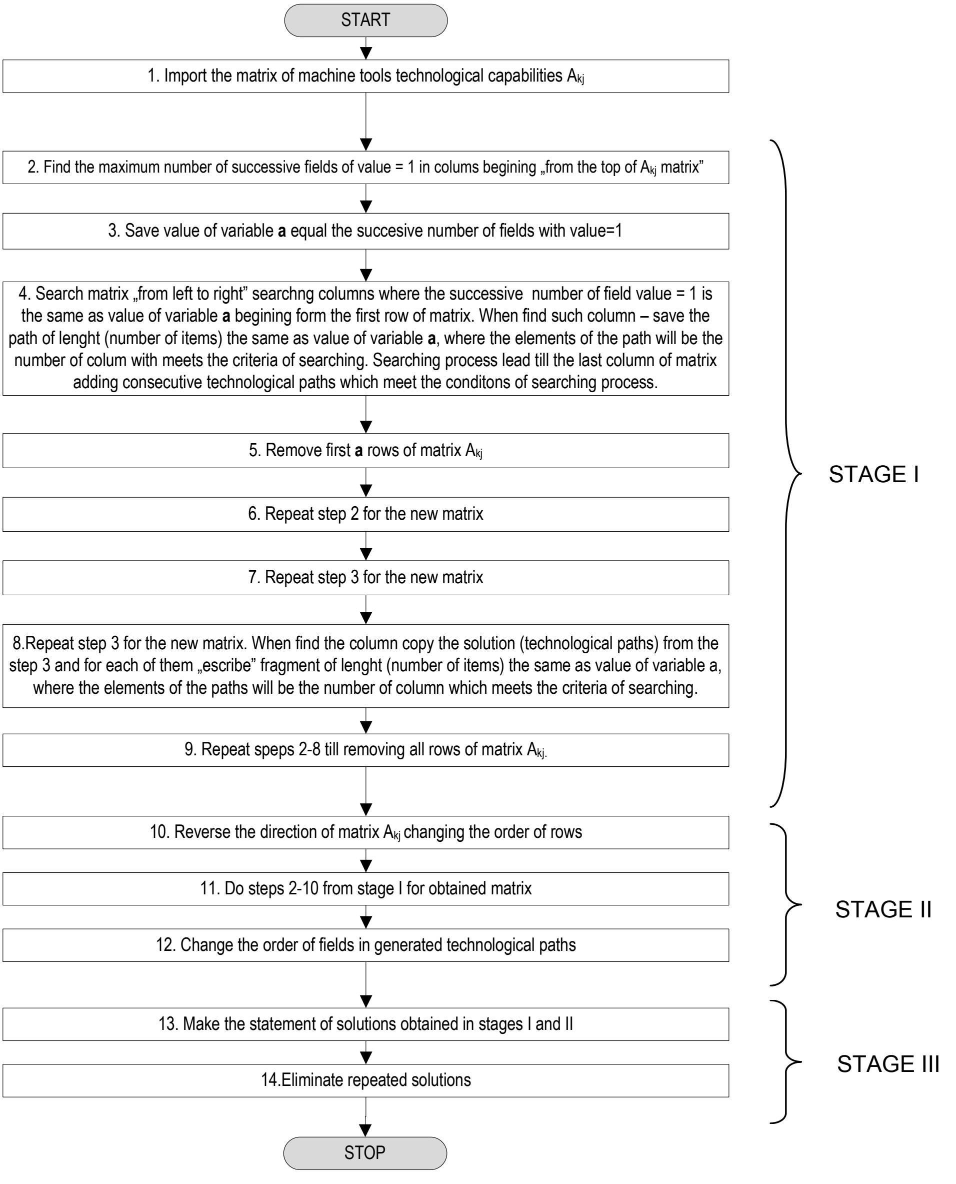
Fig. 3. The view of main panel of the <<OPTSELECT>> program

The matrix of technological capabilities of machine tools is a [0-1] matrix with number of rows adequate with the number of cuts in the technological process of synthetic product $\Delta = \{\delta_1, \delta_2, \ldots, \delta_z\} = \{\delta_j\}$ and number of columns adequate with the quantity of X set (fig. 4). The value 1 in field of matrixA_{kj} indicates the x_k machine tool has technological capability to realize the δ_j cut – value=0 means that it hasn't such capability.

$$
A_{kj} = \begin{array}{c} \\ \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \\ \\ \delta_z \end{array}
\begin{array}{c} \begin{array}{cccccccc} x_1 & x_2 & x_3 & x_4 & x_5 & \ldots & x_m \end{array} \\
\left[\begin{array}{ccccc:c}
0 & 0 & 1 & 0 & 1 & 1 \\
1 & 1 & 1 & 1 & 0 & 1 \\
0 & 1 & 1 & 1 & 0 & 1 \\
0 & 1 & 1 & 0 & 1 & 1 \\
1 & 0 & 1 & 0 & 1 & 1 \\
1 & 1 & 0 & 1 & 1 & 1 \\
\hdashline
1 & 0 & 1 & 0 & 1 & 1
\end{array}\right] \end{array}
$$

Fig. 4. The shape of matrix of machine tools technological capabilities A_{kj}

In order to solve the problem presented in point 3 the algorithm which allows to generate technological paths with minimum number of fix operations was developed. The ideological run diagram of the algorithm was presented in fig. 5.



Rys. 4. Algorytm generowania ścieżek technologicznych

The essence of the algorithm was based on assumptions of heuristic methods, what gave the possibility to avoid the necessity of searching all possible solutions, making the searching process much more faster. The essence of utilized heuristic is different than classical model used in heuristic method, where the space of searching is reduced but utilized method of searching stay the same as in searching the whole space. In developed algorithm, the paradigm of searching strategy was changed by using the method which is based on the incremental generating of solutions, what in consequence leads to sequential reduction of analyzed space of potential solutions.

4. Module of generation of technological paths in <<OPTSELECT>> program

The superior target of the module of generation of technological paths is developing technological paths basing on generated in MS Access program matrix of technological capabilities of machine tools Akj in accordance with the algorithm presented in point 3. This module was programmed in MATLAB programming environment and consists of superior program sciezki_general.m (fig. 5) and two second-class functions sciezki_I.m (fig. 7) i sciezki_II.m (fig 6).

It is possible to run the module directly by opening the file sciezki_general.m or (what is made in application environment) by starting the file OPTSELECT_2.m which run sequently modules of generation of technological paths, quantitative machine tools selection and calculating the value of target functions.

An example of solution obtained using the module of generation of technological paths was shown in fig. 8.

```
function  y = sciezki_general()

macierz = gola_access()

 macierz_flip = flipdim(macierz,1);

 sciezki_A = sciezki_I(macierz);
 sciezki_B = flipdim(sciezki_I(macierz_flip),2);

 [a b] = size(sciezki_A);
 for i = 1 : a
     if sciezki_B(1,:) == sciezki_A(i,:)
         sciezki = sciezki_A;
         y = sciezki;
         return
     end
 end

 sciezki = cat(1, sciezki_A, sciezki_B);
 y = sciezki;
```

Fig 5. Main function of algorithm of generation of technological paths

```
function [x y] = sciezki_II(macierz)
[il_operacji il_obrabiarek] = size(macierz);
indexy_obrabiarek = zeros(1,il_obrabiarek);
if il_operacji == 1
  indexy_obrabiarek = macierz;
else
  for i=1:il_obrabiarek
     temp = 1;
     for j=1:il_operacji - 1
         if macierz(j,i)==1 && macierz(j+1,i)==1
             temp = temp + 1;
             if il_operacji==temp
                 indexy_obrabiarek(i) = temp;
                 break;
             end
         else
             indexy_obrabiarek(i) = temp;
             if macierz(1,i)==0; indexy_obrabiarek(i) = 0; end
             if macierz(1,i)==0 && macierz(2,i)==0;
                 indexy_obrabiarek(i) = 0; end
             break;
         end
     end
  end
end
max_index = max(indexy_obrabiarek);
k=1;
for i = 1 : il_obrabiarek
    if indexy_obrabiarek(i) == max_index
       najlepsze_obrabiarki(1,k) = i;
       k = k + 1;
    end
end
equal = size(najlepsze_obrabiarki');
for k=1 : max_index
    for i=1 : equal(1,1)
       sciezki(i,k) = najlepsze_obrabiarki(1,i);
    end
end
for k=1 : max_index; macierz(1,:)=[]; end
x = macierz;
y = sciezki;
```

Fig 6. The structure of function sciezki_II.m of algorithm of generation of technological paths

```
function y = sciezki_I(macierz)

 [macierz sciezki] = sciezki_II(macierz);
 while ~isempty(macierz)
    [macierz sciezki_new] = sciezki_II(macierz);
    [aa bb] = size(sciezki_new);
    [a b] = size(sciezki);
    for i = 1 : aa-1
        for j=1:a
           sciezki(i*a+j,:) = sciezki(j,:);
        end
    end

    for i = 1 : a-1
       for j = 1 : aa
         sciezki_new(aa*i+j,:) = sciezki_new(j,:);
       end
    end
    sciezki = cat(2,sciezki, sciezki_new);
 end

y = sciezki;
```

Fig 7. The structure of function sciezki_I.m of algorithm of generation of technological paths

```
macierz =

     1     0     1     1
     1     1     0     1
     1     0     1     1
     0     1     1     0
     0     1     0     0
     1     0     0     1
     1     1     0     1
     1     0     1     1

sciezki =


     1     1     1     2     2     1     1     1
     1     1     1     2     2     4     4     4
     4     4     4     2     2     1     1     1
     4     4     4     2     2     4     4     4
```

Fig. 8. The result obtained from the module of generation of technological paths (example)

Summary

The problem of machine-tools selection in multi-machines manufacturing process is one of the most important research issue. When takes into account that when make a decision which machine tool should be purchased the relation objective to subjective criteria is 20/80, it is need to find solutions which helps the design to choose the proper machine with minimization of subjective aspects of decision.

In this article the conception of casing-class FMS machine tools subsystem selection, implemented in computer program <<OPTSELECT>>, was presented. In particular there was presented the module of generation of technological paths which is based on the authorship heuristic algorithm. This algorithm allows to get solutions in short time even in case of huge complexity of solving problem. Unfortunately, similarly to different methods used for solving NP-hard problems, the algorithm is characterized with possibility of generation of quasi-optimal solutions which are saddled with probability of gaining solutions which are not optimal. When take into account the targets which are defined for the problem of machine tools selection and that obtained solutions are not influential for the qualitative result of solution this algorithm can be recognized as an efficient one. Unquestionable advantage of presented solution is its simplicity and possibility of using for solution different problems in presented research area.

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Module of Generation of Technological Paths in the Program of Computer Aided Machine Tools Selection in Casing-Class FMS

Abstract

More and more complex problems connected with designing modern and future manufacturing systems and also technological processes force researchers to develop formalized, computer aided tools which help to solve these type of problems. In this paper the module of generation of technological path based on authorship algorithm was presented. This module is part and parcel of computer program <<OPTSELECT>> which realizes the process of machine tools subsystem selection in casing-class flexible manufacturing system.

Keywords : technological path, machine tools selection, flexible manufacturing system design, FMS, technological process design

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HENRYK CZARNECKI

A program for analysis of the cross-sectional contour of embossing taps

Introduction

While rolling of internal threads is widely used and technologically mastered, cold forming (embossing) of internal threads has still been little spread in domestic conditions, and internal threads are most often made with cutting taps. Threads made with a cutting thread quite often exhibit errors of form and dimensions. The difficulties in choosing the optimal tap and machining conditions mount up when machining hard-machinable materials (such as acid-resistant and heat-resisting austenitic steels) and materials of enhanced mechanical properties (such as toughened alloy steels). Dodatkowe trudności zaobserwowano podczas wykonywania gwintów w otworach nieprzelotowych.

In these and other cases, it is possible to exchange the internal thread making technology from cutting for cold plastic working by using **embossing (thread firming) taps**, whose work can be compared in approximation to screwing in of self-tapping screw. The possibility of changing the technology arises from the similarity between the two technologies in threading kinematics, many common constructional features of the tools used, and use of the same machine tools in the product manufacture process. The internal thread cold plastic forming technology can be applied to any types of material, provided that their elongation As > 8% and hardness does not exceed 28 – 32 HRC.

The relatively great interest in this technology is owing to its numerous advantages, including primarily a good quality of threads made and a higher threading process output. Threads made by this method, depending on the material worked, are characterized by an increase in strength by approx. 15-60% and in top layer hardness by approx. 30-50% compared to those made by the cutting method. In addition, the thread exhibits very high accuracy in terms of dimensions and form, and there is no so called thread "stretching". The major drawbacks of this technology include the higher required accuracy of preparation of holes to be threaded and the need to use special lubricants that must exhibit good lubricating properties at large loads.

2. Design of embossing taps

The differences between the embossing tap and the cutting tap are only in the working portion. Unlike the cutting tap, the embossing tap has a full thread form along the entire working portion length. The working portion consists of an embossing portion and a sizing portion. The embossing portion has the shape of a cone with either a curvilinear or rectilinear element (the latter option being characteristic of older solutions). This part of the tool performs the main material deformation work, and its construction also significantly affects the tool's life. The sizing portion is a cone with a small convergence backwards (0.02 - 0.05mm/100mm) and determines the dimensional and shape accuracy of the thread. In the cross-section, the working portion has the contour in the form of a convex polygon with rounded corners, which reduces the area of contact between the working portion and the workpiece and facilitates the delivery of the lubricating and cooling medium to the deformation zone. This shape of the cross-sectional contour has a torsional strength level several times that of a contour weakened by chip clearances. An example of an embossing tap design is given in Fig. 1. By varying the value of the rounding radius of the edge (corner performing the main work of metal deformation), the magnitude of the embossing torque and the tool life can be influenced to some extent.

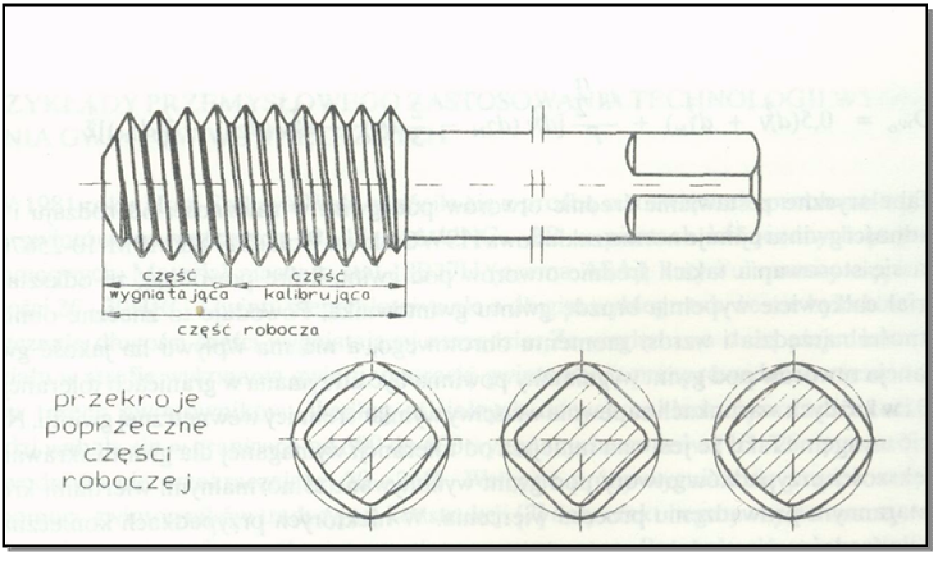

Fig. 1. Design of an embossing taps

The successive phases of the internal thread form cold plastic forming process using an embossing tap in a prior made hole is shown in Fig. 2.

If we look at the axial section of a single groove of thread being formed, we will easily notice that the radial displacement of the tap edge top, resulting from the conical shape of the embossing portion, first causes an elastic deformation and then a plastic deformation with a material displacement towards either side. Almost all material moves in the radial direction, filling voids between tap thread flanks and, depending on the diameter of the hole to be threaded, either a full or incomplete thread form will be obtained at the embossed thread crest.

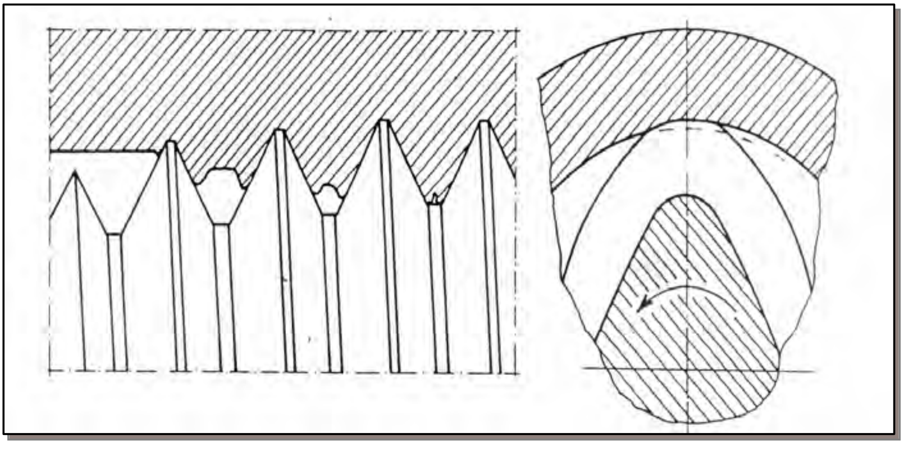

Fig. 2. Successive phases of shaping a thread form by embossing

The embossing process output and the tap life are closely associated with the tap design. At the Institute of Machines Technology and Production Automation (ITMiAP) of the Czestochowa University of Technology, studies have been conducted for several years on the development and implementation of the technology under discussion in industrial conditions. The design of a tap with a cross-sectional contour providing the tap high torsional strength has been developed [2,4,6]. An amendment to the PN-84/M-82054/01 standard relating to the shape of the embossed thread crest has also been developed and implemented, which has been published in the PKNMiJ Bulletin No.5/1991, Item 33. When carrying out implementation work, some problems were encountered, which concerned the optimization of the cross-sectional contour in larger-diameter taps. In such instances, great care must be exercised when choosing the number of edges and the lobing in order to assure the correct operation of such a tap. This is particularly true for untypical taps, that is fine-thread large-diameter taps, or small-diameter taps. Examples of the taps designed and made at the Institute are illustrated in Fig. 3.

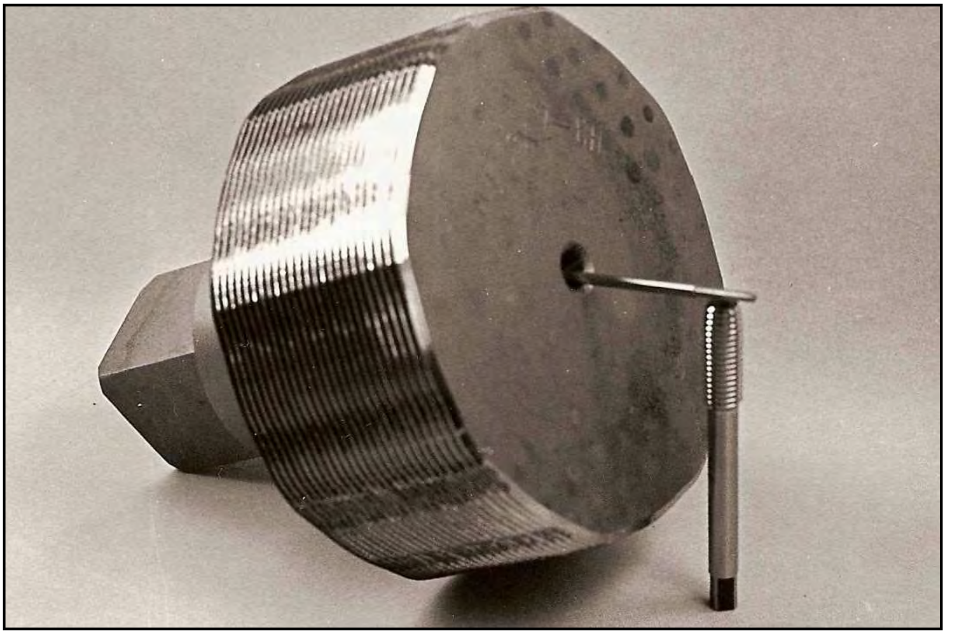

Fig. 3. View of the embossing taps for M52x1.5; M8 and M1.6 made at the ITMiAP

Designing the basic dimensions of a tap is done based on a computer program [6]. We obtain the dimensions of a tool for a given thread and the setting parameters of the thread grinder on which the tool will be made, as well as the dimensions of the cam for the backing-off process for the assumed embossing tap parameters.

3. Geometrical relationships of the tap cross-sectional contour

As has already been mentioned, during the embossing process, a certain part of material moves into the void between the flanks of the thread form on the tap. Whether this gap will be fully filled or not depends on the tool's inner diameter, $\mathbf{d_{1N}}$, and on the initial diameter of the hole to be threaded, $\mathbf{D_0}$, and will result in either a full or incomplete thread form. An incomplete thread form is characterized by a small cavity at the thread crest, and its currently permissible, as specified by the standard mentioned above. So, during tapping, individual edges shape a thread form which, at a given moment, is only formed on a specific part of the tap working portion by the vertices (edges) so that the entire

embossing allowance is displaced, thus forming a thread groove. A vast majority of embossing taps being presently in use at the Institute have the cross-section in the form of a convex polygon with rounded vertices, which assures a high level of torsional resistance of the core [1,3,], Fig. 1.

This cross-section can normally be described by a certain composite function repeating cyclically in intervals $2\pi / Z$, where Z is the number of edges.

Geometrically, the relieving pitch, $\mathbf{S_Z}$, is the difference between the largest and smallest tap radii, Fig. 4. This quantity depends on the most important tap parameters and is established during grinding of the tool contour on a thread grinder, as a representation of the cam. Hence, for the adopted contour and its parameters, it is be necessary to use appropriate cams adapted to the grinder on which the tap is to be made.

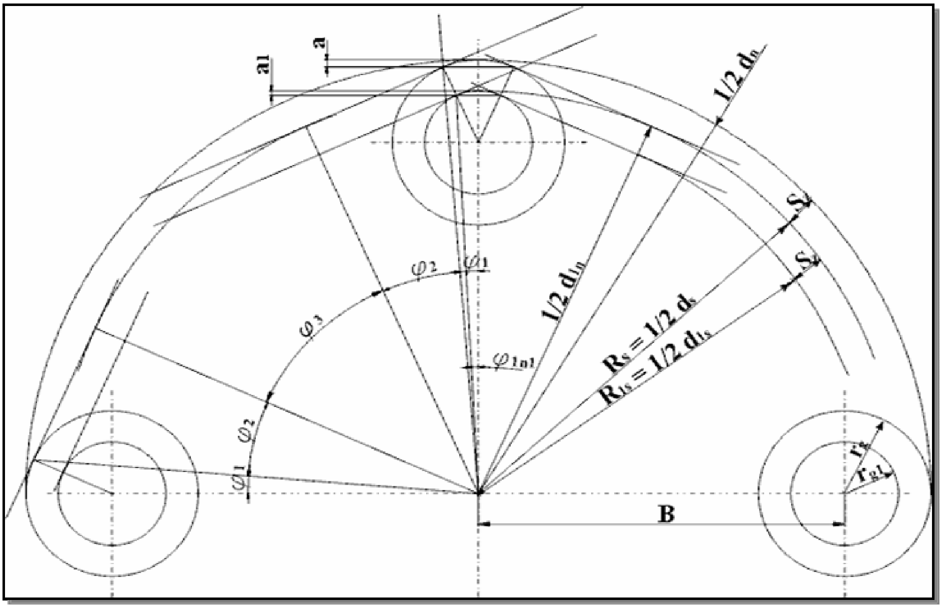

Fig. 4. A schematic of a four-edge embossing tap. S_z – relieving pitch. d_N – maximum outer tap diameter. r_g – edge vertex rounding radius. r_{g1} – edge vertex rounding radius at the groove bottom, Rs – tap radius at the relieving pitch, φ_1. φ_2, φ_3 – angles formed on the tangent to the circles determined by R_s and r_g, φ_{1n1} – angle formed on the tangent to the circles determined by R_{1s} and r_g.

Another feature characterizing the tap cross-section is the relative lobing, as described by formula (1) [1,4,5]:

$$G = \frac{2S_Z}{d_n - 2S_Z} \qquad (1)$$

In practice, depending on the type of material being worked and lubrication conditions during thread forming, lobing values from a range of approx. **0.2 – 0.02** are applied**.** In the case when we declare the lobing, the relieving pitch magnitude is (2).

$$s_z = \frac{Gd_N}{2(1+G)} \qquad (2)$$

The next parameter characteristic of the cross-section under consideration is the vertex radius, $\mathbf{r_g}$. Its value directly influences the size of the area of contact between the corner and the deformed material, and thus the friction force magnitude. This radius is defined as part of the tool diameter in the form of a factor ***c*** which is assumed at a level = **1/8; 1/16**, etc.

$$r_g = cd_N \qquad (3)$$

The number of edges, the relative lobing and the factor ***c*** are parameters characterizing the tap cross-section and constituting also a basis for the calculation of the contour of a cam to be used for grinding the tap.

The material quantity which must be deformed by the tap embossing portion is dependent on the tool outer diameter and the diameter of the hole to be threaded. As the thread is shaped by the vertices, the quantity of material per vertex will be dependent on the adopted embossing portion length, l_w, which for non-through threads amounts to a maximum of (2-3)P, while for through threads, up to 8P.

Thus, the material quantity per edge is

$$N = \frac{(d_N - D_0)P}{2l_w z} \qquad (4)$$

where d_N – maximum tap outer diameter,

D_0 – minimum threaded hole diameter

L_w – embossing portion length

Z – number of edges

P – pitch

This material allowance should be deformed on the vertex radius. This guarantees the correct tap operation and a good quality of the thread being formed. In the case where the material is formed on the straight portion instead of the arc, the embossing moment increases and the thread form worsens, which sometimes makes threading impossible, as was found when conducting experimental studies at the Institute. Hence, by making the geometrical analysis of the contour we are able to determine the angle $\boldsymbol{\varphi}$ defining the position of the points of tangency of the straight line and the points $\mathbf{r_g}$ and $\mathbf{R_s}$. To this end, a system of parametric equations describing the tangents passing through the point on the circle of a radius $\mathbf{R_s}$ has been set up, on the assumption that for the straight line to be tangential to circles, it must have the identical slopes and absolute terms. A system of four equations with four unknowns and three parameters (B, r_g, R_s) is obtained. By solving the above system of equations, while considering the conditions of physical correctness of the solution, we obtain relationships allowing the calculation of the angle $\boldsymbol{\varphi_1}$ of the radial contour and the height of the part of the vertex *a* up to the point of tangency.

These quantities have a significant effect on the process of forming the thread by the edge, considering the fact that the material moves during deformation not only sideways but also along the groove, creating a front wave, Fig. 2.

The size of this wave depends on the plastic properties of the material, and, based on model studies, this is assumed to be contained within 0.2 – 0.5 of the deformed material volume. Considering this and the condition that the deformed material be shaped on the radial vertex portion, we obtain the following condition:

$$a > k \cdot N \qquad (5)$$

While: k – is a factor being equal to 1.2 – 1.5, and

N – quantity of material per edge, as determined by relationship (5).

In a similar way, formulas for the angle φ_{1N1} and the height a_1 are determined, which define the parameters at the groove bottom.

