MODERN TECHNOLOGIES, MATERIALS AND MODELLING TECHNIQUES IN MECHANICAL ENGINEERING

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OPTIMISATION IN MECHANICAL ENGINEERING part 1

1. INTRODUCTION

What is understood under the term 'optimisation' is a conscious activity of man, which aims at obtaining the best possible results in given conditions estimated from the point of view of accepted criteria. The best achieved result is the optimal result. Man as a unit of the natural system should not violate its equilibrium in his actions.

Technology is one of the most essential fields of man's activity. Development of mechanical engineering heads generally towards complex automation of technological processes. In other words, this is the changeover from sporadic applying the automatic systems to single machines and technological devices into general applying many different automatic systems to complex technological processes, for example: machining line producing a particular article in a department or even in an automated industrial plant. All these arrangements are under command of a central unit - mathematical machine controlling them accordingly to criteria, such as: efficiency, quality of production, costs, etc.

Realisation of such comprehended principle of complex automatics requires fulfilment of at least two conditions:

- possession of the quantitative information about the technological process, especially about the state fulfilling selected criteria (the optimal state),
- possession of theoretical knowledge and techniques ensuring maintenance of the optimal state in spite of possible unexpected disturbances, which can cause deviations of the real condition of a technological process from the desirable optimal state.

This paper presents certain aspects of technology that refer to the surrounding in which engineers work. The knowledge on how to formulate optimisation task and the ability to apply suitable procedures should allow achieving such results.

2. OPTIMISATION

The problem of optimisation has become a common notion recently. It is used for solving practical economic questions, especially the ones of technical or economic character; „the optimal construction", „the optimal coefficients", „optimal technology" are widely used terms.

Optimal (lat. optimus) means the best, and more precisely: best considering the adopted criteria of judgement. Not only is this indispensable specification in full compatibility with logical thinking, but what is more with common sense, because “something” cannot be generally the best, it can be the best for an exactly defined reason. That is why the optimal technology will be the best technology, (e.g. machine engines) only under selected criteria (costs of manufacturing, efficiency, quality, etc.). The selection of optimisation criteria can be different, but that does not mean that the optimal technology (the one received under the criterion of production costs) is at the same time non-optimal, that is not being the best e.g. because of the quality. On the contrary: optimal costs (the minimal ones) can be obtained using technology that assures certain level of quality, and of course quality increases in direct proportion to optimal costs.

The inborn tendency to optimise his actions exists in every man. Usually he does it unintentionally by acting different in different situations, basing on physical condition, material supplies, feelings and using own and other people’s experience. That is why, considering the fact that engineering focuses on fulfilling needs, the offered solutions should always aim at the optimal solutions and rational ways of achieving such solutions should be further examined.

Technical activities can be evaluated according to many different measures and criteria, nevertheless, what will dominate are economical factors based on two principles:

- achieving the assumed effect under minimal expenses,
- achieving the maximal effect under limited expenses.

Most often the compromise solution, which bases on not only economic criteria but also takes into consideration the technical sense, manufacturability, ergonomic and ecological matters, is selected. Positive and negative outcomes of chemical operations are most of times reduced to being regarded as positive economical effects and that is why widely understood economic criterion is generally a deciding factor in final evaluation.

Only activities which can result in producing many different solutions are suitable for optimisation. There are, moreover, criteria which can help rate these results. Optimisation consists in finding the best solution of all examined under a selected criterion. Besides basic requirements of functionality, durability, reliability and other, in machine designing the condition of optimal solution, which considers one criterion or several criteria simultaneously, is more often imposed.

A full multi-criterial optimising process of complicated technical problems can sometimes be very difficult. Nevertheless, recently developed techniques of optimisation methods, which include the possibility of using computers, have created a chance of wide application of optimisation processes in the construction designing stage. Moreover, optimisation facilitates decision processes and allows their objective assessment; therefore the choice of the solution can be taken by computer.

Decision making consists in choosing the solution conditioned in the considerable way by the arrangement of criteria. It seems unproblematic to make a decision if it is based on one measurable criterion; however such situations occur rarely in mechanical engineering. Usually the multi-criterial system which is burdened in large stage with the subjectivism is used. Decisions taken under those circumstances will be burdened with certain risk; in fact there is no absolute certainty of the best choice. Relativity of measures and opinions and their changeability in time and space will appear. Therefore the decision-maker's responsibility can not be absolute and he must have right to take some risk in various situations.

Nevertheless, He has to clearly realise that he has legal and moral responsibility for the effects of failures and the negative consequences of an incorrect decision.

The task of achieving the best result under given conditions and selected judge criterion occurs in a whole range of man's activities – in all fields of engineering, economy, planning, management, etc. A wide range of the occurrences of optimisation problems triggered the development of formulating and solving methods for these problems, specific to various fields of science. All these methods can be formulated within a general theory of optimisation. The latter is a part of field of knowledge called operating research which are considered one of the basic sections of a general theory of systems. The block diagram is presented on fig. [1]

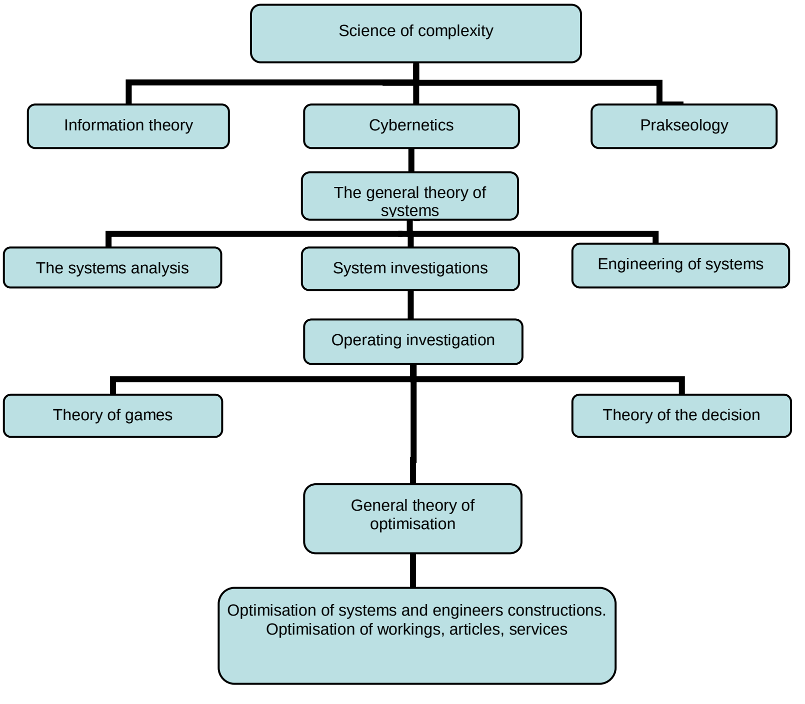

Fig. 1. Optimisation in knowledge diagram [1]

The general theory of optimisation gives the mathematical base for finding optimal solutions. The optimisation of construction is the engineering use of optimisation procedures in, for example: the system designing process of machines, parts of machines, technical devices.

Making right decisions is one of the most essential elements of every field of science introduced on fig. 1. It is especially visible in systems research or operating research, where the examined objects are units influencing one another and called systems.

Historically thinking, optimisation as a scientific discipline is a comparatively young field for it has been developing since the beginnings of nineteen fifties. Its stormy development, connected on the one hand with the demand of the industry, and on the other hand with a growing potential of computers, has been observed after 1960. Optimisation methods have been being developed in many fields of knowledge, independent of one another in terms of place and time. The heterogeneous nomenclature is one of the results of this variety. The literature defines optimisation in a number of ways e.g. as mathematical programming (linear, geometrical, dynamic etc.) or strength formation. Mathematicians, economists, politicians and engineers operate on their own nomenclatures enforced by their approach to the matter. Mathematicians approach the task of optimisation from the theoretical angle while economists and engineers from the practical one. Along with the development of computer science the unification of many concepts can be observed.

This paper relates to the term *optimisation* in a wide, system approach; it means that the aims of optimisation activities are: to create a model of certain technical reality, to formulate a certain solution assessment system, to build a physical and a mathematical model, to find the optimal solution and its to put it into practice, into technical reality.

The narrow understanding of optimisation stands in contrast with the aforementioned approach and treats it as a mathematical action, consisting in determining the extremum of a certain function (or a set of functions), without analysing the relationship of this task to the reality. Such understanding of optimisation results in obtaining mathematically correct solutions, but missing any technical sense.

Optimisation is one of the best developing fields of research nowadays. The work of many scientific communities worldwide results in numerous theoretical or implemental papers related to all human activities. Application of effective computational procedures along with the achievements of the present computational techniques allows arriving at solutions interesting from the scientific point of view. Still, basic factors of optimisation development are measurable advantages that come with the practical introduction of the designed solutions (the old proverb says that “money rules the world "). Owing to this, more and more difficult tasks that consider the most recent phenomena are being undertaken. At present, the term *multidisciplinary optimisation* operates in the world of science [19]. Not only can the term be understood as optimisation of many disciplines, but, as described earlier, a system optimisation as well.

The growth of raised engineering objects size and the range of tasks for which these objects were designed are essential factors stimulating the development of optimisation. Designing and producing these objects requires applying optimal designing, producing and assembly methods. A system approach to their designing is the only method for their successful realisation. It seems obvious that the variety of tasks to be performed by such constructions requires considering many criteria that would enable to evaluate the quality of solutions during the stage of designing process. Modern optimisation must consider aspects of designing that were entirely skipped before. Consequently, the multi-criterial optimisation becomes a general standard. The process of designing is treated as a random one since loads, material properties and different phenomena are considered random. The system understanding of optimisation requires that the received solutions could be applied in practice, in other words, solutions must have the character of discreet solutions, using for example valid industrial standards, and not continuous solutions (e.g. numbers), that is why discreet optimisation becomes another standard.

Mathematicians claim that they have to spend a lot of time eliciting from users the information on what the problem they are to solve mathematically is. The number of hours spent on a correct, real and adequate to customers' needs formulating the problem in the engineering of systems and in optimal designing is also a significant value.

We also have to realise that optimal proceeding is a natural phenomenon in everyday life of all of us. Various life problems that people encounter are solved in the best possible way according to our judgement. Nonetheless, those solutions are most often chosen disregarding objective facts. Only sometimes people are surprised that their behaviour or decisions are not accepted by the community. The rationality of proceeding requires the system approach to the ideas of optimisation.

3. TECHNOLOGICAL PROCESS DESIGNING

Designing processes and means of production is one of most essential stages in the engineering activity. Ideas for technical working are chosen during this stage along with developing conceptions of technical systems. It is during the same stage when decisions influencing effectiveness, economy and reliability and at the same time the efficiency and social usefulness of the whole system are taken. Every technical designing, including mechanical engineering, requires engagement of engineers of highest qualifications, with broad knowledge and vast experience.

Technical designing consists in designing ways of satisfying needs as a result of technical workings. Technical working plan in form of drawings, descriptions, instructions, sets of objects and cost calculations is a precise outcome of the designing activity.

Designing technological processes consists in inventing and preparing the information about the way and the order of proceedings, necessary tools, machines, devices and rooms.

It includes also information about the way of controlling all these sections. Block pattern of such working was introduced on the figure 2.

Mechanical engineering designing consist in: inventing the conception of machine's working, selecting an energy, matter and information processing systems, adequate using and associating the properties of matter and physical phenomena, designing mechanisms structures and creating desirable couplings and relations among objects. The general pattern of designing machines was introduced on fig. 3.

Detailed designing, in mechanical engineering defined as constructing, consists in choosing the constructional attributes (material, geometrical and dynamic) of a designed machine, its elements and units.

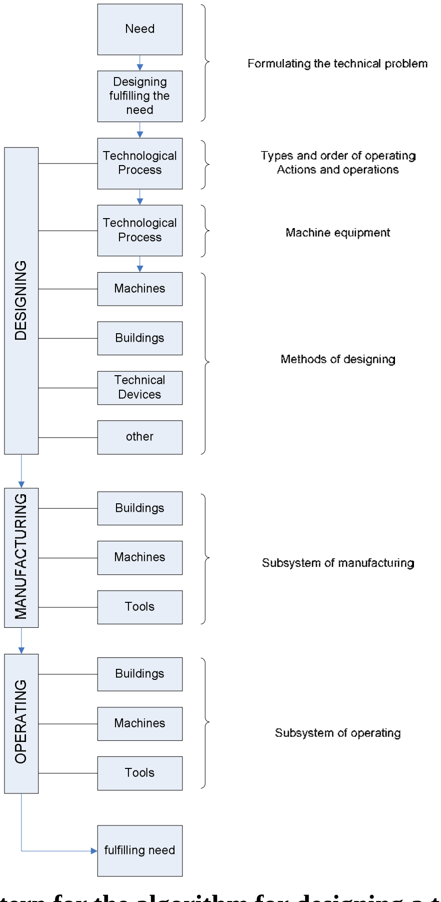

Fig. 2. A general pattern for the algorithm for designing a technical system [5]

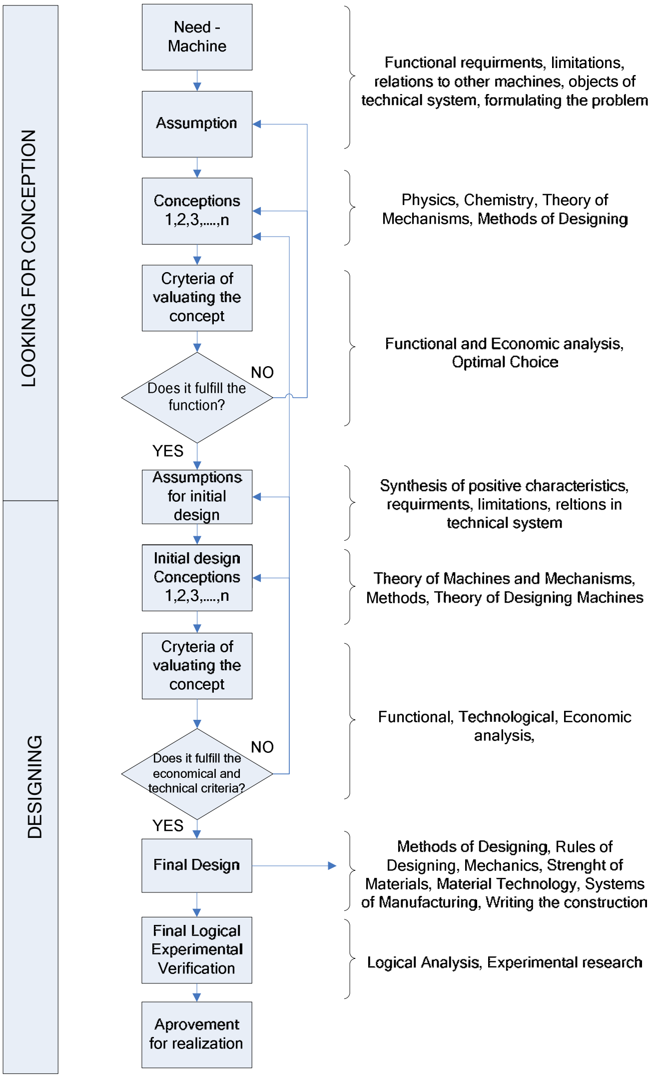

Fig. 3. The general pattern of the algorithm for designing machines

Designing precedes the constructing phase, but as works progress actions like designing and constructing may intertwine. Certain earlier plans may be alternated in order to get the construction fulfil the defined requirements in the optimal way. Breaking the process down into designing and constructing proves useful for arranging certain concepts, establishing the range and the order of works in the designing-constructional process. These two definitions shouldn't be treated too formally and the border between them should not be artificially set. It is at times acceptable to treat those two words as synonyms both referring to the whole process of designing-constructional works.

The designing-constructional process should develop according to a certain plan, which would define the range and the order of workings and would aim at obtaining the best solution. Such plan is defined as the algorithm of the designing-constructional process.

Designing machines can be divided according to the level of innovation of a designed construction as follows [2]:

- seen (imitative, reproducing),
- compilational (the selection and adaptation of existing constructions to fulfilling new, different tasks),
- evolutionary (the development and improvement of existing constructions),
- innovative (innovatory, original).

According to the way of approaching, following designing types can be distinguished:

- routine,
- intuitive,
- methodological (based on logical operations, basic and constructional sciences),
- experimental (creating and the verification of constructional information for the help of tests and investigations).

According to the way of formulating the subject:

- system (solving the subject on the background of solving the general problem in the system formulation),
- partial (the narrow formulation of the subject generally having the detailed task).

According to the dynamics of methods development:

- static (wide-spread ways, repeating others actions and typical works),
- dynamic (modern and developing techniques and the methods of designing).

The aforementioned types of designing and constructing appear often simultaneously, though in various studies their contribution can be different and some of them clearly dominate. All skills, practice and experience, inventiveness and intuition, the ability of experimenting, but most of all good scientific bases are extremely useful during designing.

Each of designing actions is necessary and deserves credit if it was conducted according to the needs, to the subject in question and the criteria of the evaluation. Innovatory projects are for the developers a source of satisfaction of creating something new for the common good, while projects of compilational and evolutionary character give the satisfaction of finding a quick and generally cheap way to satisfy a social need by using already existing and verified constructions, which sometimes after small but inventive changes, were adapted to fulfil new tasks.

4. MATHEMATICAL BASIS OF OPTIMISATION

In the process of construction optimisation the constructional problem has to be introduced as an objective function and then solved using mathematical methods. Various limitations and constructional requirements have to be replaced by mathematical formulas. They will mark the borders of the acceptable solutions area. The optimal value of an objective function lies within borders of the allowable area or on its periphery (fig. 4).

