Janusz Sempruch
Kazimierz Peszyński
Editors

Developments in machinery design and control

Vol. 2

University Press
University of Technology
and Agriculture in Bydgoszcz

Janusz Sempruch
Kazimierz Peszyński
Editors

Cz 2608

Developments in machinery design and control

Biblioteka Główna ATR w Bydgoszczy
000000116943

Vol. 2

University Press
University of Technology and Agriculture in Bydgoszcz

ASSOCIATE REVIEWERS

Prof. Zygmunt Drzymała; Marek Gawrysiak, Assoc. Prof.; Prof. Krzysztof Gołoś;
Prof. Jerzy E. Kurek; Franciszek Siemieniako, Assoc. Prof.;
Włodzimierz Świderski, Assoc. Prof.; Prof. Wojciech Tarnowski

Proof-reading: Bernadeta Gierszewska, MA
Typeset by: Dorota Ślachciak, MA
Cover design: Daniel Morzyński, MSc

AKADEMII TECHNICZNO-ROLNICZEJ Biblioteka GŁÓWNA w Bydgoszczy

Ś 32868

© Copyright
University Press
University of Technology and Agriculture, Bydgoszcz 2003

ISBN 83-89334-80-1

University Press of University of Technology and Agriculture
Editor-in-chief
Lucyna Drozdowska, Assoc. Prof.
Ks. A. Kordeckiego 20, 85-225 Bydgoszcz, phone +48(52) 3749482, 3749426
e-mail: wydawucz@atr.bydgoszcz.pl http://www.atr.bydgoszcz.pl/~wyd

---

1st edition. 100 copies. Author's sheets 5.4. Printed sheets 6.5. 3rd class printing paper.
Submitted and printing completed in November 2003. Order No 9/2003
Printed in: Small Typography of University of Technology and Agriculture
in Bydgoszcz, Ks. A. Kordeckiego 20

Herewith we address the Reader with the second volume of the series 'Developments in Machinery Design and Control'. It presents the results of scientific research, which cover the last two years, carried out by academics of the Department of Control and Machinery Design, the Faculty of Mechanical Engineering, the University of Technology and Agriculture in Bydgoszcz, and our partners. The coverage of this volume varies from designing, control and computer-aided processes which we are facing today in mechanical engineering. The three make up a common science referred to as mechatronics which is analyzed in the introductory paper 'Selected Designing Ideas; Stages, Significance and its Role'.

Janusz Sempruch, Kazimierz Peszyński

CONTENTS

Janusz Sempruch
Kazimierz Peszyński

University of Technology and Agriculture
Department of Machinery Design and Control
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

SELECTED DESIGNING IDEAS, STAGES, SIGNIFICANCE AND ITS ROLE

Summary: The present paper offers considerations about designing process facing new challenges of developing new-class products often referred to as mechatronics products. Taking a designing process of typical mechanical engineering products as a reference, the greatest differences have been identified at the first and second stages, presented in more detail.

Keywords: mechatronics, design, creation of conception

1. INTRODUCTION

The ideas presented in this paper concerning designing emerged as a result of new solutions of developing new generation products most often referred to as mechatronics solutions. Bearing in mind the synergetic symbiosis of products of this class, which is the synergy of mechanical engineering, electronics and computer science, for the benefit of this paper the product of mechatronics is considered homogenous. Also the course and features of designing have been covered, especially at the initial stage.

One should pay attention to three characteristic attributes of mechatronics; enhanced significance of the engineering project, creation of conception by the designer and team work as well as a strict connection between the project and market analysis. The designer creates new solutions which have not existed so far. The team developing the product must combine different design methodologies of mechanical engineering electronics and software developments. Enhanced potential of realizing mechatronics product functions requires a thorough analysis and evaluation of the market needs. For that reason a brief coverage of engineer's designing methodology and facilitating engineer's creation of conception are given.

So far no design methodology for mechatronics has been available. There exist only processes of designing mechanical, electronic and software development products. To combine them, it is necessary to take a systematic approach, systematic model, systematic conception and the conception of various limitations of components, optimization of mutual relations among mechanical, electronic and software components of the product, etc.

2. PRODUCT LIFE CYCLE

2.1. Comprehensive Approach to the Product

The term 'product life cycle' is very essential for design methodology. It is one of those elements which stresses that a greater emphasis should be put on initial design stage and which is a springboard for product development process (project) planning and controlling, which, due to a close link with the market needs product development and its execution, is necessary in mechanical engineering.

Each product has its own life cycle which consists of six stages:

Stage 1: **Creating the specification and planning.** The stage aims at creating a clear description of requirements which have to be met by the product in a form of its functions and capacities, availability in time, necessary investments and other descriptions. All the next stages depend on the results of this stage. Developing the product specification is the main tool when formulating market needs.

Stage 2: **Conception project**. This stage involves creating the basic image of the product, the effect it will have and what it will look like. A project execution study is carried out. The true designing creativity is concentrated here. Traditionally this stage is least controlled, least defined and least understood.

Stage 3: **Selection of product features and technological product preparation.** Here the product conception is implemented in the form of a product prepared for manufacturing. This is the most time-consuming stage. Content-wise, the processes applied at this stage are relatively very well covered. However their weakness is the time limit due to a series of mutual iterative relations between selection of product features and technological product preparation. The basic method of addressing this problem is the so-called 'concurrent designing'. It involves the approach in which this stage is understood as a team effort. We try all the necessary steps to be realized concurrently, which is to exchange partial results obtained immediately with other team members e.g. between the design engineer and process engineer the elements of product features selection are transferred iteratively, analyzed in feasibility study.