These two quantities provide the possibility of verifying whether at the tap groove bottom there is also part of surface on the edge, instead of an edge resulting from the intersection of the straight tap contour fragments, in which case the value of φ_{1N1} and a_1 must be greater than zero.

4. The computer application for the analysis of the embossing tap cross-sectional contour

To accelerate the computation process and make the tap cross-sectional contour analysis more efficient, a computer program was developed, which would allow a quick computation of the tap cross-sectional contour, while considering the relationships derived and described above [ ].

For writing the program, the Delphi programming package in the Client/Server version, supplied by Inprise (formerly Borland), was used. This is a RAD *Rapid Application Development*) type tool which is designed for fast creation of any types of professional database, web-based and other applications. The program provides convenient means to create objects that can be repeatedly used.

The developed application allows the analysis of the tap cross-sectional contour data assumed either prior to, or in the course of designing a new tool. It should be noted that the Institute has already got a computer program available, which is designed for computation of embossing taps and cams for selected grinders. So, the program presented herein constitutes an expansion of the existing computation capabilities for the design of the tools under consideration.

The application is complete, which means that, in addition to the computation option, it features also an installation part allowing the program's files and source codes to be copied to a catalogue indicated by the user. It creates shortcuts in the Start menu and allows for easy deinstalling of the application. To run, the Gwintownik (Tap) program does not need any additional libraries, so it does not copy any files from the user's system catalogue.

After installing and running of the program, a window is displayed, which serves for entering data. In the upper part there are *Main Menu* and *Toolbox* bars providing a hint at an appropriate moment upon moving the cursor onto a respective item. These enable the user to run the following options: result printing, printout preview, storing values in a file and reading the file, preview of diagrams, and application termination.

Data edition is done by entering data obtained from the embossing tap design computation program in fields appropriate for a tap under analysis, Fig. 5

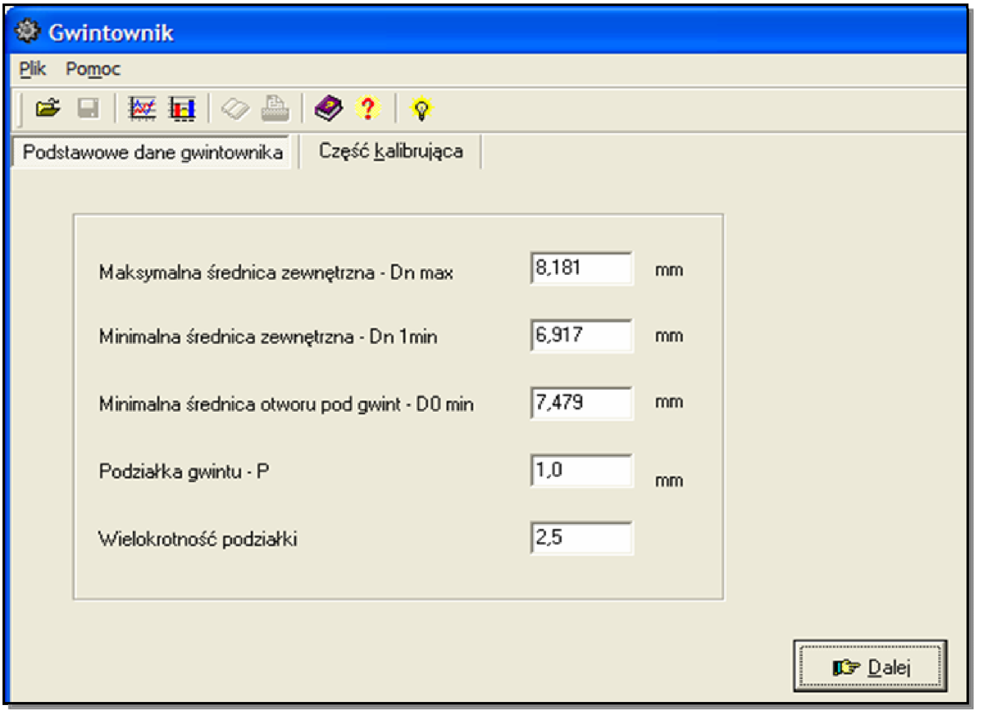

Fig. 5. View of the data entering window

After entering basic tap data and pressing on the **Dalej** (**Continue**) button, the next window opens, Fig. 6, in which we can enter or select further data. We can select the number of tap edges, *z*, and then the value of the parameter *c*. The values of the assumed factor *k* need also to be entered. In addition, we select the pitch multiplicity, which means the permissible length of the tap working portion (e.g., for non-through holes = 2.5 p).

After selecting all data and pressing on the Compute button or confirming by pressing the Enter key, the computation process will follow

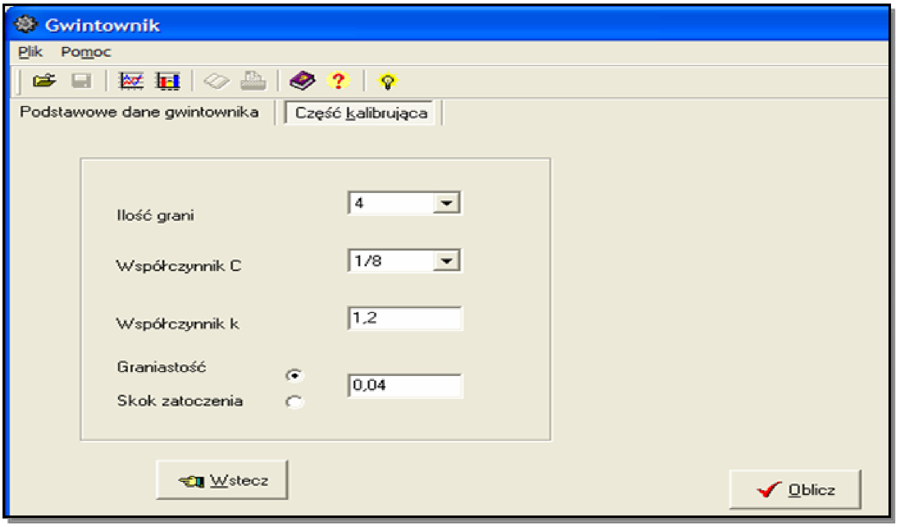

Fig. 6. The application with the highlighted „Część kalibrująca" ("Sizing portion") tab.

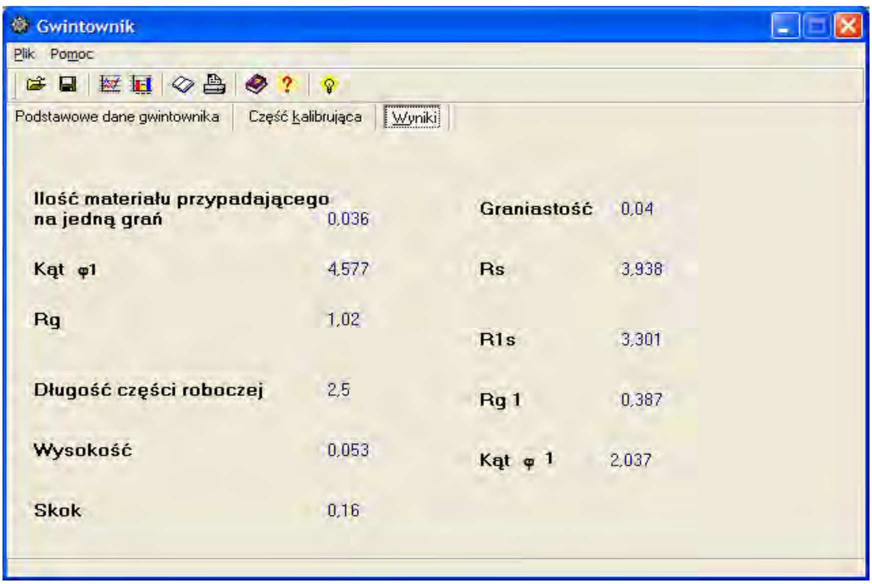

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Fig. 7. Results of tap cross-sectional contour computation

he processing of the data and displaying the results will follow, Fig. 7.

We can also obtain a report providing the possibility of printing all computed quantities, with a print preview option.

Moreover, the program offers a more general presentation in the form diagrams illustrating the effect of individual parameters. Figure 8 illustrates the effect of lobing on the chord height. We can see that with increasing lobing the chord height increases.

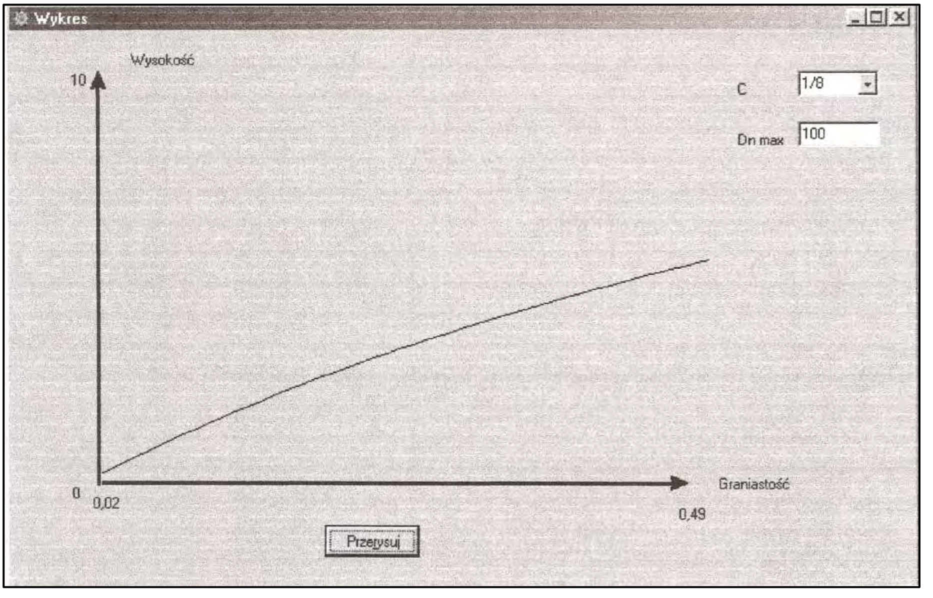

Fig. 8. Effect of lobing on the value of the parameter *a*

The data obtained from computation can be exported, as well as stored in, and red from a file.

The program has been furnished with a module enabling access to integrated assistance in the form of a Help file.

The analyzed example of M8x1 tap computation, shown in Figures 5 to 7, indicates that all selected parameters guarantee a surface to be obtained on the thread forming edge portion during embossing, since a_1 is greater than zero.

5. Summary

The presented assumptions for the analysis of the cross-sectional contour of an embossing tap and the described relationships serving for tap cross-sectional contour optimization have made it possible to develop a computer program. This program significantly contributes to the verification of assumed tool geometrical data and markedly expedites analyses of the correctness of the assumptions made. It happened in the previous practice that wrong assumptions emerged only after making a prototype tool. The program under discussion has been tested on data for taps that have been made at the Institute and implemented in many plants. Moreover, it allows a vivid presentation of interrelationships between the cross-sectional contour parameters of the embossing tap developed at the Institute of Machines Technology and Production Automation of the Czestochowa University of Technology as early as at the tap design stage.

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A program for analysis of the cross-sectional contour of embossing taps

Abstract

The article discusses problems related to designing the cross-section of an embossing tap. Basic mathematical relationships for a tap contour developed at the ITMiAP of the Czestochowa University of Technology are provided, which were used for developing a computer application enabling assumed contour parameters to be analyzed for correctness in the tap design process. A program that speeds up the computation and analyzes the effect of parameters on the edge shape is prese.

Program do analizy zarysu poprzecznego gwintowników wygniatających

Streszczenie

W artykule omówiono zagadnienia związane z projektowaniem przekroju poprzecznego gwintownika wygniatającego. Podano podstawowe zależności matematyczne dla zarysu opracowanego w ITMiAP Politechniki Częstochowskiej które posłużyły do opracowania aplikacji komputerowej pozwalającej analizować poprawność założonych parametrów tego zarysu w procesie konstrukcji gwintownika. Przedstawiono program do przyspieszenia wykonania obliczeń oraz pozwalający na analizę wpływu parametrów na kształt grani.

Program do analizy zarysu poprzecznego gwintowników wygniatających

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AGNIESZKA BOJANOWSKA

Optimization for distribution process of technical gas using informatics technology

Introduction

IT technologies used in e-business area allow to widely expand functionality of solutions in many fields of technique, production organization and distribution. **Electronic business** (called e-business) – introduced in 1995 by IBM, according to common definition, is model of business conducting based on widely understood ICT (information and communication technologies) solutions, particularly Internet applications [1]. The idea of e-business contains i.e.:

- information exchange between producers,
- distributors and consumer of products and services,
- contracts concluding, sending documents,
- videoconferencing,
- acquisition of new contracts,
- information retrieval, ect.

An example of optimization problem for distribution process of technical gas on the Lubelskie Province is shown in this paper. Trading company performs logistics maintenance in several dozen gas cylinders distribution points. These distribution points are spaced on Lubelskie Province in considerable distances from warehouse facilities located in Lublin. This company keeps two cars adapted for dangerous cargo and bears the costs of customer service in all distribution points. In this organization state access to product for customers is limited by the shops or other service points opening hours. It was also occurred that there is lack of information about empty gas cylinders in distribution point. This fact has an effect on inaccessibility of gas in point surroundings. Furthermore applications of deficiencies by telephone and randomness of this incidents make rational transport planning impossible.
This state generates higher costs of distribution points service.

The purpose of designed solution is to exploit technical measures and IT for:

- automatic acquisition of information about a storage condition of cylinders with gas in scattered points of distribution;
- capacitance of ordering gas cylinders by an Internet with possibility of receiving order in any point of distribution in any time (without participation of point stuff);
- including conditional option of delivery gas cylinder directly to customer;

- optimization of conveyance line (minimal length of line brings minimal costs).

Monitoring state of storage

Gas cylinder order should be generated when storage state in distribution point achieve a critical state. This state could be represent by such cylinder number which will be sold in time necessary to realize an order. This time is individually determined for every distribution point and is based on statistic data about average intensity of sale (depend on season). The less beneficial variant of logistic service time was included. Actually storage state of cylinders is monitored by salesperson and critical level is estimated based on his or her experience.
Cylinders are storaged in hand-closed lockers. During sale process full cylinder (ab. 14 kg) is exchanged to empty (ab. 3,5 kg).
Author of this paper proposes automation of storage service by installation of bistable sensors reactive to weight of cylinder. Summary information about a number of full cylinders is saved in cache of installation and can be send to central storage server by GSM and Internet after each change. Server software creates supply list for running day on the basis of received report. On figure 1 was shown what is the idea of automation monitoring process warehouse level cylinders with technical gas and sale them by Internet shop.

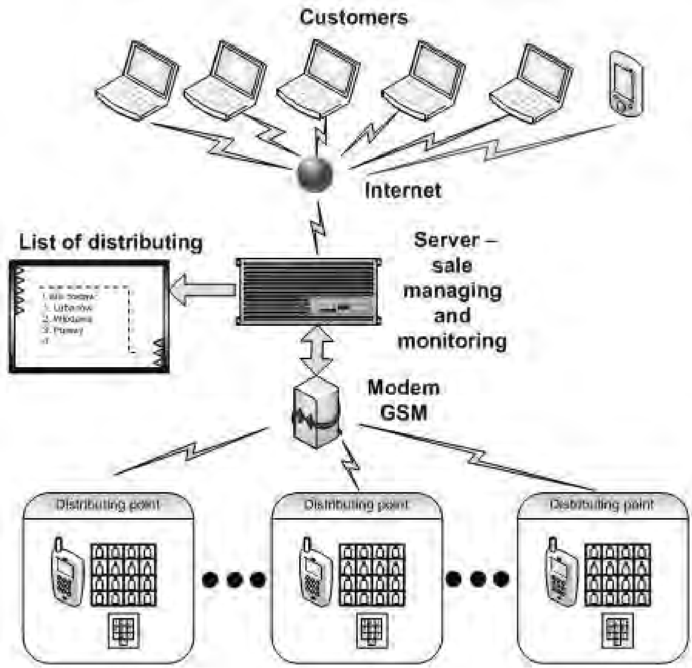

Fig. 1. Idea of automation monitoring process warehouse level cylinders with technical gas and sale them by Internet shop

An internet system of ordering for customers

Actually working system of ordering technical gases uses two ways of order sending. One way is ordering larger quantity of cylinders (for industrial purposes) by written forms by customers. Ordering technical gas to further retail sales (multi-stores and exchange points of the cylinders) is proceed by phone of e-mail. Order service and monitoring of state and sale entail personal costs or charging by additional margin value of sold gas. During retail sale it is necessary to engage salesperson in purpose to take money and give customer a cylinder.

Author of this paper propose to expand access to offered product for retail customers by launching website which allows customers to put an order, pay (by card or e-transfer) and to obtain an access code to any distribution point with cylinders. Cylinders' lockers will be equipped with code lock. Entering by customer code which he achieved during Internet transaction will unlock one cylinder and enable to exchange it to empty cylinder. This form of sale makes customer independent from distribution point opening hours but it is also possible to generate access code by salesperson after cash transaction on-site. To achieve access code by Internet customers will be obliged to make their personal data (name, address, phone number, e-mail, etc.) accessible. That can allow to perform advanced analysis for the customer relationship management (CRM) system. Additionally it will be possible to develop delivery service directly to customer home (for an additional fee).

An intelligent system for optimization the conveyance line

The manufacturing company with headquarters in Lublin has system of distribution points in: Biała Podlaska, Biłgoraj, Chełm, Hrubieszów, Janów Lubelski, Krasnystaw, Kraśnik, Lubartów, Łęczna, Łuków, Opole Lubelskie, Parczew, Puławy, Radzyń Podlaski, Ryki, Świdnik, Tomaszów Lubelski, Włodawa, Zamość.

Delivering cylinders driver should visit maximum 20 cities. In such case a number of combination of these routes, were every city is visiting one time, is (n-1)! that is 19!. The optimal solution is such permutation, for which summary distance between cities is the shortest.

In practice, order of cylinders automatically generated by earlier described server could be lower than 20 but even for lower number of points number of combinations, which should be check to find the most economic solution, is very high. Assuming that verifying solutions instructions are accomplished at computer in 1 nanosecond by one instruction, the choice of the shortest distance will last 77 years for 20 distribution points. The chart on figure 2 shows number of variants routs as a function of number distribution points.

Mathematical problem of finding optimal route can be represent as follow: having given a matrix distances between cities ($c_{i,j}$), where $c_{i,j}$ means distance between i-city and j-city $(i, j = 1, \dots, 20)$, one should find permutation (i_1, i_2, …, i_{20}) of integers from 1 to 20 which value of the expression (1) makes minimal. L_{min} – minimal route.

$$L_{min} = c_{i_1 i_2} + c_{i_2 i_3} + \cdots + c_{i_{20} i_1} \qquad (1)$$

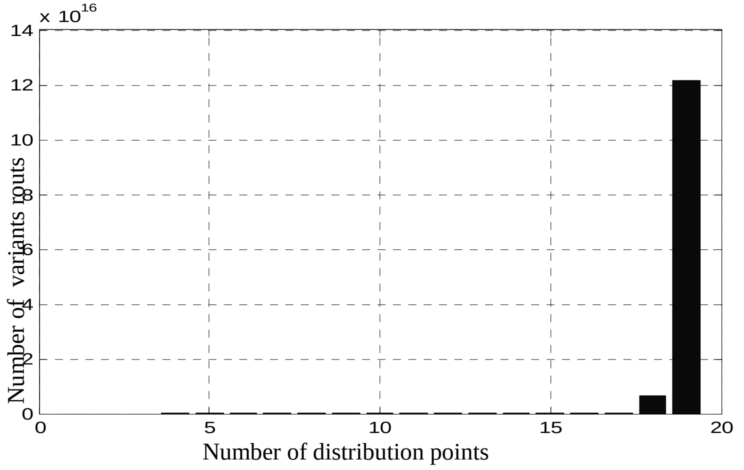

Fig. 2. Number of variants routs as a function of number distribution points

Author of this paper proposed the solution of optimization transport costs by genetic algorithm. **Genetic algorithm** is one of the methods of artificial intelligence. The essence of genetic algorithms is using evolution principle of survival of individuals with the highest degree of adaptation in purpose to transfer gens with the highest probability to the next generation. Individuals with lower degree of adaptation have much smaller probability of reproduction. Solutions of problem are recorded as a chromosomes and evaluation criteria of solution usefulness (objective function) are elaborated. Using algorithm from figure 3 brings optimal solution in acceptable time.

The features which make genetic algorithms unique in relation to remaining methods are [4]:

- lack of direct processing parameters, only coded form of them,
- conducting research, starting from such usually random population
- using only objective function,
- using probabilistic rather than deterministic selection rules.

Genetic algorithms are based on searching the solution space technique which has a purpose to find optimal solution. Process of classic genetic algorithm consists of several stages [6]:

- generate an initial population,
- assessment of population by adaptation function,

- checking the condition of detention,
- reproduction,
- using of genetic operators (crossover, mutation),
- creating new population,
- insert the output population in place of the input population.

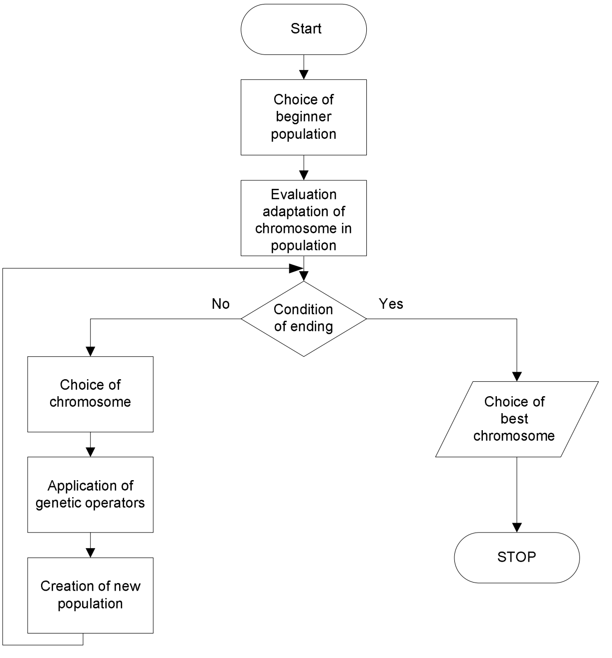

Fig. 3. Chart of genetic algorithm [2]

Distances between distribution points were nominated on the basis on Google maps. To build the algorithm author of this paper used functions implemented in MatLab computing environment of the library (Tool Box) Genetic Algorithm. A matrix distances between cities was used as input data.
In purpose to determine the optimum route for car distributed cylinders with gas by the algorithm was used only such part of the matrix which is result of distribution list generated by an order server. This list was previously designated on the base of critical storage states identified by monitoring application.
As a result of the calculation the algorithm generates list of distribution points in order to provide the shortest route for the car. The list is automatically sending and show on driver's palmtop screen. Disposition of loading calculated the number of cylinders designed to distribution, during planned drive, is sending to main warehouse by local computer network. It allows to ship calculated from orders number of cylinders.
Driver implements planned route on the base of obtained list. Having universal code to open lockers, driver refill distribution storages without local employee.

Simulation of automatic distribution of technical gas system functioning

Paper's author carries out a simulation in MatLab in purpose to verify accuracy of activity of developed algorithms which automates distribution process, monitoring and retail sale of gas cylinders. Simulink program which is integrated module of MatLab was use to solve this problem. This software allows to construct functional blocks which can process information in a programmed manner. In designed system of distribution control were some separated logical blocks:

- Block which represents information processing by distribution point. The number of sold cylinders in analyzed time is an input data. The storage state at the end of analyzed time is an output data.
- Block of storage state monitor and generator of distribution lists. Input data are received from distribution points by wireless connection and Internet. Output data are actual list of points where storage state should be refill.
- Block of intelligent driver witch optimizes the route of the car which refill storage state in cylinders storages. Input is a distribution list generated by block of storage state monitor. This list contains names of distribution points in order of achieving a critical level of stock. Output data is list ordered by criterion of minimal route length.
- Block generating data to simulate. This block was realized by using random number generator. It randomly generates distribution of the daily sales of the cylinders. This distribution was established on the base on analysis of statistic data from previous months registered in storage documents of company. The data are generated for every distribution point separately because of large variations in demand.

On figure 4 was shown the model of distribution system made in Simulink. To achieve transparency of the model details of each block were hidden in block forms – subsystems.

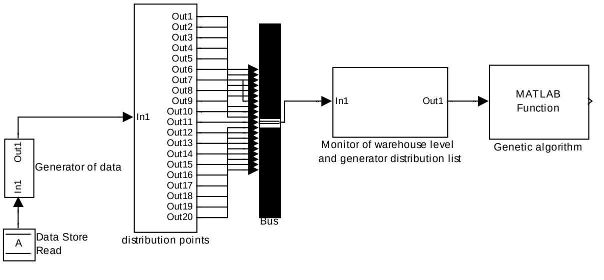

Fig. 4. The model of distribution of gas cylinders system made in Simulink

A series of experiments were made on developed model. The result was estimation of effectiveness of adopted solutions. Main goal of proposed changes in distribution process control was cost reduction. During simulation it has being calculated whole distance which should be passed by the car refilling distribution point. It was made for subsequent random (but very possible) generated states of distribution system. Diagram of the route can be obtained during a few seconds of simulation. Example route generated by genetic algorithm is illustrated on figure 5. It was assumed that car should refill all 20 points of distribution in one route. The length f the distance was 824 km. It is possible to achieve it with two drivers in 16 hours. Assuming that summary order isn't higher than 160 cylinders (car capacity). From statistic data registered in conventional control of distribution period flows information that number of cities on distribution list for one day wasn't higher than 14 in 90 %. In addition, the volume of orders also wasn't higher than 8 cylinders for one distribution point.

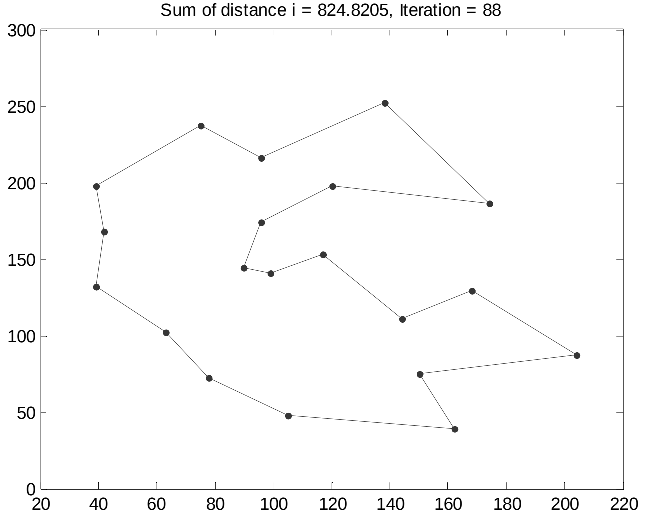

Fig. 5. Example of optimal car's route generated by genetic algorithm for 20 distribution points

Simulation system allows to complex estimate quality of optimization process. Searching the best solution ends when in successive iterations improvement of the objective function value is less than assumed. This is shown on diagram on figure 6d. For illustrated case after 90 iterations improvement of solution wasn't observed.