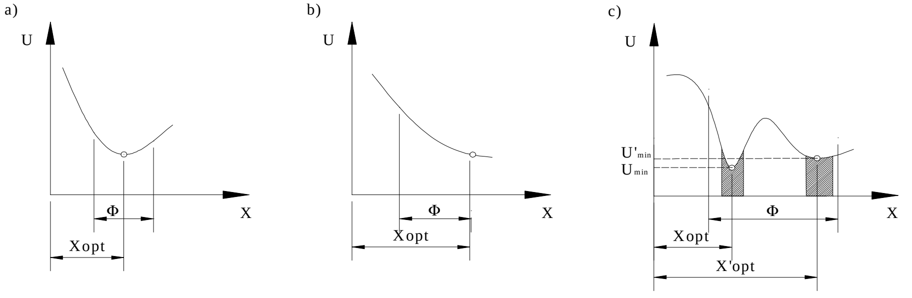

Fig. 4. The optimum of an objective function: a) within the acceptable area b) on the border of that area c) some relative extremes [2]

If the problem can be described by a simple function $U = f(x)$, monotonic in the area of admissible solutions Φ (fig. 3.1a), then this function is also an objective function, and optimisation problem boils down to finding its minimum or maximum:

$$(U = U_{min/max}) \Rightarrow (x = x_{opt}).$$

In that case is optimisation is either simple or elementary.

When there exist several relative extremes in the admissible area (fig. 4c) it is possible to be more beneficial to not choose x_{opt} for U_{min}, but situation a slightly worse: x'_{opt} for U'_{min}. In practice we do have to foresee the dispersion of x values, approaching the x_{opt} within certain limits of tolerance. The results of moving in the area of tolerance x_{opt}, and x'_{opt} are clearly different for the U value, what presents fig. 3.1c.

Another example of elementary optimisation with two-criterial opposite dependences is introduced on fig.5. The general formula for this case is presented below:

$$U_1 = f_1(x), \quad U_2 = f_2(x)$$

and

$$[([U1 + U_2) = U_{min}] \Rightarrow (x = x_{opt}).$$

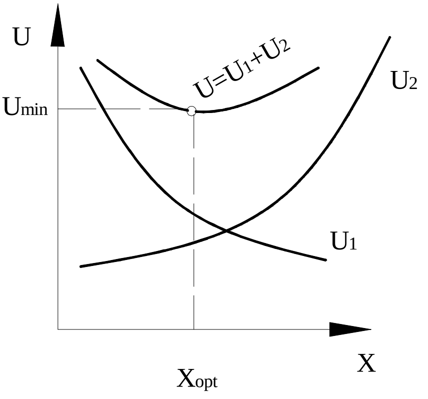

Fig. 5. Optimisation when adding two opposite dependences [5]

Currently known methods of optimisation may to a little extent be used while developing new, original machines conceptions. On the other hand, on the stage of preparing detailed construction of sets and the methods seem far more useful considerably improving designing works.

Following stages can be distinguished in the general process of optimisation:

- formulating the mathematical model and criterional function,
- choosing an optimisation method,
- computer calculations.

Variables $x_1, x_2, ..., x_n$, describing the construction in an n-dimensional space, can be divided into: variables at constructor's disposal and parameters established or enforced by a given task. A point in this space represents a model of the construction: $x =(x_1, ..., x_n)$. Decisional variables follow the limitations:

- functional

$$(\varphi_j(x_1, ..., x_n) = 0, \quad j = 1 , ... , m,$$

the number of functional limitations has to be smaller than the number of independent variables $m < n$;

- superficial

$$\psi_k = (x_1, ..., x_n) = 0, \; k = l ,..., q.$$

The number of superficial limitations is not limited. Functional and superficial limitations define the allowable area Φ together.

Constructional model described by co-ordinates in the n-dimension space E^n has to fulfil the condition: $x \in \Phi$, $\Phi \subset E^n$, which is why the construction has to belong to the admissible area Φ within precincts of the n-dimension space E^n. In order to choose the construction fulfilling the condition of optimisation, objective function (the function of optimisation criterion: $At = At(x_1, ..., x_n)$) needs to be determined. Decisional variables need to be chosen so that the objective function reaches the optimal value (minimum or maximum) in the acceptable area:

$$U \to U_{min/max} \quad for\, x \in \Phi$$

The condition of minimum mass, the maximum load, the minimum of energetic losses or the maximum of efficiency are all taken into the objective function.

To recapitulate: we can say that formulating a mathematical model includes following actions:

- defining values occurring in the dealt with problem: decisional variables, the values of which seeks the designer, and parameters for which values have to be known;
- defining the acceptable area, from which values of decisional variables can be chosen.

Mathematical model makes it possible to detach from the real, physical nature of a problem and investigate it in the categories of abstract concepts and mathematical equations. The difficulty of designer's task depends here on obtaining the adequacy of mathematical representation, because only then abstract mathematical actions can lead to the solution which has the physical sense and practical meaning.

Finding the optimal solution is hindered by complicated arrangements with large number of decisional variables. Since there is little possibility of applying derivative functions in solving the problem different methods of optimisation need to be used, with for instance, the random walk method (Monte Carlo method) and the method of systematic searching find use quite often [12].

OPTYMALIZACJA W BUDOWIE MASZYN

Streszczenie

Wiedza o tym jak sformułować zadanie optymalizacji i możliwość, by stosować odpowiednie procedury pozwala osiągać najlepsze rozwiązania w budowie maszyn i ogólnie w każdym polu działalności ludzi. W pracy przedstawiono podstawy optymalizacji i skupiono się na procesie optymalizowania średnic długiego wału zamocowanego w dwóch ułożyskowanych podporach z zamocowanym dyskiem. Przedstawiono również podstawy matematyczne i model matematyczny optymalizacji.

Słowa kluczowe: *optymalizacja, modelowanie matematyczne, jakość, wały o małej sztywności, obróbka wałów*

OPTIMISATION IN MECHANICAL ENGINEERING

Abstract

The knowledge on how to formulate optimisation task and the ability to apply suitable procedures allows achieving the best results in mechanical engineering and generally in every field of humans activities.

The paper presents background of optimisation and focuses on process of optimizing diameters of a long shaft mounted in two bearings with a disk mounted on it. Mathematical basis and the model of optimisation are also presented.

Key words: optimisation, mathematical modelling, quality, low stiffness shafts, shafts pocessing

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OPTIMISATION IN MECHANICAL ENGINEERING part 2

5. MATHEMATICAL MODELS OF OPTIMISATION

Each construction is determined by a set of parameters described in previous section. If a certain number is assigned for every parameter, then the whole construction can be described using the set of n numbers, where n - the number of attributes describing the construction, so the construction is a vector $\bar{x}$ in an N-dimension Euclidean space. This vector is a mathematical model of construction

$$\bar{x} = (x_1, x_2, \ldots, x_N), \qquad \bar{x} \in R^N \tag{5.1}$$

The co-ordinates of vector $\bar{x}$ can be divided into constant parameters and parameters which are defined during optimisation – decisional variables

$$\bar{x} = (x_1, x_n, x_{n+1}, \ldots, x_N), \tag{5.2}$$

where: $x_1, \ldots, x_n$ - *decisional variables,*
$x_{n+1}, \ldots, x_n$ - *the rest of parameters (constant),*
n - *the number of decisional variables,*
p - *the number of constant parameters,* $p = N - n$.

Equational limitations are presented by:

$$h_j(x_1, \ldots, x_n) = 0, \qquad j = l, 2, \ldots, m, \tag{5.3}$$

and inequational limitations:

$$g_i = (x_1, \ldots, x_n) \geq 0, \tag{5.4}$$

or

$$\varphi_i = (x_1, \ldots, x_n) \leq 0, \qquad i = l, 2, \ldots, q. \tag{5.5}$$

The set of acceptable solutions (an acceptable area) is a set of points in an N-dimension Euclidean space, fulfilling conditions described by equations (5.3) and (5.4). After marking it with X and making an assumption, that this is a non-empty set $X \neq \bar{0}$, mathematical notation of 1st principle of constructing are received [1]:

$$\bar{x} \in X, \quad X \subset R^n \tag{5.6}$$

The construction fulfilling dependence (4.6) is a good construction.

The 2nd principle of the construction states that the best construction (the optimal construction) is selected from all correct constructions under selected criterion. The criterion is expressed through an objective function $Q(\bar{x}) = Q(x_1, \ldots, x_n)$. The objective function should approach the optimal value (minimum or maximum) under the suitable selection of decisional variables:

$$Q(\overline{x}) \to Q_{opt}\left(\overline{x}*\right) = \begin{cases} Q_{\min} \\ Q_{\max} \end{cases}$$

where: $\overline{x}* = (x_1*, \ldots, x_n*) \in X$ describes the optimal construction.

The 2nd principle of the construction can be presented as follows:

$$Q(\overline{x}) \to \min\ (\max), \quad \overline{x} \in X . \tag{5.7}$$

For minimisation of an objective function the 2nd principle of construction can be presented as follows:

$$(\overline{x}* \in X) : \left\{ \bigwedge_{\overline{x} \in X} Q(\overline{x}) \geq Q(\overline{x}*) \right\} \tag{5.8}$$

For maximisation:

$$(\overline{x}* \in X) : \left\{ \bigwedge_{\overline{x} \in X} Q(\overline{x}) \leq Q(\overline{x}*) \right\}. \tag{5.9}$$

The formulation of a mathematical model has basic meaning for the correct solution of an optimisation task. Mathematical model allows to transform the reality into a physical model, using abstract mathematical notions. In the system approach to the task a mathematical model should be adequate to the real problem. Mathematical methods supported by computer techniques allow to solve almost every model, even if it is formulated inconsistent with the principles of engineering and is devoid of any technical sense. By extending the model, an engineer can imitate the reality better, however it cannot result in extending the time necessary for its solving. The model should be as simple as it is possible, but it has to include basic proprieties of the construction. In certain situations several objective function have to be applied in order to describe the construction correctly - such a problem is ranked among multi-criterial optimisation.

The mathematical model of construction consists of the following units [3]:

- an objective function (or a set of those functions), which is a mathematical record of optimisation criterion,
- a set of decisional variables and other parameters describing the construction,
- a set of limitations (restrictive conditions).

Mathematical models of optimisation are classified according to various aspects of a problem. According to the parameters of the task, three models are distinguished:

- The necessitarian model, where all the parameters are determined (i.e. well-known and constant). The one and only one value of an objective function corresponds to every possible decision.
- The probabilitical model, when there is one or several random variables described by a known probability distribution.
- The statistical model, when one or several parameters are random variables and their probability distribution is unknown or when

distribution of parameters in a time function is known (Stochastic model).

According to a character of a set of decisional variables, there were distinguished:

- The model of a discreet optimisation, when the set of decisional variables is a finite set of discreet values, e.g. compatible with standards.
- The model of a continuous optimisation, without the limitation on the range of variables.

According to the number of objective functions (optimisation criteria) we distinguish :

- The model of a scalar optimisation, when the task uses only one objective function.
- The model of a multi-criterial optimisation (vectorial), with several objective functions.

And finally according to an objective function type and the type of limitations we can distinguish:

- The linear model, when the objective function and all limitations are linear functions.
- The non-linear model, when at least one of the objective functions or limitations is a non-linear function.

Designing the mathematical model of constructions optimisation is one of the objectives of the optimal designing process, that is why the system approach has to be used. Designing the model includes:

1. defining objective functions,
2. defining decisional variables,
3. defining the acceptable area (the area of acceptable solutions).

According to example (4.1), the construction can be treated as a vector in a constructional space. If the co-ordinates of this vectors are numbers, the constructional space is a N-dimension Euclidean space

$$\overline{x} = (x_1, \ldots, x_N) \in R^N.$$

When the co-ordinates of the vector are functions, the constructional space is a functional N-dimension Hilberts space[9]. As it was already mentioned, the co-ordinates of a construction can be divided into parameters and decisional variables. The set of decisional variables defines a vector in the new space which is reduced relatively to the constructional space. This new space is called the space of decisional variables

$$\overline{x} \in R^n \subset R^N \qquad (5.10)$$

where: $n = N - p$,

N – the number of parameters of construction,,

n – the number of decisional parameters,

p – the number of parameters predetermined by an engineer.

The acceptable area (an acceptable set, the set of allowable solutions) is the subspace (subset) of a decisional variables space.

$$X \subset R^n \quad (5.11)$$

The situation in which the R^n space overlaps the area of the X set is somewhat frequent

$$X \equiv R^n, \quad (5.12)$$

and is called an optimisation without limitations.

The acceptable area is created as a result of putting equational and non-equational limitations on the construction. With regard to the abovementioned groups of limitations, the acceptable area is a product of a following set:

$$X = E \cap W \cap P \cap B, \quad (5.13)$$

where: *E - the limitation of the economic type,*

In - the limitation of the dimension type,

P - the limitation of the qualitative type,

B - the limitation of the exploational type.

Fig.6 presents the example of a acceptable solutions set defined by a dependence (4.13)

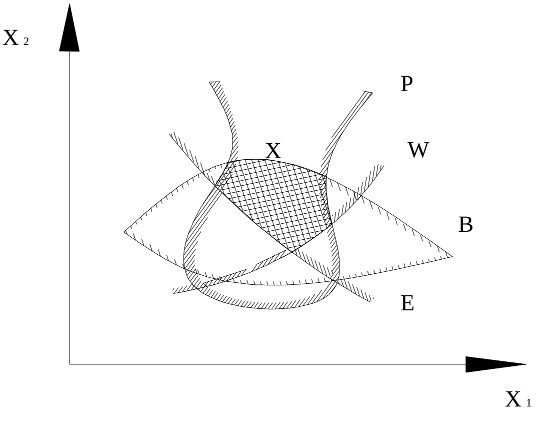

Fig. 6. An acceptable area as a result of operation on different type limitations [17]

The number of nonequational limitations can be large but the set *X* can not be a null set. The number of equational limitations has to be smaller than the number of decisional variables. Equational limitations reduce the dimensionality of an acceptable area

$$dimX = n - m,$$

where: n - the number of decisional variables, m - the number of equational limitations. If the number of equational limitations is equal to the number of decisional variables optimisation problem becomes degenerate. Fig. 7. presents examples of acceptable areas.

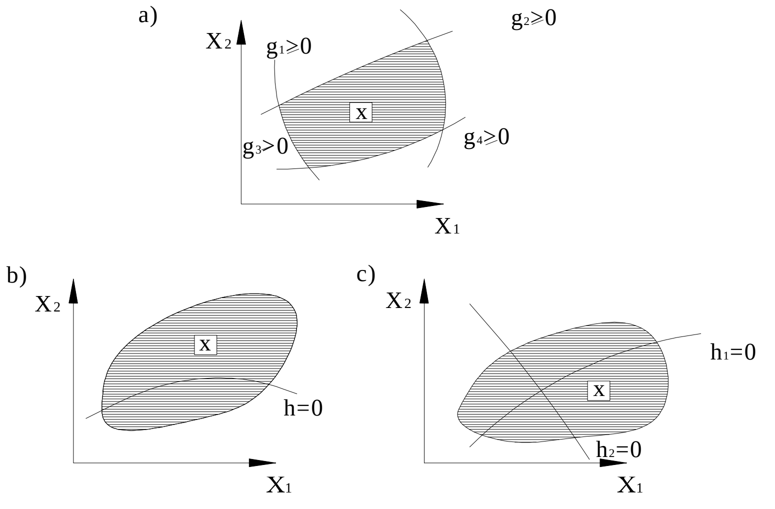

Fig. 7. Examples of acceptable areas for 2 dimensional task $\bar{x}$ =(x_1,x_2):

a) An acceptable area under non-equational limitations, b) the task is reduced to a one-dimensional-under-equational limitation c) the problem degenerated for two equational limitations.

Transformations of non-equational limitations are often practiced:

$$b_1(\bar{x}) \le 0 \Leftrightarrow -b_1(\bar{x}) \ge 0. \qquad (5.14)$$

Often, equational limitations also become transformed into a set of non-equational limitations, especially the needs of optimisation procedure:

$$h_i,(\bar{x}) = 0 \Leftrightarrow \begin{cases} h_i(\bar{x}) \ge 0 \\ -h_i(\bar{x}) \ge 0 \end{cases} \qquad (5.15)$$

An objective function (optimisation criterion) can be introduced as an operator an transforming acceptable area X in a different area Y. This operator transforms the space of decisional variables R^n into the R^q space, called a criterial space, the space of attainable targets, the space of objective function, the space of quality:

$$Q : X \to Y \; lub \; Q : R^n \to R^q \qquad (5.16)$$

Fig. 8 presents a graphical illustration of a scalar optimisation (single criterional).

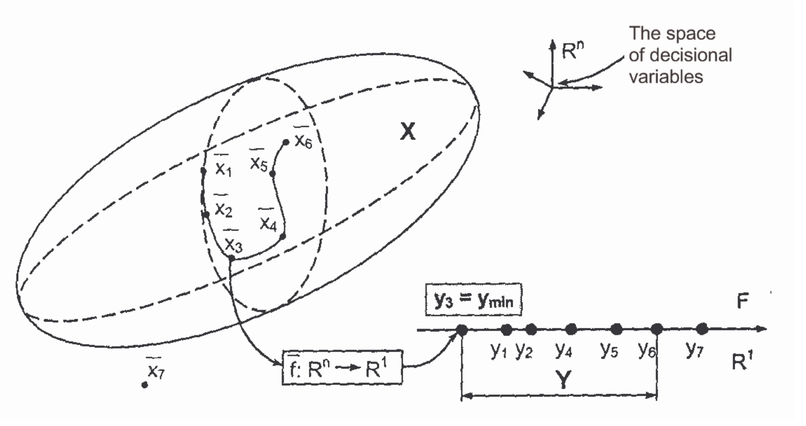

Fig. 8. The graphic model of a scalar optimisation: X – acceptable area, Y - the area of attainable targets [17]

The space of objective functions is a numerical axis $R^q = R^1$. This means that Q operator assigns a certain real number, which is a part of the space R^1, to every vector from the X set. Such situation occurs most often in engineering tasks, that is why the term optimisation is often associated with just a scalar, single-criterional optimisation. The relation „≥" that refers to minimisation and was introduced in example (5.8), is in the topological formulation a linear relation, in case of a single-criterional optimisation - well-known arithmetical relation.