Stage 4: **Product manufacturing.** It involves a real manufacturing process. From the point of view of mechatronics, quality and cost reduction experience is important, both in mass production and piece production.

Stage 5: **Product operation.** At that stage the product exists on the market at the client's (end-user's). Here feedback connected with a given or future specification is essential.

Stage 6: **Product disposal.** Each product is the beginning of another product. From the point of view of functional properties of the product, one should not ignore e.g. ecological properties, how the product can be recycled.

The first three stages refer to the true designing (selection of product features). However, from the perspective of creation of conception only the two first are essential since applicable efficient processes already exist. We will consider them in more detail.

2.2. Designing as Problem-Solving

Designing from psychological point of view is a problem-solving task. And so respective stages of designer's work follow the order below:

Voicing a demand, stating a problem.

Understanding the problem.

Generating potential solutions to the problem.

Evaluation of proposed solutions by comparison and selecting the best.

Reporting the work progress and results which facilitate communication.

Depending on the degree of difficulty of the designing tasks solved, the following types can be enumerated:

- **Designing by selection**: the task is to select an item from the list, for example a section of the product from the catalogue.
- **Configuration**: all the components have been developed, the task is to combine (assembly) them into one product, for example assembling a computer from components.
- **Designing by parameters**: the product is described with parameters and their mutual limits, the task is to select the parameters which, when put together, will make the new product have the desired parameters.
- **Original designing**: its task is to invent the product which has never existed.
- **Other types of designing**: repeated project, routine project.

2.3. Effect of Designing on Costs, Quality and Product Development Time

The experience connected with the course of product life cycle shows that the significance of designing stages is irreplaceable. Costs at the true project stage are very little as compared with the costs of product manufacturing, which makes at this stage the time required to manufacture it underestimated. However, the decision taken when designing has the greatest effect on the product cost. Yet even this effect decreases progressively starting from stages 1 and 2, where it is the greatest. The same applies to the product quality. Over product development, the later the changes in the design are made, the more expensive they are (sometimes much more expensive). All those statements justify the necessity of paying a special attention to designing at its earliest stages. It is of even greater importance for mechatronics. Designing is a transfer of inadequately defined problem to the end-product.

2.4. Development of Specification and Planning

The engineering project aims at creating a product which would satisfy the requirements of the market. The product must be understood very generally as a realization of engineer's effort. Also the market has a very general meaning here as the sale of the product. If the product does not comply with requirements of the market, it is a failure, even if it were an excellent solution. Therefore understanding the needs of the market is a prerequisite for the success of the project and the designer.

Developing a specification of the product is facilitated by some formalized methods which provide precious guidelines for its implementation. The requirements of the market are defined to follow categories: the **purpose** and **limitations**. They can be easily differentiated as the purposes are defined in general terms and do not include quantitative expressions (e.g. cheap, esthetic, pleasant), while the limitations are described with quantitative expressions (e.g. capacity of 1 liter, 3-gear box). For the product specification, a **tree of purposes** is created. It is a formal dynamic measure which is used to 'order ideas' of the designer to understand the purposes and to communicate in the team. It is created in the process of gradual replying to the question, 'What do we understand by this idea?' We start from the initial formulation of the requirement concerning the product and we develop it into branches and twigs. We must, however, differentiate them from the answer to the questions, 'How will we achieve it?', 'Which purposes presented in the tree can become means to achieve the purpose?' The tree of purposes is branching out gradually, usually it is restructured many times with a growing understanding of the requirements.

Having created the tree of purposes, we create **a product project specification.** It is an important document which both represents the contract with the customer and it is, at the same time, means to compare different design solutions at next stages, with market analysis, with the competition etc. It is, in fact, a structural description of possibly most detailed product requirements. It includes functions: capacity, the environmental properties, product life, maintenance, number of the products, dimensions, ergonomic properties, safety regulations, energy prices, standards etc. Formulating the requirements while developing specification faces the final feasibility question as well as the optimal selection to offer the most competitive price. All that is finally addressed at the next stage; hence the specification of **requirements** and **wishes,** e.g. the 5% accuracy achieved is a requirement, while the wish is 3%.

Another parallel guideline for project specification development is a process of **quality functions breaching out**, which has been offered by Japanese companies. What is essential is how to translate the customer requirements to measurable engineering (technological) specifications. It starts from identification of the customer the product is meant for. It is continued by defining the customer's wishes (requirements) and listing the requirements in order of priority. Then benchmarking against the competition follows. Finally the customer's requirements are translated into measurable engineering requirements and defining the project purposes. Both processes, obviously, complement each other.

Comprehensive planning of the product development project constitutes an element of the first stage. Having defined the project purposes, it is necessary to identify each task and purposes of each designer attributed to each task, which is followed by the evaluation of time requirements and designers involved in each task. The tasks are scheduled and presented in a graphic form and, finally, the total project costs are estimated. Such a plan is a basis for successful project control.

2.5. Conceptional Project

Having specified 'what to manufacture', one has to define 'how to manufacture it'. The procedure involves creating *structure, form* based on the required functional features. A frequent mistake which occurs is the application of the first or the favorite idea. *If we come up with one idea of a solution only, probably it will be the wrong one; if we generate twenty ideas, we can find among them one which is a good one.* For that reason the conceptional project is realized at two steps: **solution conceptions** generating and **solution conceptions** evaluation.