Other diagrams show proposed route map (figure 6c), illustrated in greyscale map of distances between points (figure 6b) and map of distribution points' location which is used by genetic algorithm to draw a route (figure 6a).

a) b) c) d)

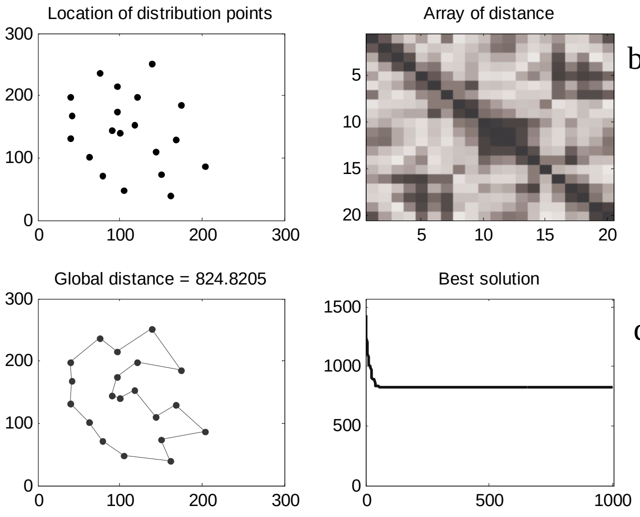

Fig. 6. Graphic illustration of distribution route optimization process

Expected effects of distribution system implementation – summary

Taking into account different categories of business activity costs in retail gas cylinders distribution, author of the paper made cost analysis in one month scale. Costs include:

- The cost of retail customer service in 20 distribution points (average margin receiving by salesperson) – 400 PLN for a month x 20 = 8000 PLN
- Transport costs – ab. 5000 km for a month x 1,34 PLN/km = 6700 PLN

Sum of variable costs for current method of distribution control is ab. 14700 PLN for a month.

After implementation Internet sale system cost of service in distribution points can be reduced by 50%. Salespersons can get margin only for personally sold cylinders.

Comparison of average distributing gas cylinders car mileage, now with results of simulation for the same distribution lists, shows reduced route length by about 23%. It means that car will cover in a month distance around 3850 km. Cost of covering this distance will be 3850 x 1,34 = 5159 PLN.

Predicted sum of variable costs in month is 9159 PLN. Which is 62 % of costs incurred now. It means that implementation of technical gas distribution control system based on e-business and artificial intelligence methods can bring 67032 PLN of profit yearly with minimal capital expenditure.

Estimated costs of equipment and software needed to implementation presented conception of distribution system control won’t be higher than 20000 PLN.

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Optimization for distribution process of technical gas using informatics technology

Abstract

A problem of optimization for distribution process of technical gas on the Lubelskie Province was shown in this paper. There were proposed some solutions based on technologies e-business. This solutions allow to optimize costs and provide permanent availability of gas at the point of distribution. To obtain input information for optimization algorithms were used methods of data transition with use of an Internet. The optimization was achieved with application of genetic algorithms.

Key words: e-business, gas distribution, optimization algorithms, Internet, genetic algorithms

Optimization for distribution process of technical gas using informatics technology

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Identification and simulation of milling process

Introduction

The milling process is a machining technology, very often used for machining some complicated shapes of object. These shapes occur in such a construction as follows: a housing, bracket, rocker etc. which are common in the aerospace and automotive industries. The mass production of this kinds of parts demands using high-speed machining to improve productivity. At the same time, it is indispensable to ensure a high accuracy and repeatability of the processing. Due to the nature of the machined surfaces, spherical mills are very often used as tools. These tools allow for mapping in the metal the very complex shapes using the controlled machines with 3 to 5 axes.

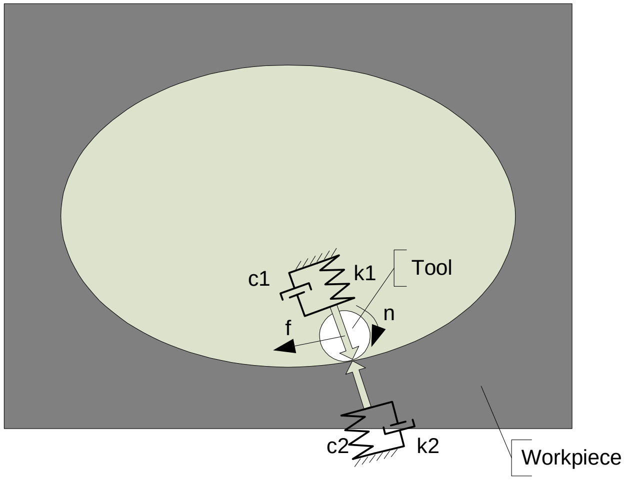
During the machining, the dynamic reactions of cutting forces are problematic. Due to the design of machines and tools which allows to high cutting speed, these forces take a considerable value. The result is that there are differences between the established by the technologist tool path and the actual one. A solution to the problem is such a machining planning strategy that in the low stiffness areas of the workpiece one needs to apply reduced cutting parameters. This helps to reduce the values of forces, so as the deformations to the level which ensures the constant measurement tolerance of the worked surface. However, this is not entirely acceptable solution for the series and mass production. Here, the productivity together with the product quality established at the manufacturer level are most important.

It may be noticed that if during the process of milling, when an error occurs and the dynamic properties are known, one is able to foreseen the workpiece path's errors. This can be achieved by measuring the cutting force. These errors are rooted in the machine treat's material. However, there is a difficulty in the process, namely, the model which appears in the cutting sphere is very complex and nonlinear. The result of the force interactions is the mutual movement of the object and tool in their area of their contact. An additional problem comes from the nonstationarity of the process. It originates from the nature of the spherical plane mill motion. The path on which the tool is moved forward is close to the more or less vulnerable parts of the workpiece. Moreover, depending on the machining phase, the spherical tool is in contact with the object on a surface with variable parameters. That results from both, the stiffness in the cutting zone which is changeable, and the cutting conditions that directly affect the power. The question arises whether these conditions can be predicted.

If the process of errors forms in the spherical mill path as a control object, the identification of that object is needed. What is more, one needs to determine the model's observable inputs and outputs which are formed during the identification. From the viewpoint of a technologist, the dimension of errors' values are measured along the tool's path. These values are measurable only after the completion of machining (eg. measuring machine) as a deviation from the nominal size. A factor that determines errors is the variable component of the cutting force, perpendicular oriented to the workpiece, and the tool in the next contact points along the programmed path. The force is difficult to measure, because one has to it install a ternary dynamometer in the machine table or tool's holder. Such a solution is hard to be applied at this industrial stage. However, the strong correlation between processing parameters such as feed, cutting speed, and thickness, still can be observed. While both the feed, and cutting speed are parameters that can be controlled precisely, thus, in the case of the profile milling through the spherical mill, the cutting depth can be changed within fairly wide limits during the machining. This may be different at various points of the tool's path. [3, 4]

From the milling formed process observation one is able to observe that the model parameters change significantly during the machining. Factors, such as stiffness, and area of cutting are different. Along with them, the value of the exciting force is changing. The introduction of energy to the process modeled by the primary motion of mill, and the start of the feed, as well as the determination of the initial depth of cutting, causes the appearance of force. This force is changing, and is different at several points of the tool's path. The force that influences the objects and tool (a mass-elastic system), generates an instantaneous elastic deformation , the effects of which is the shape of the machined surface. The modeled object can be approximated by a set of mass-elastic objects, having different properties along the tool's path, which motion enforces the impact variable forces in the function of the road [5].

If one adopts that kind of concept of a milling process, the emergence of the model should be based on knowledge of the characteristics of the selected points in the next tool's path. By registering the action and its outcome in the selected points, one receives a set of models, adequate to the behavior of the modeled process. In case of the numerical control, a conclusive identification and the registration of these points' location in the work space, is relatively easy, and precise because of the application of coordinates to the system's machine or workpiece. A larger problem appears when one wants to obtain information about the excitations, and the dynamics of the object. The below presented diagram (Fig. 1) displays the proposal of the model.



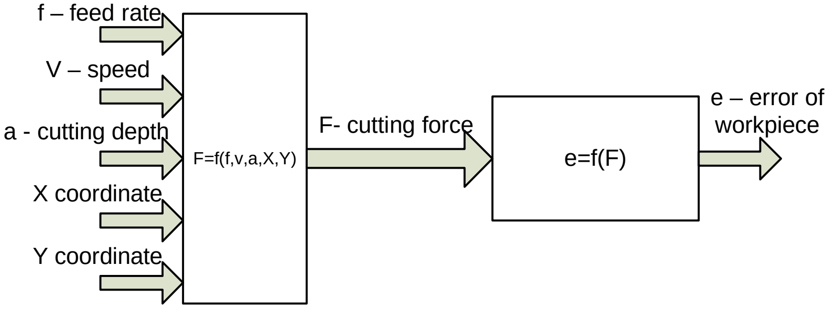


Fig. 1. Proposal of milling model

If for the industrial conditions, one assumes, that it is not possible to install the dynamometer, the most controllable and accessible factors are as follows: feed (f), cutting speed (v) and the assumed average cutting depth (a). However, it may be realized that the resultant cutting force (F) may be changing due to the local conditions of the process at different points in the path.

As the output parameter one needs to accept the workpiece error (e) created by the force excitation. This can be measured after the machining in the selected points of the workpiece. Registering force changes and correlating them with the error changes of geometry course, one receives a more accurate model. The model, unfortunately, will not be adequate to the current properties of the process due to the variability of the modeled object's stiffness. The same value of the force causes a different effect in different places of the tool's path. This depends on the shape of the stock and a tool's path, prepared by the technologist.

In this work, the solution to the problem of identification, and a model were proposed. The assumption is that the machining parameters and the effects of processing in specified points of the workpiece are known. If we assume that a particular part of the machining process is exactly repeatable, it can also be assumed that the excitation force and the machining conditions at selected points of the tool's path, are also repeatable. We must also adopt certain requirements for the accuracy of this assumption, namely, that the machining is done with a sharp tool, and with a stable cycles for the next cutting machining parameters. By changing the machining parameters, one can build more models.

Taking the complexity and well documented [5] non-linearity into account, so defined a profile milling process model, does not seem to be practical and analytical, based on an analysis of physical phenomena accompanying the formation errors of the shape, under the influence of cutting forces. A better solution is to build a black box model, based on observations of inputs and outputs parameters. Tools which are useful for building such models are neural networks that can reproduce after learning with considerable accuracy of the behavior of the modeled processes.

2. Tools used for modeling technological process

We can characterizes production process if we know dependents between input parameters of technological process and output parameters of workpiece. This dependence we can describe thru define mathematical equations, but in many cases building this equations is very difficult and result using them as a model is not satisfy. To build mathematical model we must know exactly shape of physical process relations between input and output. In many cases it is impossible. [1]

Described in this work case presented analogical problem. We want to find relation between five independent input:

- Feed rate (f);
- Cutting speed (v);
- Cutting depth (a);
- X coordinate;
- Y coordinate;

and one output:

- Error of workpiece (e).

We try to applied Neural network to solve this problem. Elementary component of Neural networks is neuron. In practically applied it is mathematical model of biological neuron. An elementary neuron with R inputs is shown below. Each input is weighted with an appropriate *w*. The sum of the weighted inputs and the bias forms the input to the transfer function f. Neurons can use any differentiable transfer function f to generate their output. [2]

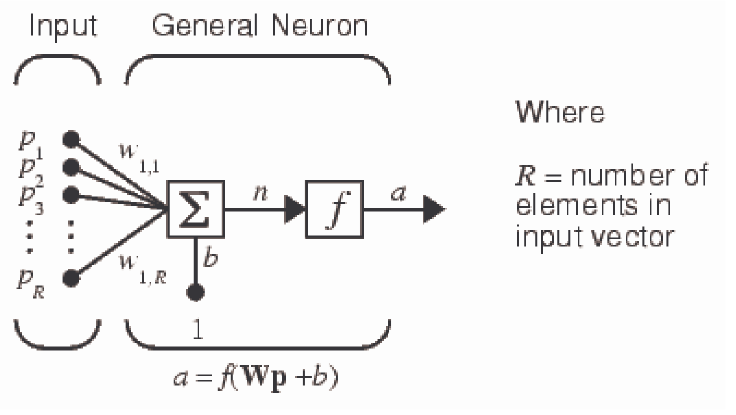


Fig. 2. Functional model of neuron

The Transfer function f have many form depend of application. Can be used log-sigmoid, tan-sigmoid or linear function as is shown on Fig. 3.

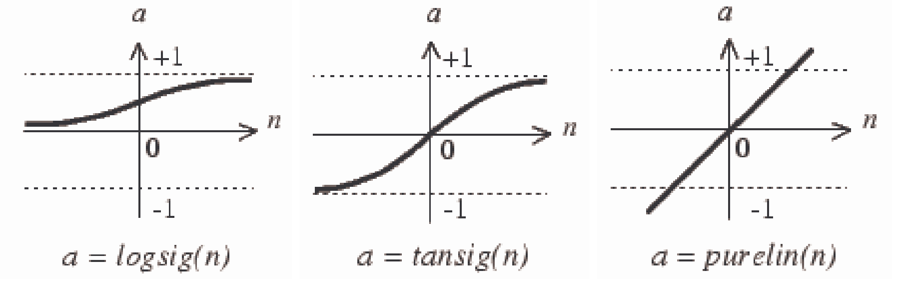


Fig. 3. Transfer functions

Multilayer networks often use the log-sigmoid transfer function. The function logsig generates outputs between 0 and 1 as the neuron's net input goes from negative to positive infinity.

Feedforward networks often have one or more hidden layers of sigmoid neurons followed by an output layer of linear neurons. Multiple layers of neurons with nonlinear transfer functions allow the network to learn nonlinear and linear relationships between input and output vectors. The linear output layer lets the network produce values outside the range -1 to +1.

In most of practical using neural network has been implicated two layer: hidden and output as shown on Fig. 4. Hidden layers can be more than one, but using only one we can successfully modeling nonlinear dependence.

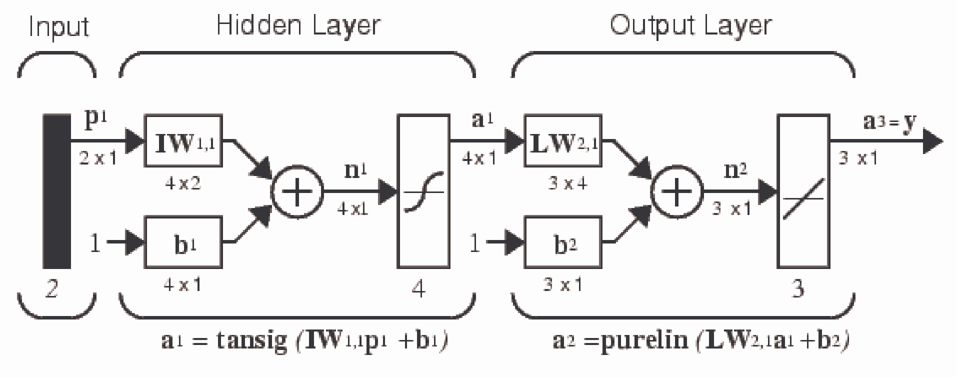


Fig. 4. Neural network structure

For modeling technological problem has been construct neural networks, for find e as output. Collection of input parameters was: feed rate (f), cutting speed (v), cutting depth (a), X coordinate, Y coordinate.

Neural networks has been train on collection 270 cases from experiment. In 30 points has been recorded shape error of workpiece after milling on machining center. Process has been repeated 9 times for deferent sets of input cutting parameters. Error of workpiece shape was measured on measuring machines. One example of result this measurement is display on Fig.5.

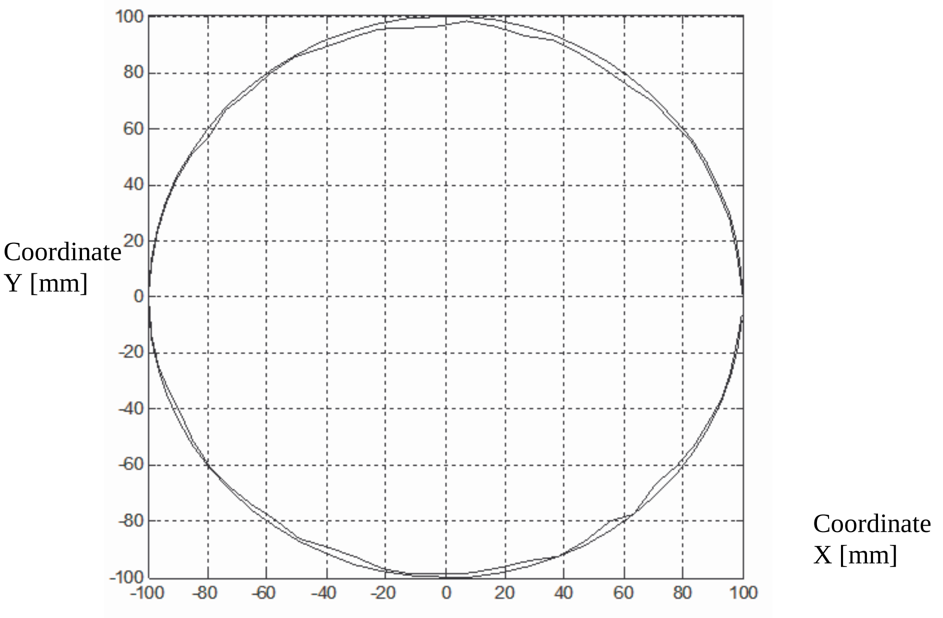


Fig.5. Example of result of shape error measurement. Error was display in magnified x 100 on background ideal shape.

Accuracy of neural network model has been verified using deferent data then used to learn. On Fig. 6 was shown relative error examined neural network for 63 collection input parameters. This error is low then 11% for neural network modeling function e=f(f, v, a, X, Y). Best results has been obtain for 7 neurons in hidden layer. For training neural network and then examining it was used Matlab programming environment.

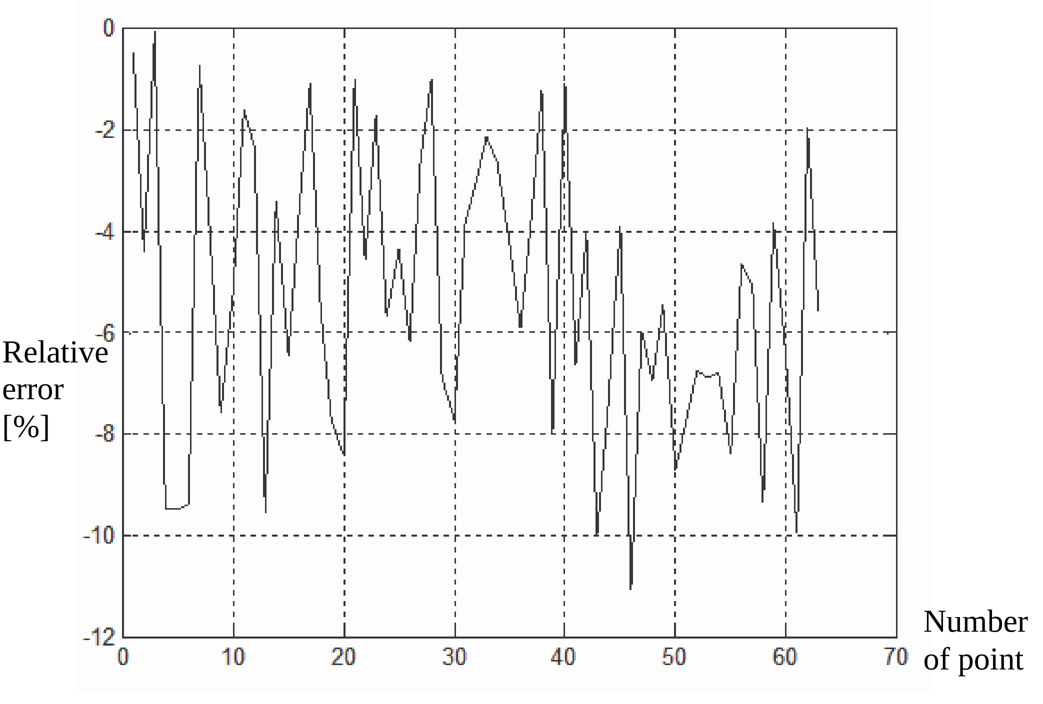


Fig. 6. Accuracy of neural network model

Computer aided design of the technological milling process profile using the developed model

An important problem that must be resolved by a technologist while developing the technological process of milling of complex shapes of objects made in series, is to provide the high efficiency of the process. Of course, productivity growth can not be paid with the emergence of geometry errors and deterioration in the quality of machined surface. Controllable parameters which are available to speed of rotation mill, and the related dependency straight cutting speed, feed, and founded cutting depth in one pass. These parameters were used to build the model as data input. Differences in geometric dimension, in each point of the machined surface, related to the ideal, programmed shape, generates the developed model on output.

On the basis of the model built, the system for the technologist's decision assistance process concerning the selection of machining parameters has been developed. The program selected for parameters choice with the use of machining process model, operates according to the algorithm shown in Fig. 7.

To begin with, the technologist must determine the extent of variability of process control. Cutting speed range of variation depends on changes in speed of rotation mill for the selected machine. A feed range must have such a variability of the area that can be is acceptable to the machined surface. Since the optimized milling phase aims at the exact shape of the milling object, an machining allowance is being calculated (and thus, the cutting depth) to a minimum. However, it must be determined in such a way, so as to minimize the total number of transitions. The loop algorithm for the *i* feed of the changed parameters, and *j* cutting speed make the simulation process by obtaining shape errors forecast after working with the model. The algorithm determines the maximum error value for the tested combination feed, and cutting speed. It calculates the processing time for this variant. The solution verification consists of checking whether the forecast error is equal to, or less than acceptable one, and whether the processing time is less than the shortest of the already analyzed solution. This means that the algorithm does not seek an absolute value to achieve the smallest possible error. If so, it would implement the lowest possible parameters, which means less efficient processing. The algorithm stores the set of optimal parameters achieved in the sample, and analyzes the next point in the parameter's space. After exhausting all combinations of feed – a cutting speed in the program memory leaves such a set of parameters which will be the shortest with the processing times while maintaining error shaped surface in established tolerances. The algorithm displays these parameters and ends the work.

With the assistance of the proposed expert system one can make a type case analysis. For example, when changing the allowance for the finishing pass, one can verify the certain number of passes in machining program being sure that the change will not influence the accuracy. The system allows the maximum utilization of machine's performance in complying with the dimensional criteria for the quality of the product.

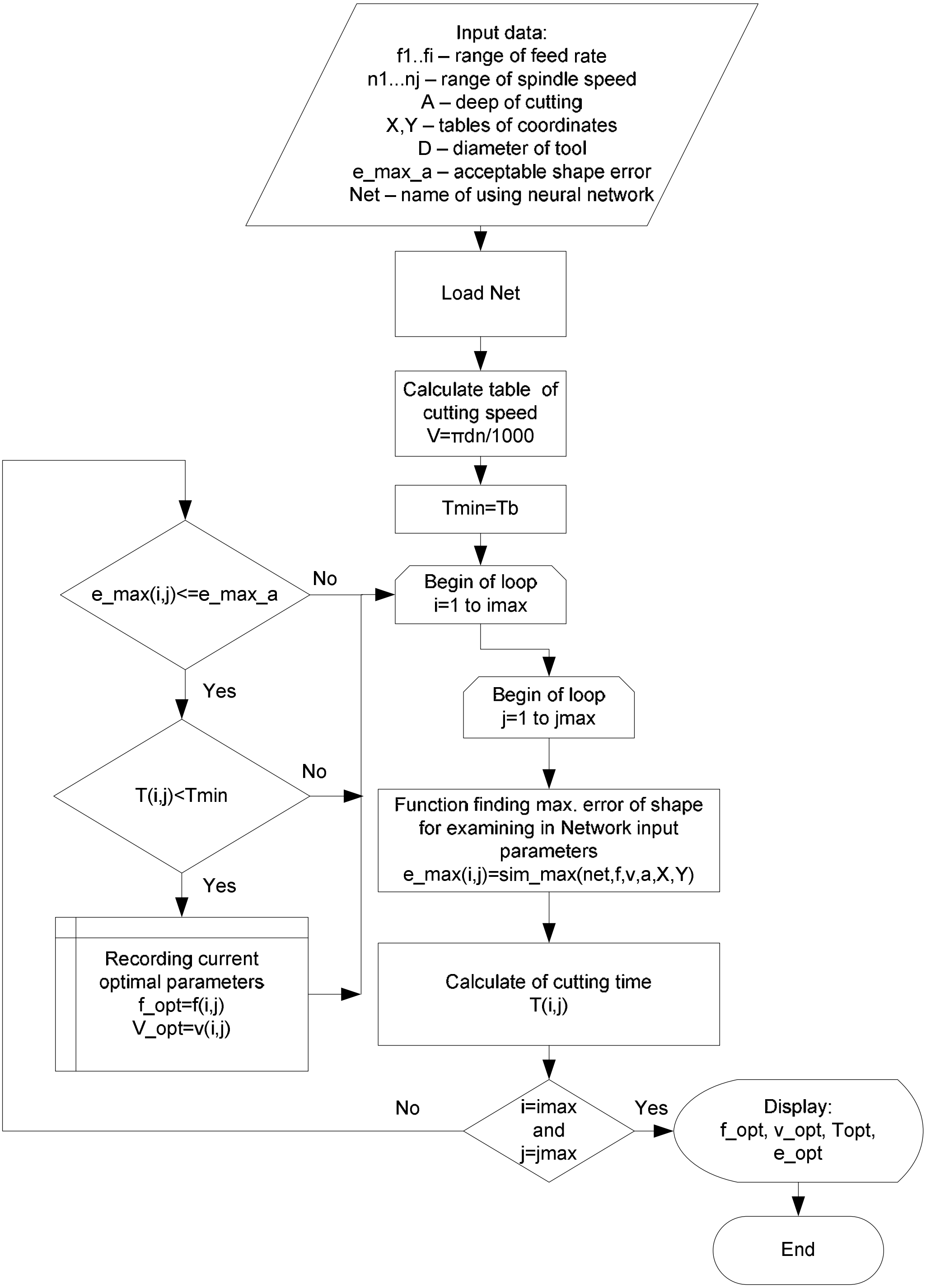


Fig. 7. Algorithm for looking up optimal parameters of milling

The milling process model application in the neural network for the shape errors of workpiece compensation

The more appropriate solution using the milling process in neural network modeling can be a model building conception of the shape error during the processing. Thus, this requires an operation of the system in real time and online measurement of cutting forces. The constructed model is dynamic, so it maps the dynamic properties of the error process tool's path. The collection of data for the model requires several machining cycles with the registration of cutting force at certain points of the tool's path, and measuring the same points of the resulting errors. The resulting model which appears during the network of learning, working in NARX structure, enables the error prediction in the n +1 point of the tool's path. Here, the algorithm uses the current value of the force, and value of the pre-and current, estimated value of the error. Such a model can be applied to the real-time controlling process for error compensation.

We can consider the output of the NARX network to be an estimate of the output of some nonlinear dynamic system that we are trying to model. The output is fed back to the input of the feedforward neural network as part of the standard NARX architecture, as shown in the Fig.8a. Because the true output is available during the training of the network, could be create a series-parallel architecture in which the true output is used instead of feeding back the estimated output, as shown in the Fig.8b. This has two advantages. The first is that the input to the feedforward network is more accurate. The second is that the resulting network has a purely feedforward architecture, and static backpropagation can be used for training.