While solving technical tasks it often occurs that the task of maximisation needs to be solved as a task of minimisation. It can be done according to the following transformation:

$$max\ Q(\bar{x}) = -\ min\ (-Q(\bar{x})). \qquad (5.17)$$

Fig. 9 represents a graphic interpretation of the abovementioned transformation.

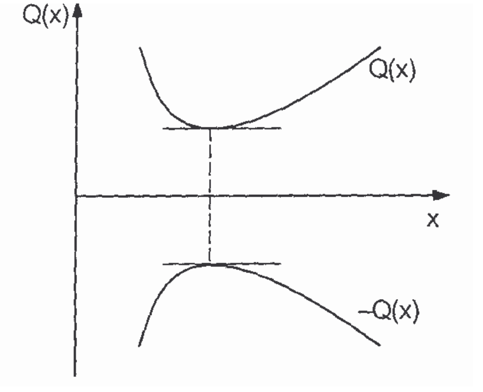

Fig. 9.The equality of minimisation and maximisation task for one variable function [19]

Operator Q, which represents optimisation criteria, can be treated as a hypersurface stretched over the acceptable set. For $X = R^2$, the objective function $Q = Q(x_1, x_2)$ is the surface defined in the three-dimensional Euclidean space. Fig. 10 presents graphic illustration of two-dimensional task (two decisional variables x_1 and x_2).

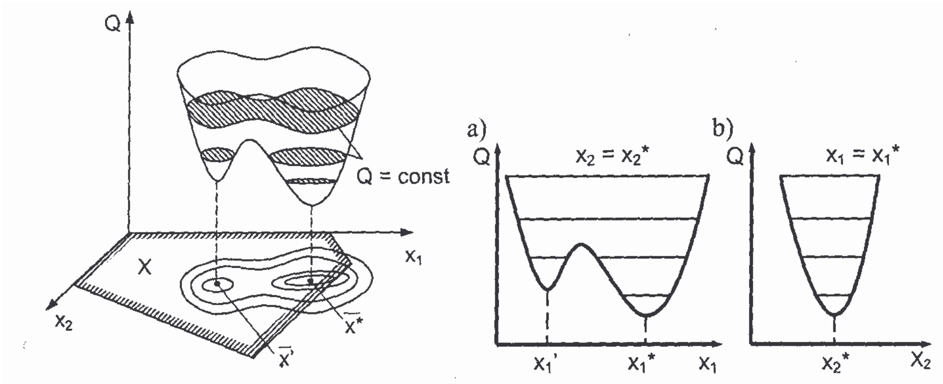

Fig. 10. A graphic illustration of optimisation task with two decisional variables: a) the $x_1 = x_1$ section *, b) the $x_2 = x_2$ section* [17]

6. OPTIMISATIONAL ANALYSIS OF A ROTATING SHAFT

The first object of optimisation is a shaft mounted in two bearings with a disk mounted on it, that weights Q, and is much heavier than the shaft (fig. 11). Diameters d_1 and d_2 of a shaft need to be calculated under condition that the weight of a shaft needs to be as small as possible and the angular velocity of a shaft should be smaller than the frequency of proper transverse vibrations of the shaft (shafts critical frequency). The turning moment transferred by the shaft is small and does not influence the dimensions of a shaft.

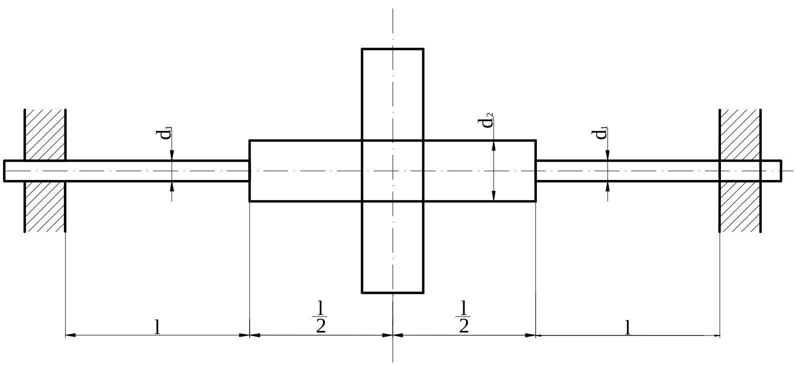

Fig. 11. The constructional model of a shaft

Input data: l = 40 cm, Q = 2100 N, $n = 3000 \frac{1}{\min}$, Young's modulus of a shaft material

$E = 2{,}1 * 10^7 \frac{N}{cm^2}$.

The solution

The frequency of proper transverse vibrations of a shaft is expressed as[16]:

$\omega_0 = \sqrt{\frac{shaft's\ stiffness}{vibrating\ mass}}$, assuming $\delta_{st} = \sqrt{\frac{mass \cdot\ acceleration\ of\ gravity}{shaft's\ stiffness}}$

we receive the dependence:

$$\omega_0 = \sqrt{\frac{g}{\delta_{st}}} \tag{6.1}$$

where:

g – *acceleration of gravity (9,81 $\frac{m}{s^2}$),*

δ_{st}– *static distortion of a shaft mounted both ends in bearings as a result of the mass Q*

$$\delta_{st} = 10{,}67 \frac{Ql^3}{\pi E}\left(\frac{1}{d_1^4} + \frac{2{,}81}{d_2^4}\right) [22] \tag{6.2}$$

The optimal shaft should be stiff enough, so:

$$k\frac{\pi n}{30} \leq \left(\frac{\pi E g}{10{,}67 Q l^3 \left(\frac{1}{d_1^4} + \frac{2{,}81}{d_2^4}\right)}\right)^{\frac{1}{2}} \tag{6.3}$$

where: k - *the arbitrarily assumed coefficient of safety, under the foreseen fluctuation of the turning velocity of a shaft,*

N - the turning velocity of a shaft.

From here, introducing an auxiliary term:

$$a = \frac{\pi E g}{10{,}67 Q l^3 \left(\frac{\pi n}{30} k\right)^2}$$

we receive:

$$\frac{1}{d_1^4} + \frac{2{,}81}{d_2^4} \leq a \tag{6.4}$$

We aim at minimising the weight of a shaft. By minimising the volume of the cylinder divided by the product of the lengths of one section and π we will obviously receive the same result (lengths all of three sections of the cylinder are equal). Marking the minimised function by F we have:

$$F = 2d_1^2 + 2d_2^2 \tag{6.5}$$

Additional condition related to the technical sense of variables d_1 i d_2 is
$d_1 > 0, \quad d_2 > 0,$

As it results from equations (5.4) and (5.5), reducing d_1 and d_2 takes effect in reducing F, but at the same time it increases the left side of inequality (5.4). Therefore we can assume, that the point in which F reaches minimum lies on a boundary curve for condition (5.4). The equation of this curve is:

$$\frac{1}{d_1^4} + \frac{2{,}81}{d_2^4} - a = 0 \tag{6.6}$$

We will mark the optimum using the indeterminated Lagrange'a mulitplier.
We have

$$F_0 = \left(2d_1^2 + 2d_2^2\right) + \lambda\left(\frac{1}{d_1^4} + \frac{2{,}81}{d_2^4} - a\right) \tag{6.7}$$

and

$$\frac{\partial F_0}{\partial d_1} = 4d_1 - \lambda\frac{4}{d_1^5} = 0$$

$$\frac{\partial F_0}{\partial d_2} = 2d_2 - \lambda\frac{4 \cdot 2{,}81}{d_2^5} = 0$$

We determine from the abovementioned equations

$$d_1^* = \sqrt[6]{\lambda}\,,\; d_2^* = 1{,}34\sqrt[6]{\lambda} \tag{6.8}$$

Therefore the optimal values of diameters d_1 and d_2 will be related to the dependence $$d_2^* = 1{,}34 d_1^* \tag{6.9}$$

Using equation (5.6) we receive the optimal value d_1

$$d_1^* = \sqrt[4]{\frac{1{,}90}{a}} \tag{6.10}$$

Graphic analysis (fig. 12) confirms the received result.

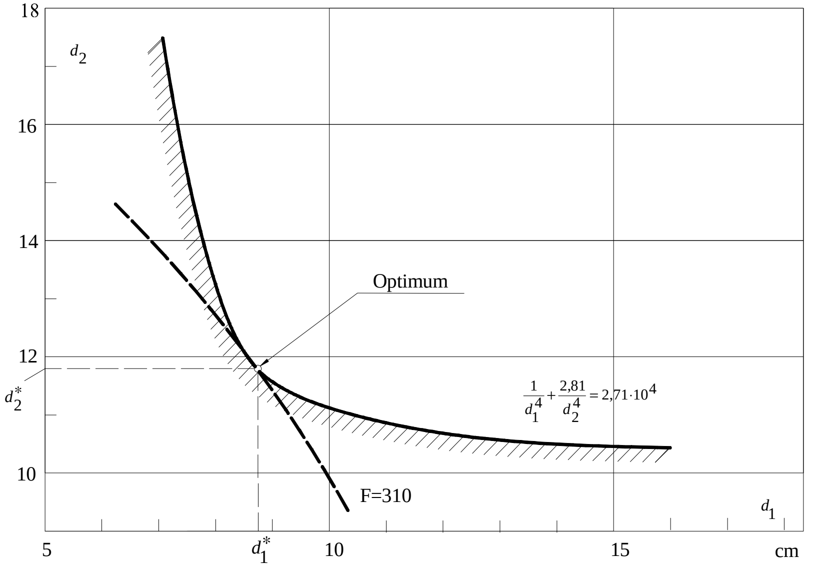

Fig. 12. The optimal diameters of shafts sections

We assume the coefficient of safety k = 1,3 and calculate that $a = 2,71 \cdot 10^{-4}$. From here optimal values of the diameters of shafts sections are:

$$d_1^* = 9,15\,\text{cm}$$

$$d_2^* = 11,9\,\text{cm}$$

The minimum value of the function F

$$F_{min} = 310\,\text{cm}^2$$

Fig. 12 shows the graph of a function which restricts the area of acceptable solutions

$$\frac{1}{d_1^4} + \frac{2,81}{d_2^4} = 2,71 \cdot 10^4$$

with the optimal point and the line of the constant value of the minimalised function ***F*** that goes through optimum. This drawing confirms that the gradient of limitation and the gradient of the minimalised function are collinear in the optimum.

SUMMARY

Creating new machines, devices, technologies or systems that will satisfy future user's needs are the tasks of an engineer. Designing understood as a process of creation requires making decisions about choosing the best variant of solutions throughout the project. The best variant is very often the one that in a limited number of possibilities allows achieving the maximal advantage or assures the realisation of a project at minimum costs.

The decisions on choosing the solution are made basing on knowledge, experience and intuition, but also often by trials and errors. Present projects are more and more complicated that is why engineers struggle to shorten the time of its development and increase the effects/investments ratio. The margin of error which is left to an engineer-designer, becomes smaller and that is why decisions are taken basing on a solution of a suitably formulated and written down in the formalised way task. The branch of engineering which deals with those problems is called the theory of designing. According to the theory the choice of a solution is a result of a process called optimisation. If the effect, which is to be achieved in the project, can be described in numbers (the objective function can be defined) and at the same time it will depend on value of some set of values (decisional values), that are within the border marking the area of possible solutions (acceptable set) then the task is to find such variable decisional values for which objective function achieves minimum or maximum in the acceptable set. Such formulated task is an optimisation task, ready to be solved, and the solution may be treated as an optimal variant of a project.

The quest for the optimal forms of a construction is not only a set of mathematical methods and criteria more or less connected with the economy of projected buildings. Optimisation includes a considerably wider range of questions and aims resulting from the pursuit of satisfying customer's needs fully and from the pursuit of aesthetical values. The economical issues of construction materials are only a part of general questions. Both of these endeavours are proper for human activity. Through optimisation it is possible to achieve larger construction capacity with the same quantity of materials or using the same financial investments

Fulfilment of optimisation conditions leads to such shapes of construction in which the arrangement of working forces is well ordered. Engineers achieve constructions matching natural aesthetical requirements by: avoiding concentration of forces, notches and groundless discontinuities of shapes, purposeful choosing the arrangements of internal strengths for best transferring of loads and by adapting shapes of constructional units to achieve the most proper transfer of strengths. Undertaking and solving such understood questions of optimisation is motivated by psychological attitude and philosophical beliefs.

The choice of a proper optimisation procedure taken as means of solving engineering problems is one of crucial stages of optimal designing of a construction. This choice is not a simple matter, because, there is no universal method, which would be effective in solving all engineering problems. We can even talk about certain psychological barrier connected with large number of procedures which makes choosing the right optimisation method difficult.

Choosing the procedure, engineer should take into consideration the following aspects of a process of optimal designing:

- the type of a considered problem – whether it is a inear or a non-linear problem;

- the size of the problem, the number of decisional variables, the number of limitations;
- the number of optimisation criteria - or whether the problem is scalar or vectorial (multi-criterial);
- the type of decisional variables – whether they are continuous or discreet;
- the type of limitations;
- the necessity of calculating the derivatives of objective and limitation functions;
- the required exactitude of calculations;
- the required reliability of finding the global minimum;
- access to technical software;
- uncomplicated adaptation of software for concrete task;
- information about the efficiency of a procedure in similar engineering problems;
- uncomplicated producing and interpreting results (graphic interface).

The analytic methods of solving optimisation questions were changed together with the general development of mathematical methods. The efficiency of optimisation as an effective solution for more and more complicated questions depends on using recent achievements in the field of mathematical methods.

During last decade the relationship between the construction optimisation and the mathematical theory of optimisation opened new directions and possibilities not only in the range of solving questions, but what is more important in the range of formulating these questions.

Optimisation finds application not only in constructions, but also in designing chemical processes. The questions regarding transportation in defining the line of transport and the arrangement of connections are also solved by looking for extremes of functions. The future of optimisation theory is designing technological processes and looking for strategic solutions.

OPTYMALIZACJA W BUDOWIE MASZYN

Streszczenie

Wiedza o tym jak sformułować zadanie optymalizacji i możliwość, by stosować odpowiednie procedury pozwala osiągać najlepsze rozwiązania w budowie maszyn i ogólnie w każdym polu działalności ludzi. W pracy przedstawiono podstawy optymalizacji i skupiono się na procesie optymalizowania średnic długiego wału zamocowanego w dwóch ułożyskowanych podporach z zamocowanym dyskiem. Przedstawiono również podstawy matematyczne i model matematyczny optymalizacji.

Słowa kluczowe: *optymalizacja, modelowanie matematyczne, jakość, wały o małej sztywności, obróbka wałów*

OPTIMISATION IN MECHANICAL ENGINEERING

Abstract

The knowledge on how to formulate optimisation task and the ability to apply suitable procedures allows achieving the best results in mechanical engineering and generally in every field of humans activities. The paper presents background of optimisation and focuses on process of optimizing diameters of a long shaft mounted in two bearings with a disk mounted on it. Mathematical basis and the model of optimisation are also presented.

Key words: optimisation, mathematical modelling, quality, low stiffness shafts, shafts pocessing

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PIOTR PENKAŁA

SIMULATION OF MATRIX BOTTOM BOTTLE TREATMENT IN UNIGRAPHICS NX6 SYSTEM

Introduction

Unigraphics NX is a system of higher-class CAD / CAM / CAE / PLM widely used in industry, especially the global aerospace, automotive, utility and consumer goods. Version of a program called NX 6 is available from mid-July 2008 - work was also underway on the national version of the package. Major changes have occurred in the latest version of the *CAx* integrated system, which introduced a novel modeling technique - Synchronous Technology. NX 6 is the first fully developed by *Siemens PLM Software*, a new version of the program. Siemens after the acquisition of *UGS* (May 2007) began to develop strong editing and construction techniques [3]. NX is based on *Parasolid* kernel, which is the exact geometric modeler developed by UGS, Cambridge (England). The basis of the software, are modules for spatial modeling (Modeling), mounting assemblies (Assembly) and technical drawing (Drafting). For the analysis of the strength, of part or assemblies in NX is used *NX Nastran* or other so-called external solvers. It capable, making an analysis of kinematics and dynamics of mechanisms (Motion simulation). Very strong side *Unigraphics / NX'a* is *Manufacturing module* to generate tool paths for CNC machining for programming in the full range up to 5 controlled axes continuously. A very important module is the module NX6 gateway. It is management module, which contains graphic *work environment*, creating infrastructure linking all the modules of the system *Unigraphics NX*. To perform basic operations such as, opening existing files with the parts, creating new files, print drawings and images from the monitor, move the files in *Parasolid* format and *CGM (Computer Graphics Metafiles).* It allows to manage the various layers of the drawing, define view and configure the image on the screen display control includes hiding objects and access to the scheme. The module also contains a spreadsheet that allows families to build and manage the elements and associations between parameters of different parts. It also provides tools to carry out various studies, from the simplest such as calculation of surface area, volume, measurement of the angle or arc length at a sophisticated analysis of the curves and surfaces (e.g., radii of curvature, reflections, slope) [3].
The main function, which distinguishes *CAM Unigraphics* from other computer systems, is a clear definition of objects in the working environment. The most important unique feature of this solution is can be indicated for the treatment of the entire model or directly to the surface (wall / face of solids) without definition of the working range.