Two framework procedures for conceptions generating are presented further in the sections. **Functional decomposition** is one of them. It involves a breakdown of the problem into partial functional relatively independent subsystems. At the same time again we must ask the question, 'what do we need?', and not 'how to achieve it?'. The second technique is **generating conceptions** based on **functional features**. First, for each function decomposed the maximum possible number of conceptions is generated and then they are combined, which is close to **morphological analysis** by Zwicki. The aim is the combination of the elements of a given phenomenon in the way which would result in a brand new solution. In fact the idea is to formulate a matrix whose rows include characteristic features (e.g. functional features) and in columns the possible executions are assigned to those features (e.g. of a given function). Then all the possible combinations of solutions are examined with different execution variants obtained by selecting one execution from respective columns for each row. One of the variants is **a quantitative analysis** used to define the direction of a given product innovation.

The basic problem is, of course, searching for ideas for the conception. One way to go about it is to refer to experience, know-how literature, manuals, patent review etc. One can also use the methods facilitating the creation of conception and invention engineering.

The second steps of the conceptional project is the evaluation of the conception generated. It is very difficult to evaluate abstract non-specific conceptions whose parameters are difficult to measure. In spite of that, its possible to examine the conceptions generated which would reduce a big number of conceptions down to a few most promising ones. First a realization potential is evaluated based on the reaction of the designer: 'it cannot work', 'it can work under a condition', 'it is worth a further analysis'. Then the feasibility study is carried out, 'can it be manufactured?', 'are the technologies required available?' Then the customer's requirements are evaluated.

It is here where the product project specification is used; each item must be marked as 'fulfilled' or 'unfulfilled'. As a result, we come up with absolute conceptions valuation. Such a method can be also applied to create new conceptions. If 'unfulfilled' appears only a few times, it is useful to examine the modification of conception. Finally we will carry out a relative cross-conception comparison. For this purpose **Phug's decision matrix method** is used. Respective columns are filled with the conceptions compared and respective rows – with the comparison criteria which create the product specification. Te the matrix includes the results of respective conceptions for respective criteria. The comparison can be relative for each point of view. The procedure is frequently applied to cross-conception comparison also when we cannot make an absolute comparison of conceptions based on the product specification. The result can be defined using any scale, however, it is convenient to use positive and negative values, e.g. with three or seven degrees, as for fuzzy numbers. It is convenient to calculate the total result in different variants: positive values, negative values, integer and weighted, where the importance of the criteria used is considered.

3. FACILITATING THE CREATION OF THE CONCEPTION

Creation of the conception is essential for most of the above tasks. Psychology offers many methods of facilitating the creation of the conception which can be divided into individual and teamwork (collective). The individual methods include autogenic training in a traditional form or technically-aided methods using simultaneous tapes or tapes with sound or light stimulation of electric waves in human brain. Due to a limited coverage of this paper only the teamwork methods are presented further, namely brainstorming and synectics.

Brainstorming (brainstorming for ideas) is a method based on experience that an immediate evaluation of an idea one has come up with has a limited effect on idea development. In that way in our mind we often reject an idea much earlier than it can be developed in a form which would give a chance for success. Therefore the aim of brainstorming is putting off the evaluation of ideas, which makes it possible to generate the greatest possible number of ideas for solutions to a given problem, hoping the quantity will result in quality. This is the way it looks: a selected team of 8-12 members is faced with a precisely and clearly formulated problem. Each member of the team tries to present the greatest number of ideas. Ideas can be, at first glance, ridiculous, individual ideas are assumed to be related. No evaluation, criticism or mocking is allowed. The meting takes less than an hour and finishes once the members are short of ideas. The ideas presented are written down, each on a separate piece of paper. The brainstorming must be followed by the evaluation of ideas. Here the mapping of ideas and network thinking are recommended. These methods refer to the knowledge on the structure of human memory which creates skeleton structures and shortcut connotations. More details can be obtained from the Japanese method KJ.

Synectics is a method based on the knowledge that the creation of the conception can be facilitated by emotional and irrational elements of creativity penetrating into psychology. The basis of synectics is a change in the established approach to the problem. Synectics involves a team of 5-6 members. A given problem is talked about in a form of an unstructured discussion. The evaluation of the problem is also put off. Analogies, metamorphoses, unusual sides of the problem, referring the subject to the wider context are searched for. The connection to bionics, the study of mechanical systems that function like living organisms or parts of living organisms, is obvious.

To sum up this section, let us look at some methods applied by Japanese companies. KJ method, which was originated by a Japanese anthropologist Kawakita, is a method targeted at discovering the relationships among sets of knowledge (experience). It is a variant of mapping of ideas. It starts from facts about a given problem, each written down on a separate piece of paper, later sorted to bigger groups which are interrelated. Each group is given a new name on a separate piece of paper. Then mutual relations are searched for across groups which are presented in a graphic form with a network of connections on a bigger piece of paper. Finally the script of functioning of a given problem is projected based on the interpretation of the network obtained.

NM method (developed by Nakayama) is a Japanese method, similar to American synectics, which draws on KJ method. Analogies are created to each piece of paper which are written down on other pieces and combined with the other pieces (ideas), e.g. spatial or time combinations.