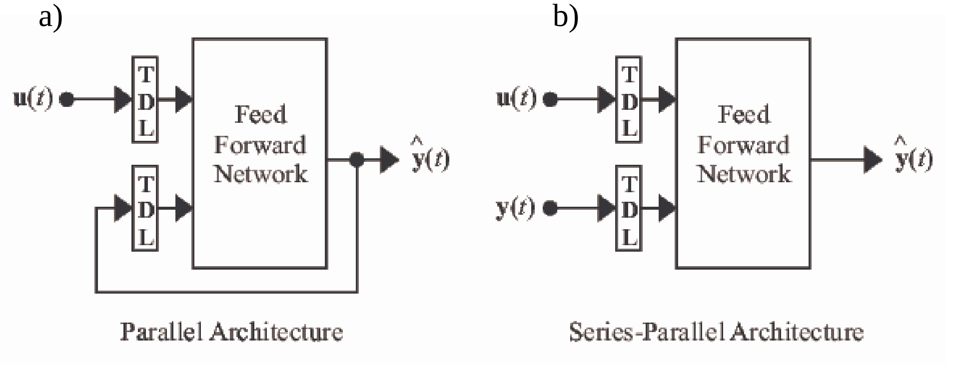


Fig.8. Neural network as part of NARX architecture (parallel architecture), series-parallel architecture during the training of the network, TDL- time delay line

Summary

The presented concept of using the technological process model with the neural network demands a collection of the necessary data to learn the network. During the process, several experiments cycles of machining using various parameters and measurement surfaces errors need to be taken . This takes up the machine time, and for some sets of parameters, can even generate the test defective workpieces. However, with the complexity of the phenomena that generates dimensionally-shaped errors, there is no other option than to teach them to anticipate system behaviors of such a complex object. This kind of solution, with a moderate spending, enables the neural network. The concept of modeling and its use as the expert system in the work of a technologist has been tested and proven in the laboratory conditions. In the industrial conditions, the process requires algorithmization and automation of the date collection process, and the network learning.

An installation of dynamometers on the advanced technological machining centers allows the application of concepts arising in real-time compensation of the shape errors from the milling workpieces, For this purpose, a neural network can be learnt of the dynamic properties of a particular process, and picked up using a control algorithm to construct by the network traffic prediction tool. This solution, however, required the interference of numerical control machine tool systems.

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Abstract

Towards the complexity of phenomena that generate the dimensionally-shaped errors in milling process, a model construction with the use of a neural network has been proposed. The present paper describe the concept of modeling and its utilization as a main part of the expert system support the work of a technologist. The model has been tested and proven in the laboratory conditions. In the industrial environments, the process of data collection and a network learning require algorithmization and automating.

Identification and simulation of milling process

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JERZY LIPSKI

Modelling on the ballizing process of holes in workpieces made of C45 steel

1. Introduction

Ballizing process is one of the methods of finishing of holes in machine elements. The ballizing is the forcing of a hardened steel or tungsten carbide ball through a pre-machined hole. A diameter of hole is smaller than the diameter of ball. In surface layer of finished hole deformation process of worked material occurs. This deformation causes increase of surface layer microhardness. Moving ball smooth of a hole surface and decreases a roughness. Ballizing produces improvements roundness and bearing ratio significantly [2]. Besides the ballizing improves fatigue life and corrosion resistance [1].

The ballizing process can be carried out dry or with lubricant, for example oil or soap solution. The lubricant brings one's influence to bear on axial ballizing force and surface roughness [9].

The ballizing can be static burnishing or burnishing while machined specimen is rotated. As the specimen rotated speed increased, the Ra parameter value decreased up to a certain speed and then such value increased again [1].

This method of holes finishing is highly efficient compared with some of the conventional hole-finishing process as reaming, grinding, lapping and honing [7]. The ballizing is very productive process and great saver in energy and production cost [9].

A multi-ring high-speed steel tools can be used for burnishing of holes too [3,4,8,10]. These tools can to make possible cutting and burnishing a workpiece.

Our early research work was carried out in order to estimate the accuracy and surface roughness of ballized holes [5, 6, 15, 16]. Different work-piece materials such as steel, brass and titanium alloy were used in the investigation. The aim of this research was to compare the effect ballizing parameter on microhardness and surface roughness of ballized holes.

2. Experimental work

A set-up of the ballizing process is shown in Fig. 1. A push rod (1) is used to force a ball (2) through the workpiece (3). The workpiece is loosely located in a support. The ball remains floating and closely follows the original axis of the hole in the workpiece. A hydraulic press that was used with the loading speed is being kept constant. Machine oil was used as lubricant.

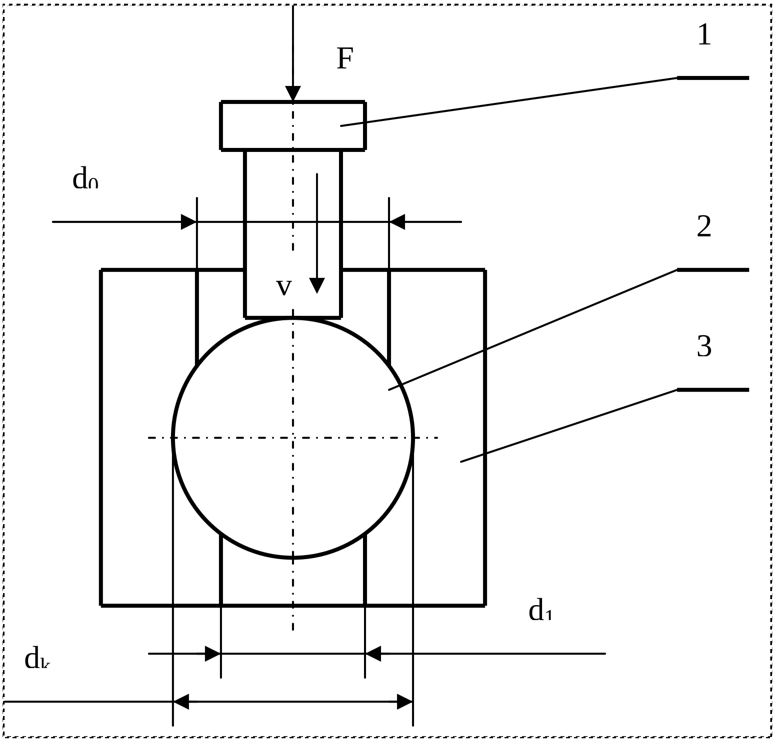


Fig. 1. Schematic arrangement of the experimental setup: 1 – push rod, 2 – ball, 3 – work-piece

The ringshaped workpieces were first drilled and then bored with boring cutter. C45 steel was used a test material (C – 0,45%, Mn – 0,55%, Ni – 0,24%, Si – 0,21%, Cr – 0,15%, Cu – 0,08%, S – 0,02%, P – 0,01%, Fe – rest).The external diameter of the workpiece was kept at 60 mm and the height – 20 mm. The internal diameter of the workpiece was varied from 9,689 mm to 28,44 mm. The initial surface finish of the bore was varied from 1,52 μm to 9,8 μm Ra by using different machining parameters. Balls, which are employed in ball-bearings, were used in this study. The diameter of the balls was varied from 9,922 mm to 28,575 mm.

Surface roughness measurements were made with Rank Taylor – Hobson Surtronic 3+ profile gauge. Microhardness of surface layer was measured with Leco LM – 700 AT microhardness tester. Vickers method was used.

There were following variable parameters of ballizing process:

- initial diameter of hole d_0,
- initial surface roughness Ra_0,
- relative interference w_w.

The value of relative interference was obtained by equation:

$$w_w = 100\frac{d_1 - d_0}{d_0}\% \tag{1}$$

Where: d_1 – final diameter of hole.

Final surface roughness Ra_1 and degree of strain hardening w_w were investigated. The value of degree of strain hardening was calculated by following formula:

$$e_H = 100\frac{HV_1 - HV_0}{HV_0}\% \tag{2}$$

Where: HV_1 – microhardness of surface layer, HV_0 – microhardness of workpiece core.

3. Tools used for modeling technological process

We can characterize production process if we know dependence between input parameters of technological process and output parameters of workpiece. We can describe this dependence through define mathematical equations, but in many cases building this equations is very difficult and result of using them as a model is not satisfying. To build mathematical model we must know exactly shape of physical process relations between input and output. In many cases it is impossible.

Described in this work case presented analogical problem. We wanted to find relation between three independent input and two output. We tried to apply neural network to solve this problem. Elementary component of neural networks is neuron. Practically applied it is mathematical model of biological neuron [11, 14]. An elementary neuron with *R* inputs is shown below. Each input is weighted with an appropriate *w*. The sum of the weighted inputs and the bias forms the input to the transfer function *f*. Neurons can use any differentiable transfer function *f* to generate their output.

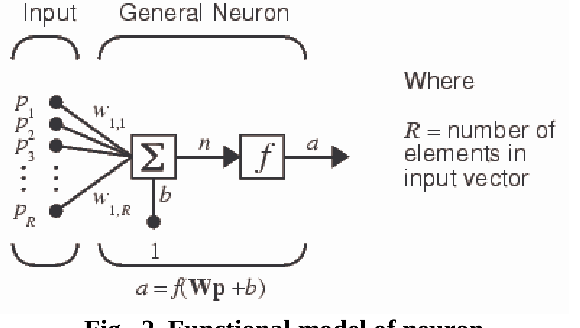
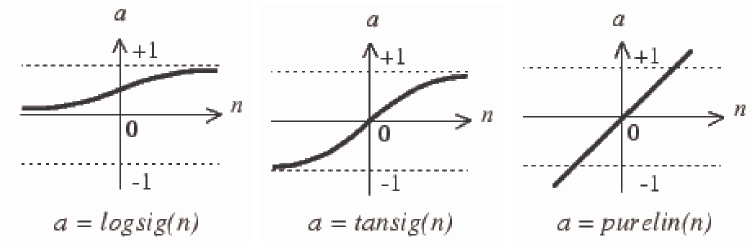


Fig. 2. Functional model of neuron

The Transfer function f have many forms depending of application. Can be used log-sigmoid, tan-sigmoid or linear function as shown on Fig. 3.



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Multilayer networks often use the log-sigmoid transfer function. The function logsig generates outputs between 0 and 1 as the neuron's net input goes from negative to positive infinity.

Feedforward networks often have one or more hidden layers of sigmoid neurons followed by an output layer of linear neurons. Multiple layers of neurons with nonlinear transfer functions allow the network to learn nonlinear and linear relationships between input and output vectors. The linear output layer lets the network produce values outside the range -1 to +1.In most of practical applications neural network has been implicated two layer: hidden and output as shown on Fig. 4. There can be more than one hidden layer, but using only one we can successfully modeling nonlinear dependence.

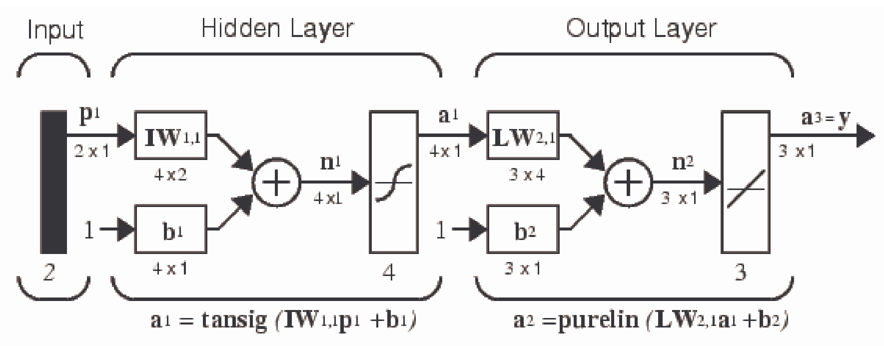

Fig. 4. Neural network structure

For modeling of technological problem two neural networks, one for modeling Ra_1 and one for e_H as output has been constructed. Collection of input parameters was the same: d_0, w_w and Ra_0. Neural networks has been trained on collection 125 cases from experiment. Accuracy of neural network model has been verified using different data then used to learn. On Fig. 5 relative error examined neural network for 125 collection input parameters was shown. This error is lower then 0,12 for neural network modeling function $Ra_1=f(d_0, w_w, R_0)$ and lower then 0,07 for modeling function $e_H=f(d_0, w_w, Ra_0)$. The best results for 7 neurons in hidden layer has been obtained. For training neural network and then examining it Matlab programming environment was used.

Based on results of modeling application build in Matlab graphical user environment has been proposed [12, 13]. This application can help process engineers find optimal parameters for modeling industrial process. If user inputs three parameters: d_0, w_w and Ra_0, neural network model shows him very probable value of Ra_1 and e_H. It is a kind of expert system which can be helpful in technological process project. Interface of this application is shown on Fig. 6.

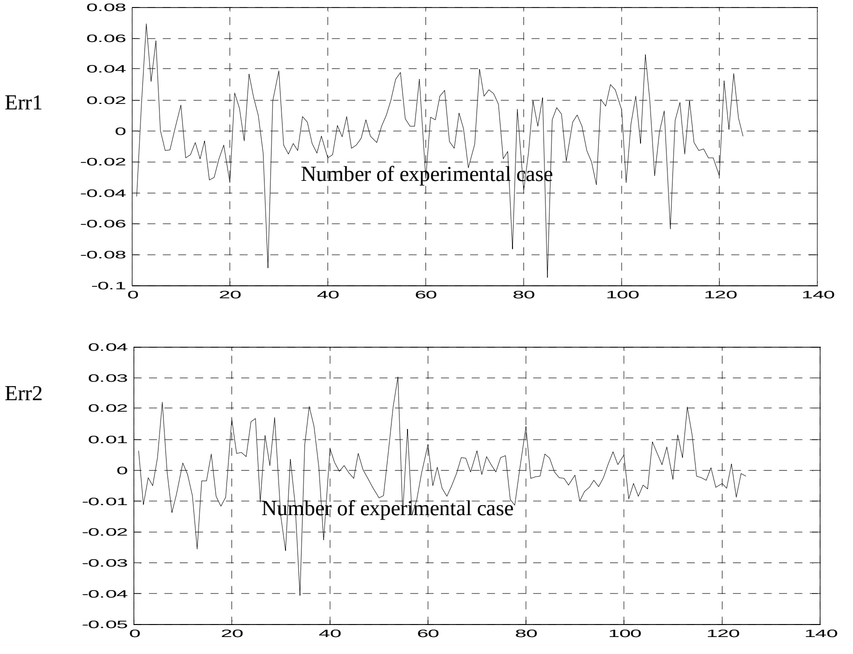

Fig. 5. Verification of neural network models: Err1 - relative error of prediction Ra_1; Err2 – relative error of prediction e_H

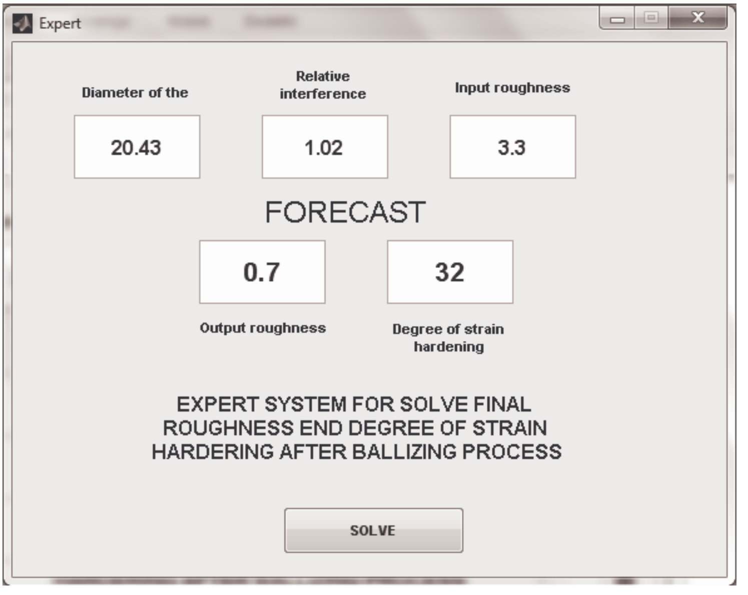

Fig. 6. Interface of expert system based on neural network model

4. Experimental results and discussion

The relation between final surface roughness and parameters of ballizing process is shown in Fig. 7 – 9. Surface roughness measurements showed that the present method of holes working greatly improved the final surface roughness. Average Ra was reduced from 1,52 – 10,8 µm (after boring) to 0,34 – 6,1 µm (after ballizing). As relative interference increased, the Ra_1 value (surface roughness after ballizing) decreased up to a certain relative interference w_w and then such value is approximately constant. As initial surface roughness increased, the Ra_1 value increased too in all investigated interval.

Some irregularity appears on graphs illustrating effect of relative interference on final surface roughness for different initial diameter of hole (Fig. 9). We may say, that as initial diameter of hole increased, the Ra_1 value have a tendency to decrease.

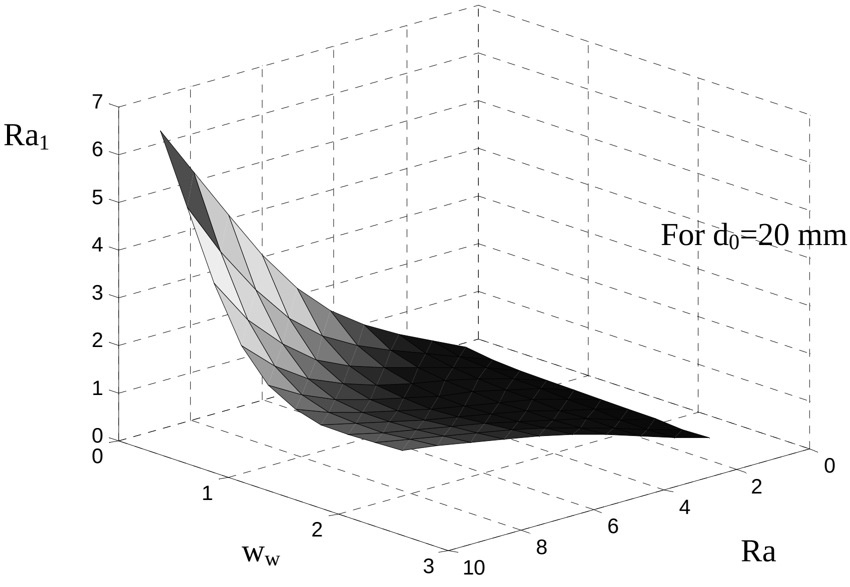

Fig. 7. Effect of relative interference and initial surface roughness on final surface roughness (initial diameter of hole – constant)

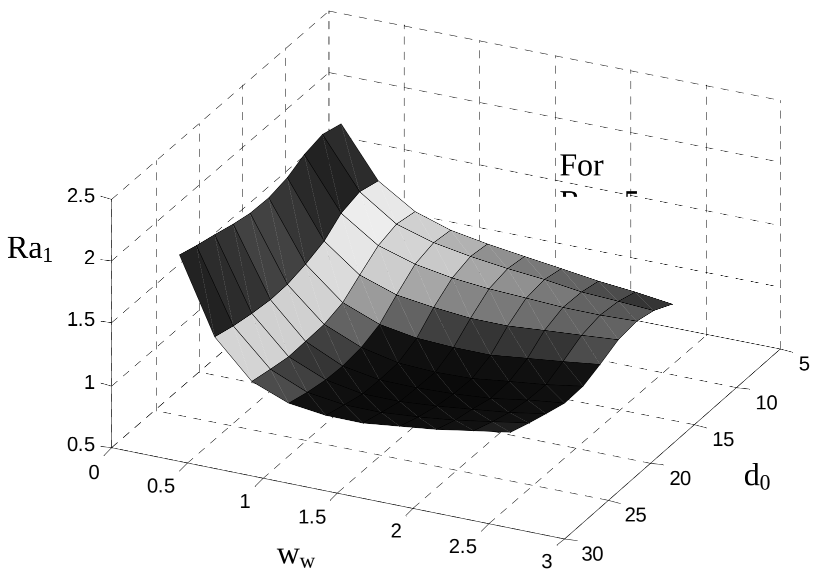

Fig. 8. Effect of relative interference and initial diameter of hole on final surface roughness (initial surface roughness – constant)

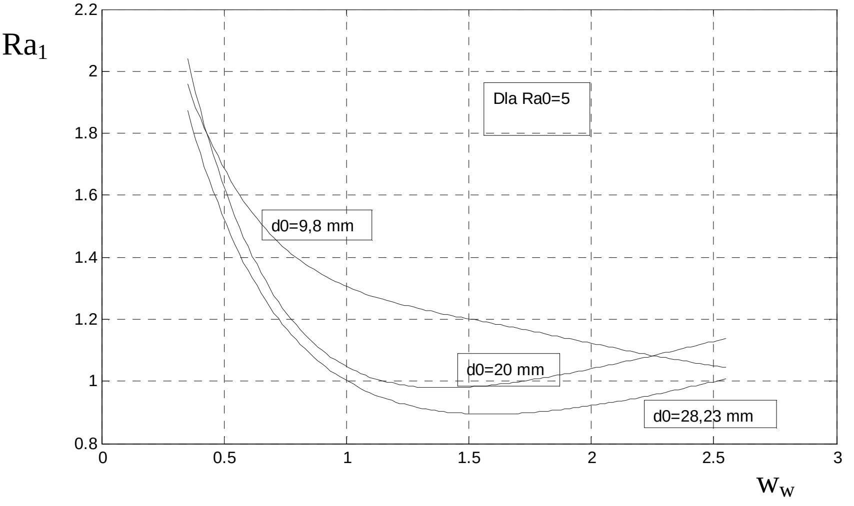

Fig. 9. Relationship between relative interference and final surface roughness

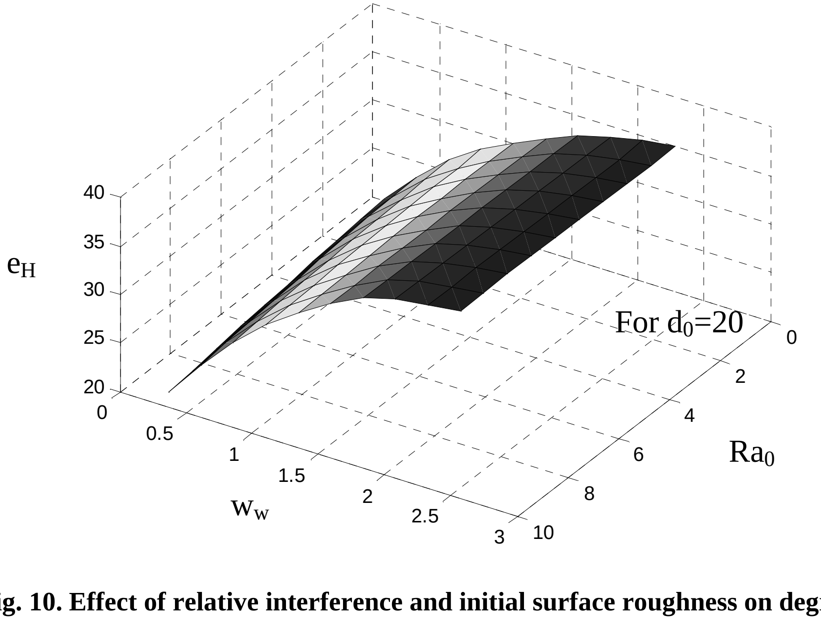

Fig. 10. Effect of relative interference and initial surface roughness on degree of strain hardening (initial diameter of hole – constant)

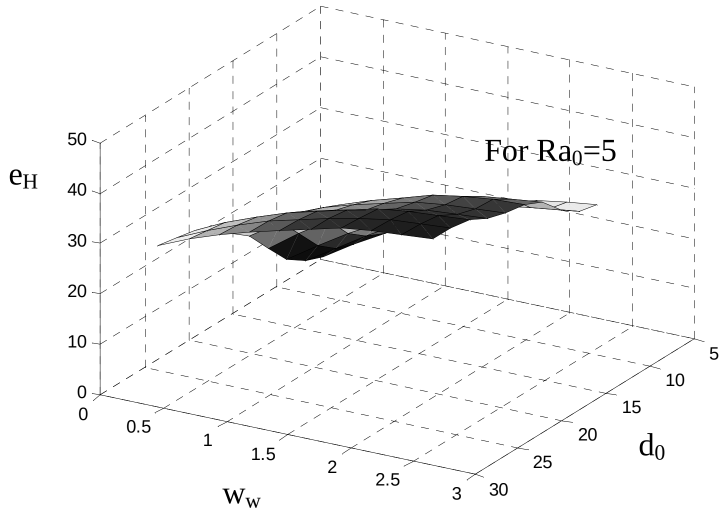

Fig. 11. Effect of relative interference and initial diameter of hole on degree of strain hardening (initial surface roughness – constant)

The ballizing process causes a strain hardening of surface layer of holes in machined workpieces. The relative interference after ballizing varied between 8 and 43%. Effect of ballizing parameters on degree of strain hardening is shown in Fig. 10 and 11. The relative interference causes the best effect on degree of strain hardening. As relative interference w_w increased, the degree of strain hardening e_H increased to certain value of relative interference and then such e_H value was approximately constant. As initial diameter of hole d_0 increased, the e_H value increased too. This dependence is especially visible for a little relative interference. As initial surface roughness Ra_0 increased, the e_H value a little decreased.

5. Conclusion

The following conclusions may be written on the basis of the experimental results a neural network modeling:

(1) The ballizing process of holes of C45 steel workpieces causes the surface roughness Ra parameter decrease and microhardness of surface layer increase.

(2) The ballizing parameters have an influence on final surface roughness and degree of strain hardening.

(3) Artificial neural network can be used for modeling of ballizing process.

(4) Relative error of neural network model is lower then 0,12 for function $Ra_1 = f(d_0, w_w, Ra_0)$ and lower then 0,07 for function $e_H = (d_0, w_w, Ra_0)$.

(5) Expert system based on neural network model can be helpful in project of technological process.

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Modelling on the ballizing process of holes in work-pieces made of C45 steel

Abstract

In this paper results of research of influence of ballizing parameters on surface roughness and surface layer microhardness are presented. Based on results of research, neural network model and expert system were made. Expert system can be helpful in project of ballizing technological process.

Key words: ballizing, surface roughness, surface layer, microhardness, neural networks, expert system.

Modelowanie procesu nagniatającego przepychania ślizgowego otworów w przedmiotach ze stali C45

Streszczenie

W pracy przedstawiono wyniki badań wpływu parametrów nagniatającego przepychania ślizgowego na chropowatość powierzchni i mikrotwardość warstwy wierzchniej. Na podstawie wyników badań doświadczalnych opracowano model neuronowy oraz system ekspertowy. System ekspertowy może być pomocny w projektowaniu procesów technologicznych nagniatającego przepychania ślizgowego.
Słowa kluczowe: nagniatające przepychanie ślizgowe, chropowatość powierzchni, warstwa wierzchnia, mikrotwardość, sieć neuronowa, system ekspertowy.