When you generate the path the system takes a model of that there were no collisions, but the paths are created only on selected surfaces in contact with an automatic positioning tool. This eliminates the well-known from other systems, time-consuming processing of the definition of ranges depending on the diameter of tool. The *NX CAM* treatments can be defined ranges, but they fulfill a supporting part [3].

Submission of finished components in the module Assembly Modeling

The module not only allows to create the submission of pre-made parts, but also to design parts in the context of the assemblies and the creation of reference models (master models) of those parts, namely the work by the "top - down." Location of elements in the assembly can be determined relative to a frame of reference, or by flexible bonds with other elements of the submission. This way the location of the system increases the efficiency and reduces storage requirements. Parametric modeling of assemblies provides additional possibilities for the description of the relationship between the components (which detects collisions and simplistic analysis of the traffic). The adopted architecture allows share a very complex structure of the fragments, allowing the design team. Team members have the opportunity to work in parallel. Access to the proposed combination of components is governed by permissions of the user, or is consistent with the principles set in the *Module Manager* [2]. *Unigraphics* program in the system with family run standard Windows by clicking the icon NX 6. Then start the program interface *Unigraphics*. After opening the window to choose New - it create a new file. Now they have several options to choose from simple modeling, sheet metal creating a structure to perform strength calculations.

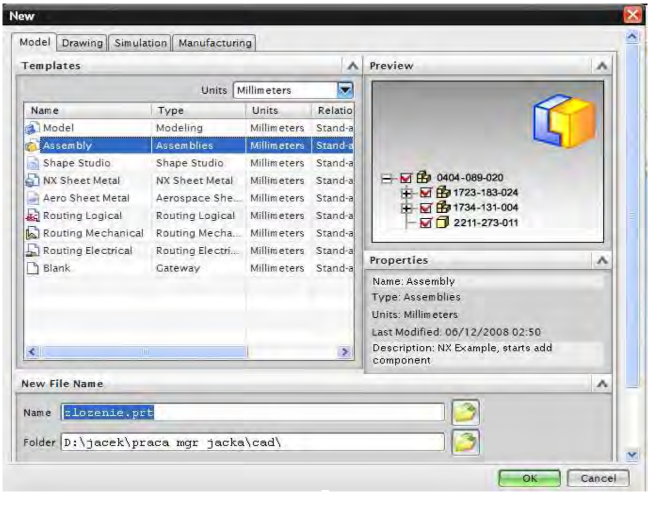


Fig. 1. Window of interface *New File*

Executed submission of machining will be made in *Assembly* option. It will be used in module *Unigraphics CAM* program, in which treatment will be simulated. The concept of the *master model* requires the creation of a new file in the main assemblies in which all parts are included and are placed. After you enter the file name and choose the places where the file should be located, the program displays a dialog *add component*. In this window they specify the information that they want to add elements and how to pair them with other (through bonds or other elements of the coordinate system).

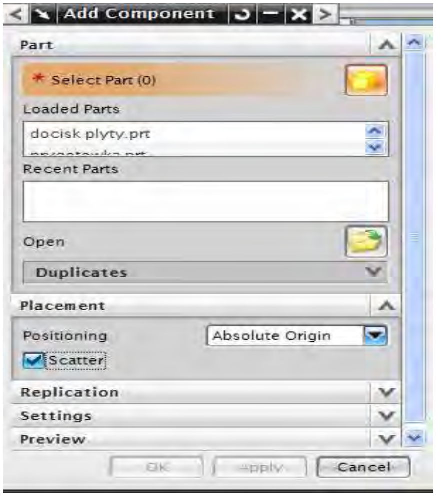


Fig. 2. Window of *add component*

Defining the steps:

1st Step: Section part  - an icon of *open* - they choose the component which is to be assemblies.

2nd Step: *Placement* section - select the menu option *positioning* 

. This places the item in the middle of the base coordinate system. They accept the setting element *Apply* button.

3rd Step: in the *part* click open, select the component which is to be in assemblies.

4th Step: broadcasting relationship  *Assembly Constraints* - elements in the assemblies are linked together by relationships.

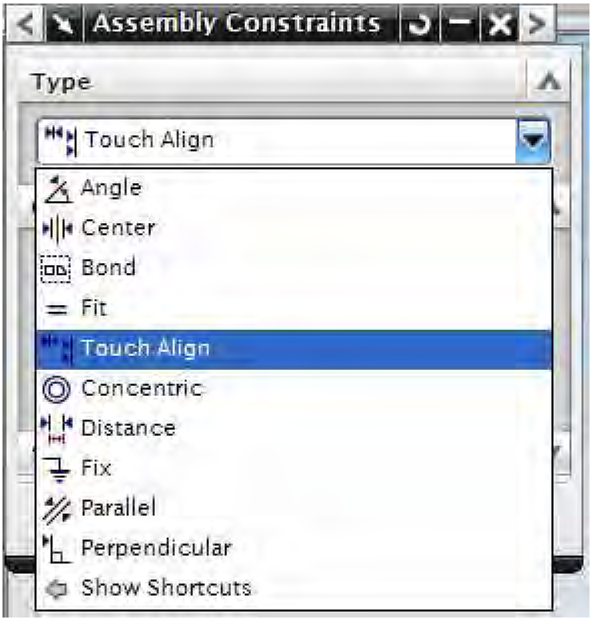


Fig. 3. Window of defining relations

If they give of the relationship of all components, the assembly is ready to make machining in CAM module.

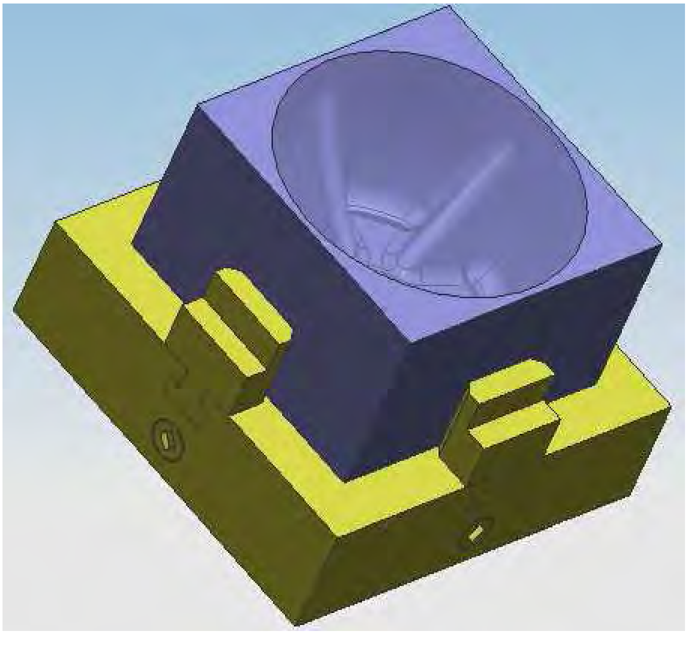


Fig. 4. Submission of machining performed in the module assembly (mounting)

Description of the *Manufacturing module*

Unigraphics NX CAM software provides a comprehensive and easy to use set of tools for creating *Paths NC* and to perform simulation and verification. Unigraphics NX CAM provides effective treatment of any shapes of the profiles of air holes. It provides many opportunities for treatment. Its modular design provides scalability and adaptation to specific customer needs. [1] The use of *Unigraphics NX CAM* can be divided into three main areas: engineering, manufacturing tools (molds, dies and matrixes), and advanced manufacturing (mass production of aeronautical parts such as ribs, shoulder blades, compressor and turbine rotors and the mass production of cutting tools.) For the engineering industry is characterized by the following operations: drilling (which may be applicable module *Holemaking* automating programming drilling operations), planning the walls, flat pocket milling and profile, turning. The most important tools for the production functions are three axis machining strategies: coarse, levels in the "Z", rhymed the surface, the automatic processing of corners supplemented by elements such as the interpolation of *NURBS*, memorizing the shape of the object during the processing and packaging machines for cutting wire. In advanced manufacturing, the following functions: verse surface with a variable axis of tools, milling sequence (the end of the tool is based on the surface of the side and is tangential to the surface of the driver), machining a pocket or a sloping wall profiles. The choice of *Unigraphics NX CAM* meets all the requirements of producers in need of specialist CAM software. *Unigraphics NX CAM* is effective, increasing productivity tool, both as part of a uniform system of CAD / CAM and in an environment where data may come from different CAD systems. The whole group of translators (STEP, IGES, DXF / DWG) fitted to the position of *Unigraphics NX CAM* and portability through the format of the *Parasolid* geometry (over 1 million jobs working on the basis of this kernel system) makes the geometry of the various CAD systems can be easily transferred to *Unigraphics NX*. As a unified CAD / CAM system, *Unigraphics NX* provides full associativity between geometry and the generated tool paths. The ability to automatically upgrade path after changing geometry, use of templates of typical operation (for the production profile) and other facilitation work with the system makes *Unigraphics NX* meets all the requirements of even the most demanding users. [1] A characteristic feature of *Unigraphics NX CAM* is the use of well programmed sequence of operation or operations as a model (template) to program the next operation, the new geometry. The pattern is transferred to the tool, a machining, motion In / Out tool material, machine parameters (feed, speed). Operations can be grouped in sequence (with a module for working in 3 axes are supplied ready-made templates for the processing of car body dies and dies molds). This means that, for example, a manufacturer of injection molds may include experience and technological expertise of its best specialists in the form of templates, which will then be used in any work.

Created forms need only read the set, template, upload and start making geometry. Guide to lead you through the manufacturing process forms can be edited and refined that even novice users will be able to take advantage of the system and meet the demands full and repeated use [1].

Manufacturing interface module does not deviate much from the interface module *Modeling*. There are new toolbars such as the *Create Manufacturing, Manufacturing Operations and Manufacturing Objects. Navigation* bar expands the *Operation Navigator.* Operation Navigator is a tool for managing of the operations and parameters for the active part. Navigator provides an overview of operations in four basic views: Program: Order - Order Processing, Machine Tool - Machine, of Geometry - Geometry and Method - method. *Create Manufacturing* bar operations allows to create parent groups (program, tool geometry and the method) and their modification.

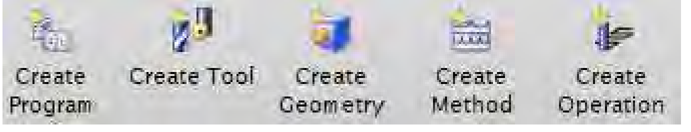


Fig. 5. View of Create Manufacturing bar. Manufacturing

Operations bar allows generate and verify tool paths, the creation of NC code and documentation.

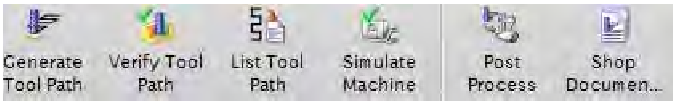


Figure 6. View of Manufacturing Operations bar

Manufacturing Objects lets view and record the shape of the workpiece after the machining step.

Figure 7. View of Manufacturing Objects ar

Task processing creating

First step is to create a new file in the *Manufacturing* module, and choose of machine tools the environment.

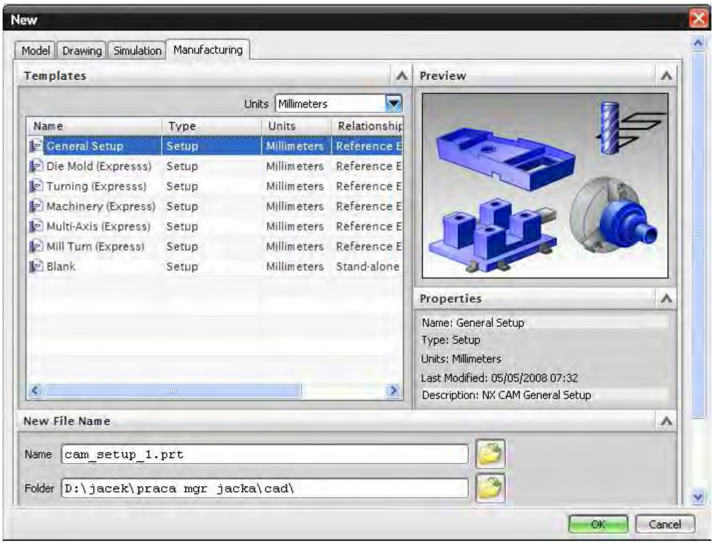
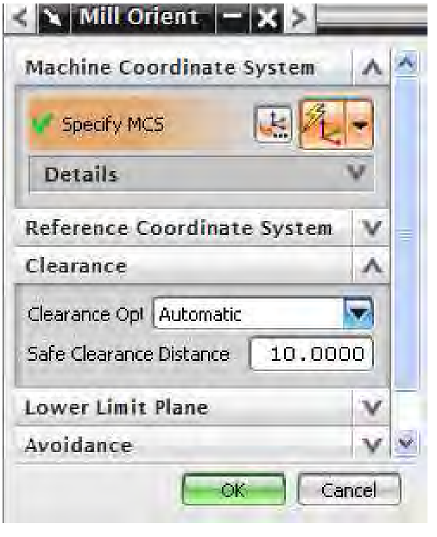


Fig. 8. Choice of machine environment

The next step is to set the machine datum. MCS in our case is in the axis of the bottle according to the spindle axis. Machine frame of reference can be set by the WCS. To do this, change the view before Operation Navigator on Geometry



and edit an existing MCS.

Fig. 9. Editing MCS

To make group settings *Workpiece* tool geometry should choose a section - part  - that is, the geometry of the workpiece, Blank  - and a blank check  - geometry avoided. In the dialog box geometry is also possible to make allowance - offset - which may be a material inaccuracy. In the description of section, select the material of part. Thanks in advance, defining the geometry, they eliminate the need for identifying specific geometry of the creation of individual operations.

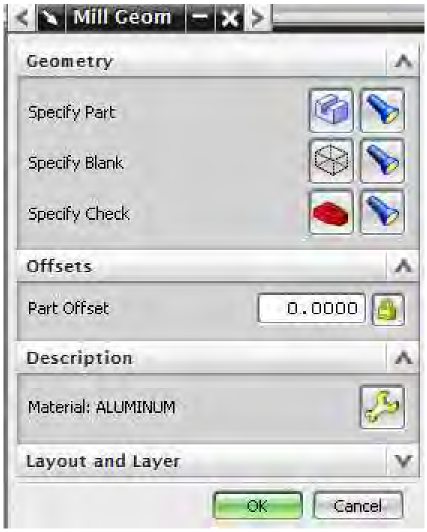


Fig. 10. Dialog defining geometry

Roughing - rough milling of matrix bottom bottle

To be able to join the milling operation must first create a tool that will be used for this. For this purpose, select Edit Tool icon  and proceed to define the socket -  - Pocket_01 as Type select - mill contour and define the type of cutter - Ball_10 (diameter spherical cutter 10).

Fig. 11. Dialog creation tools

Upon approval, select Ok. This brings us to another window in which we will define the specific parameters of cutter (diameter, length of the working tool and cutter material.)

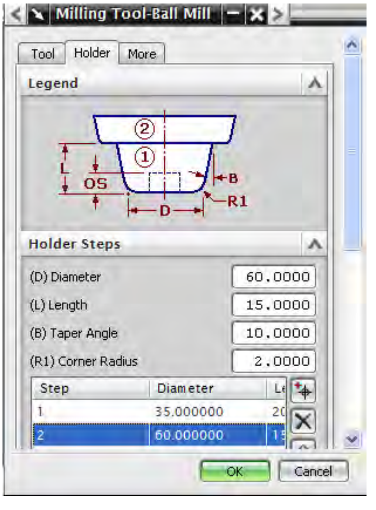


Fig. 12. Tab. *Holder*

Modeled together with the cutter holder presents fig.13.

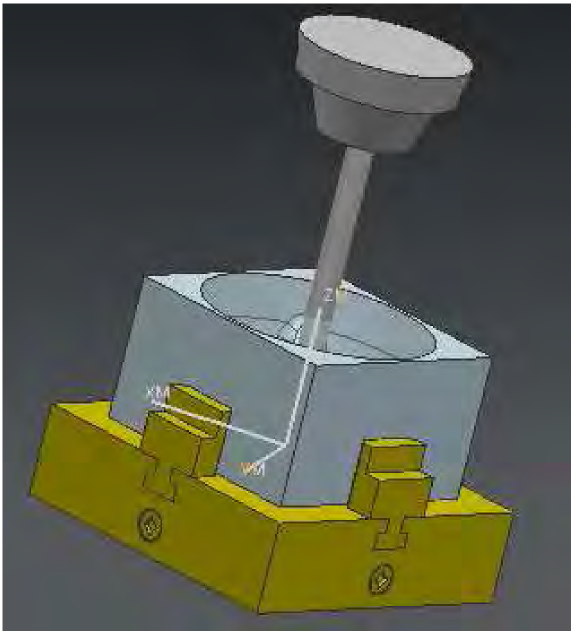


Fig. 13. Views modeled with a cutter holder

Summary

The paper presents the capabilities of Unigraphics NX6 an example matrix for blowing bottles. Intuitive interface and a multitude of features to help in a logical way to create a variety of designs, which are usually the most difficult part in modeling the plastic bottle. In the CAM program itself defines the parameters of machining, and the generated path is automatically modified when you change the geometry.

W pracy zaprezentowano możliwości programu Unigraphics NX6 na przykładzie matrycy do wydmuchiwania butelek. Intuicyjny interfejs oraz mnogość funkcji pozwalających w logiczny sposób tworzyć różnorodne wzory, które stanowią zazwyczaj najtrudniejszą część w modelowaniu butelki plastikowej. W module CAM program sam definiuje parametry obrabiania, a wygenerowana ścieżka zostaje automatycznie modyfikowana po zmianie geometrii.