Key–Needs method is a method which addresses a creation of new conceptions of products compliant with the needs of end-users. First keywords are defined for which problems are formulated. As an option, by brainstorming, everyday needs of the customer are found. Reasons are proposed for no solutions to these problems or needs; they are expressed as positive or negative statements and then mutually combined. The combinations are the basis for ideas what the new product could solve.

Kepner-Tregoe method is a method which consists of 4 techniques facilitating decision-making and analysis of the problem. It is based on a conscious separation and differentiation of individual activities of the mind while problem solving: analysis, evaluation and selection. First the *problem analysis* is carried out by collecting the information available, followed by the *decision analysis*. The aims are formulated together with their alternative solutions, which are then compared. Then the analysis of potential problems takes place, considering possible future problems based on respective alternative solutions. Finally the evaluation of the aims of the situations is conducted. The results help to see the current situation and future possibilities. Priorities can be defined and solutions accepted.

Another considerable contribution of Japanese procedures is **Taguchi's robust project method**. While designing, there always exists some freedom of choice dimensions (parameters). Taguchi's method gives instructions on how to make this selection in the way which would ensure the functional features of the end-product insusceptible to production inaccuracy or a changeable effect of the environment.

It involves an enumeration of susceptibility functions of the product, depending on the tolerance parameters and optimization as functions of basic sizes, which replaces expensive production of low tolerance with a robust project.

4. CONCLUSIONS

Based on the above considerations, an algorithm can be developed to be used to solve tasks of creation of the conception which is made up of the following:

1. Problem description: the original problem is formulated again without psychological restriction, e.g. time limit, space and price can be changed freely (0 do ∞).
2. Model development for the problem to address a technical contradiction identified.
3. Problem model analysis: the contradiction is formulated again in a form of the so-called ideal final solution.
4. Eliminating the contradiction: problem-solving methods are applied.
5. Preliminary evaluation of the solution obtained: the solution is analyzed from the point of view of experience and technical systems development principles.
6. Extending the solution: applying the technical systems development principles.
7. Solution analysis: analysis of the difference between a given solution and the theoretical one.

REFERENCES

[1] Andrejsek K., Beneš J., 1984. Metody řešení technických problemů. SNTL Praha.
[2] Bradly D.A., Dawson D., Burd N.C., Loader A.J., 1991. Mechatronics – Electronic in Products and Processes. Chapman and Hall London.
[3] Buur J., 1989. Mechatronics Design in Japan. Technical University of Denmark, Lyngby.
[4] Dietrych J., 1985. System i konstrukcja. WNT Warszawa.
[5] Kratochvíl C. at all, 1997. Mechatronika. Proceedings of Engineering Mechanics '97, Academy of Science of Czech Republic, 49-59 (in Czech).
[6] Ullman D.G., 1992. The Mechanical design Process. McGraw Hill New York
[7] Valášek M. at all, 1996. Mechatronika. Vydavatelství ČVUT Praha (in Czech).
[8] Wymare A.W., 1967. A Mathematical Theory of System Engineering – the Elements. A. Wiley New York.

Artur Cichański
Jakub Maciejewski
University of Technology and Agriculture
Department of Machinery Design and Control
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

NUMERICAL ANALYSIS OF CHOSEN PARAMETERS OF AN INDUSTRIAL ROBOT PL-7

Summary: The paper presents an industrial robot movement numerical simulation in the Visual Nastran 4D commercial software environment. Geometrical features, weights and temporary courses of particular elements movements used for modelling have been assigned experimentally on the basis of PL-7 robot measurements. To analyse the created numerical model appropriateness, the test results have been compared with the experimental results.

Keywords: movement simulation, kinematics, dynamics, industrial robot

1. INTRODUCTION

Strict market rules force machine producers to reduce the new product manufacturing time. One of the widely used methods rationalising the machine design and development time is implementing the CAD system. In this system, the design geometrical features are stored in 3D standard. One of the advantages of this technique is the possibility of instantly assigning or optimising the strength of particular design elements by means of numerical analysis done by the designer, e.g. in the ANSYS program [1]. Advanced computing systems allow to analyse the behaviour of not only single design elements, but also of whole machines, e.g. Visual Nastran 4D pack [2]. All the range of activities, called together virtual prototyping, allow assigning and, if needed, modifying the kinematic and dynamic properties at the stage of design [3].

In the paper, it has been assumed that in the environment of Visual Nastran 4D software it is possible to model a physical object, namely, an industrial robot, and to carry out reliable numerical simulations of kinematic and dynamic behaviours. At the stage of modelling, the dimensions and density of particular elements were restored, and the appropriate number of freedom degrees ascribed for the elements. In the phase of experimental tests execution times and displacements of particular robots actuators were assigned. In the phase of numerical studies displacements measurements of the model motions were made and motions velocities of particular robot assemblies were assigned. To analyse the numerical model formula appropriateness, the results of experimental measurements were compared with the robot movement simulation. The model verified was used to estimate the time of composing exemplary cyclograms. Three different cyclograms were realised by means of simple and complex motions.

2. OBJECT TESTED

The target object of the tests was an industrial robot PL-7, located in the Department of Control and Machinery Design, the Mechanical Faculty of the University of Technology and Agriculture in Bydgoszcz (Fig. 1).