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Cellular process of polymer materials

1. Introduction

Extrusion of cellular plastics differs from extrusion of solid plastics in that the product obtained as a result of processing displays a diphase plastic-gas structure, with possibly smallest and evenly distributed gas bubbles. Cellular structure is obtained due to the insertion of a blowing agent (porophor) in the form of an inert gas, low-boiling liquid or a solid body into the input plastic which, when in liquid or solid state, transforms into gas under determined conditions of the extrusion process. Inert gases and low-boiling liquids are introduced under pressure, by means of special dispensing devices, directly into the feeding zone of the plasticizing system in the extruder during extrusion [1, 3, 8, 11, 12]. By contrast, some liquids and solid bodies, for instance pigments, are mixed with polymer plastics in a typical way, i.e. before their delivery to the extrusion machine dispenser, or they are introduced into the plastic already during the extrusion process. When in the proper temperature the process of gas emission is started, numerous microspheres which are then generated dissolve in the ambient plastic material due to the operation of pressure and surface expansion. The obtained cells may be filled either with air or with other gases, such as e.g. CO_2 or N_2, but later as a result of diffusion, they are replaced by air [2, 4, 6, 10, 13].

2. Blowing agents in the extrusion process

The blowing agent (porophor) is selected so as to match the type of plastic material, and its decomposition temperature has to be higher than the melting point of the plastic material, yet lower than the temperature during plastic extrusion. Cellular plastic in liquid form is still not a stable system because as a result of interfacial tension at the plastic – gas contact point, and as a result of diffusion, the number of cells in the plastic is reduced, whereas their dimensions enlarge, which comprises an undesirable effect. The obtained cells keep enlarging until gas pressure and interfacial tension are balanced. Favourable small-cell structure can be maintained in the plastic product by its immediate cooling and solidification. During the extrusion process, blowing agents are exposed to exactly the same conditions as the processed plastic, i.e. to heating, compression, homogenizing treatment and carrying already before gas emission [1, 2, 6, 7, 8].

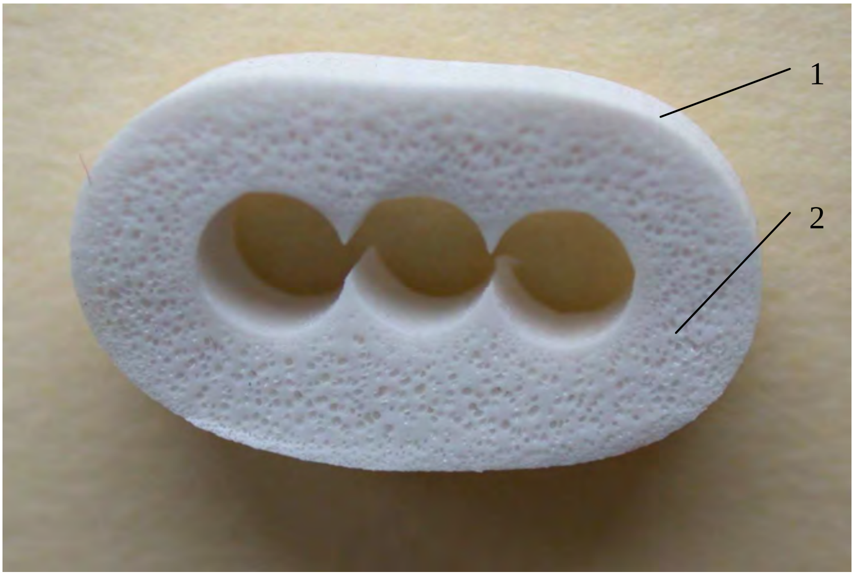

Fig. 1. Cross – section view of PVC cellular multilayer (power cable YDYp): 1- core zone, 2– surface zones

Cellular extrusion of thermoplastic materials may be conducted with the use of:

- chemical blowing agents (to maintain low cost of technical equipment and machines used in the processing);
- physical blowing liquids (gases) to obtain high degree of porosity.

Physical blowing agents include: hydrocarbons (e.g. pentane), water, nitrogen and carbon dioxide added in a liquid or gaseous form to the polymer melted in the plasticizing system and mixed with nucleants (very often, talc).

By contracts, chemical blowing agents are added to the granulated polymer as solids (powder, granulated product) fed to the plasticizing system, most often by means of gravimetric or volumetric dispensers. Plastic mixed with the blowing agent is then processed in the plasticizing system and shaped in a traditional tool (injection mould, extruder head etc.). As it is the case with physical blowing agents, gas dissolved in a polymer is obtained.

Chemical blowing agents especially include nitric compounds, sodium bicarbonate and mixtures of organic acids and hydrocarbons. The reaction may be endothermic or exothermic. What should be considered when using chemical blowing agents during processing, is that typical (decomposition) temperature must be exceeded for a specified period of time, in order to obtain relevant amount of gas [1, 2, 14, 15].

In practice, polymer materials are fed with blowing agents using the following four methods:

Melted plastic is saturated under pressure with gas or easily volatile liquid; as a result, after cooling, the plastic contains dissolved liquid or gaseous blowing agents.

The plastic is mixed (mechanically) with solid blowing agents which are then rinsed with solvents (e.g. domestic salt and ammonium sulphate are rinsed with water).

Bonding monomers into polymers in the presence of (liquid or solid) blowing agents which get absorbed into a polymer.

Introduction of air (by means of mechanical stirrers) into resins containing blowing agents, after which the resin is cured [9].

Type and volume of the added blowing agents affects final density of the cellular plastic and determines cellular extrusion method. Proper feeding system is the basic warrant of effectiveness. Blowing agents should be dissolved in a polymer. Cellular extrusion comprises final stage of the process of saturating the polymer with blowing agents.

Fig. 2. Microscopic image of the cross section of the cable covering made of cellular polymer of the amount of the endothermic blowing agent 0.6% mass.

Extrusion process which involves application of blowing agents, results in obtaining new, modified physical and technological properties of cellular products. Advantages of cellular products in comparison to solid products are as follows:

- they are lighter, due to reduced density,
- they are more rigid, having the same or smaller weight,
- they display higher bending resistance,
- lower permittivity, lower thermal conduction,
- excellent insulating performance,

- favourable mechanical and noise suppressing properties,
- they ensure saving of materials [1, 4, 6].

The obtained product may have a fully solid or cellular structure, or it may be cellular in its entirety, or it can have the cellular topcoat and solid surface [1, 4, 5, 6]. Proper distribution of temperature in the plasticizing system of the extruder and the extruder head is required to obtain favorable cellular structure in the extrusion process. Temperature in the first, second and alternatively third functional zone of the plasticizing system should be lower than initial decomposition temperature of the blowing agent. Only in the fourth zone of the plasticizing system, temperature should be higher than decomposition temperature of the blowing agent, whereas temperature inside the extruder head should approximate or be lower than decomposition temperature of the blowing agent [1, 3, 15].

Fig. 3. Cross – section view of PE-HD cellular singlelayer

Depending on the temperature of cooling, different distribution of cellular structure may be obtained in the product, and solidification of cellular products takes longer than solidification of solid products. Although thermal capacity of cellular plastic is lower, yet thermal conduction is significantly deteriorated. Cooling of the cellular product (scope and intensity) determines creation of the cellular structure of the product. Insufficient cooling may lead to emergence of a non-uniform cellular structure [2, 3, 8, 11, 14, 9].

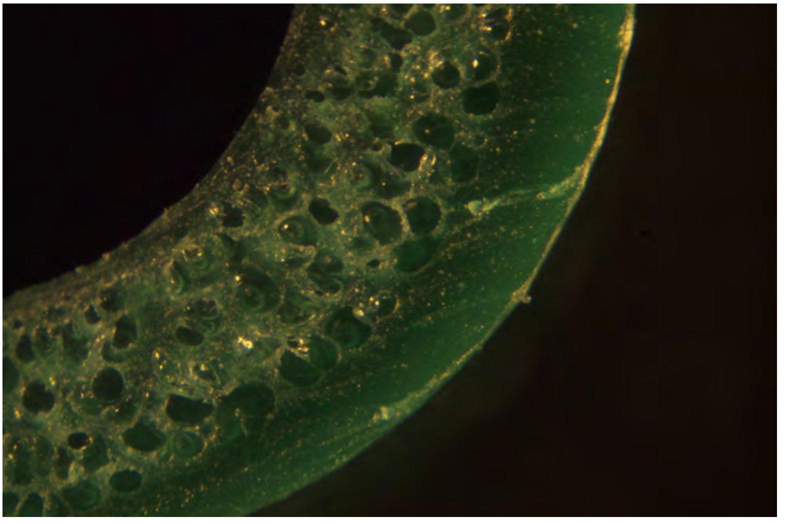

Fig. 4. View of double-layered coatings microstructure inclusive blowing agent in amount 0,3%, magnify 100x

Fig. 5. View of bended double – layer wire with 32% degree of porosity

Blowing agents used during cellular extrusion of plastics may display exothermic or endothermic decomposition characteristics [4, 6, 8, 10].

During decomposition, exothermic porophors release more energy than it is actually required in this reaction. The initiated decomposition proceeds spontaneously, even after energy cut-off. For this reason, products extruded with the use of this type of agents must be intensely cooled for a long time to prevent strains. This may be the cause of local overheating and generation of irregular cellular structure of the product [4, 5, 8, 13].

Main representatives of this group of agents include hydrazides, e.g. sulfohydrazide and azo compounds, for instance azodicarbamide. This compound is widely used in cellular extrusion of polyethylene, polyvinyl chlorine, polystyrene and polyamide.

In case of blowing agents having endothermic decomposition characteristics, emission of gas during processing is violently stopped when the energy supply is cut off. Application of this kind of blowing agents considerably shortens the cooling time. Examples belonging to this group especially include bicarbonates, e.g. sodium bicarbonate, ammonium bicarbonate and 2-Hydroxy-propanetricarboxylic acid [7, 9].

In comparison to porophors with exothermic characteristics, porophors with endothermic characteristics significantly shorten cooling time of the product, which also leads to shortening of the manufacturing cycle. Basic materials for porophors with endothermic decomposition characteristics are bicarbonates and citric acid. As these substances are used as food additives, their use poses no problem.

3. Research

Studies on cellular extrusion conducted in the Department of Polymer Processing [3, 4, 5, 6, 7, 10] especially focus on the manufacture of thin-walled cellular products comprising coatings of conduits, cables, steel wires of various types and applications. Results of research conducted to date have led especially to decreased consumption of plastic during processing, reduced energy costs and improved productivity.

This article presents selected results of the study on the manufacture of thin-walled cellular coatings for electric cables. Electric cable coatings made of plastic fed by blowing agents were produced, with the use of a standard process line for extrusion coating. The process line was used for the production of single-layer coatings for cables of different type and use.

The line was composed of an angular extrusion head used in co-extrusion coating (Fig. 6), cooling device (bath), collecting devices and other necessary process line components. Temperature in particular zones of the plasticizing system was ranging from 160 to 180^0C; temperature inside the extrusion head in three heating zones was ranging from 165 to 175^0C.

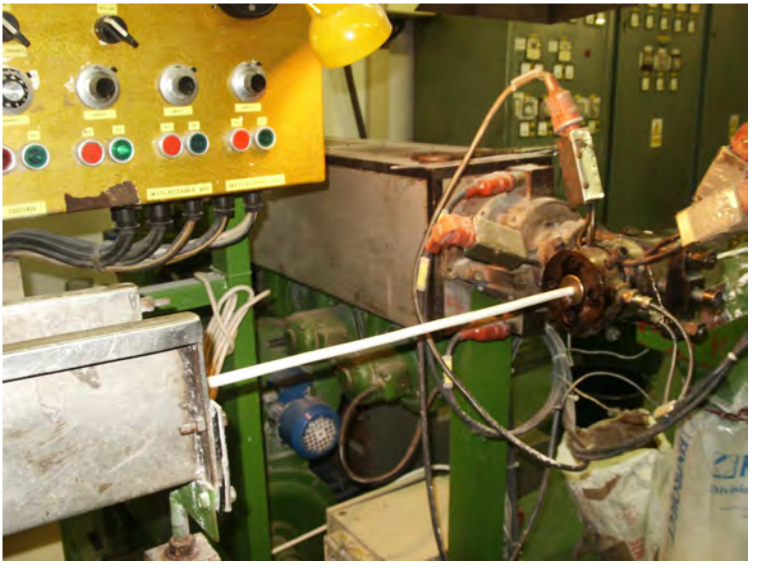

Fig. 6. Fragment of cellular co-extrusion line of PVC cable layer

The plastic was modified with the use of two types of granulated blowing agents dispensed as 0.4% to 0.8 % of the mass. In the study, the used blowing agent was Hydrocerol ITP 751 having exothermic decomposition characteristics, as well as Hydrocerol BIH70 having endothermic decomposition characteristics.

Blowing agents were selected to match the type of the processed plastic and applied study method.

Fig. 7. Structure view of PVC double-layer cable, magnify 20x

As a result of extrusion coating of PVC with the use of blowing agents, layer cellular cable coating was obtained. (Fig. 7). External diameter of the manufactured conductor was 7,8÷8,0 mm and the coating was 1,3÷2,0 mm thick, in accordance with relevant industry standards [9].

Density of sample cellular PVC extrusion products was determined with the use of specific gravity bottle [9]. Measurements were conducted with respect to refined particles of sample extrusion product, whose mass ranged from 1 to 5 g.

TABLE 1. Results of measuring apparent density, foaming of porosity of coatings and hardness of cable coat modified by a blowing agent

No.	Content of blowing agent, %	Foaming of porosity %	Density kg/m^3	Hardness Sh D
1	0	0	1370	65
2	0,2	19	1157	60
3	0,4	22	1070	60
4	0,6	36	1013	55
5	0,8	40	820	50
6	1,0	42	800	51

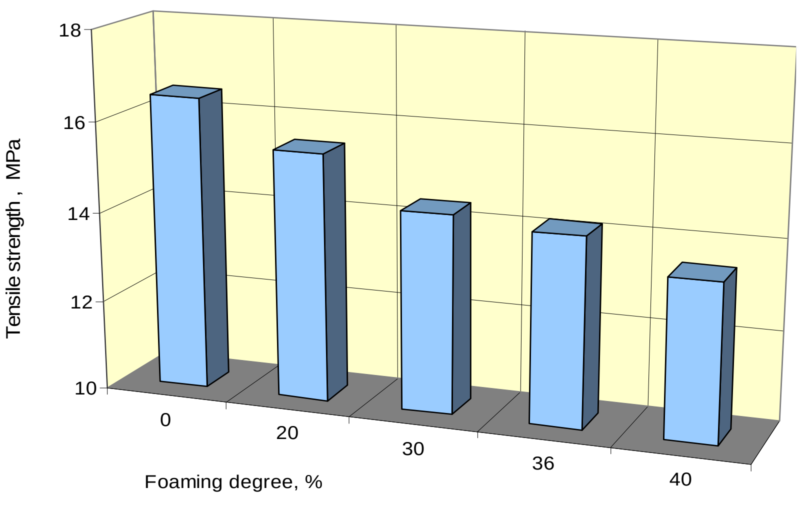

Fig. 8. The dependence of the tensile strength of the foaming degree value

In order to determine selected mechanical properties of thin-walled cable coatings, tensile strength and ultimate elongation were tested. Sample shapes and sizes were used in the examination, in accordance with relevant standards [9]. Samples of product coating after prior removal of a copper wire were used in the measurements.

Measurements were conducted with the use of PT-250 M-2 testing machine.. Tension rate was 1.66 mm/s (100 mm/min), bias ranging 0÷500 N and accuracy of force measurements of ±1N. (figures 8).

In order to determine geometric structure of the obtained thin-walled coatings, microscopic examination of cellular cable coatings was conducted. Figure 9 and Figure 10 present microstructure of cable coatings manufactured with the use of blowing agents having endothermic or endothermic decomposition characteristics. The photographs were taken using analytic stand for cellular structure of plastics, developed as part of a research project of the Ministry of Science and Higher Education.

Fig. 9. Microscopic image of the cross section of the cable coating made of cellular PVC of the amount of the blowing agent (PLC 751) 1,0% mas., magnify 100x

4. Findings and conclusions

Dispensing the blowing agent into PVC by manual stirring during technological tests proved to be effective. No visual changes and no changed properties of the examined product resulting from the manner of dispensing and mixing PVC with the blowing agent have been observed.

Quality of the obtained product, considering degree of porosity and density, was very good. Obtained product had a coating whose degree of porosity ranged from 19 to 42% and density 1157 to 800 kg/m^3 respectively, depending on the type and content of the blowing agent in the modified plastic.

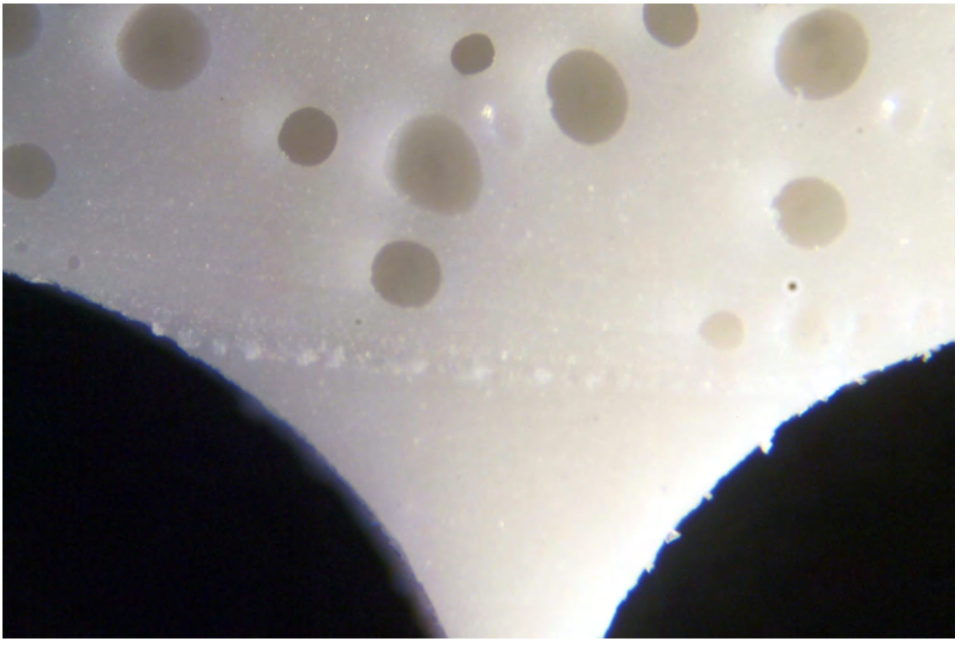

Fig. 10. Microscopic image of the cross section of the cable coating made of cellular PVC of the amount of the blowing agent (BIH 70) 0,4% mas., magnify 100x

Application of blowing agents with endothermic decomposition characteristics already as 0.4÷0.8% of the mass as well as blowing agents with exothermic decomposition characteristics as 0.4÷0.6% of the mass in the process of coating extrusion, enables to obtain a product whose manufacturing process is very cost-effective.

Results of tensile strength tests for cable coatings are compliant with expected values and requirements of relevant standards for determination of materials for insulation and coatings. Tensile strength of cellular coatings is lower only by average of 20÷30%, in comparison to solid coatings whose tensile strength ranges from 16.10÷13.15 MPa. Relative elongation ranges from 209 to 257%, depending on the type and content of the blowing agent in a cable coating.

An advantage of coatings of wires and cables manufactured in the process of cellular extrusion is their microcellular structure, which results in reduced volume of polymer plastic, even by as much as 30 to 40%, needed for their manufacture. Cables containing elements of cellular polyvinyl chloride are lighter and display enhanced noise suppressing qualities and reduced shrinkage, owing to the application of special blowing agents with endothermic decomposition characteristics. Cellular co-extrusion in the manufacture of coatings of wires and cables offers significantly reduced consumption of plastic materials and electricity during manufacture.

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Cellular process of polymer materials

Abstract

In recent years, cellular extrusion of thermoplastic materials has been one of the fastest growing processing methods. It is used especially to obtain sections, bars, pipes and cellular coatings free from strains on the product surface, displaying reduced density and minimum shrinkage, at the same time maintaining similar properties of products extruded in a conventional way. In order to obtain cellular structure, product properties are modified by application of proper plastics or adding the blowing agents.

The article provides description of cellular product manufacturing processes. It gives characteristics of blowing agents used in the extrusion process and of processing conditions. Also, it discusses selected results of examining properties of obtained cellular products.

Keywords: cellular extrusion, blowing agents, cellular coatings

Procesy porowania tworzyw polimerowych

Streszczenie
Technologia wytłaczania porującego tworzyw termoplastycznych jest w ostatnich latach jedną z szybciej rozwijających się metod przetwórstwa tych materiałów. Ma ona na celu otrzymanie między innymi kształtowników, prętów, rur, powłok porowatych o zmniejszonej gęstości oraz pozbawionych zapadnięć na powierzchni wytłoczyny i wykazujących minimalny skurcz przy jednoczesnym zachowaniu zbliżonych właściwości wytworów wytłaczanych metodą konwencjonalną. W celu uzyskania struktury porowatej modyfikuje się właściwości wytłoczyny poprzez zastosowanie odpowiedniego tworzywa lub wprowadzenie do niego środków porujących.
W artykule scharakteryzowano procesy wytwarzania wyrobów porowatych. Przedstawiono specyfikę środka porującego zastosowanego w procesie wytłaczania oraz warunki przetwórstwa. Omówiono wybrane wyniki badań właściwości otrzymanych wytworów porowatych.
Słowa kluczowe: wytłaczanie porujące, środki porujące, powłoki porowane

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JAKUB SZABELSKI

Measurements of the work of adhesion for different structural materials typical surface treatment methods

Introduction

Gluing as a technological operation consists in producing a durable connection between the surface layers of joined materials. Obtaining a strong connection is often impossible without prior preparation of adhered surfaces. The work of adhesion is one of the factors describing the adhesive proprieties of a surface. It defines the minimum energy indispensable to divide the surface layer from the liquid and can be treated as the determinant of surface preparation for gluing operation.

Determining the work of adhesion by measuring the wetting angle

The work of adhesion, which characterises the surface state, can be determined by measuring the wetting angle between the drop of liquid and a solid surface. The work of adhesion is understood as the surface free energy required to achieve a reversible phase equilibrium in constant pressure and temperature conditions (Fig. 1). The work formula takes the form of the Young-Dupre equation.

$$W_a = \sigma_{cl}\left(1 + \cos\theta\right)$$

where: σ_{cl} – measuring liquid surface free energy [mJ/m^2], θ – wetting angle. The wetting angle is measured between the solid surface and tangent to a liquid meniscus curve on the liquid-solid contact surface [1]. Drawing from the aforementioned definition, it would seem that the choice of a surface treatment operation which will provide the highest work of adhesion is the most advantageous. In practice, however, it appears that in certain cases (e.g. with an oxide film on a steel surface) low adhesive joint strength is observed regardless of high surface energy state [9, 11].

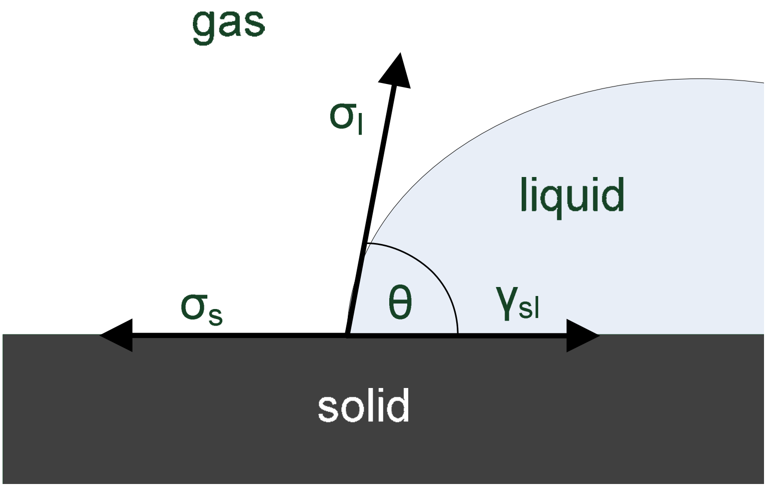

Fig. 1. Three phases, wetting angle measurement

The article scrutinises the influence of surface preparation methods on the work of adhesion of different structural materials, such as aluminium alloys: PA1, PA7; polymers: epoxy-glass composite laminate, Tarnamid T-27, polyvinyl chloride (PVC), polytetrafluoroethylene (PTFE), and structural steel: S235JR, 1H18N9TA. In the tests, the work of adhesion was measured on a station [2] enabling computer testing software based direct measurement of the wetting angle; distilled water was used as the measuring liquid. The application of computer vision in the work of adhesion tests enabled to simplify the measurements and to conduct them in a complex form. Owing to the purpose-made test stand connected to the computer equipped with a “MicroScan” handler programme it was possible to monitor the sample on the computer screen, additionally, the results could be immediately processed with spreadsheet software [3]. The handler programme provides a number of functions improving picture quality, which allow the morphological and mathematical transformations of the image. It is, furthermore, possible to edit and retouch a given image. The wetting angle value measurements were conducted by drawing the generating lines of a desired angle (Fig. 1), which was enabled by the application of a programme module for direct measurement of a wetting angle geometrical values. An alternative testing method consists in measuring the dimensions of a drop, knowing which allows an engineer to calculate the θ angle from geometrical dependences. The magnifying power of the stereoscopic microscope used in tests ranges between 10-126 times, which allows close observation of the sample as well as high accuracy when determining the necessary values.

Abrasive treatment

Abrasive granular tools machining plays an important role in the surface layer preparation for gluing. Abrasive granular tools prove especially suitable due to their accessibility, uncomplicated operation requiring no additional devices, and high cost-efficiency. One of the advantages of this surface preparation method is the non-directional tool mark, particularly convenient for constructional gluing.

Treatment with such tools constitutes adhesive properties of the surface layer, predominantly owing to surface development (i.e. extending the real surface), removing organic or inorganic contaminants and mechanochemical interaction.

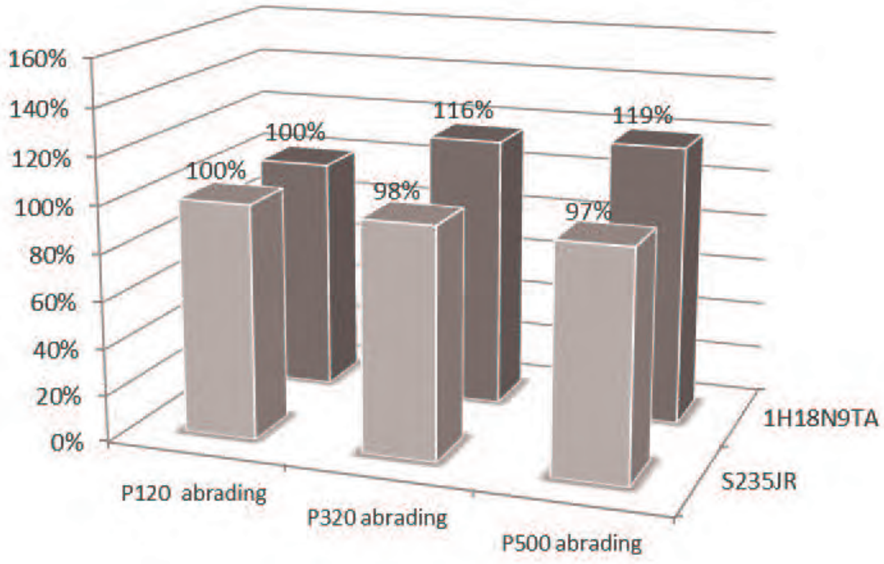

Fig. 2. Relative change of the work of adhesion for chosen structural steel samples depending on the grain size.