References

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3) http://pl.wikipedia.org/wiki/Unigraphics

Abstract

CAD / CAM systems are used in almost every industry productive capacity and improving production and increasing business productivity while reducing costs. In terms of economic and marketing experiences that change primarily a consumer who spends less funds by purchasing a high quality product. If the company is capable of producing the product in the short term, it means that she uses for this purpose less effort, so the price of the product will be relatively smaller. The paper presents the possibility of a modern program category CAD / CAM in the treatment of numerical simulation matrixes. This is an issue that the current industrial development is very important significance.

Key words: simulation, CAD / CAM software, the matrix, manufacturing.

MARIUSZ WALCZAK

WEAR CHARACTERISTIC OF SOL-GEL COATINGS ON TITANIUM AND Ti6Al4VELI TITANIUM ALLOY

Introduction

In the group of metallic biomaterials, titanium and its alloys, partly due to advantageous properties such as: corrosion resistance, low density, good mechanical properties and biocompatibility are a base for applications in the medical and dental fields [1-3].

In recent years many studies on the methods of obtaining intermediate layers on titanium have been carried out. Sol-gel processing has been intensely studied as an alternative method for preparing ceramic coatings for a wide variety of applications including biomaterials. These coatings are characterised by low thickness, high homogeneity and mechanical and chemical stability [2,3]. It is known that the tribological or mechanical properties of the ceramics coated on the titanium substrate will influence their function, lifetime, and productivity. Unfortunately, less knowledge is available about the tribological and mechanical properties of sol-gel coatings.

In this study, sol-gel coatings (SiO_2, SiO_2-TiO_2) of double layers were deposited on titanium substrates. Microstructure of sol-gel layers, bonding with the titanium and wear resistance are investigated. The wear behaviors of the coatings have been investigated. The friction and wear mechanisms are discussed in detail.

Properties and structures of titanium and titanium alloys

Titanium was once considered a rare metal, but nowadays it is one of the most important metals in the industry. Chemically, titanium is one of the transition elements in group IV and period 4 of Mendeleef's periodic table. It has an atomic number of 22 and an atomic weight of 47.9. The incomplete shell enables titanium to form solid solutions with most substitution elements having a size factor within ±20%. In the elemental form, titanium has a high melting point (1668 °C) and possesses a hexagonal closely packed crystal structure (hcp) a up to a temperature of 882.5 °C. Titanium transforms into a body centered cubic structure (bcc) b above this temperature [4,5].

Titanium alloys may be classified as a, near-α, α + β, metastable β, or stable β depending upon the room temperature microstructure [4,6]. In this regard, alloying elements for titanium fall into three categories [4]:

(1) α-stabilizers, such as Al, O, N, C;
(2) β -stabilizers, such as Mo, V, Nb, Ta (isomorphous), Fe, W, Cr, Si, Co, Mn, H (eutectoid);
(3) neutrals, such as Zr and Sn.

The α and near-α titanium alloys exhibit superior corrosion resistance but have limited low temperature strength. In contrast, the α + β alloys exhibit higher strength due to the presence of both the a and b phases. The properties of the materials depend on the composition, relative proportions of the α and β phases, thermal treatment, and thermo–mechanical processing conditions. The β alloys also offer the unique characteristic of low elastic modulus and superior corrosion resistance [4,7,8]. In the picture fig. 1 very popular microstructure of Ti commercially pure and Ti-6Al-4V alloy were presented.

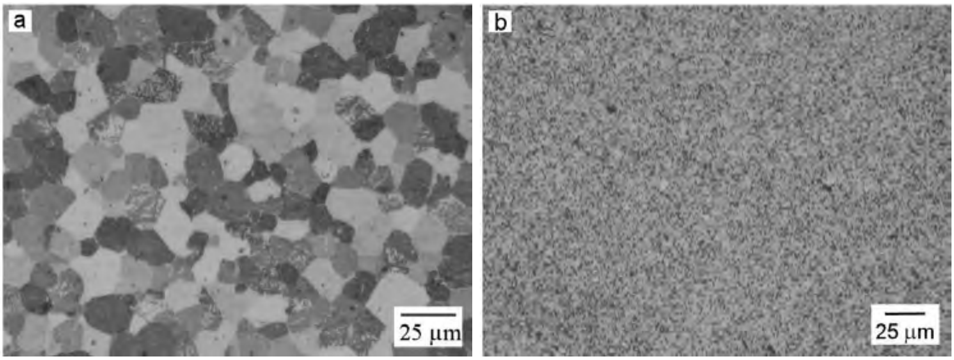

Fig. 1. Microstructure of materials: (a) Ti commercially pure (ASTM - grade 2) – α microstructure and (b) Ti6Al4V alloy (ASTM – grade 5) – α + β microstructure

The mechanical properties of titanium and its alloys are summarized in table I. . Titanium is very promising in orthopedics due to its high specific strength and low elastic modulus. However, titanium has low wear and abrasion resistance because of its low hardness.

TABLE I. Mechanical properties of a typical titanium and its alloys [9]

Grade	**Tensile strength Rm=MPa**	**0,2% yield strength Rp 0.2=MPa**	**Elongation A5=% min.**
Grade 1	min. 240	170-310	24
Grade 2	min. 345	275-450	20
Grade 3	min. 450	380-550	18
Grade 4	min. 550	483-655	15
Grade 5 6Al-4V	min. 895	Min. 825	10
Grade 7 + Pd	min. 345	275-450	20
Grade 11 +Pd	min. 240	170-310	24

Corrosion resistance

The excellent corrosion resistance of titanium alloys results from the formation of very stable, continuous, highly adherent, and protective oxide films on metal surfaces. Because titanium metal is highly reactive and has an extremely high affinity for oxygen, these beneficial surface oxide films form spontaneously and instantly when fresh metal surfaces are exposed to air and moisture. In fact, a damaged oxide film can generally reheat itself instantaneously if at least traces of oxygen or water are present in the environment. However, anhydrous conditions in the absence of a source of oxygen may result in titanium corrosion, because the protective film may not be regenerated if damaged [10].

The nature, composition, and thickness of the protective surface oxides that form on titanium alloys depend on environmental conditions. In most aqueous environments, the oxide is typically TiO_2, but may consist of mixtures of other titanium oxides, including TiO_2, Ti_2O_3 and TiO.

High-temperature oxidation tends to promote the formation of the chemically resistant, highly crystalline form of TiO, known as rutile, whereas lower temperatures often generate the more amorphous form of TiO, anatase, or a mixture of rutile and anatase [4,10].

According to literature data [11,12], spontaneous (after time already 10^{-9}s) form coating titanium oxide on titanium substrate about 1,5 ÷ 5 nm thickness.

Although these naturally formed films are typically less than 10 nm thick and are invisible to the eye, the TiO; oxide is highly chemically resistant and is attacked by very few substances, including hot, concentrated HCl, H_2SO_4, NaOH and (most notably) HF. This thin surface oxide is also a highly effective barrier to hydrogen [4,10].

The methods of expanding the corrosion resistance of titanium into reducing environments include [10]:

- Increasing the surface oxide film thickness by anodizing or thermal oxidation;
- Anodic polarizing the alloy (anodic protection) by impressed anodic current or galvanic coupling with a more noble metal in order to maintain the surface oxide film;
- Applying precious metal (or certain metal oxides) surface coatings;
- Alloying titanium with certain elements;
- Adding oxidizing species (inhibitors) to the reducing environment to permit oxide film stabilization.

Titanium alloys, like other metals, are subject to corrosion in certain environments. The primary forms of corrosion that have been observed on these alloys include general corrosion, crevice corrosion, anodic pitting, hydrogen damage, and stress-corrosion cracking.

In any contemplated application of titanium, its susceptibility to degradation by any of these forms of corrosion should be considered. In order to understand the advantages and limitations of titanium alloys, each of these forms of corrosion will be explained. Although they are not common limitations to titanium alloy performance, galvanic corrosion, corrosion fatigue, and erosion-corrosion are included in the interest of completeness [10].

Corrosion is characterized by a relatively uniform attack over the exposed surface of the metal. At times, general corrosion in aqueous media may take the form of mottled, severely roughened metal surfaces that resemble localized attack. This often results from variations in the corrosion rates of localized surface patches due to localized masking of metal surfaces by process scales, corrosion products, or gas bubbles; such localized masking can prevent true uniform surface attack.

Titanium alloys may be subject to localized attack in tight crevices exposed to hot (>70 ^{o}C) chloride, bromide, iodide, fluoride, or sulfate-containing solutions. Crevices can stem from adhering process stream deposits or scales, metal-to-metal joints (for example, poor weld joint design or tube-to-tubesheet joints), and gasket-to-metal flange and other seal joints [4,10].

Pitting is defined as localized corrosion attack occurring on openly exposed metal surfaces in the absence of any apparent crevices. This pitting occurs when the potential of the metal exceeds the anodic breakdown potential of the metal oxide film in a given environment. When the anodic breakdown potential of the metal is equal to or less than the corrosion potential under a given set of conditions, spontaneous pitting can be expected.

Titanium alloys are widely used in hydrogen containing environments and under conditions in which galvanic couples or cathodic charging causes hydrogen to be evolved on metal surfaces. Although excellent performance is revealed for these alloys in most cases, hydrogen embitterment has been observed.

The surface oxide film of titanium is a highly effective barrier to hydrogen penetration. Traces of moisture or oxygen in hydrogen-containing environments very effectively maintain this protective film, thus avoiding or limiting hydrogen uptake. On the other hand, anhydrous hydrogen gas atmospheres may lead to absorption, particularly as temperatures and pressures increase.

Stress-corrosion cracking is a fracture, or cracking, phenomenon caused by the combined action of tensile stress, a susceptible alloy, and a corrosive environment. The metal normally shows no evidence of general corrosion attack, although slight localized attack in the form of pitting may be visible. Usually, only specific combinations of metallurgical and environmental conditions cause stress-corrosion cracking. This is important because it is often possible to eliminate or reduce stress-corrosion cracking sensitivity by modifying either the metallurgical characteristics of the metal or the makeup of the environment.

Another important characteristic of stress-corrosion cracking is the requirement that tensile stress is present. These stresses may be provided by cold work, residual stresses from fabrication, or externally applied loads.

The key to understanding stress-corrosion cracking of titanium alloys is the observation that no apparent corrosion, either uniform or localized, usually precedes the cracking process. As a result, it can sometimes be difficult to initiate cracking in laboratory tests by using conventional test techniques.

It is also important to distinguish between the two classes of titanium alloys. The first class, which includes ASTM grades 1, 2, 7, 11 and 12, is immune to stress-corrosion cracking except in a few specific environments. These specific environments include anhydrous methanol/halide solutions, nitrogen tetroxide (N_2O_4) and liquid or solid cadmium. The second class of titanium alloys, including the aerospace titanium alloys, has been found to be susceptible to several additional environments, most notably aqueous chloride solutions [4,5,10].

The coupling of titanium with dissimilar metals usually does not accelerate the corrosion of titanium. The exception is in strongly reducing environments in which titanium is severely corroding and not readily oxidizable. In this uncommon situation, accelerated corrosion may occur when titanium is coupled to more noble metals. In its normal passive condition, materials that exhibit more noble corrosion potentials beneficially influence titanium.

The general corrosion resistance of titanium can be improved or expanded by one or a combination of the following strategies: alloying, inhibitor additions to the environment, precious metal surface treatments, thermal oxidation and anodic protection.

Perhaps the most effective and preferred means of extending resistance to general corrosion in reducing environments has been by alloying titanium with certain elements. Beneficial alloying elements include precious metals (>0.05 wt% Pd), nickel (>= 0.5 wt%), and/or molybdenum (>= 4 wt%). These additions facilitate cathodic depolarization by providing sites of low hydrogen overvoltage, which shifts alloy potential in the noble direction where oxide film passivation is possible. Relatively small concentrations of certain precious metals (of the order of 0.1 wt%) are sufficient to expand significantly the corrosion resistance of titanium in reducing acid media [4,10].

These beneficial alloying additions have been incorporated into several commercially available titanium alloys, including the titanium-palladium alloys (grades 7 and 11), Ti-0.3Mo-0.8Ni (grade 12), Ti-3Al-8V-6Cr-4Zr-4Mo, Ti-15Mo-5Zr, and Ti-6Al-2Sn-4Zr-6Mo. These alloys all offer expanded application into hotter and/or stronger HCl, H_2SO_4, H_3PO_4, and other reducing acids as compared to unalloyed titanium. The high-molybdenum alloys offer a unique combination of high strength, low density, and superior corrosion resistance [10].

Experimental procedure

Commercially pure titanium (ASTM-grade 2) and Ti6Al4VELI alloy (ASTM-grade 5) were used. Ti (cp) was forged and annealed. Titanium alloy was hot-rolled and solution treated. Table II shows the chemical compositions of these materials.

TABLE II. The chemical compositions of Ti (cp) and Ti6Al4V alloy (wt.%)

	Fe max	O max	N max	C max	H max	Al	V	**Ti**
Ti (cp)	0.3	0.25	0,03	0.08	0.015	—	—	bal.
Ti6Al4VELI	0.25	0.13	0.05	0.08	0.015	5.5-6.75	3.5-4.5	bal.

SiO_2 and SiO_2-TiO_2 on titanium coatings were deposited using sol-gel method. Silica sol was prepared by hydrolysis of tetraethoxysilane ($Si(OC_2H_5)_4$; abbreviated as TEOS) diluted in ethanol with addition of HCl as a catalyst. Titania-silica sol was prepared by hydrolysis of titanium propoxide $Ti(OC_3H_7)_4$ and TEOS with addition of HCl as a catalyst.

The deposition of layers consisted of withdrawing the metal discs from sol solution with constant speed of 3.3 mm/s. Thickness of the deposit was controlled by multiple dipping. After the completion of deposition, the as-deposited coatings were carefully dried and annealed in 550°C an argon atmosphere. The heating removed water and residual organic substances, densified the layer and increased its extent of bonding with the substrate.

The wear resistance of the sol-gel coatings and of dental ceramics were determined using a pin-on-disc method. The schematic diagram of the tester is shown in Fig. 2. The test apparatus consisted of a 0.5 mm diameter WC-6%Co ball. A load (normal force) of 0.29 N was applied on the ball for layers sol-gel. Whereas load 0.78 N was applied for wear test of dental porcelain. The ball was rubbing against the sample fixed on a rotating disc. The samples were in the form of discs of about 25 mm diameter and 0.5 ÷ 0.8 mm thickness. During wear tests of coatings sol-gel, the sliding speeds between the rubbing surface were from 37 mm/s to 53 mm/s. In case of dental ceramics sliding velocity 53 mm/s was used. The tests were performed at 150, 300 and 600 cycles for sol-gel coatings. All wear experiments were conducted under atmospheric humidity conditions ranging between 29 and 34% at the room temperature (about 25°C). The wear test were evaluated from the cross-sectional profiles of the wear tracks measured by means of a Taylor Hobson Profilometer. The microstructure of coatings, and wear after pin–on-disc test, were studied using a scanning electron microscope LEO 1430VP with EDX-Roentec.

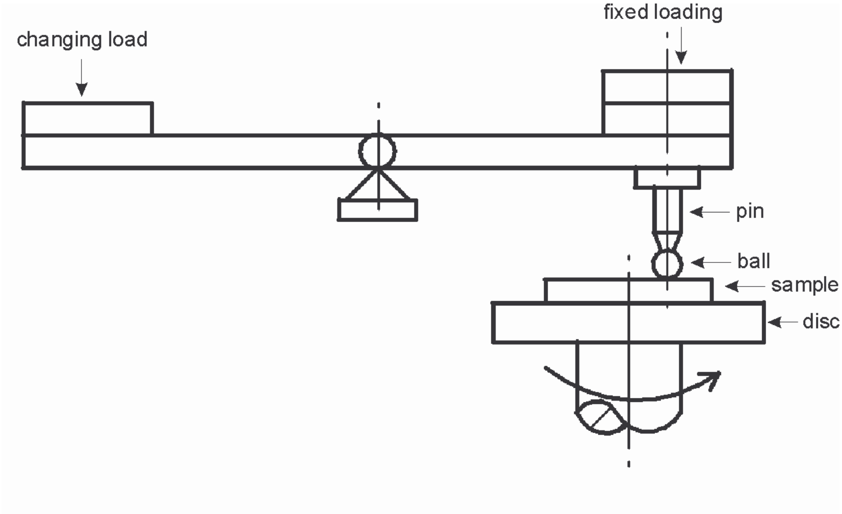

Fig. 2. The schematic diagram of pin-on-disc method using by test

Results and discussion

The microstructures of the SiO_2 and SiO_2-TiO_2 coatings on titanium are presented in Fig. 3. The SiO_2 and SiO_2-TiO_2 coatings are compact and chemically homogeneous. In the microstructure of SiO_2 coating, numerous microcracks were observed. In the SiO_2-TiO_2 coating was obtain the composite structure of SiO_2 particles in the TiO_2 matrix. The thickness of the ceramic coatings were about 3-5 µm.

a) b)

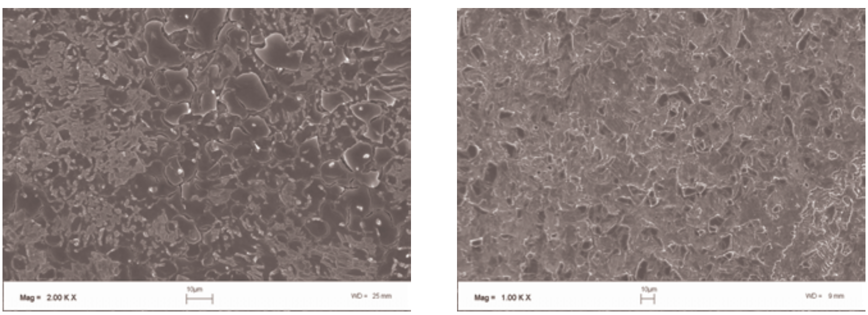

Fig. 3. Microstructure of intermediate coatings on titanium: (a) SiO_2 and (b) SiO_2-TiO_2

In both cases bonding between coating and metal is quite satisfactory. In the microstructure of SiO_2 coating numerous cracks were observed. These cracks are a result of the influence of high temperature of soaking during the sol-gel process. However, the cracks do go deep into the SiO_2 coatings and do not influence their mechanical and physical properties. According to Milella et al. [13], cracks formed due to shrinkage occurring during the thermal process can supply points of "mechanical interlocking" to promote osteintegration. Guillén et al. [14] proposed that the formation of the cracks is affected by the number and thickness of deposited layers. During the production of several layers with each heat treatment the mechanical stresses are accumulated.