The robot is controlled automatically by electromagnetic valve through programmable electric controller, or manually by means of switchers in the control unit. Although all its drives are efficient, its automatic control system has not been fully activated yet. In consequence, it is only possible to perform simple motions. The robot executes movements within stops and blockages, without any intermediate states. Linear motion stops are set manually, while vertical column turn blockages are remote - controlled. The range of manipulator rotation is set manually.

All the movements are made due to pneumatic supply, and movement change characteristics are described through choking regulation. As a result, an experimentally assigned course of particular robot element movements is valid only for the configuration of choking settings considered.

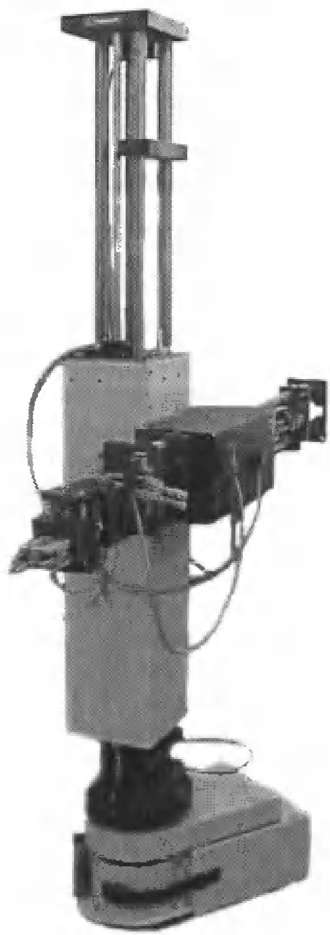


Fig. 1. Industrial robot PL-7

3. MODELLING OF THE OBJECT TESTED

3.1. Geometrical Model

The geometrical model was created in the advanced environment of graphical solid processor Mechanical Desktop 6.0. The real object was reproduced with the accuracy of 1 mm.

Sets of mechanisms closed in their cases were simplified to their outer geometrical dimensions. The power leads were omitted. The 3D model generated is projected in Fig. 2.

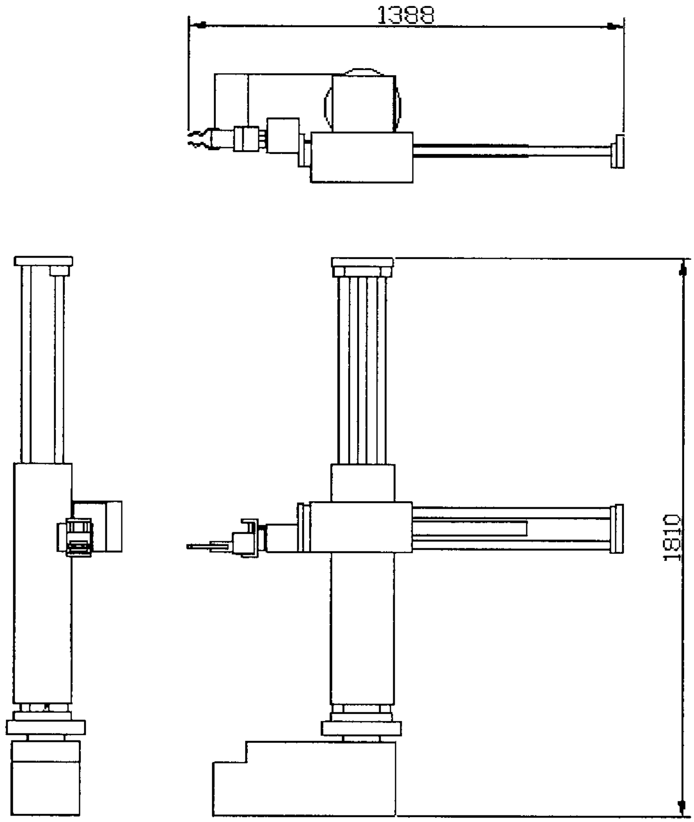
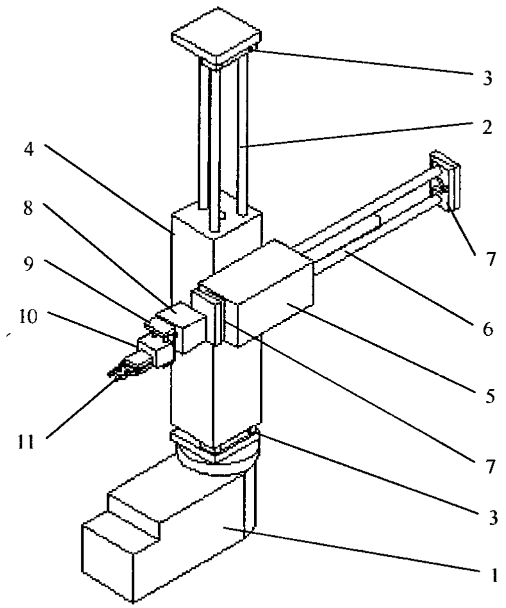


Fig. 2. Robot geometrical model

3.2. Numerical Representation of the Robot Model

The geometrical model was repositioned to the environment of simulation pack of Visual Nastran 4D. Simulation application initially allocated constrains between elements based on geometrical statement. The constrains agreed were corrected by assigning the appropriate number of freedom degrees for each of them, and new indispensable fixing constrains receiving chosen degrees of freedom were introduced. To make the object move, drives of suitably selected movement parameters were initiated in positions corresponding to the actuators.