The grain size is a factor to consider in the selection of abrasive granular tools. Bigger grain size tools remove the material surface, including the physisorbed layer, more efficiently. However, due to the fact that the adsorbed substances layer is erased to a lesser degree, these are smaller grain size tools which provide better surface development.

The test were conducted for P120, P320 and P500 grain size abrasive granular tools, with distilled water as the measuring liquid. Fig. 1–3 present relative change of the work of adhesion following surface treatment with abrasive granular tools (abrasive paper) for increasing grain size, for the following selected materials: structural steel, polymers, aluminium alloys [4, 6, 7].

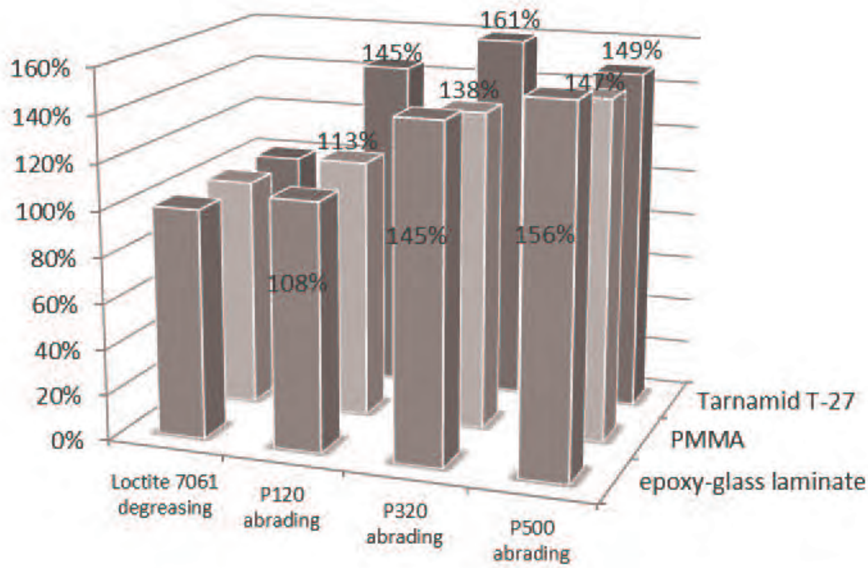

Fig. 3. Relative change of the work of adhesion for chosen polymer samples depending on the grain size.

Surface degreasing

Removing organic and inorganic surface contaminants prior to gluing process may be performed by means of degreasing operation, which can be applied on both raw and machined surfaces. The degreasing process in the tests was conducted in accordance with the manufacturer's standards and followed the procedure: the samples, previously coated with the aerosol degreasing agent, were cleaned with a swab, re-coated and left to dry for approx. a minute. Fig. 4, 5 and 6 present the results of the work of adhesion measurements following degreasing with Loctite 7061 and Chester Cleaner agents for selected structural steel, polymer and aluminium alloy samples [4, 6, 7].

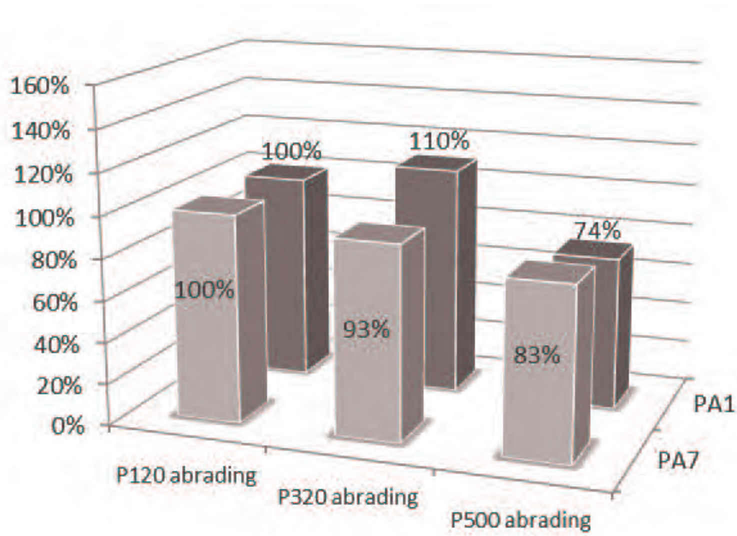

Fig. 4. Relative change of the work of adhesion for chosen aluminium alloy samples depending on the grain size.

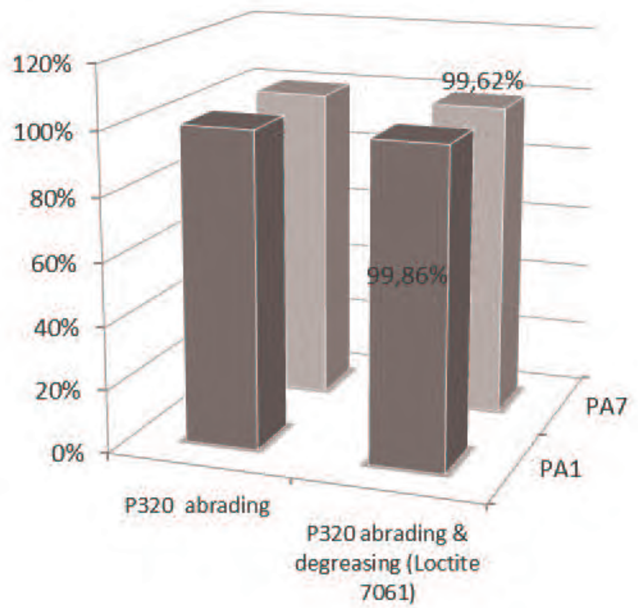

Fig. 5. Relative change of the work of adhesion for chosen aluminium alloy samples following degreasing.

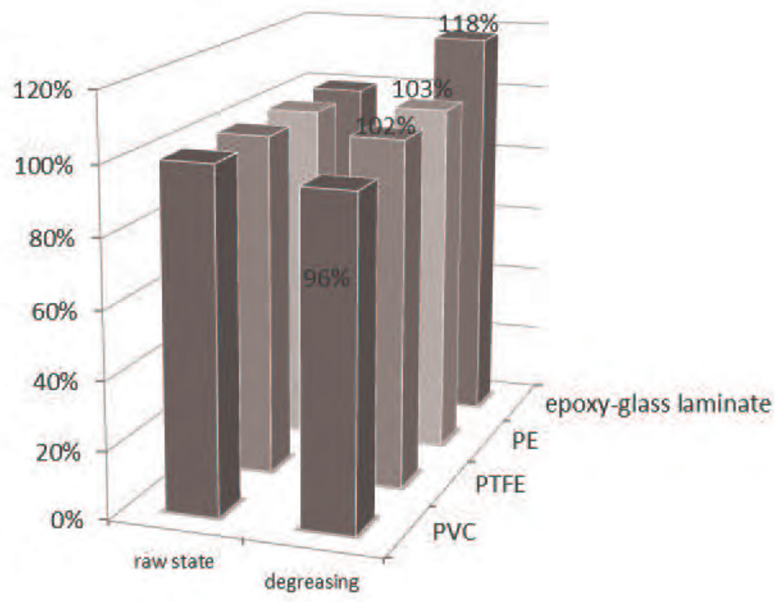

Fig. 6. Relative change of the work of adhesion for chosen polymer samples following degreasing.

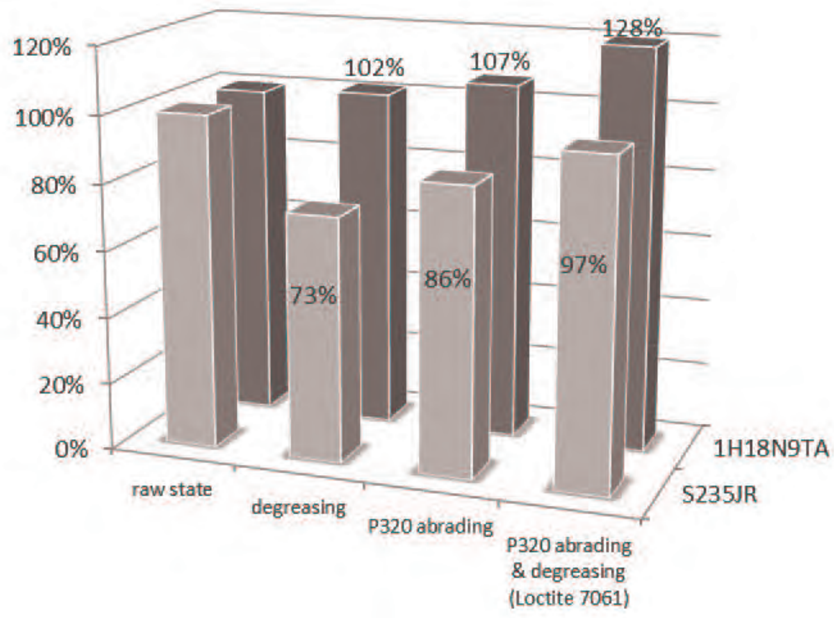

Fig. 7. Relative change of the work of adhesion for chosen structural steel samples following degreasing.

Chemical treatment

Similarly to the application of the aforementioned surface preparation operations, chemical treatment is aimed at removing the physisorbed phase along with surface development, which makes it a suitable gluing surface preparation method.

In the tests, the method employed for chemical treatment was a bath in the following solution: H_2SO_4 – three parts, $Na_2Cr_2O_7$ – two parts, H_2O – seven parts. The immersion time for the samples was 10 minutes, nevertheless, in the case of aluminium alloy samples the other, 20 minute time variant was tested. The chemical treatment was followed by rinsing the samples in running water, which were subsequently left to dry in ambient temperature for 30 minutes [4, 6, 7]. The results of surface energy state tests are presented in Fig. 7, 8, 9.

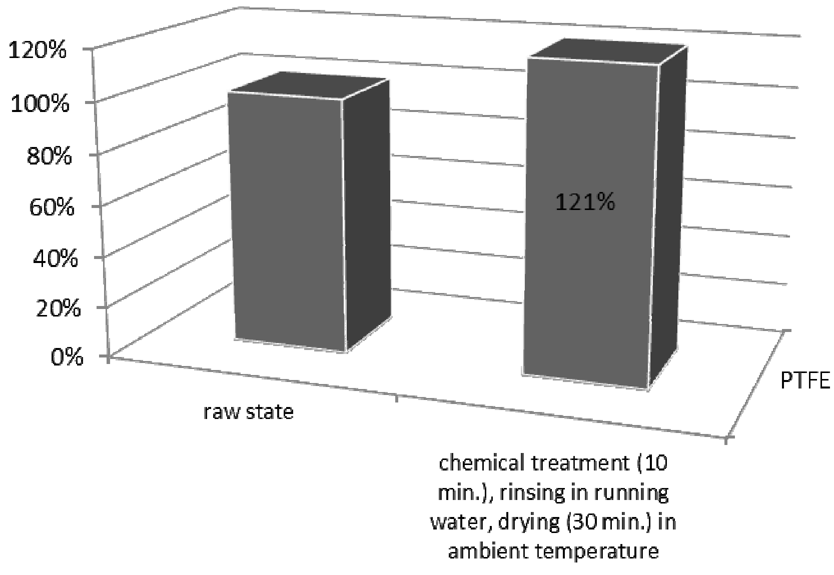

Fig. 8. Relative change of the work of adhesion for chosen PTFE samples following chemical treatment.

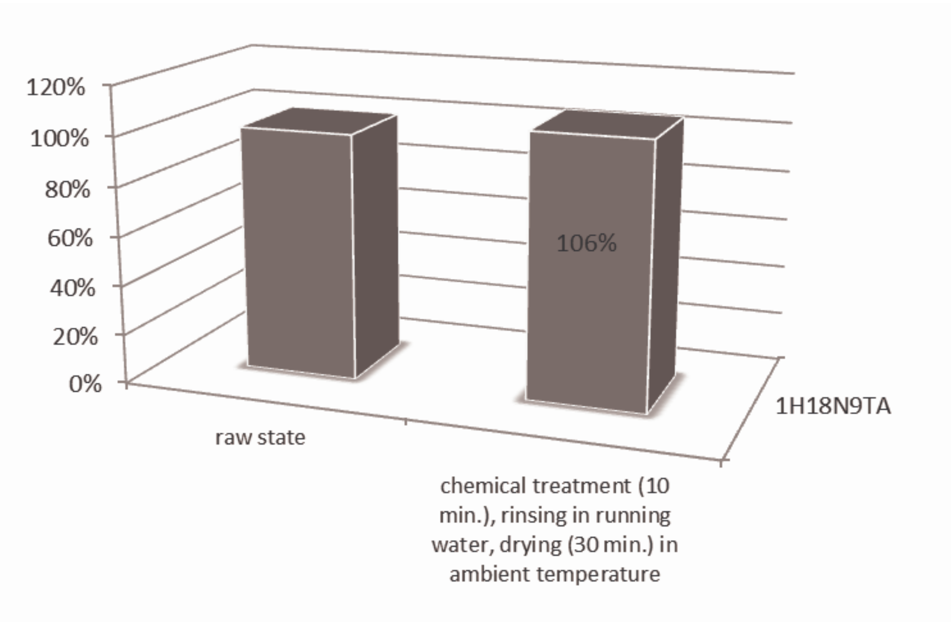

Fig. 9. Relative change of the work of adhesion for chosen 1H19N9TA samples following chemical treatment.

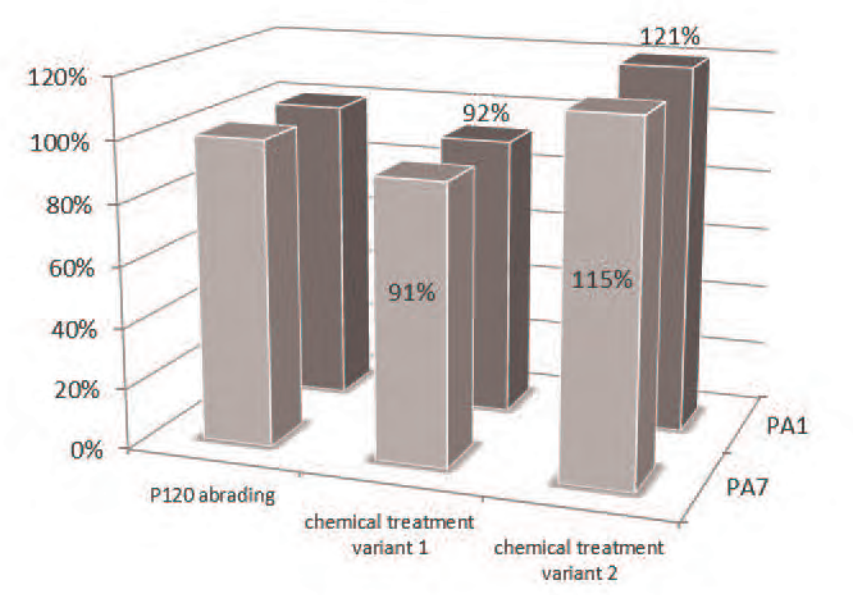

Fig. 10. Relative change of the work of adhesion for chosen aluminium alloy samples following chemical treatment.

Conclusions

Based on the results of experimental study, certain noteworthy conclusions may be drawn in terms of the influence of the scrutinised surface preparation methods on the surface energy state properties. The abrasive granular tools machining operations show no significant impact on the work of adhesion in the case of S235JR carbon steel, however, for 1H18N9TA alloy steel there is significant correlation between the tool grain size and the work of adhesion, amounting to 150%. The results indicate negligible change of the work of adhesion when machined with bigger grain size tools. In the case of plastic materials the rise in the energy activity reaches 160%, and shows an almost linear dependence on the abrasive tool grain size [10]. Quite the opposite situation was observed for aluminium alloy samples where the increase of grain size resulted in lower work of adhesion. Such occurrence may be explained by the fact that bigger grain size abrasive tools fail to remove such surface contaminants as grease and oil. Degreasing, on the other hand, proved an ineffective method of removing organic and inorganic contaminants from the surface of aluminium alloy and most polymer samples [5]. The change in the work of adhesion values for these materials was insignificant to an extent which heavily undermines, for economic reasons, the idea of implementing the method in question into practical use. Moreover, similar conclusions may be drawn for S235JR carbon steel. Nevertheless, abraded and degreased alloy steel samples displayed the increase of adhesive properties by >25%. What is worth noting is the observation that degreasing with no prior abrasive treatment resulted in lowering the work of adhesion by approx. 30%. Epoxy-glass composite laminate was the only material which responded positively to degreasing, in the case of which the increase in the work of adhesion amounted to approx. 20% [8]. The results of chemical treatment proved the most uniform for all the tested samples, provided sufficient operation time, and increased the surface free energy; however, certain polymers cannot undergo the process. Additionally, reduced bath time may lead to the decrease of the work of adhesion as the pickling agent will be unable to remove adsorbed low-energy contaminants from the surface and may fail to develop the surface.

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Pomiar pracy adhezji dla różnych/typowych metod przygotowania powierzchni wybranych materiałów konstrukcyjnych

Streszczenie

W pracy opisano metodykę badań zależności przeprowadzonej obróbki przygotowania powierzchni na właściwości adhezyjne powierzchni. Badania przeprowadzono metodą bezpośredniego pomiaru kąta zwilżania na stanowisku pomiarowym z wykorzystaniem mikroskopu i komputerowych technik wizyjnych, tzn. oprogramowania do odczytu i analizy otrzymanych danych. Artykuł przedstawia wyniki i opisuje ich interpretacją dla trzech sposobów obróbki powierzchni: odtłuszczania, obróbki ściernej narzędziami nasypowymi oraz trawienia chemicznego. Wyniki przedstawiono w postaci wykresów opisujących bezwzględną zmianę wartości pracy adhezji po dokonanych operacjach.

Słowa kluczowe: praca adhezji, obróbka ścierna, odtłuszczanie, trawienie chemiczne

Measurements of the work of adhesion for different structural materials typical surface treatment methods

Abstract

The article presents the test method for the experimental study of the influence of surface preparation operations on the adhesive properties of the surface. The test were conducted applying direct measurement of the wetting angle on the test stand equipped with a microscope and computer vision, i.e. software for data reading and analysis. The paper is focused on results and their interpretation for three surface preparation methods: degreasing, abrasive granular tools machining and chemical treatment. The result were presented in the form of diagrams of a relative change of the work of adhesion following various operations.

Keywords: work of adhesion, abrasive treatment, degreasing, chemical treatment

Measurements of the work of adhesion for different structural materials typical surface treatment methods

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GRZEGORZ KOZIEŁ

A sound steganographic methods review

Due to the explosive development of digital technologies various communication channels enable remote communication. On the one hand it is very useful for users but on the other it creates a potential for breaches in the security domain. Many people try to get information in the unauthorized way, thus, the proper protection is necessary. Good levels of protection might be provided using cryptography techniques. These techniques can protect against unauthorized reading but do not hide the fact that communication is occuring which in itself is of value. Also, it is impossible to protect against deleting or modifying data sent through the compromised communication channel which is known to contain encrypted information. Moreover, eventual introduction of quantum computers can end the cryptographic techniques use as massive computing power might be easily used to break any applied codes. Steganography offers a solution to these problems. It is a new domain of science dealing with information protection. Steganography protects valuable information by hiding it inside other data which does not have value. Hiding information gives us additional possibilities that are not provided by cryptography. Steganography makes it possible not only to protect communication against unauthorized reading but also makes it possible to hide the fact that communication is occuring and to provide anonymity for the communicating sites.

Hidden communication is usually done by hiding sent data inside the other non-significant data by using particular method and steganographic key. That key must be known to both communicating sites. As a result we get stegocontainer which contains the protected data hidden directly inside the cover data. The prepared stegocontainer is placed in a public location - very often it is a public web site - or is sent through a public communication channel. The information receiver gets the stegocontainer and extracts the hidden data. Thanks to using the public medium accessed by a very large group of people, both communicating sites remain anonymous. Nobody is able to detect that communication is taking place because nobody knows where the hidden data is placed. Moreover nobody knows that hidden data exists. Additionally the steganography is not sensitive to the computing power increase because an attacker needs first to know that the hidden data exists before he can proceed with breaking into it.. It makes it necessary to find the stegocontainer among the very big amount other similar containers which do not contain the hidden data. Even the biggest computing power can not be helpful in this situation because without breaking of the used algorithm or defining characteristic changes introduced by this algorithm it is impossible to determine which data can be a possible stegocontainer. Moreover in the case of using the Internet it occurs that number of files inside is so big and it changes so quickly that it is impossible to analyze all data. In this article the review of the present state of the sound steganographic methods is presented. This work is based on the research made for the PhD dissertation [27].

Least Significant Bits methods

Hiding data with Least Significant Bits methods (LSB) relies on attaching information by modifying the least significant bits of the container signal of the hiding data bits. The most often these bits are simply replaced by the hidden data bits. It allows for attaching a big amount of additional data without introducing noticeable changes. The disadvantage of this method is very small robustness of hidden data. It is because each operation applied to the carrier, compression or format change introduces changes to the least significant bits. Moreover each bit of hidden data is placed only in one location what causes significant robustness decrease. Apart of this the LSB methods are very popular in the hidden communication domain [9, 20]. They were used in the watermarking domain too but very low robustness of the introduced watermark was the reason for resigning from this method in this domain.

Using each sample of the signal allows for obtaining the biggest steganographic capacity but significantly decreases the method's robustness because it is enough to analyze the least significant bits of each sample to determine if the hidden data exists inside. Robustness increase is possible by using the steganographic key. It is used to determine which samples or bits will be used to hide data. It allows for hiding protected information bits only in particular locations which is very distressing to anyone attempting unauthorized access and increases the steganographic security. The disadvantage of this solution is steganographic capacity decrease.

It is possible to take into account sound parameters and adjust the introduced modifications' character to the signal parameters while using the algorithm to determine samples in which to hide data. This allows to obtain the best impercepbility results and the best hiding quality [4,12, 20]. The interference influence can be reduced by choosing the proper carrier signal. A good example is the noise produced by audience during a concert which is provides excellent masking of the introduced interference [21]. The other possibility presented in [9] is formation of the hidden bits sequence to adjust it to the original signal characteristic. It allows for obtaining the stegocontainer having similar characteristic to the original signal and reduces the noticeable interference level.

The most important problem while using the LSB methods is their lack of robustness for hidden data damage. Such methods as multiplying introduced data or adding correction codes used to improve robustness, do not work, because the redundant data is still added in the area that is very sensitive to damage.

Some authors describe using LSB methods in the transform domain. It relies on transforming the original signal to the chosen biorthogonal base. After that, the obtained coefficients are modified by hiding in them additional bits with LSB method. After the reverse transform we obtain the resultant signal containing the hidden data. This method can be applied to any transform: Fourier, cosine, wavelet or other.

To obtain greater steganographic capacity and reduce the introduced interference level, the LSB method is combined with error dispersion technique, taking into account the human auditory system psychoacoustic model [7, 8] and using the masking effect to hide introduced interference [1]. Very big steganographic capacity was obtained by the authors [1,6,11] with LSB method working in the wavelet transform domain with masking effect use.

Echo adding

Imperfect time resolution of human auditory system does not allow to detect a sound having amplitude of less than 40% of the original signal amplitude. It happens when the echo occurs 2 milliseconds after the signal or directly before it[5,15,16,24]. It is possible to use that phenomenon to hide additional data. In the hiding process the controllable delaying filter is used. Its job is to add a delayed copy of the signal to the original one. The delay depends on the hiding value. Adding echo process is presented in the figure 1.

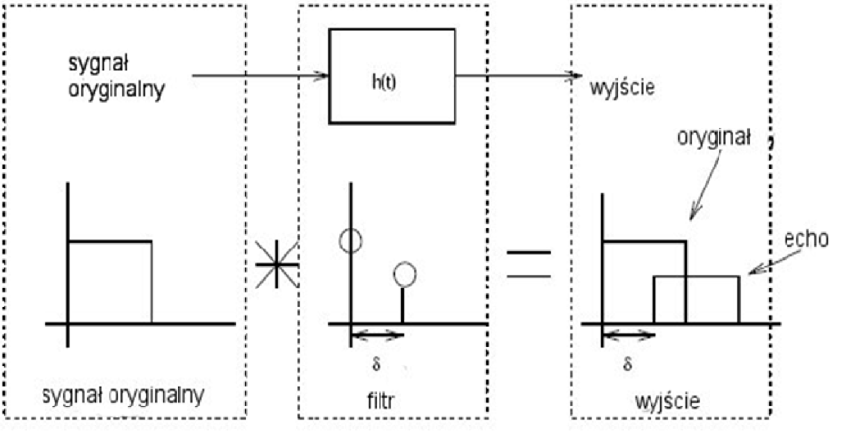

Figure 1. Echo adding process [16]

To have the possibility of coding different bit values by echo adding it is enough to assign them different echo delay values, for example, echo having 1ms can code the binary 0 while the one having 2ms delay can code binary 1 [9,13,20,32].

The added signal echo perception conditions are defined in the works [14,33]. The terminal inaudibility parameters are considered as delays ranging from 1ms to 2ms and amplitude ranging from 0,3 to 0,5 of the original signal amplitude.

It is necessary to divide signal into blocks to code binary data inside the carrier. In each block the independent shift corresponding with the hiding value is applied. In the real situation it is better to create two signals having different shifts. In the first signal we apply the shift corresponding to binary 1. In the second one the shift is corresponding to binary 0. After that these two signals are divided into the blocks. Blocks in the both signals have the same placement and size. Resultant signal is created by taking blocks from the first or second signal, according to the coded value. Much more problematic is the delay change. It causes the audible interference to create a hurtling effect. We should not exceed 0.05 ms delay changes and do not introduce them more often than once per 10 ms. It allows to avoid this interference introduction. It is possible to obtain good effect by smooth delay changing [13].

Hidden signal detection is possible by autocorrelation counting with the delays corresponding with the logical values 0 and 1 [5]. It is possible to use the amplitude characteristic of the filter used to introduce delay to cepstrum counting. As a result we get stripes on the k position and on the positions equal to k multiplicity, where k means echo delay measured in samples number. The biggest stripe placement shows the attached echo delay and allows hidden bit value reading. In [14,33] the advantageous influence of spectrum whitening is presented. This operation allows to reduce the read errors level. To minimize the bit error rate (BER) we should apply bigger distance between echoes coding binary 0 and 1 or use different echo delays when the same value coding [13]. It is possible to use pre-echo. It is the echo signal added before the original one. In this case binary value 0 is coded by adding pre-echo and binary 1 is coded by adding echo following the signal. It this method the time masking phenomenon is used. In this phenomenon loud sounds do not allow for perception of the the lower ones that come directly before or after the louder sound. It is necessary to ensure that masked echo signals will be placed in the direct neighborhood of the masker sound and their loudness will be respectively lower to meet masking conditions.

In [22] authors present the polar echo use. It allows for resigning from coding information in the distance from the original function. Coding is organized by adding echoes having different polarization. Echo having positive polarization is used for coding binary 1. Echo having negative polarization is used for coding binary 0. Polar echo using increases method robustness but introduces the sound tone change. In [34] authors propose using bipolar echo to reduce this disadvantageous phenomenon. In this method the interference caused by echo introducing is reduced by adding the second, weaker echo, having opposite polarization immediately after the first one.