Results of pin-on-disc testing are summarized in Fig. 4. A measure of wear of coatings is the transverse field section of wiping trace on the sample.

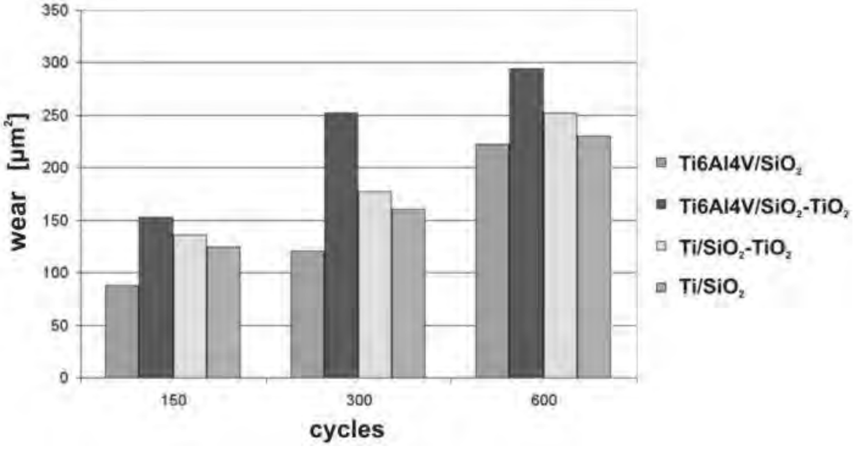

Fig. 4. Wear measurements of the coatings with numbers of cycles

Figure 4 shows that the wear of SiO_2 coatings is smaller than that of SiO_2-TiO_2 coatings. Such a dependence was observed in all cycles. In the case of SiO_2 coatings the test shows that the total layers rupture occurs near 600 cycles. During this trial the ball begins to wear off titanium. However, in the case of SiO_2-TiO_2 coating almost complete rupture of the layer occurs already near 300 cycles. The difference in wear is associated with differences in the microstructure of the layers and their roughness. Coating about higher roughness more wear, that is SiO_2-TiO_2 ($R_a = 0.82$ μm). Whereas SiO_2 layers had roughness $R_a = 0.63$ μm. The phase SiO_2 is considerably harder from phase TiO_2 and more resistant on wear.

The SEM analysis of wear tracks showed that the rupture of layers occurs by the detachment of coating fragments from the sites of higher crack concentration. This feature is clearly seen in Fig. 5.

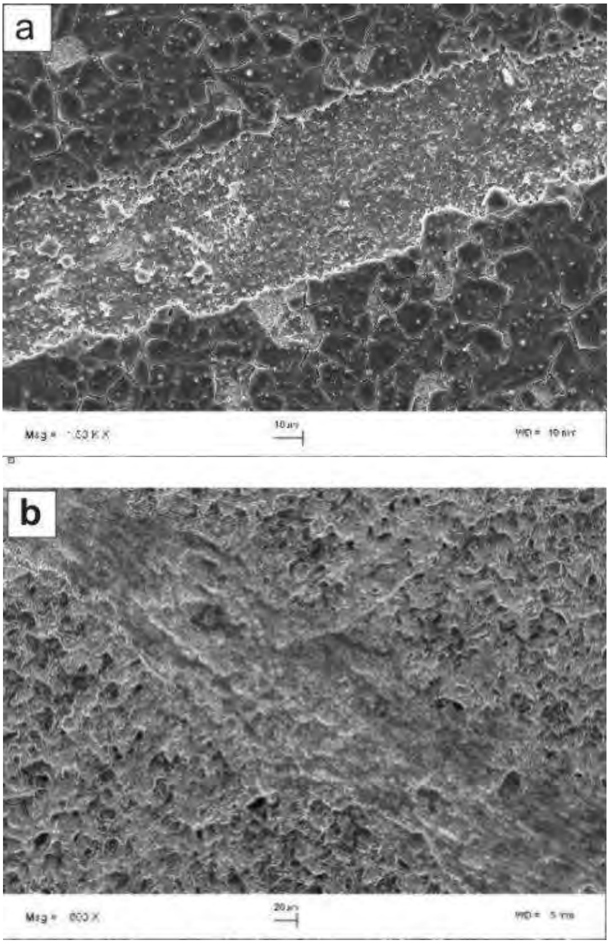

Fig. 5. Worn surfaces of: (a) SiO_2 coatings and (b) SiO_2-TiO_2 coatings - after 300 cycles

In the initial wear stage shear of the highest peaks of roughness is observed (fig 5.). The behaviour of this wear is similar for both types of coatings. The visible sites of torn out fragments are in the vicinity of the traces of the wear.

This type of behaviour is typical for bioceramics [15], of brittle material with high yield strength but low fracture toughness (such as bioceramics sol-gel coatings). The damage zone beneath the indenter is basically elastic and a pin crack forms near the perimeter of the indenter. However, until now there is no published work on the nature of wear of SiO_2 and SiO_2-TiO_2 coatings deposited by using sol-gel method on titanium

The coefficient of friction for coating SiO_2 on titanium was observed average 0.6. Whereas for coating SiO_2-TiO_2 on titanium was observed average 0.3.

According to the author study and literature data [3,16], SiO_2 and SiO_2-TiO_2 coatings manufactured by sol-gel method show diffusive character, which has a positive influence on the adhesion to titanium substrate.

Summary

The process of synthesis of coatings using sol-gel methods allows to obtain coatings with attractive physical properties and a wide range of applications. SiO_2-TiO_2 and SiO_2 coating are characterised by low thickness and high structural homogeneity. The wear of SiO_2 coating was smaller than of TiO_2-SiO_2 coating. Whereas the coefficient of friction for coating SiO_2 was larger than of TiO_2-SiO_2 coating. The wear and coefficient of friction was dependent on the surface topography (roughness) and the composite structure of SiO_2-TiO_2 coating and amorphous of SiO_2 coating.

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Wear characteristics of sol-gel coatings on titanium and Ti6Al4VELI titanium alloy

Abstract

The paper presents the study of SiO_2 and SiO_2-TiO_2 sol-gel coatings on titanium and Ti6Al4VELI titanium alloy. Surface microstructures and wear behaviour by pin-on-disc method of the ceramic coatings were investigated. The analysis revealed: (1) a compact, homogenous SiO_2 and SiO_2-TiO_2 coating, and (2) that pin-on-disc test showed good adhesion of ceramic sol-gel coatings to base metal, and (3) that SiO_2 coatings shows high wear resistance.

Key words: titanium, titanium alloys, sol-gel coating, wear test

Charakterystyka zużycia powłok zol-żel na tytanie i stopie tytanu Ti6Al4VELI

Streszczenie

W artykule przedstawiono badania powłok zol-żel SiO_2 i SiO_2-TiO_2 na tytanie i stopie tytanu Ti6Al4VELI. Analizowano strukturę warstwy wierzchniej przed i po teście zużycia metodą pin-on-disc. Analiza ujawniła: (1) jednorodność chemiczną powłoki SiO_2 i SiO_2-TiO_2, (2) testy pin-no-disc wykazują dobrą przyczepność do metalowego podłoża, (3) porcelana dentystyczna na warstwach SiO_2 i TiO_2 wykazuje dużą odporność na zużycie.

Słowa kluczowe: tytan, stopy tytanu, powłoki zol-żel, test zużycia

Wear characteristics of sol-gel coatings on titanium and Ti6Al4VELI titanium alloy

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JACEK DOMIŃCZUK

APPLICATION OF GLUING TECHNOLOGY FOR THREAD JOINT PROTECTION

Introduction

The technology of gluing plays very important role in the development of modern constructions. In many cases it is used as an alternative for applied so far methods of joining, sealing up or the regeneration of the part of machines. Moreover gluing creates new possibilities in whole range of process of joining materials of various physical and geometrical characteristics and also allows reducing dimensions of connected elements thanks to reducing their construction [1, 2, 3]. Glues are also wide used in repairs when using the process of regeneration of parts their costs of manufacturing are significantly decreased.

As research showed the endurance of glue connections is very complicated problem. Number of constructional and technological factors influences it [4, 5, 6].

Thanks to application of set of methods for forecasting the endurance of glue connections more and more often gluing is used as the alternative technology of joining which creates new possibilities of developing products. This allows introducing changes in our surroundings. Gluing is also applicable for protecting thread joint which are widely used in mechanical engineering. Screw joints is currently the most important temporary fastening method in the construction of mechanical engineering, assembly and maintenance [7].

The two main causes for the failure of a threaded assembly are: relaxation of tension, and self-loosening.

A threaded assembly 'relaxes' when a permanent change in the length of the bolt occurs in the direction of its axis, or the substrate itself relaxes as in gasketed surfaces. This reduces the bolt tension and thus also reduces the residual clamping force. Permanent changes in length may be produced by [8, 9]:

a. Settling - The rough faces of the contiguous parts (e.g. nut, washer) become smoother under the pressure of the bolt tension.
b. Creeping - The surface pressure on the bearing surface of the bolt or nut exceeds the compressive strength of the material of the stressed part.

Preventing self-loosening

If the elasticity of the assembly can be increased so that the expected amount of settling and creeping can be compensated for, then the drop in prestress force can largely be prevented. This is made possible by:

a. bolts with a high l/d ratio (I = shaft length, d = shaft diameter);

b. collar bolts and collar nuts as well as hardened and tempered washers which reduce surface pressure and thus settling on the bearing surfaces;
c. bolts and nuts with pressed-on spring head washer or concave bearing washer;
d. rigid conical spring washers or cup springs.

The threaded assembly loosens itself when sliding movements occur between the contact surfaces. These forced relative movements overcome the frictional forces in the threaded assembly and the self-locking effect of the thread is eliminated. Only when the clamping force is great enough to prevent such movements can moment M_L be overcome to loosen the assembly [10].

$$M_L = F_V \cdot \frac{d_2}{2} \cdot \tan\rho + F_V = \mu_A \cdot r_A - F_V \cdot \frac{d_2}{2} \cdot \tan\varphi$$

Here, the following applies:
ML = self-loosening torque,
Fv = available prestress force,
d2 = pitch diameter of thread,
φ = helix angle of thread,
ρ = angle of friction of thread,
μA= coefficient of friction of bearing surfaces,
rA = lever arm of frictional force at the bearing surfaces.

If the binding force of the threaded assembly cannot prevent relative movements between the parts under stress, then the bolt makes a rocking movement: the flanks of the thread slide over one another and the bolt becomes almost frictionless. The loosening torque is then:

$$M_i = -F_V \cdot \frac{d_2}{2} \tan\varphi$$

This loosening moment M_i, which is only dependent on the prestress force, the pitch diameter and the helix angle of the thread, acts against the direction of tightening and causes the threaded assembly to loosen. Sliding movements between the contact surfaces can be caused by:

a. Dynamic load in the direction of the axis: A pulsating axial overload leads to a relative movement at the flanks of the thread.
b. Dynamic load at right angles to the direction of the axis: Bending different thermal expansion rates of the materials, impacts or vibrations overcome the forces of friction between the bearing parts.

These measures can prevent uncontrolled loosening of correctly loaded bolts:

- The use of high-tensile bolts allows higher prestress forces which are high enough to prevent relative movements.

- Design which increases the l/d ratio (I = engagement length, d = bolt diameter) increases the elasticity of the assembly. (Historically, l/d ratio > 6 have been optimum).
- Friction can be increased by influencing the surface finish and structure on the bearing surfaces of the bolt and nut.
- By applying adhesive, the degree of freedom for lateral movements is eliminated due to the fact that the gaps are completely filled, and at the same time thread friction is increased by interfacial connection after the adhesive has cured [11, 12].
- By creating a positive connection (e.g. bodyfit bolts, welding spots), slip in the thread can be limited [13].

Threadlocking -Types and Methods

Threadlocking types and methods can be subdivided into three groups:
1. The settling method.
2. Loss prevention devices.
3. Self-loosening prevention devices.

The settling method increases the elasticity of the assembly and thus compensates for settling in the assembly. The prestressed force is thus largely retained and relaxation of the threaded assembly is prevented. The settling method, however, cannot prevent self-loosening of the threaded assembly if relative movements between the stressed parts are forced. Examples of the settling method are: conical spring washers, cup springs of high rigidity. The locking effect of other elements, for example, spring washers, elastic washers, toothed and fan-type washers, are inadequate. They are unsuitable for securing bolts of property 8.8 or higher [10, 13].

Loss prevention devices allow partial relaxation or loosening, but prevent the threaded assembly from falling apart. Examples: crown nuts, wire retainers, bolts with thread inserts made of metal or plastic. These techniques often avoid loss of the fixture but are ineffective in maintaining clamp load.

Self-loosening prevention devices prevent threaded assemblies from loosening themselves. These include:
- bolts and nuts with locking teeth
- ribbed flange bolts
- adhesives (fig. 1, 2).

Fig. 1. Example of using glue to protect screws in power transmittion system

Fig. 2. A lubricating nipple secured with an anaerobic threadlocking agent

Glue protection of threads

Devices to prevent self-loosening must meet the highest standards with respect to threadlocking. Manufactured has developed single-component liquid adhesives which completely fill the microscopic gaps between interfacing threads. They cure to a tough solid when they come into contact with metal in the absence of air. The adhesive creates an interracial connection — keying to the surface roughness to prevent any movement of the threads. The problem is thus solved where it arises: in the threads. This is why gluing are among the most effective means for locking fasteners [14].

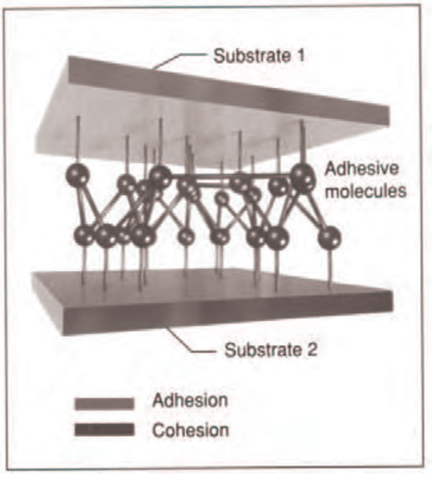

Fig. 3. The bonding forces in the adhesive joint

The endurance of every glued joint is qualified by adhesive and cohesive forces (fig.3). The cohesive force is measure of internal substances endurance. It depends from intermolecular strengths, their value and range of crosslinking. Adhesive force is measure of endurance of two substances bond, and spread of this force depends on the chemical structure of both substances and their physical properties. Adhesion is the bonding force at the contact surfaces of the materials. Physical forces of attraction and absorption, which together are described as "van der Waals forces," have the greatest significance in bonding. The range of these intermolecular forces is considerably lower if the adhesive material does not come in intimate contact with bonding sites due to the relative surface roughness of mechanically treated surfaces. This is why the adhesive must penetrate right into the surface roughness and wet the complete surface. The strength of the adhesive force thus depends on the penetration of the wetting (to adhesive the fullest intermolecular exchange) and, on the other hand, on the adhesive capacity of the surface. At a given surface tension of the adhesive, wetting depends on the surface energy of the substrate and the viscosity of the adhesive.

Wetting can also be reduced if surface contaminants are present. This causes in fact that the preparation of the surface of materials is so very important [9,15]. Endurance of the joint depends on this factor in the large measure.

Cohesion is the force prevailing between the molecules within an adhesive which keeps the material together. These forces include:

- intermolecular forces of attraction (van der Waals forces) and
- interlocking of the polymer molecules among themselves

In accordance with the rule that a chain is only as strong as its weakest link, the forces of adhesion and cohesion in a bonded joint should be about equal.

In glue connections the glue is hardened with the simultaneous creation of the adhesive bind and tightening the connection. Most adhesives are reactive polymers. They change from liquids to solids through various chemical polymerization reaction. Company has developed numerous adhesives with special curing properties for unique situations. It is possible to classify adhesives into the following groups on the basis of curing properties:

- anaerobic reaction,
- exposure to ultraviolet (UV) light (also secondary curing options),
- anionic reaction (cyanoacrylates),
- activation system (modified acrylics),
- moisture curing (silicones, urethanes).

Such connections operate well in the conditions of dynamic load as the vibration absorber, preventing corrosion, fretting and micro-displacements.

The bearing part of the surface also grows up. It remains above the level of 80%, what influences the endurance of the connection fundamentally.

Correct surface pretreatment is necessary for optimum bonding. Bond strength is determined to a great extent by the adhesion between the joint surfaces and the adhesive. It is important to understand that adhesive joints are stronger the more thoroughly the surfaces are cleaned (fig.4) Adhesion is improved by:

- removing unwanted surface films by degreasing or mechanical abrasion, and, if needed,
- building up new, active surface by coating with primers.

Large influence on the endurance of the glue connection has the condition of surface. The proper cleanness of the surface gained after chemical or mechanical preparation, and the proper roughness of the surface have large meaning. From results of own investigations (fig.5) conducted for steel St3 conclusion can be drawn, that the highest endurance of the connection is after the processing using tool number P120 what fits $R_a=6\div20$ μm. Such roughness can be also gained through turning or sand blasting.