Picture description:
1 – base with rotary motor,
2 – vertical column guide,
3 – vertical column stops,
4 – vertical column with actuator,
5 – horizontal column with actuator,
6 – horizontal column guide,
7 – horizontal column stops,
8 – manipulator clamping with rotary motor,
9 – manipulator guide,
10 – manipulator crane with rotary motor,
11 – gripping device.

Fig. 3. Robot scheme

The particular assemblies of the mechanism were brought to the form of closed solids of the appropriate weight. In the cases where a subassembly was made of different materials and was simplified to a substitute solid, e.g. the base, the average density resulting from the weight and volume of the subassembly was applied. The division into elements and subassemblies used in the model is presented in Fig. 3.

3.3. Drives Description

Drives in the robot structure:

Vertical column actuator (Fig. 3, pos. 4) causes vertical position change in columns u_{k1} and u_{k2}:

- element: Linear Actuator,
- max. travel: 350 mm,
- freedom degrees: 3 rotary,
  1 translatory (local Z axis),
- controlling: velocity table.

Horizontal column actuator (Fig. 3, pos. 5) causes horizontal displacement of horizontal column guides u_{r1} and u_{r2}:

- element: Linear Actuator,
- max. travel: 375 mm,
- freedom degrees: 3 rotary,
  1 translatory (local Z axis),
- controlling: velocity table.

Manipulator actuator (Fig. 3, pos. 10) allows the gripping device to move in one direction within short travel of u_{m1} and u_{m2}:

- element: Linear Actuator,
- max. travel: 15 mm,
- freedom degrees: 3 rotary,
  1 translatory (local Z axis),
- controlling: velocity table.

Base revolute motor (Fig. 3, pos. 1) allows the horizontal columns $\varphi_{z(1-3)}$ and $\varphi_{p(1-3)}$ to rotate:

- element: Revolute Motor,
- max. revolution: 300°,
- freedom degrees: 1 rotary (local Z axis),
  0 translatory,
- controlling: velocity table.

Manipulator revolute motor (Fig. 3, pos. 8) allows the manipulator to turn the held objects φ_{mz} and φ_{mp}:

- element: Revolute Motor,
- max. revolution: 180°,
- freedom degrees: 1 rotary (local Z axis),
  0 translatory,
- controlling: velocity tale.

The velocity tables applied were set to interpret proportionally the values between the limit points.

3.4. Element Weights and Materials

Due to their complexity, particular robot design assemblies that had been simplified to combined elements were weighed. After defining their volume, the substitute density was identified. Table 1 presents the numerical model elements with their weights. Robot elements numeration is consistent with Figure 3.

Table 1. Material properties of robot elements

Element	Material	Weight [kg]
Vertical column guide (2)	ANSI C 1020 steel	46.70
Vertical column stops (3)	ANSI C 1020 steel	2.16
Vertical column with actuator (4)	various	22.02
Horizontal column with actuator (5)	various	25.67
Horizontal column guide (6)	ANSI C 1020 steel	6.11
Horizontal column stops (7)	ANSI C 1020 steel	1.10
Manipulator clamping (8)	various	3.00
Manipulator guide (9)	ANSI S 304 steel	1.02
Manipulator crane (10)	various	1.48
Gripping device (11)	2024-T3 aluminium	0.53

4. EXPERIMENTAL STUDIES

4.1. Experimental Studies Aims, Conditions and Range

The aim of the studies was to define the PL-7 industrial robot execution time of complex movements mirroring the work performed by such a unit in an automatic workplace. Exact describing the simple and complex motions time should allow to coordinate the robot-operated processes.

Displacement characteristic measurements were conducted with the use of an inductive sensor of 0.01 mm accuracy, which was coupled with the MCG extensometer bridge. Displacement characteristic measurements were filtered through a program filter of the 1 kHz disconnection frequency. The measurement was accomplished at the frequency of 50 Hz. Rotary elements displacement times were defined by means of a measurement card with the accuracy of 0.05 s. Using the same card, deceleration times were measured. Initial data was gathered in a computer and stored in text files. Constant 5 bar pressure was maintained in the pneumatic supply system during all the measurements.

Particular robot movement experimental identification was conducted in two series for each of the simple motions. In each of the series, ten measurements were made, where one series was equivalent to one motion direction.

4.2. Simple Motions Experimental Studies

The experimental results selected for u_r horizontal column guide displacement measurements have been presented in Fig. 4 and for v_{r2} horizontal column guide retreatment velocity measurements in Fig. 5.