Steganographic capacity of the method depends on the used blocks size, spaces between them and data redundancy. Methods that use the echo adding to hide data have good robustness (because of using the audible band and spreading each bit in the all block space). That type of methods do not allow for obtaining big steganographic capacity.

Spread spectrum techniques

To make it maximally difficult to detect the fact of the modifications introduction it is necessary to reduce introduced changes values. Unfortunately it can result in robustness decrease. This problem can be eliminated by using technique of spreading information in the whole signal spectrum. It allows for unequivocal attaching data to the container even if the hidden signal power is smaller than a noise power [21]. Moreover it allows taking advantage of using different frequencies. The low frequencies allow for obtaining good robustness. Using high frequencies gives us good transparency of the hidden data. Data spreading in the all frequencies allows obtaining compromise between hidden information transparency and robustness. Data attached in the presented way causes very small changes in the container signal and is robust for damage, because it is very difficult to clean the whole signal without destroying it largely.

The method of spreading information comes from telecommunication, where it is applied to make radio communication. Implementation in the steganography is based on multiplying the hiding signal with the second signal (pseudo random sequence) having bigger bit rate [3,9,10,12,23]. It causes signal spectrum spreading. That spectrum is associated with the container signal. In the receiver, the broadband signal is multiplied with the same pseudo random sequence with EX-OR operation use. As the operation effect we obtain compressed spectrum which gives us possibility of reading hidden data. To be sure that the interference level is low enough it is necessary to keep the watermark signal power under 0.5% of container signal power [5].

The spread spectrum technique is one of the best steganographic methods due to good resistance to detection, damage and removal and big steganographic capacity [21].

Transform domain methods

Transformation methods are based on traditional signal transformation in the applied transform domain. Data hiding is realized by modifying obtained transform coefficients. After applying demanded changes the signal is transformed back to the time domain. As a result we get signal containing the hidden data inside [21]. In [2,3,6,11,29] authors describe algorithms that use wavelet transformation to hide additional data in chosen transform coefficients or in the least significant bits of each coefficient. In [3] the watermarking algorithm based on the wavelet transform is presented. This algorithm has very good robustness gained at the expense of significant steganographic capacity reduction. In [29] additional data is hidden by modifying the container statistical features in the wavelet transform domain. In the article [36] the algorithm resistant to transformation to the analogue form of the signal is presented.

Methods using as transformations Fourier transform, cosine transform (DCT) and other similar transformations are presented in [17,19,28,31]. Algorithm described in [19] is based on narrowband noise attaching to the chosen band of frequencies with DCT. Author of [18] proposes attaching synchronization signal to the watermark which is introduced to the signal in the DCT domain. The human auditory system properties are considered in this proposition too. It allows to obtain better robustness for transformations and transparency increase. Presented group of methods based on DCT are sensitive for mp3 compression. Solution of this problem is shown in [31]. Its basis is the cosine transform spectrum energy modification in the signal fragments.

Work [35] proposed the solution gathering advantages of DCT and wavelet transform combination.

Algorithm shown in [28] hides information by introducing changes to chosen signal cepstrum coefficients with DFT. The same transformation was used in [17]. In this method the energy distribution in time was into account. It allowed to obtain the robustness for removing or inserting the small fragments of the signal. In the article [37] is presented the method attaching the watermark by signal spectrum significant stripe modifying. Unfortunately this method does not gain good robustness for signal compression.

Generally transformation methods obtain good results in the robustness domain, but they are not robust for modifications in the time scale applied to the stegocontainer.

Significant signal fragments using

Very disturbing dangers for all steganographic techniques are operations that modify the time scale of the signal – time scale modifications (TSM) [24]. Very few methods are able to hide data in such a way that the hidden data can outlast reduction or elongation of a few percent. It gives an attacker the possibility of easy hidden information removal, especially that HAS is not very sensitive for TSM. Nowadays, used TSM algorithms are projected in such a way to preserve the best quality of the scaled sound. It is possible by differentiation operations applied to individual signal fragments. Sound is not uniformly stretched. First the analysis is done to determine on which fragments of sound the HAS is especially sensitive. These fragments are not changed during TSM or they are modified in a small way. Other fragments are modified in such a way as to make it possible to obtain the desired record length. In [30] authors noticed that it gives us a possibility of attaching the watermark that will be robust to TSM attacks. They proposed using the fragments that are not changed during TSM. To find these regions we should apply the band pass filtering to the signal.

After filtering the signal should contain only d3 band having the range from 3 kHz to 5 kHz. It is the range of frequencies that is very well received by HAS so the TSM algorithms do not change it. The important thing is that sound made by most of the instruments contains this range of frequencies. Maxima existing in the analyzed band point out the regions that are modified only in a small way during TSM. Lee and Xue proposed using these fragments to attach the watermark.

The maximum size of attached sequence that does not introduce audible interference to the signal was determined at the level of 64 bits per 4096 samples size block. Before attaching, the hidden sequence is modified with binary phase keying algorithm. As a result we obtain the W' sequence. The following bits of the W' sequence are added to the region by performing Fourier transform coefficients changing.

The inverse Fourier transform is used to go back to the time domain.

Experiments done by the authors of the algorithm showed that data hidden with presented algorithm is robust to mp3 compression having 32 bps bit rate, lowpass filtering, noise adding, sampling frequency changing, echo adding, random cropping with fragments having size up to 10000 samples, noise removal and TSM up to 16%.

Other authors propose very similar method of watermarking. In this method the signal edges or the local energy maxima are used to attach the watermark.

There is the other group of algorithms designed for the particular kind of sound signal working by modifying time dependences existing in the signal. The example can be a method presented in [26}, which hides data by introducing rhythm shifts to the music records.

Summary

The different steganographic methods analysis showed that people failed in trying to create the ideal steganographic method, although plenty various algorithms exist. Each of the presented solutions has its advantages and defects. This is due to the contradictory requirements between steganographic capacity, transparency and robustness. Improving one of the listed parameters we cause deterioration of the others. This rule concerns each steganographic method.

It is impossible to rate which method is the best because each method has its own individual set of properties and features. It is necessary to choose a method for the individual application. The chosen method has to address the needs of the application.

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Przegląd metod steganograficznych opracowanych dla sygnału dźwiękowego

Streszczenie

W artykule dokonano analizy obecnego stanu steganorgafii komputerowej. Dokonano przeglądu głównych metod ukrywania informacji oraz określono główne cechy prezentowanych metod. Dokonano analizy możliwości jakie dają różne techniki dołączania dodatkowych danych.

Słowa kluczowe: steganografia, ochrona informacji, znakowanie wodne

A sound steganographic methods review

Abstract

An analysis of the present steganography situation is presented in this article. The main methods of hiding information are reviewed and their main features are determined. The analysis of possibilities given by these methods is included in the article.

Key words: steganography, information protection, watermarking

Przegląd metod steganograficznych opracowanych dla sygnału dźwiękowego

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Profibus DP in a dispersed control system

Introduction

Modern manufacturing processes rely on industrial automatics solutions. Microprocessor control elements are used, the most important of which include PLCs, embedded systems and specialized industrial computer systems. Initially, these were standalone systems operating independently of one another and controlling specific stages of a manufacturing process. The development of technology has enabled those elements to be combined into an integrated system making use of the network technology being known from computer science. Specialized industrial transmission networks have come into being, allowing dispersed control systems to be created. One of the most common industrial networks in Europe is the Profibus network and its latest variant, Profibus DP, developed by Siemens. Thousands of industrial applications are available in the market, which make use of this network. Even third-party companies (especially those based in the Far East) being present in the European market, have Profibus DP network-based products in their offer, in spite of having also their own network solutions (such as the CC-Link). At the Institute of Machines Technology and Production Automation (ITMiAP) of the Czestochowa University of Technology, a model of a multilink manipulator has been created, which uses some proprietary solutions by Mitsubishi (such as PLCs and communication modules). One of the major problems in the design of the control system was to meet the time-motion relationships between individual modules of the manipulator and to integrate it with the existing network infrastructure. A Profibus DP network-based dispersed control system was developed to coordinate the operation of the manipulator's elements and to be supervised by an operator's station and a supervisory station.

1. The dispersed control system

One of the basic features of a modern manufacturing environment is its dispersion. This exists both on a macro scale (the entire enterprise) and a micro scale (single operations or treatments). Classical automated production management systems are being replaced by decentralized systems (e.g. modules, microcontrollers) providing interaction and possibilities of individual decision-making. Dispersed systems are divided into the layers of: process automation (acquiring information on the process and controlling), communication networks (transmission of data through computer or industrial communication networks), the user's interface (a control station application), and production management. The first Dispersed Control System (DCS) was launched in 1975 by the American company Honeywell under the name TDC 2000, and has been in use to date in the refinery and chemical industries [11].

A characteristic element of dispersed control systems are system nodes, whose function is performed by either a single controller or a group of controllers. The task of the system node (controller) is to execute a program residing in the internal memory. The application has an encoded numerical control algorithm. With its functions, the controller becomes similar to a small real-time operation system.

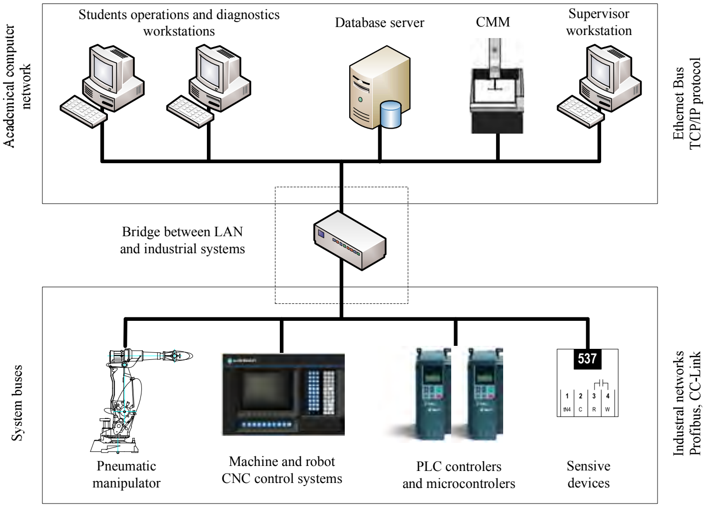


Fig. 1. The design of a dispersed control system at the ITMiAP of the Czestochowa University of Technology

Based on the assumptions presented above, a dispersed control system has been designed at the ITMiAP of the Czestochowa University of Technology (Fig. 1), which is used for the purposes of both research and classes conducted in the Mechanical and Mechatronic subjects. It is composed of many functional blocks divided functionally into two basic parts interconnected with an inter-system bridge. The first part includes student's operating & diagnostic stands enabling the programming of particular system elements, and a database server to store diagnostic data providing a basis for the creation of reports. The key element is a supervisory station enabling the person conducting the classes to oversee the teaching process and the entire control system. All nodes are connected to a common computer network that uses the traditional network protocol, TCP/IP v.4., for communication. The second part consists of typical industrial objects featuring specialized elements playing the role of object's subscribers.

A pneumatic manipulator, numerically-controlled machine tools ((Mitsubishi Meldas and Mazatrol Matrix), industrial robots, teaching sets of PLCs (Mitsubishi and Siemens) and pickups (temperature sensors, limit switches, etc.) can be distinguished within this part. They are interconnected by system buses – the Profibus DP, CC-Link and 1-wire field networks. The system is universal and open. It allows programming and production process supervision, but is also able to independently make decisions in response to an occurred situation. For example, in the event of the operation temperature has been exceeded, the microcontrollers stop the process until the temperature falls, and then resume it automatically. It can be simply extended by subsequent functional blocks. Currently, the teaching and supervisory parts are ready. A pneumatic manipulator using the Profibus DP network has been made. As the inter-system coupling, a Mitsubishi FX3U-16MT/DSS PLC with dedicated modules for the Profibus DP field network and an Ethernet-type computer network are used. This is not the ideal solution, since the user has to supervise the system buses via PLC's functions which are not too extensive. In the future, it will be replaced by a specialized industrial system with interfaces for industrial networks and computer networks.

2. Industrial networks in the Profibus and Profibus DP standards

The data exchange in the industrial computer system has a hierarchical structure. At the lowest level, this concerns the operation of devices, object’s subscribers (dedicated modules) which have direct contact with the devices handling the industrial process and are determined in time, e.g. PLCs, computers or embedded systems. This is the so called field level. Typical devices at this level include: I/O modules, sensors, transducers, drives, valves and operator’s panels. The transmission of process data takes place cyclically, whereas the configuration, process and interruption data are sent acyclically on demand [3]. Most often, synchronization relies on the mark-up transmission technology, being known from the Token Ring network. This distinguishes the industrial networks from traditional computer networks, in which transmission is asynchronous.

The field network allows the industrial communication of field devices with a CPU or a master system using different transmission media (e.g. copper cable, optical fibre, and sometimes radio waves) [5]. Most often, this is master-slave standard communication, where the supervisory role is played by specialized units (modules) that initiate and control the transmission, while the subordinate role is played by either advanced or simple executive systems responding to the commands and executing the ordered instructions. In the case of dispersed systems, they additionally inform of an “independent” decision having been made in response of an occurred situation [11].

An industrial network is an information communications network that enables devices to communicate in a standardized manner under industrial conditions. In networks of this type, frequent exchange of short pieces of information (e.g. a single bit or a single word) occurs. The industrial network can be categorized into local area networks (LAN) of the extent limited to the size of a shop floor, production line or a controlled installation. It should be noted, however, that there are industrial networks that, by geographical classification, can be numbered among networks of the MAN type (urban networks), since the distances between individual nodes may be as large as several kilometres. These networks are an element of an inhomogeneous wide area network by joining with other segments of organization-wide networks [14].

Definitely the most popular industrial network in Europe is the Profibus network. An organization that took up developing a communications network for dispersed field stations was set up based on 21 enterprises and scientific institutions clustered around the Siemens company. Working on the standard was started in 1987. The first comprehensive solution introduced by this organization in 1989 was the Profibus FMS Fieldbus Message Specification) standard. After that, in 1993, the Profibus DP (Decentralized Periphery) standard was introduced, which was faster and simpler than its predecessor. This protocol exists currently in three versions: DP-V0, DP-V1 and DP-V2, with each successive of them expanding the capabilities of its predecessor. Originally, the Profibus network was specified by the DIN 19245 standard [1,2]. Currently, these are the ISO 61158 and ISO 61784 standards [7,8,9]. The Profibus network is undergoing constant evolution, whereby new standards form, such as Profibus PA (Profibus for Process Automation), which was developed in 1996 and is intended for simple measuring and control devices. A basic aspect that distinguishes Profibus PA from its predecessors is the possibility of powering the devices via two-core cable (following the example of the 1-wire network), which, in addition, allows parametrization and readout of data from numerous devices. Introducing the ProfiNet protocol, operating at the management level, has enabled Profibus networks to be used in dispersed control systems. They combine the capabilities to serve a range of facilities, from very simple industrial facilities (the AS interface), through advanced microcontrollers (Profibus DP) to systems supervising and monitoring the operation of an entire system (ProfiNet).

The chief asset of the Profibus network is the PNO organization [14] which has been active since the issuance of the first version of the standard, and which embraces now over 1400 Profibus network users and manufacturers. Together with 25 regional Profibus organizations and 24 advisory centres active under the common aegis of Profibus International (PI), PNO is involved in developing and defining standards associated with the development of the standard. Moreover, the organization’s activities include the provision of technical assistance to hardware users and manufacturers [5,6].

The Profibus protocol defines three layers in the ISO/OSI RM model: a physical, data link and an application layers, which in the reference model corresponds to layers 1, 2 and 7. The application layer in the Profibus standard is an optional layer. According to rules specified in the ISO/OSI model, data in the transmitter is transferred from a higher layer to a lower layer, while in the receiver, in the opposite direction (Fig. 2). During the transfer of data in the transmitter, a data encapsulation process takes place, which consists in adding, by lower situated layers, information necessary for the execution of the data transmission process in the form of headers and tails. The Profibus is an interface using either synchronous of asynchronous series transmission.

Nadajnik	Odbiornik	Opis i zastosowanie danej warstwy	
7	7	Warstwa aplikacji	Interfejs dla programów aplikacyjnych poprzez komendy read, write
6	6	Warstwa prezentacji	Reprezentacja (kodowanie) danych dla analizy i interpretacji w następnej warstwie
5	5	Warstwa sesji	Tworzenie oraz anulowanie chwilowego połączenia stacji, synchronizacja procesu komunikacji
4	4	Warstwa transportowa	Kontrola transmisji danych dla warstwy 5 (błąd przesylania, błąd w paczce danych)
3	3	Warstwa sieciowa	Tworzenie oraz anulowanie połączenia, unikanie kolizji w sieci
2	2	Warstwa łącza danych	Opisuje protokół dostępu do sieci (Media Access Control, MAC), oraz zabezpieczenia danych
1	1	Warstwa fizyczna	Definiuje medium (hardware), kodowanie i prędkość transmisji danych
Medium transmisji			

Fig. 2. The reference ISO/OSI model with indication of layers used by Profibus [12]

In the Profibus network, the physical layer relies basically on the series hardware specification, RS 485. This entails a maximum permissible number of nodes in a segment which may amount up to 32 (128), and because of the 7-bit address field, 127 network nodes can be addressed. The number of segments in the Profibus network is limited to four connected into a chain. This limitation can be overcome by connecting segments in a star or three arrangement. The most common are copper transmission media (screened twisted pair) ended with terminators, whose task is to counteract signal rebounds and to assure logic 1 to be at rest. To eliminate any interferences, differential transmission is used, at a rate from 9.6 Kb/s do 1.5 Mb/s for B-type cable (Profibus) and from 9.6 Kb/s to 12 Mb/s for A-type cable (Profibus DP). The maximum attenuation may not exceed 6 dB for a network segment [14]. Safe (sparkproof) versions of the RS485-IS interface, conforming to the IEC 1158-2 standard, are also used.

In the Profibus standard, the logic link sub-layer defines two types of service: the reliable transmission of a message with a response or confirmation, and the transmission of a message without a confirmation, including also a broadcast. The cable access sub-layer in the Profibus network makes use of an algorithm with token passing and polling (Fig. 3). [4]

The Profibus DP standard requires the master station to poll all slave stations in a single token circulation cycle. To satisfy the requirements for transmission rate, the number of master nodes operating on a common transmission medium have been limited to three. In a mixed network (DP, FMS), the load should be scheduled so that the relationships for the TTR(FMS) token rotation time, as defined in either the FMS master node or the DP master node of the second kind, are maintained

$T_{TR(FMS)} > \sum T_{TSLP}$

where: $\sum T_{TSLP}$ – the sum of the times of polling all slave nodes by all DP master nodes of the first kind.

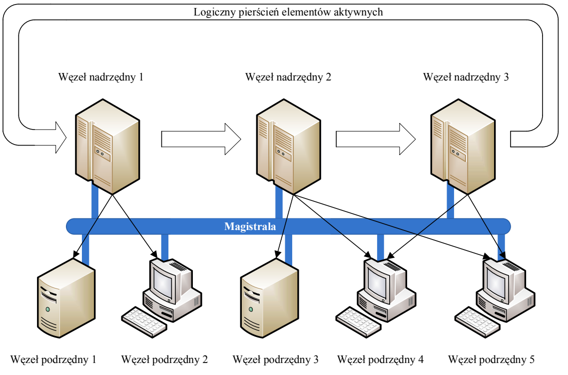


Fig. 3. Schematic of data exchange in Profibus [4]

The creators of the Profibus standard have developed a universal method of describing devices that are used in a Profibus-managed control system. The manufacturer of a given device draws up a list of communication parameters in the form of GSD (general station description) files and attaches it to the device. This is a text file containing a general communication specification. Each field contains a description of features and functionalities supported by the station. A configuration tool (e.g. GX IEC Developer), using keywords, reads out the station’s identifiers, parameters, relevant data types and permissible value limits for the station to which that file applies. The GSD file consists of three parts: a general specification, the specification of master devices and the specification of the slave devices. The information contained in the specification concerns, e.g., the number of supported devices, the type of Input/Output channels and the supported transmission rate. Each Profibus slave station and each master station of the first class must have a unique ID number.

3. The modular pneumatic manipulator

Within research on automatics systems using an industrial network, a model of a two-link pneumatic manipulator of a modular design has been developed at the Institute of Machines Technology and Production Automation (ITMiAP) of the Czestochowa University of Technology (Figs. 5, 6). The main aim was to create a simple dispersed control system using cheap and common automatic system control modules. As basic modules, Mitsubishi PLC controllers (Fig. 4) with Profibus DP and Ethernet network modules and pneumatic elements supplied by SMC were used.

Fig. 4. Mitsubishi PLC controllers with Profibus DP modules: a) FX3U-16MT/DSS with an FX3U-64DP-M module, b) FX1N-14MT/DSS with an FX0N-32NT-DP [10]

Regardless its theoretically uniform construction (Fig. 5), in order to test the capability of the time-motion correlation using the field network, the manipulator was divided into two logically independent elements (Fig. 6). The first one is the movable arm with a pneumatic gripping device, and the other is the main body controlled by a valve isle. Both elements are managed by independent PLC controllers interconnected with the Profibus DP network. The first of the controllers plays the role of a master, while the other, that of a slave. Despite the fact that the distance between the controllers is only a few centimetres (they are placed on a common bus), in industrial practice, due to the use of a field network, the distance between the nodes is determined by the transmission medium used for network construction and may be as large as several kilometres. The developed stand is a model enabling simulation of the operation of a two-link manipulator delivering to, and receiving elements from one line and transferring them to the other line, whose one part is from several to a dozen or so metres long (e.g. a rail feeder). Due to the size, the classical design, in which PLCs are connected with ordinary conductors, could not be used in this case. In the constructed stand, a 6e-category copper shielded twisted pair of a maximum frequency of 500 MHz, conforming to the EIA/TIA 568B2 standard, was employed as the transmission medium. Each pair of conductors have a separate insulation and, in addition, all pairs are wrapped with metal foil, which assures very high resistance to interferences under industrial conditions. These cables are terminated on both sides with a Sub-D plug by Mitsubishi Electric. Four conductors are used: two for data transmission, one as the data cable earth conductor, and one as the terminators power supply. During the tests, the transmission medium length was varied from 1 to 305 m to test the effect of the length, and hence the delay and attenuation of the signal on the performance of the manipulator. For programming and monitoring the manipulator’s operation, student operator's stations and a supervisory station were adapted, which were build from standard PC computers connected to the master module with an Ethernet type computer network using the TCP/IP v. 4 transmission protocol. Thus, a simple, three-node dispersed control system was created (Fig. 6) using two types of data transmission networks: a synchronous industrial network and an asynchronous local computer network.

3.1. Description of the manipulator

In the upper part of the manipulator there is a compact MGPM-20TF-200 actuator by SMC with two slide guides, hereinafter called the "platform". Each of the two rolls in the guides has a diameter of 200 millimetres. A slide takes place with a step in the range from 20 to 400 millimetres. The piston velocity is contained in the range from 50 to 500 mm/s. The distance of the centre of gravity from the end plate is 50 mm. The actuator operates bilaterally. The working medium is compressed air of an operating pressure from 0.1 to 1 MPa.

Directly to upper platform, two sensors SMC D-Z73 are screwed down. These mark out the positions of picking up and giving back an element being transferred. The D-Z73 is a proximity detector which is activated at the moment of approach of a magnet mounted at the end of the piston in the platform. As the piston approaches, the magnetic field closes the switch and turns on a diode signalling the detection of presence of an element. In the case of the D-Z73 detector, the hysteresis area is 12.5 mm. The sensors are power supplied with a direct voltage of 24 V. The sensor is characterized by high repeatability (0.005) and the operation time at a level of 1.2 ms.

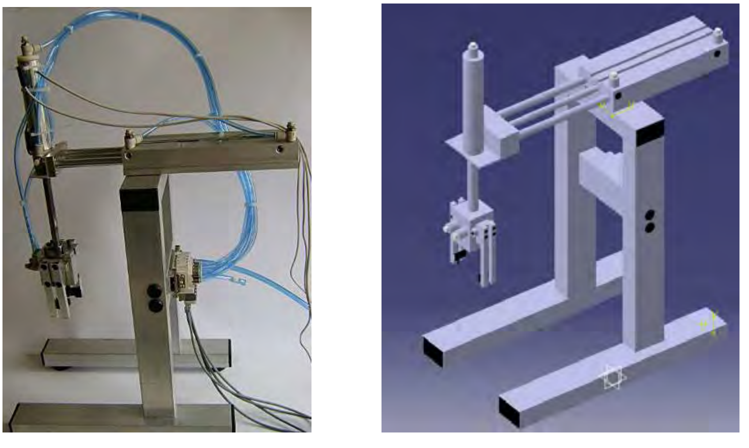


Fig. 5. Schematic of the pneumatic manipulator with the dispersed control system [10]

On the gripping device lowering actuator, two SMC D-C73 sensors are mounted. These were bound with special strip that holds down the sensors to the actuator. The sensors set the positions of the maximum and minimum lowering of the gripping device. The hysteresis area of the sensor is 9.5 mm. They are powered with a direct voltage of 24 V. The maximum load current ranges from 5 to 40 mA. Both sensors are contactron (magnetic) sensors [10].

SMC polyurethane air tubes are connected to the platform, gripping device and the gripping device height control actuator, which are terminated with plastic SMC AS2201F elbow valves. These valves are screwed into the platform and have the tube connected on the other side. The maximum operating pressure of the TU-0604-BU tube is 0.8 MPa and the tube diameter is 6 mm. The valves provide the metric control of flow in one direction and the capability to freely set the air flow level.

An important part of the control system is a valve isle. It holds SY 3160-5LOU-C6-Q monostable solenoid valves manufactured by SMC. Their operation is to open or shut down the compressed air flow. By this action they control the outputs Y of the Master controller. The output Y with a set logic value of 1 means an open valve, while with a logic value of 0, a closed valve. Individual solenoid valves are connected with the AS2201F valves at the actuators. The valve isle operating pressure is contained in the range from 0.15 to 0.7 MPa, while the switch-over time is approx. 10 ms. The valve isle life is about 50 million switchovers [10].

The actuator and the gripping device have been constructed by the Institute's workers. The employed monostable valves cause the actuator to stop only in the extreme positions (with no possibility of stopping in-between). Plastic blocks are mounted on the gripping device to facilitate getting hold of an object (Fig. 5).

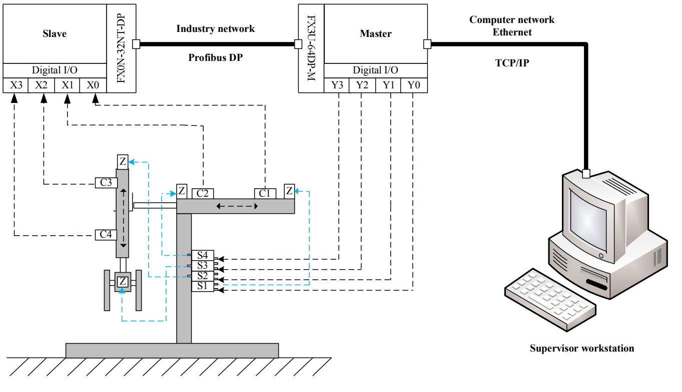


Fig. 6. Logic diagram of the stand

3.2. Configuration of the Profibus DP network in the manipulator's system

The Profibus DP network-based application controlling the manipulator is composed of two parts. The first part has been installed on the Master station, and the second part, on the Slave station. When creating the program in the ladder language, the Mitsubishi Electric GX IEC Developer v. 7.04 programming environment was used (Fig. 7). The division of the program into simple tasks called subroutines is done using POU_Pool units. In addition, the program is divided into single working spaces called networks. Both stations operate on 4-bit words. The running of the application is aimed at simulating a feeder transferring elements from one production line to another using two Mitsubishi Electric controllers connected with the Profibus DP network. The configuration of the network starts from setting the transmission rate on the Master station (managing and coordinating the network's operation). Due to the very small length of the transmission cable, a maximum rate of 12 Mb/s permissible the Profibus DP network was chosen. However, in the course of tests, due to a change in the cable length (from 30 cm to 305 cm), the transmission rate was varied, too, in the range from 9.6 Kb/s to12 Mb/s. The second operation is to run the POU_Ini subroutine on the Slave station to address it (address 1). On this basis, the Master finds the slave station and sends configuration data to it, after which cyclic data exchange starts. The main task performed by the Slave station is that of constantly updating the values of registers that contain data on the current status indicated by sensors. This task is contained in MAIN_Prg.