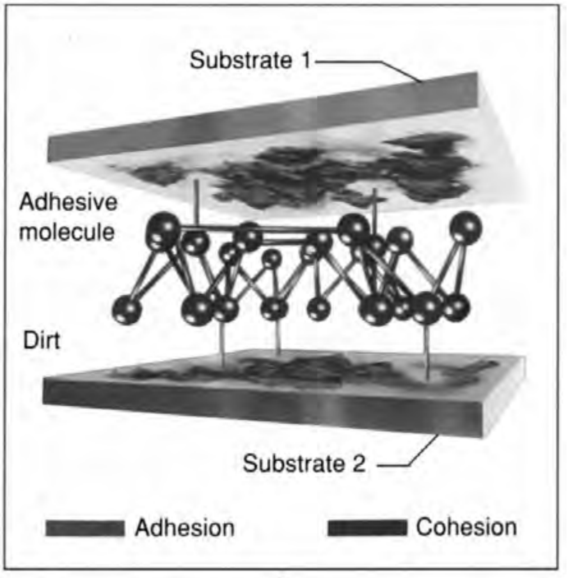

Fig. 4. Contamination on the surfaces of the substrates reduces adhesion

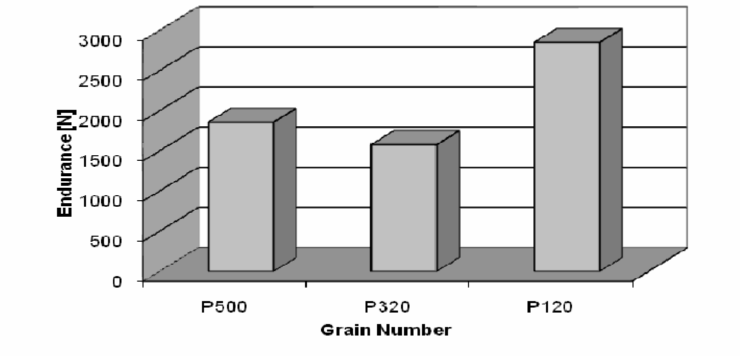

Fig. 5. Relationship between the endurance of glue connection and the condition of top layer

When using glues to protect thread joints it is important that the total length of the thread be wetted, and that there is no restriction to the curing of the adhesive. (Certain oils or cleaning systems can impede or even completely prevent the adhesives from curing by anaerobic reaction.)

The liquid adhesive may be applied by hand or with the help of special dispensing devices. Proper wetting of a thread is dependent on the following parameters: the size of the thread, the viscosity of the adhesive and the geometry of the parts. If the parts are of larger dimensions, then wetting both faces provides the necessary reliability for the adequate application of the adhesive. With blind hole threads, it is essential that the adhesive be applied to the bottom of the threaded hole. The quantity must be such that after assembly, the displaced adhesive should fill the whole length of the thread (fig.6).

Fig. 6. If a blind drilled hole is used as an "adhesive reservoir", the adhesive is generally prevented from being pressed out by compressed air when the parts are joined. Adhesive waste can be minimized in large parts with the use of rubber plugs in the holes. In the case of blind holes, applying adhesive to the stud will result in lower than desired strength due to lack of adhesive getting into the joint [10]

If hand application of adhesive is not desired on a continuous assembly line, or if dispensing units cannot be used, then bolts precoated with adhesive are an alternative. Microcapsules containing an active ingredient are pre-applied to the threads in a dry film adhesive coating. When the fastener is assembled, the capsules are crushed causing the chemical reaction (yielding locking strength). Self-loosening of the bolt is prevented. Precoated bolts are treated and stored as normal bulk material. This coating system uses water (in most cases) as the carrier agent, making it user-friendly (fig. 7).

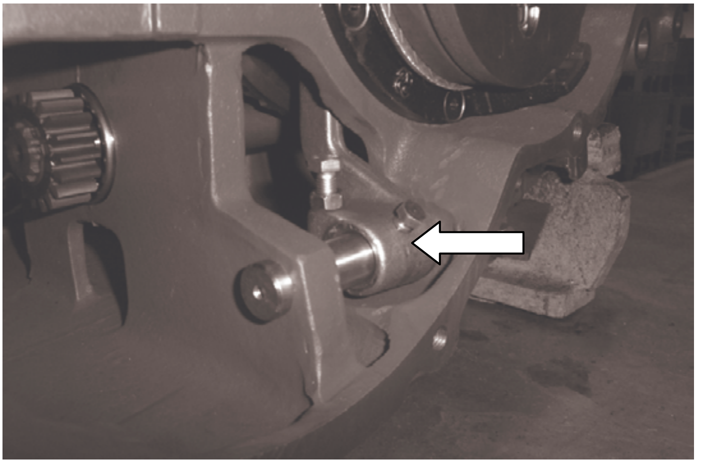

Fig. 7. An example of using pre-coating screw

A comparison of threadlocking methods

The best way to evaluate a threadlocked connection is to test its behavior under load cycles in a dynamic test machine. The lower the loss in bolt tension, the more reliable the assembly.

To determine clampload retention curves for various locking devices, a bolt test stand similar to the Junker machine [10] was used by the author.

The braced bolt is stressed vertically to the bolt axis by a displacement unit which is adjusted with a cam (fig.7).

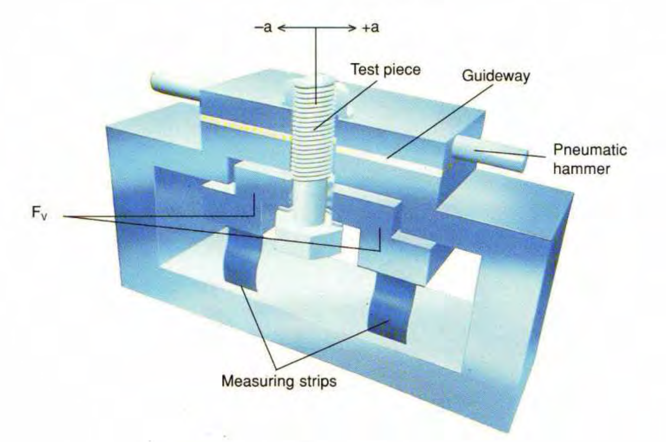

Fig. 8. Bolt test stand for comparative tests of threadlocking systems (transverse shock and vibration machine according to the Junker system). Pneumatic hammers force a relative movement of the stressed parts by a displacement of± a. At the same time the existing prestress force F_v is continuously measured for the number of load cycles. Characteristic clampload retention curves of various locking methods can be compared with the results [10]

As can be seen in figure 8, Loctite liquid threadlocker has the best clampload retention performance among those tested. Most mechanical methods fail this test. This does not mean that these methods are not useful up to a certain degree. However, when their functional operation is compared with their cost, they are difficult to justify. With the adhesive threadlocking system, there is no further effort or expense required for mechanical locking elements because "one size" fits all. Most threadlocking problems are thus solved in an economical way.

A similarly favorable load cycle performance is shown only by the surface-compacting ribbed flange bolt. Its disadvantages include: high costs, the relatively large amount of space required for flange-bearing surface, and the unavoidable damage to the surface of the braced parts around the bolt-bearing surface. Teeth on bolts with a saw-tooth flange penetrate the bearing surface of the braced material. Bearing surfaces of the head and the nut are damaged during loosening, limiting their possible applications. Parts with hardened surfaces cannot be reliably connected [10].

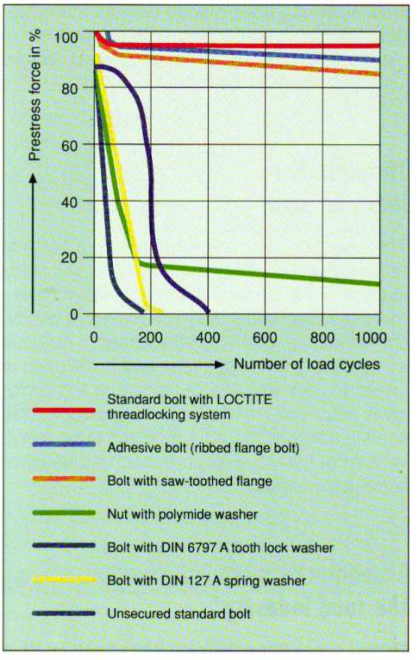

Fig. 9. The characteristic clamp-load retention performance of various threadlocking systems as tested on the bolt test stand [10]

Threadlockers guarantee more than functional reliability: the cured liquid which fills the voids in the threads not only prevents relative movement - it also seals the joint. Excellent chemical resistance allows threadlockers to be used as sealants with most gases and fluids used in industry. They also seal out moisture and corrosives which can cut the life of the assembly. This sealing effect allows through holes to be drilled instead of blind holes, an easier and cheaper assembly method.

Summary

The gluing technology allows to improve the quality of thread joints. Using it one can obtain connections resistant to loosening and leakproof in the same time what is essential in many applications. Due to glue use such connections are considerably more resistant on corrosion, therefore in such applications the use of threaded through holes is possible what considerably simplifies the manufacturing process. Glues must be selected (taking into consideration its properties) so that connection is easily separable – when periodical disassembly is required, or difficult to disassembly – often special tools or technology needs to be used then. The simplicity of realization is undoubtedly main advantage of applying the glue as the agent preventing loosening thread joints.

As it is not necessary to apply any special techniques of surface preparation neither to use screws different than normally used, the overall costs decrease when applying thread joints is evident. The application of this protection technology allows simplifying the assembly process, making it more automatable and increasing the efficiency of thread joints. Proprieties of glues described above explain using it on assembly lines more and more often.

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Wykorzystanie technologii klejenia do zabezpieczania połączeń gwintowych

Streszczenie

W artykule zaprezentowano możliwość wykorzystania technologii klejenia do zabezpieczania połączeń gwintowych przed odkręceniem. Przedstawiono główne problemy występujące w połączeniach gwintowych oraz sposoby przeciwdziałania zawodności tego typu połączeń. Jednym ze sposobów zabezpieczenia przed samoczynnym odkręceniem połączenia gwintowego jest klejenie przy wykorzystaniu klei ciekłych i półstałych. W artykule opisano sposób wykorzystania tego typu wzmocnienia połączenia. Podano przykłady aplikacji technologii klejenia jak i przedstawiono podstawowe czynniki na które należy zwrócić uwagę przy projektowaniu połączeń klejowych zabezpieczających przed odkręceniem.
Artykuł zawiera również porównanie efektywności różnych metod zabezpieczania przed odkręceniem.

Słowa kluczowe: połączenie śrubowe, zabezpieczenie, połączenia adhezyjne, montaż

Application of gluing technology for thread joint protection

Abstract

The possibility of utilization gluing technology to protecting thread joints from unscrewing was presented in the article. The main problems occurring in thread joints and ways of the counteracting failures of this connections type were introduced. Sticking using liquid or semi-solid glues is one of solutions to protect thread joint from self-unscrewing. The paper describes possibilities of using such strengthening of connection. Examples of application of gluing technology were shown as well as basic factors on which one should take notice when designing glue protection from unscrewing. The article contains also the comparison of the efficiency of the various methods of protecting against unscrewing.

Keywords: thread joint, protection, adhesive joint, assembly

Application of gluing technology for thread joint protection

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MARIAN MAREK JANCZAREK

SCIENTIFIC AND TECHNOLOGICAL DESCRIPTION OF HEAT AND MASS TRANSFER PROCESSES IN THERMAL TECHNICAL CHAMBERS

1. Introduction

The main purpose for fruit storage in central European climate is to provide products of high consumption quality during autumn, winter and spring. Financial inputs connected with the maintenance of the storage are obviously related with the final cost of apple or any other fruit. It is necessary to prolong storage period energetically efficiently to maintain affordable price of apple. Contemporary technological processes make possible to inhibit biochemical and physiological processes that lead to ripening or overripe fruit. The prolongation of storage period is mainly achieved by the storage of apple of pear in chambers that can maintain low temperature of fruit, i.e.: within the range between 0 ÷ +1.5^{o}C. Beside temperature conditions, it is necessary to provide the air of low oxygen and carbon dioxide contents and of high humidity and circulation in the interior of the cooling chamber. The differences among particular cases of thermal energy demand for storage depends mainly on different construction of cooling chambers. The construction can differ in materials and dimensions which results in different thermal resistance of external walls. Problems of thermal conductivity can be analyzed by many methods, for example: Laplace transformations method, Fourier transforms, etc. The paper presents two models: analog one and differential one. They can help to control heat processes during storage periods.

The presented new concept of thermal analysis is derived from periodic character of temperature changes in storage environment. The analytical approach seems appropriate to obtain established purposes i.e.: the description of temperature changes and heat transfer within the chamber walls and its gaseous environment. The storage parameters of apple range is the following: temperature 1 – 3^{0}C, oxygen (O_2) concentration 1,5 – 3%, carbon dioxide (CO_2) concentration 1-5%.

Observations of the ambient air temperature in Deblin and Lublin (and also in a large number of meteorological stations in all over the world, for example in Sophia - Anthipolis in France) showing, that the variations of the temperature from the heat by day to the cold by night and yearly changes from the cold of winter to the heat of summer may vary harmonically – figures 1. - 5. These variations of external temperature have influence upon the internal temperature, which depending upon the conductive heat transfer through walls of thermal technical spaces.

By the suitable construction of the enclosure walls composed of several slabs of different thickness and conductivities we can obtain phase angle displacement (when the time lag attains twelve hours it is the best situation), which reduce the amplitude of internal temperature inside buildings.

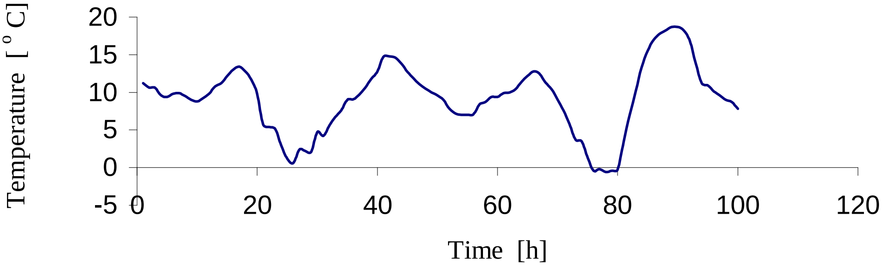

Fig. 1. Diagram of atmospherics temperature in the four days of April.

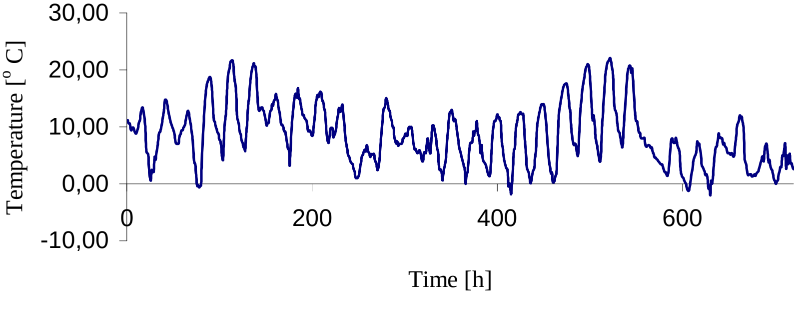

Fig. 2. Diagram of atmospherics temperature in the month of April.

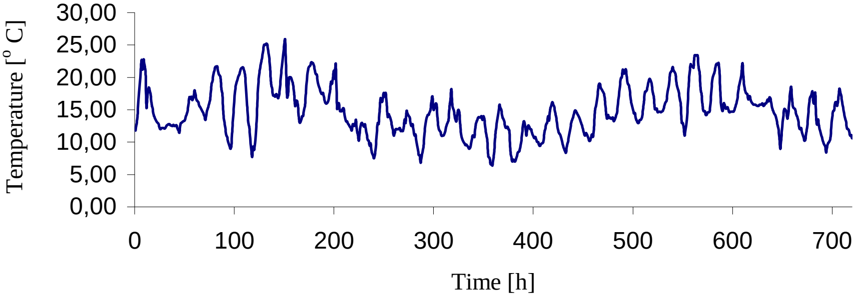

Fig. 3. Diagram of atmospherics temperature in the month of June.

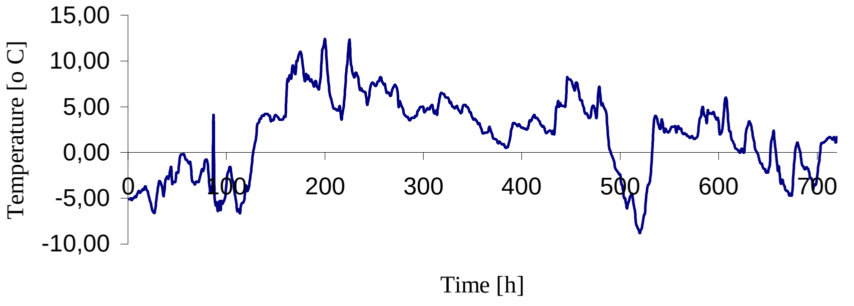

Fig. 4. Diagram of atmospherics temperature in the month of December.

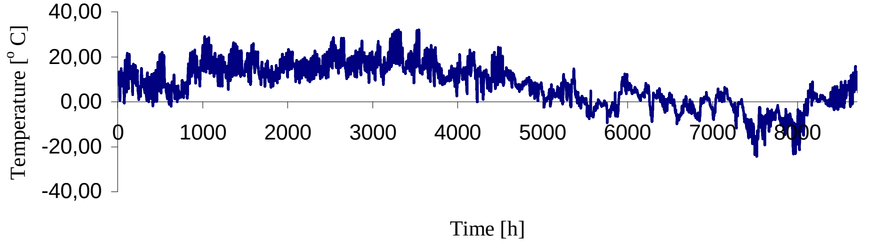

Fig. 5. Diagram of atmospherics temperature of the year 2007 in Lublin.