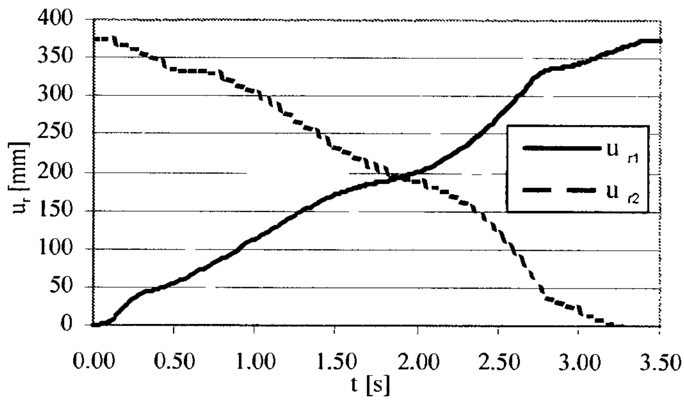


Fig. 4. u_{r1} u_{r2} horizontal column guide displacement measurements results

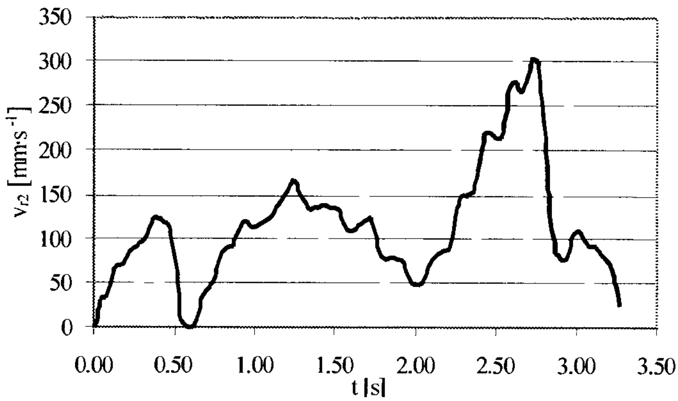


Fig. 5. v_{r2} horizontal column guide retreatment velocity course

The measurement result analysis shows a considerable wear of robot co-operating subassemblies and extensive friction force appearing on the surface of co-operating elements. An additional factor raising the measurement inaccuracy are gaps in the part joints, which is specially visible in changes in spot velocity.

Moreover, the measurement method is burdened with an error, which, despite the filter applied, was highlighted with the mechanism vibrations. The measurement error corresponds to spot velocity alterations produced by sensor inertia.

5. NUMERICAL STUDIES

5.1. Numerical Studies Aims, Conditions and Range

The aim of the first stage of numerical studies was to check the appropriateness of robot model representation of simple motions. At this phase, displacement measurements were made and motion velocities of particular robot assemblies were assigned.

With the next step, the times of realising three motion sets, described by cyclograms, were defined. These cyclograms reflect exemplary tasks taken into consideration. In the first phase, the realisation times of pre-set cyclograms accomplished by means of simple motions were studied. Subsequently, the model was programmed to perform the same cyclograms with the application of complex motions. Simple motion cyclograms are marked with 1, 2 and 3, while corresponding modified cyclograms, realised by complex motions, analogously with 1a, 2a and 3a. Fig. 6 shows an example of cyclogram 2, realised with simple motions.

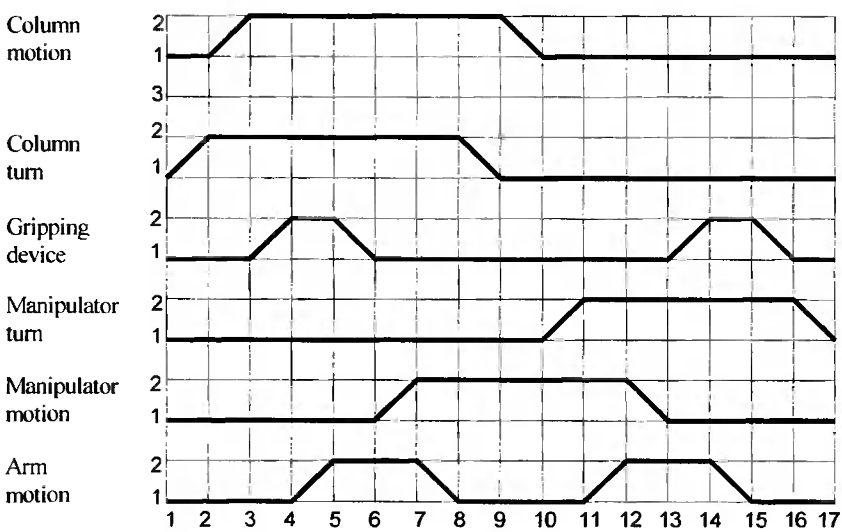


Fig. 6. Cyclogram 2 with robot motions record

Each of the drive assemblies possesses states indicated with numbers. At the bottom of cyclograms, individual steps of a given cycle were numbered. The description of the robot assemblies states (Fig. 6) is presented below; the numbering is consistent with Fig. 3:

Vertical column (4) motion:
- 1 – column down,
- 2 – column up.

Vertical column guide (2) turn:
- 1 – column position 0°,
- 2 – column position 90°,
- 3 – column position 180°.

Gripping device (11):
- 1 – closed,
- 2 – open.

Manipulator guide (9) turn:
- 1 – manipulator position 0°,
- 2 – manipulator position 90°.

Manipulator crane (10) motion:
- 1 – manipulator is down,
- 2 – manipulator is up.

Horizontal column guide (6) motion:
- 1 – the arm retreated,
- 2 – the arm advanced.

5.2. Simple Motions Numerical Studies

With the use of robot model representation in the Visual Nastran software environment a numerical test were made. During these tests displacements and motions velocities of robot parts shown in Fig. 3 were assigned. Numerical simulations results of particular robot parts movements were compared with experimental tests results. The exemplary comparison for the v_{r2} – horizontal column movement velocity measurements, is presented in Fig. 7. The results of Visual Nastran simulations are shown by a solid line. Experimental test results are shown by the dotted line.