The principle of the application running is to have the status of the Slave station's individual registers to be cyclically red out by the Master station. For example, in step 6 it is verified whether the arm is lifted (if M13=1) and whether it is in the position of picking up elements (if M10=1). This position is set by extending the arm for 45 mm. The value of the auxiliary variable M15, whose task is to indicate whether the arm is in this position for the first time in the cycle, is also verified. If it is, then the arm is brought to a stop (Y0 = 0, Y3 = 1), the grapping device is opened (Y2 = 1) and the arm is lowered (Y1 = 1). This is the first cycle of transferring an element. There are many blocks like that in the created application.

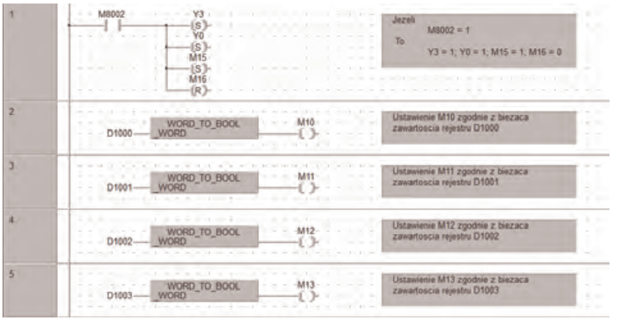


Fig. 7. The application controlling the Profibus DP network in the Mitsubishi GX IEC Developer environment. [10]

The main program of the Slave station consists of eight steps and comes down to entering a value red out from the sensor in a respective register with the instruction TO_M. The data from those registers, via the Profibus network, gets to the Master station's registers according to the settings done at the stage of configuration. For example, the first and second steps execute the tasks of entering the current value of the variable X0 in the register BFM#0 which, through the DP Profibus network, gets to the register D1000 of the Master station.

3.3. Monitoring the operation of the Profibus DP network

A PC with installed diagnostic software and monitoring the operation of the Profibus DP network, being connected to it, plays the role of a second class Mater device. The GX Configurator DP software features a wide range of tools controlling the operation of the Profibus DP network and is an excellent diagnostic tool for students operating (programming) controllers, providing information on any errors made by the students on the supervisory station. For example, in the event of an addressing error, the diagnostic tool Slave Status indicates a lack of connection with slave station no. 1 (Fig. 8a). Upon setting the address in the Slave station (the POU_Ini program) to the value of 1, the network recovers to the normal state.

a) 

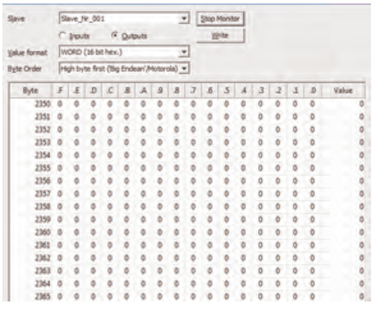
b) 

Fig. 8. a). Diagnosis of the connections status, b) Monitoring of the outputs status. [10]

In line with the philosophy of network operation in a dispersed control system, for each event, relevant diagnostic messages are generated, which are delivered within the Diagnosis Messages tool. A message includes the date and time of the problem occurring, the name of the returning station, its physical address, error status, and a diagnostic note detailing the occurred error. The error status may be indicated with a yellow triangle or a red triangle (a critical error). Ultimately, all messages will be recorded on a dedicated database server (Fig. 1).

They will be presented using clear diagrams. The diagnostic tool is very versatile and allows monitoring of a slave station's inputs and outputs using the Slave I/O Test tool (Fig. 8b). The GX IEC Developer software has also tools for monitoring network operation. For example, values stored in registers or variables can be monitored and modified. Modification of input and output statuses is also possible.

Summary

The dispersed control system developed by the ITMiAP of the Czestochowa University of Technology (Fig. 1) relies on the use of two basic types of network. This is a typical IT network and industrial networks. As the basic network for connecting industrial facilities, Poland's most popular network, Profibus DP, has been chosen. This meets all requirements imposed on networks to be used in control systems. It transmits data in a synchronous manner over long distances under industrial conditions. The two-link pneumatic manipulator designed and made at the ITMiAP makes use of the Profibus DP network for transmitting data between two PLC controllers. The transmission of data takes place through Profibus DP network modules dedicated to the PLCs. These introduce delays because of the time taken by displaying the data by the transmitting station in registers assigned to the transmission module, reading out and encoding those data, sending them over via the transmission medium, and then decoding the data in the receiving station, displaying the red-out data in the register, and reading them out by the controller. Obviously, aside from the capacity of the PLCs themselves, a determining factor is the transmission medium length and the transmission rate. The tests carried out showed that, due to the low speed of the manipulator's operation and the time delays introduced by the contactron sensors even at the maximal transmission medium length (305 m) and the lowest transmission rate in the Profibus network (9.6 Kb/s), there was no negative effect on the manipulator's performance. The tests, carried out under machine room conditions and in the presence of many thyristor systems, confirmed the very high resistance of the employed transmission medium and the Profibus DP protocol to interferences. No instances of package loss or transmission desynchronizing occurred. The reliability and versatility of the Profibus family systems was confirmed in Poland's largest dispersed control system, which is the Warsaw underground.

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Profibus DP w rozproszonym układzie sterowania

Nowoczesne procesy produkcyjne opierają się na rozwiązaniach z zakresu automatyki przemysłowej. Wykorzystywane są elementy sterowania mikroprocesorowego oraz specjalizowane przemysłowe systemy komputerowe. Rozwój technologii umożliwił połączenie tych elementów w jeden, zintegrowany system, wykorzystujący znaną z informatyki technologię sieciową. Jedną z najpopularniejszych sieci przemysłowych w Europie jest sieć Profibus DP opracowane przez firmę Siemens. W ITMiAP Politechniki Częstochowskiej został opracowany model wieloczłonowego manipulatora pneumatycznego wieloczłonowego. Jednym z najważniejszych problemów w trakcie projektowania układu sterowania było spełnienie zależności czasowo-ruchowych między poszczególnymi modułami manipulatora oraz integracja z istniejącą komputerową infrastrukturą sieciową. Został opracowany rozproszony układ sterowania oparty na sieci Profibus DP, koordynujący pracę elementów manipulatora i nadzorowany przez stacje operatorskie i stację nadzorczą.

Profibus DP in a dispersed control system

Modern manufacturing processes rely on industrial automatics solutions. The development of technology has enabled those elements to be combined into an integrated system making use of the network technology being known from computer science. Specialized industrial transmission networks have come into being, allowing dispersed control systems to be created. One of the most

common industrial networks in Europe is the Profibus DP developed by Siemens. At the Institute of Machines Technology and Production Automation (ITMiAP) of the Czestochowa University of Technology, a model of a multilink manipulator has been created. One of the major problems in the design of the control system was to meet the time-motion relationships between individual modules of the manipulator and to integrate it with the existing network infrastructure. A Profibus DP network-based dispersed control system was developed to coordinate the operation of the manipulator's elements and to be supervised by an operator's station and a supervisory station.

Profibus DP in a dispersed control system

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Adaptive control of the beet slicing machine operation

Introduction

In the present study an algorithm for the beet slicing machine operation algorithm in an industrial environment has been proposed. The slicing machine control is achieved by PLC microprocessor controllers.

Due to the complicated process characteristics, the classical control method (PID proportional-integral-derivative controller) did not meet the expectations of the operators and as a result manual control was used. Manual control required a lot of operator’s time. Apart from the variables related to the operation of the slicing machine, the operator had to control a significant number or variables ranging from a dozen or so to a few dozen. In practice it meant that the operator did not have tea breaks and had his meals next to the machine.

One of the most serious problems in the control of slicing machines operation was the uniqueness of their characteristics (characteristics: input signal – beet slice mass flow). Moreover, there were technological breaks during machine operation resulting contamination of beets. Following the break, the operator not always would replace the knives and consequently, the slicing machine mass flow oscillated from a few to over ten percent. The operator not always would have detailed information on the condition of slicing machine knives, which with time would wear out losing their sharpness, which resulted in deterioration of the beet slices quality. From the process point of view it is required that the beet slice flow rate be even and any breaks in the beet slice flow have a negative impact on the process liquidity.

In order to improve the beet slice flow and to reduce the operator’s work load an adaptive control algorithm for a slicing machine operation was designed. In the PLC controller a programme to determine the slicing machine’s characteristics was implemented. These characteristics were used in the automatic control system. Apart from the slicing machine’s characteristics and the control in the PLC controller, the switching algorithm was also implemented. It ensured proper operation of the system. This solution facilitated a more fluid switching over of slicing machines and automatic control.

The control algorithm was entirely implemented in the PLC controller, whereas the PC was used to monitor the process and to tune the algorithm.

Selection of controller type

The selection procedure for the controller type depending on the type of dynamic properties of the system:

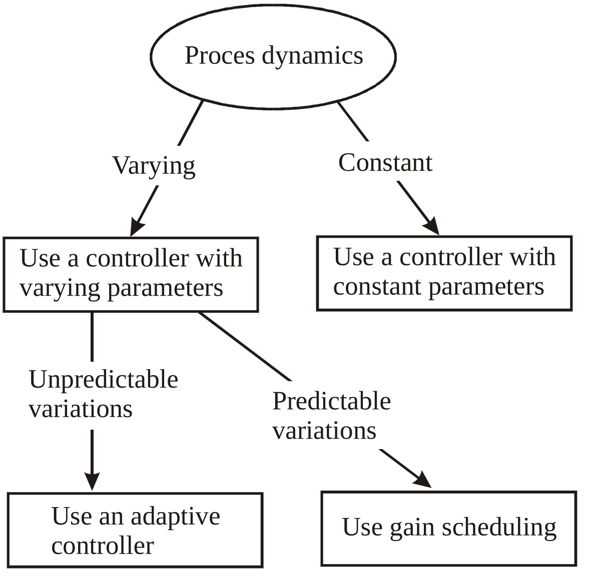

Fig. 1. Procedure to decide what type of controller to use [1].

The process dynamic properties are changeable and unpredictable therefore the proper controller in this case is the adaptive controller.

Adaptive control

"Adaptive Controller is a controller with adjustable parameters and a mechanism for adjusting the parameters." [1]
Adaptive control is an automatic adjustment of controller parameters to the changing properties of the process and its surroundings in such a way as to ensure a greater resistance of the system to the changes resulting from:
- effect of various types of interferences which are usually unpredictable,
- change to the properties or parameters of the process itself.

In the adaptive control the controller's settings are on each occasion adapted depending on the changes in the process properties [2].
The underlying principle of each adaptive system is collecting information about the controlled process:
1. Control systems with programmed changes to controller parameters.
2. Control systems with model identification.

Control systems with programmed changes to controller parameters

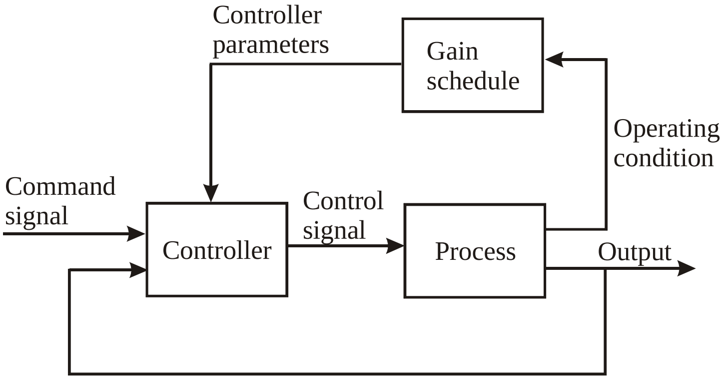

Fig. 2. Block diagram of a system with gain scheduling [1].

The underlying principle of this control is achieving constant dependence of controller parameters on the leading variable, which allows us to achieve the control objective and can be achieved in terms of measurement.

The control parameter that is most frequently programmed in the function of a given leading variable the controller gain – “gain scheduling” controller.

The prerequisite for executing such a control is the knowledge of the model combining rcontrol parameters with the value of the leading variable.

The drawback of this method is a considerable “blindness” to the changes of the system characteristics which are not related to the leading variable.

The advantage of this method is a considerable theoretical simplicity as well as a simplicity of execution.

Control systems with model identification

The underlying principle of this control is that controller parameters are determined by the results of the current identification of the parametric model carried out based on current measurement of the control value and the size of the controlled process.

The advantage of this method is the universality, i.e. possibility to use it for all processes, as well as the possibility to detect all (big enough) changes to process parameters disregarding their origin.

The disadvantage of the method – significant theoretical complexity, the adaptive control system with the identification of the model is a non-linear model, non-stationary, most frequently exposed to random interferences.

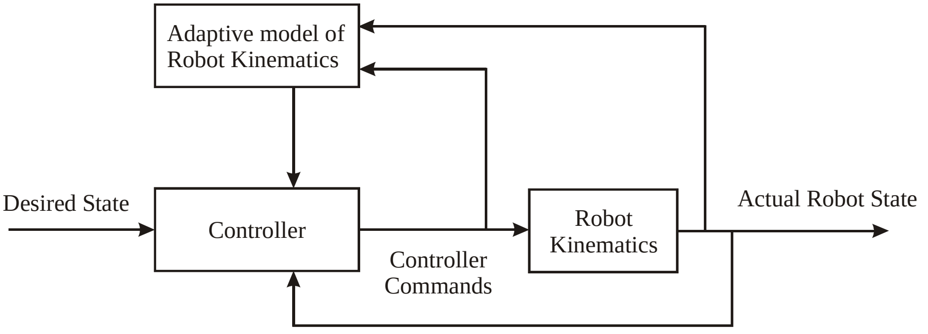

Fig. 3. Control systems with model identification [3].

While defining the adaptive control system with the model identification a solution method should be determined [4]:

- indirect adaptive control - the identified model is a process model. Based on the knowledge of the process model and the control objective we carry out the controller synthesis, determining its parameters. It means that appropriate controller parameters are reached in an indirect way i.e. through the process.
- direct adaptive control – the identified model is the target model of the controller. As a result of identification, controller parameters are achieved in a direct way.

Deterministic self-tuning controls

Self-tuning control (STR) prove a required response to the control signal.
The model parameters are estimated on-line. The “estimation” block determines process parameters. The “design” section contains calculations that are required to design a control (estimated parameters and external data – design criteria). The “control” block is an implementation of the controller whose parameters are calculated in the “design” section. The main advantage of using the adaptive control is ensuring the continuity of the process.

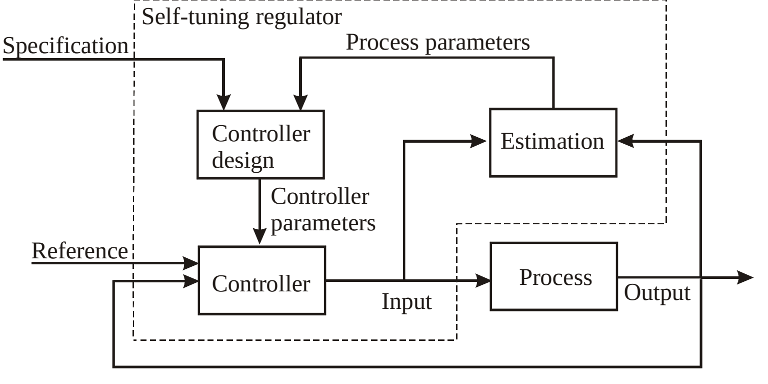

Fig. 4. Block diagram of a self-tuning regulator (STR) [1].

Underlying idea of the solution:
1.Indirect adaptive algorithm:
- estimation of process parameters e.g. recurrent least squares method;
- transferring them to the design section of the control set point – e.g. pole shifting method
2. Direct adaptive algorithm – control parameters are estimated directly – model reparametrisation is used which gives directly control parameters.

Stochastic self-tuning controls – stochastic models are used to describe interferences. An important issue while designing is the elimination or maximum reduction of undesired noise. This problem leads to:
- minimum-variance controllers – MV;
- pole shifting and Linear Quadratic Gaussian – LQG;

Model-reference adaptive system

Model –reference adaptive system (MRAS) – a system which provides a required response to the set signal; the desired process response is described by the reference model.

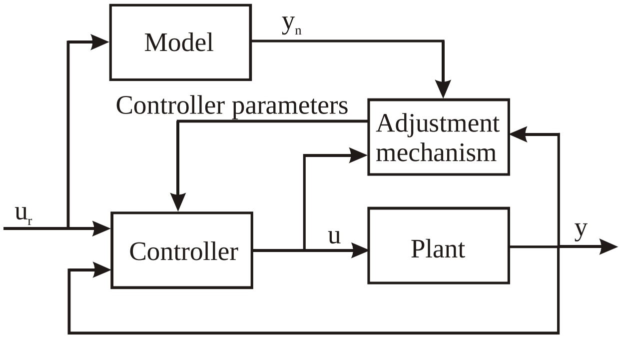

Fig. 5. Block diagram of a model reference adaptive system (MRAS) [1]

We can differentiate two feedback loops:
- internal or basic – composed of the process and the controller,
- external – for the change of controller settings; parameters are tuned based on the error feedback which is the difference between the system output and the reference model output [5].
Parameters adjustment mechanism can be achieved in two ways:
- by means of gradient methods,
- by using Lagunov stability theory.

Slicing machine characteristics

Slicing machine control is achieved in the current loop circuit of GE-Fanuc 90-30 controller. In emergency situations or during the start-up the control is achieved by the Eftronik control station or Eftronik X control unit. 4- 20 [mA] electrical signal is sent to the slicing machine. The electronic system of the slicing machine converts this value and as a results the slicing machine's speed is achieved.
The characteristics are the linear function with the following equation:

$$y(t) = a + k \cdot u(t) \tag{1}$$

gdzie:
$y(t)$ - output signal (masowy przepływ krajanki [T/h],
$u(t)$ - input signal [mA],
k – coefficient of proportionality,
a – constant.

The input value is the current signal u(t), whereas the output value is the slicing machine speed y(t). This dependence has been presented in Fig. 6.

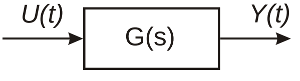

Fig. 6. Block diagram of a process.

Equation (1) has been transformed using Laplace transform and the transfer function was determined:

$$G(s) = \frac{Y(s)}{U(s)} = k \tag{2}$$

The dynamic properties of the system have the properties of the proportioning element *G(s)=k*.
The table presents the values of the factor of proportionality "k". In a situation when the slicing machine has extremely worn blades we can observe with time slow the decrease in the mass flow. The increase in the control signal does not add to the increase of this flow.

TABLE 1. Value of coefficient of proportionality.

State of cutting tools	Coefficient „k”
Cutting tools are sharp (time of work of slicer < 1 hour)	2.0 - 3.0
Cutting tools are sharp (time of work of slicer from 1 to 3 hour)	1.4 – 2.0
Cutting tools are dull	1.0 – 1.4
Cutting tools are very dull	Lower then 1.0

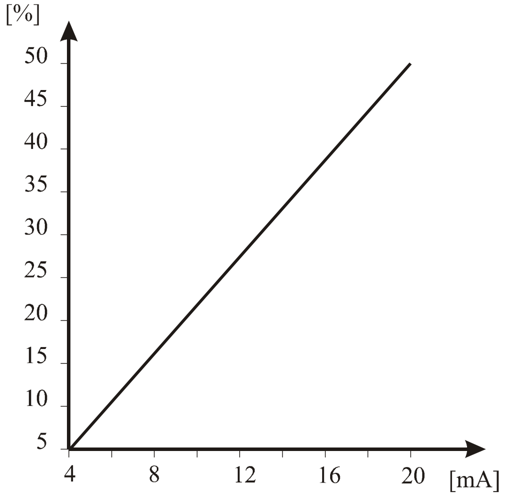

Fig. 7. Static characteristics of the slicing machine

However, for the diffusion station operation control it is not the slicing machine speed (r.p.m) that is significant, but the slicing machine mass flow. The slicing machine mass flow depends not only on the speed, but also on the knives quality and it changes depending on the time of the slicing machine operation. Apart from mass flow the beet slices quality has a significant impact on the results obtained (beet juice quantity and quality). What is used to describe physical characteristics of beet slices is primarily the Silin number. What causes problems is in particular the contamination (impurities) of beetroots as a result of which it is necessary to stop the slicing machine. After the machine is re-started the quality of beet slices usually deteriorates and its mass flow gets disturbed. Fig. 8 and 9 presents the examples of characteristics of the slicing machine mass flow.

Fig. 8 Shows two characteristics of the slicing machine that were recorded for two extreme cases involving newly replaced knives. Theoretical characteristics 1 and 2 should overlap. Apart from the shift of characteristics there can be one more change to the factor of proportionality, this situation has been presented in Fig. 9.

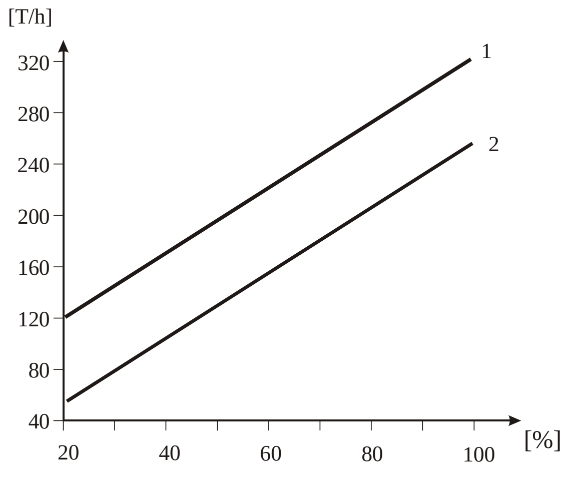

Fig. 8. Characteristics of the slicing machine mass flow.

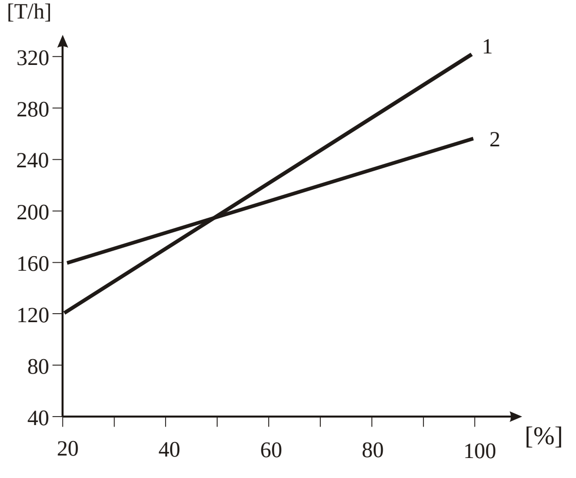

Fig. 9. Characteristics of the slicing machine mass flow.

Selection of the adaptive control algorithm for beet slicing machines

The slicing machine characteristics continue to change, which entails the use of advanced control algorithms. Thus, adaptive control was designed with model identification. The designed algorithm uses the indirect adaptive control, the process model is identified and afterwards the controller settings are selected. For control purposes a PI controller was used due to overshoot that can occur for the PID algorithm and is dangerous for the diffusion station. The diffusion process requires a smooth flow of beet slices without any abrupt changes. Fig. 10 presents a schematic drawing of the control system.

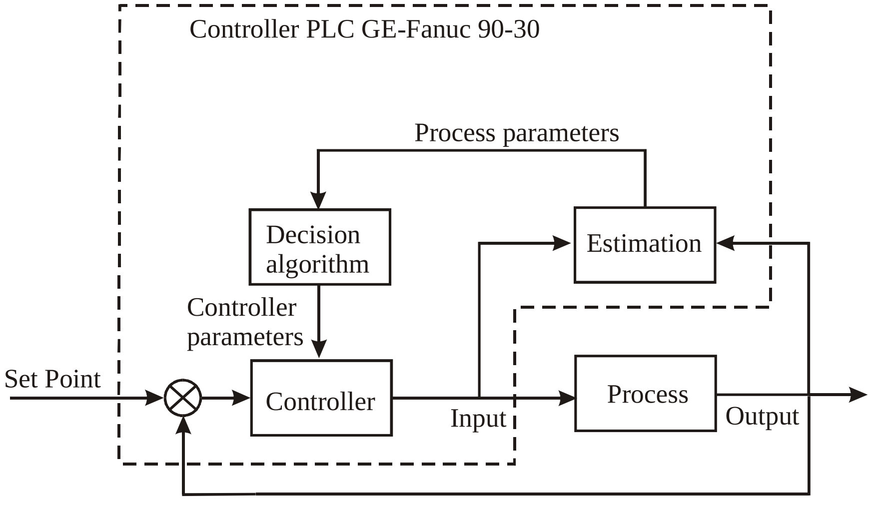

Fig. 10. Adaptive control of the beet slicing machine operation.

Conclusions

The adaptive control tuning is much more complicated than the classical PID control. However, in the cases when the classical PID control cannot be used or when the control quality is not satisfying, we have to look for other solutions. In such cases the adaptive control is recommended [6].
The control systems used nowadays enable this type of control without additional costs for purchasing equipment. PLC microprocessor controllers that have been in use for many years are sufficient to carry out the adaptive control.

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Adaptive control of the beet slicing machine operation

Summary

This paper presents problems related to the beet slicing machine control in a sugar plant. Continuous changes to the characteristics of the slicing machine operation entail the use of advanced control algorithms.
For this reason we designed the adaptive control with the model identification. The designed algorithm uses indirect adaptive control, the process model is identified and afterwards controller settings are selected. This control was implemented in the PLC microprocessor controller. The system does not require any additional control systems.

Key words: Adaptive control, Sugar Factory, Control of the beet slicing

Sterowanie adaptacyjne pracą krajalnicy buraka cukrowego

Streszczenie

W artykule przedstawiono problemy występujące podczas sterowania pracą krajalnicy buraka cukrowego w cukrowni. Ciągłe zmiany charakterystyki pracy krajalnicy wymuszają stosowanie zaawansowanych algorytmów sterowania.
Opracowane zostało sterowanie adaptacyjne z identyfikacją modelu.
Opracowany algorytm wykorzystuje pośrednią regulację adaptacyjną, wyznaczany jest model obiektu a następnie dobierane są nastawy regulatora.
Sterowanie to zostało zaimplementowane w sterowniku mikroprocesorowym PLC. Układ nie wymaga żadnych dodatkowych systemów sterowania.

Słowa kluczowe: Sterowanie adaptacyjne, Cukrownictwo, Sterowanie krajalnicą buraka cukrowego

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