The paper presents also the physical model of heat transfer through chamber walls by means of a mathematical model suitable for sine waveform of internal temperature changes.

The analysis has been performed on the basis of original numerical algorithms. They take into consideration hourly changes of ambient temperature in the central – eastern region of Poland. The accepted methodology of performance takes advantage of temperature dynamics which is necessary to solve physical and mathematical problems related to heat transfer processes occurring in chambers.

2. Models of heat transfer through wall

The purpose of this paper is to describe the design of control systems of cooling and air conditioning systems in storage spaces. For a control systems its necessary to use only three elements: sensor, controller and controlled device. The main of those elements is temperature sensor which shows the picture of thermal decomposition in cold store. The very important are also devices, which provide control of humidity and cyclic potential motion of air in space.

It must be noted, that all the control actions depend mainly on measurement of a controlled variable. It is, therefore, necessary to analyze very carefully what is actually being measured, how it may vary with time and which degree of accuracy is necessary in the measurement. Mostly, the temperature of the surfaces on which the sensors are mounted is different from the air temperature.

Conduction take place when a temperature gradient exists in a solid (or stationary fluid) medium. Energy is transferred from the more energetic to the less energetic molecules when neighboring molecules collide. Conductive heat flow occur in the direction of decreasing temperature because higher temperature is associated with higher molecular energy. The equation used to express heat transfer by conduction is known as Fourier's Law. The article presents the physical model of heat transfer through chamber walls by means of a mathematical model suitable for sine waveform of internal temperature changes.

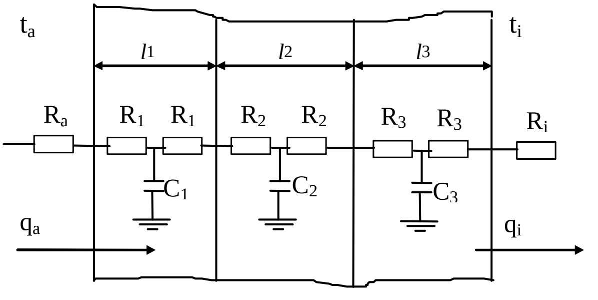

Fig. 6. Model of wall composed of three layers in electrical analogy

From it we can get matrix notation (eventually for n – layers of wall) and the final result of this calculation is a pair of linear relations between the temperature and fluxes at the two surfaces of the composite slabs.

$$[\Delta t_i(p), \Delta q_i(p)] = [\Delta t_a(p); \Delta q_a(p)] \begin{bmatrix} 1 & 0 \\ -R_1 & 1 \end{bmatrix} \begin{bmatrix} 1 & -pC_1 \\ 0 & 1 \end{bmatrix} \ldots\ldots \begin{bmatrix} 1 & -pC_n \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ -R_{n+1} & 1 \end{bmatrix} \quad (1)$$

The relation is precisely analogous to Ohm's law for the steady flow of electric current: the flux corresponds to the electric current, and the drop of temperature to the drop of potential. Thus R may be called the thermal resistance of the slab. Next suppose we have a composite wall composed of n slabs of different thickness and conductivities. If the slabs are in perfect thermal contact mat their surfaces of separation, the fall of temperature over the whole wall will be the sum of the falls over the component slabs and since the flux is the same at every point, this sum is evidently.

This is equivalent to the statement that the thermal resistance of a composite wall is the sum of the thermal resistance's of the separate layers, assuming perfect thermal contact between them. Finally, consider a composite wall as before, but with contact resistances between the layers such that the flux of heat between the surfaces of consecutive layers is H times the temperature difference between these surfaces. The differential equation to be solved is Fourier's equation.

These models we can confront with computer program modelica, which allow to construct the walls of technical chambers.

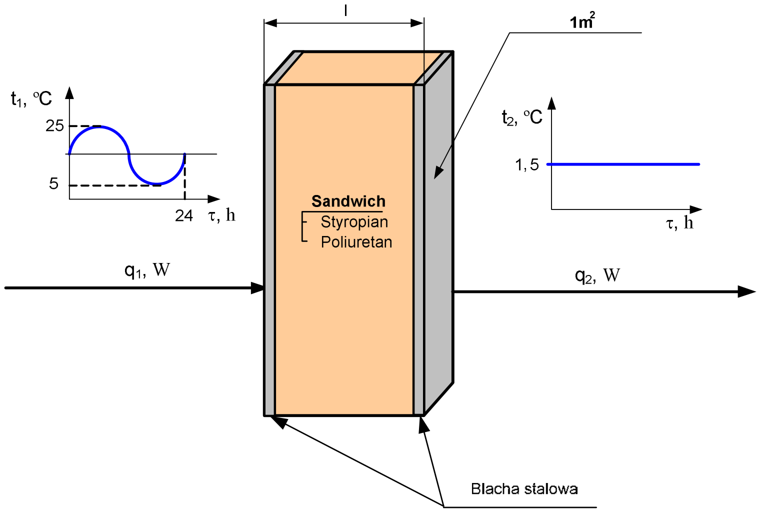

Fig. 7. Ideal model of wall

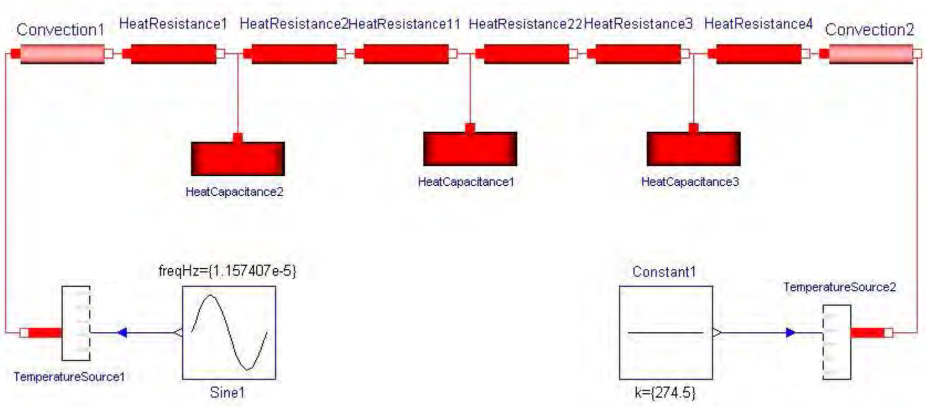

Fig. 8. Block schema using electrical analogue

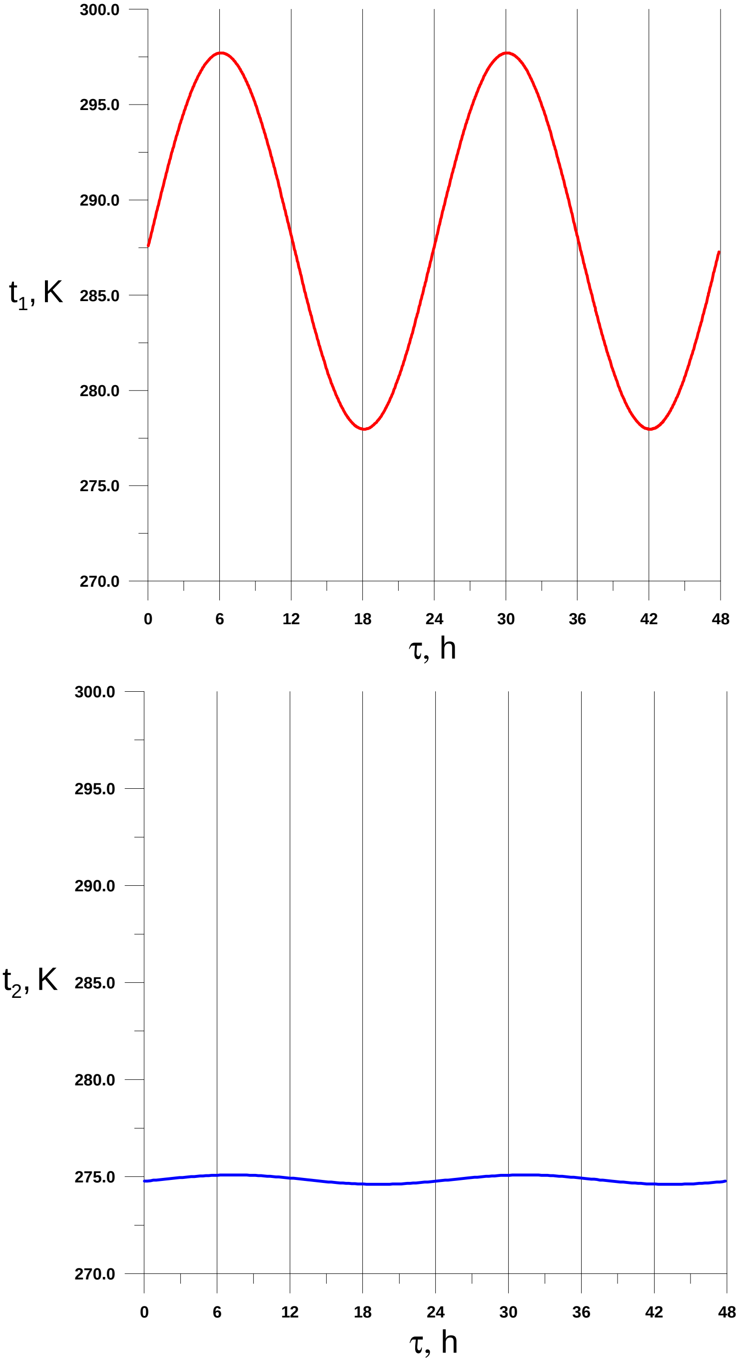

Fig. 9. Periodically temperature signal on the wall.

3. Research and experimental work of heat transfer through wall

The originally constructed laboratory system consists of fully automatic stands to test construction material thermal characteristics (Fig.10). These characteristics form the basis to formulate the principles of temperature changes between adjacent layers. The laboratory enables also to trace the heat transfer on external border surfaces. The experimentally obtained results have been subjected to computer analysis.

The verification of the accepted methodology and results have been performed on the data thermal flux density obtained from rural thermal chamber in Radzyń Podlaski (Poland). The small sensor of low inertia has been developed especially for the purpose of the research. This sensor has been used to measure the heat flux density. The experimental analysis proves the necessity to consider the dynamic character of internal temperature when thermal chamber analysis is performed. The thesis includes also the presentation of elaborated methodology of analysis of industrial long term storage.

Two fruit storages have been subjected to the analysis of temperature distribution on the surfaces of technical chambers (Fig. 11). The storages are constructed of materials of different physical properties.

Fig. 10. Registering positions laboratory

The purpose for the research is to point out areas subjected to the highest energy loss caused by building construction and geographical orientation of walls. Thermal detectors have been installed on external surfaces, internal surfaces and inside wall layers to measure temperature. The graphical presentation of temperature field distribution on wall surfaces have been performed by means of a thermal vision camera (Fig.12, 13.). The camera enables to distinguish visually the areas of the highest thermal loss from storages. The analysis of temperature distribution on vertical walls of storages makes possible to indicate proper building construction of objects. The analysis results are presented in figures. Moreover, temperature measurements taken on chamber external surfaces let us distinguish rooms that serve for other purpose than storage, e.g. a technical room. This room additionally protects the storage from disadvantageous influence of atmospheric conditions.

Article includes analysis of changeable influence in time of variable weather temperature on internal temperature of construction object depending on thermal inertia of building. Taken advantage influence of sinusoidal change external temperature on internal temperature of thermal technical spaces of thermo stability object will allow to get drop of cost of expendable energy of construction object on keeping of definite thermal condition in accommodation properly spaces. It shows harmonist of exemplary characteristic depending on length of time of measurement course of temperature and seasons of the year.

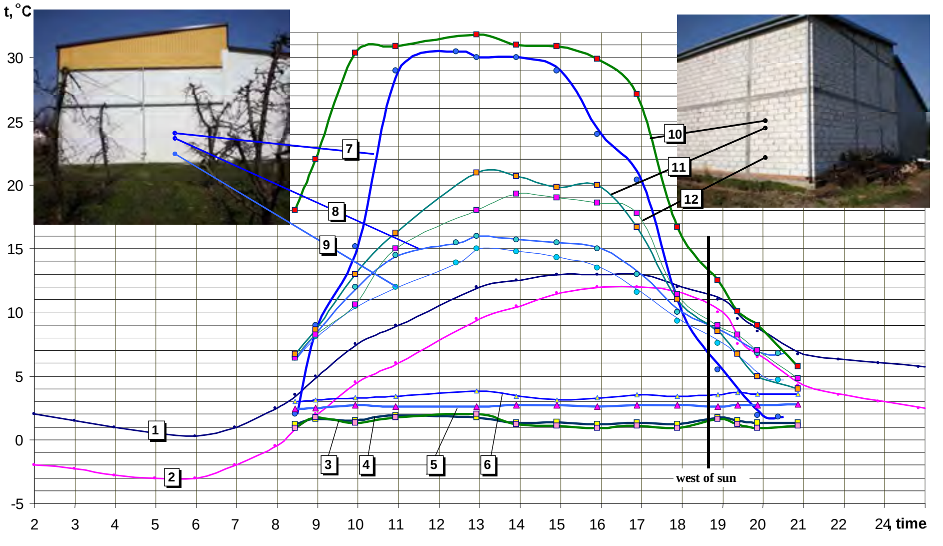

Fig. 11. Presentation of temperature field distribution on wall surfaces

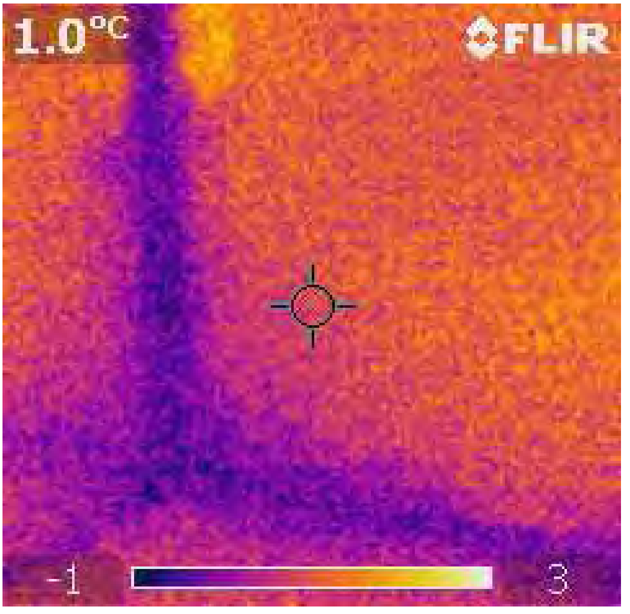

Fig. 12. Temperature field distribution on the corner of wall.

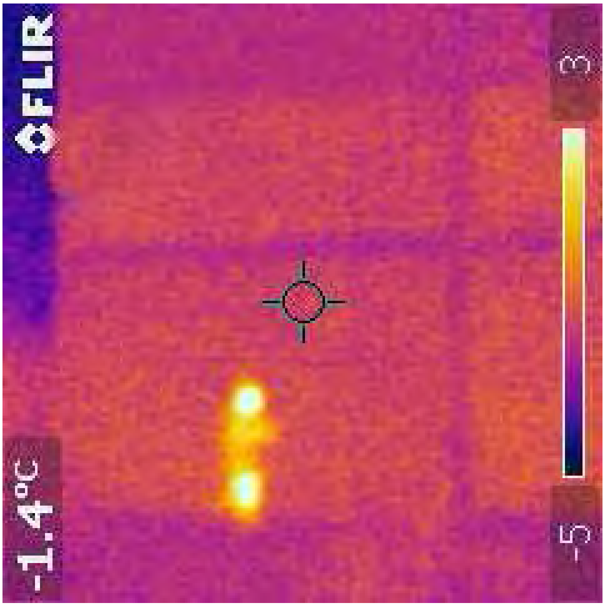

Fig. 13. Temperature field distribution on wall surfaces

4. Conclusion

The paper describes atmospheric temperature analysis and their variability in time in aspect of their influence upon the thermal technical chambers – fruit storages. This analysis shows the periodic variability of outside temperature, changing in periods of each day and also in the year with maximum value in the afternoon or in summer and minimum value in the night or winter time. The influence of this periodically changing temperature on the inside storages climate is depending on thermal inertia of technical spaces. The proper construction of an object with prescribed thermo-stability characteristic can use the phase difference between internal and external temperature and allow to lower costs of energy, necessary for cooling or heating the technical spaces. By the suitable construction of the enclosure walls composed of several slabs of different thicknesses and conductivities, we can obtain phase shift (when the time lag attains twelve hours it is the best situation), which reduce the amplitude of internal temperature inside technical chamber and, in consequence, give equivalent of using energy. The influence of this periodically changing weather temperature upon the inside storages climate is depending on the material of walls and inertial property of thermal technical spaces, it means a fruit storage.

5. References

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SCIENTIFIC AND TECHNOLOGICAL DESCRIPTION OF HEAT AND MASS TRANSFER PROCESSES IN THERMAL TECHNICAL CHAMBERS

Summary:

This paper describes research work on methods concerning heat transfers through walls of thermal technical chambers – especially in a fruit storages. The paper presents the analysis of complex problems in the field of energy savings and material selection during long term storage of fruit in thermal chambers in controlled gaseous environment. The purpose for the research is to point out areas subjected to the highest energy losses caused by building's construction and geographical orientation of walls in the aspect of daily atmospheric temperature changes emerging on chamber exterior. The presented paper is focused on the new concept of thermal analysis derived from harmonic character of temperature changes in building environment –fruit storages – with aspect on conductive heat transfers through walls. This changeable influence of variable weather temperature on internal temperature of technical chamber depends on thermal inertia of building. The paper presents exemplary measurement results taken in Lublin region during various periods throughout a year.

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