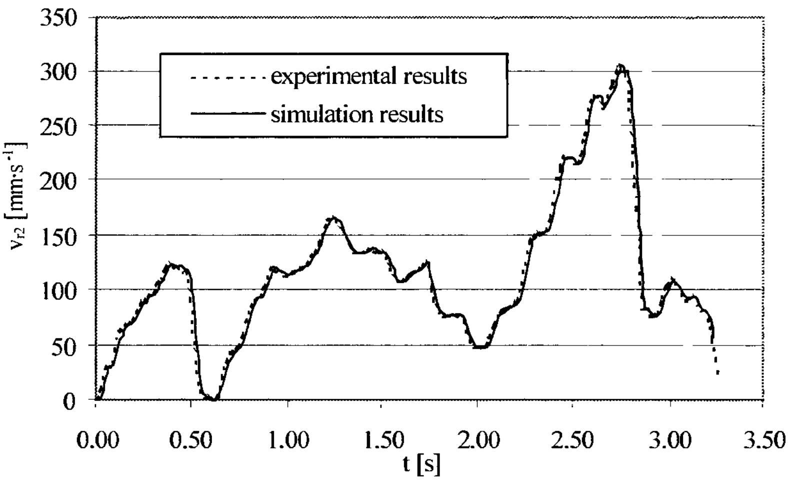


Fig. 7. v_{r2} horizontal column guide retreatment velocity course – experimental and simulation results comparison

After analysing the numerical model measurements, it can be ascertained that the created numerical model reflects the physical object very well. As it may be seen in the diagrams correlating the values measured, the simulation results only insignificantly stray from the values defined experimentally. Slight time shifts result from the real measurement data filtering. This way of filtering was necessary because of the measuring device high sensitivity, which caused blurring of the border between the standstill and motion.

In the comparative diagrams, a slight levelling of the simulation results line can also be seen. This effect disappears with the increase in the control values resolution. Due to the high sampling frequency applied during motion experimental measurements, results of high accuracy allowing exact reflecting the motion of the object studied were achieved. Simulation calculations were also set at the same as measurements resolution, which resulted in a slight shift of both diagrams.

5.3. Cyclogram Numerical Studies

The numerical model was studied while performing each of the primary motions as well as during the three cyclograms prepared and the complex motion cyclograms. Variable parameters courses of model primary motions and the total time of making each of the cyclograms were defined. Gravitational acceleration was set along the robot vertical column axis. Table 2 puts together the calculation and simulation times of full cyclogram performance.

Table 2. Cyclogram performance time statement

	Cycle time [s]		Relative error [%]
	Estimated	Simulated	
Cyclogram 1	51.6	49.3	4.67
Cyclogram 2	39.7	37.7	5.31
Cyclogram 3	59.6	56.9	4.75
Cyclogram 1a	41.7	39.4	5.84
Cyclogram 2a	31.9	29.9	6.69
Cyclogram 3a	52.6	49.9	4.41

6. CONCLUSIONS

1. Visual Nastran 4D software is a good environment to conduct simulation analysis. The program used can be applied in strength, kinematic and dynamic motion calculations. The complete configuration makes engineering problem-solving possible with various methods.
2. Experimental identification of kinematic and dynamic properties of an industrial robot provided much information about the object studied. A considerable wear of robot actuators and gaps in the setting on the guides has been highlighted. The velocity falls visible in the diagrams indicate significant friction between sliding elements.

3. Putting together the results of measurements and simulation of robot kinematic and dynamic behaviours confirms the appropriateness of the numerical model formula.
4. The simulated cyclograms have shown the necessity of time breaks in the robot operation. Movement simulation has allowed checking the possibility of shortened cycles and estimating the minimal times of correct task performance.

REFERENCES

[1] Kleiber M., 1995. Komputerowe Metody Mechaniki Ciał Stałych. Wyd. Nauk. PWN Warszawa.
[2] MSC Software Corporation, http://www.mscsoftware.com.
[3] Wawrzyńczak E., 1984. Metoda Elementów Skończonych w dynamice konstrukcji. Arkady Warszawa.

Kazimierz Dzierżek
Franciszek Siemieniako

Białystok Technical University
Department of Mechatronics
Wiejska 45c, 15-351 Białystok

DEVICE FOR TESTING PROGRAMMES USED IN DISCRETE PROCESS CONTROLLERS

Summary: The article presents the construction and operating principles of the discrete processes simulator. The simulator has been developed and tested by the authors in the Department of Mechatronics. A stand necessary for the discrete processes simulation is shown as well as an example process controled by the device.

Keywords: discrete process. control. simulation

1. INTRODUCTION

Designing software for the PLC controllers, there is often a necessity of the process simulation. Such a simulation allows us to monitor the programme and to make necessary changes online. Most often it takes place through the manual forcing the states on the controller inputs. Knowing the discrete process course makes it possible to simulate it automatically. To that aim the programmable discrete objects simulator has been developed.

The designed discrete processes simulator should have the following possibilities:

- the ability to force the input signals to the controller,
- the ability to set up forcing programme,
- the ability to read the input signals from the controller,
- the ability to simulate in real time,
- the ability of multiple programme repetition.

The tasks can only be carried out with discrete objects simulator equipped with the microprocessor.

2. SIMULATOR DESIGN

The block diagram of proposed discrete objects simulator is presented in Fig. 1. The simulator consists of following blocks:

- a microprocessor,
- a bus line,
- digital inputs,
- digital outputs,
- forcing push-buttons,
- push-buttons of the programmes (starting the regular programmes and the variable program),

– diode signaling (connected with digital outputs).

Each block has strictly definite functions attributed.

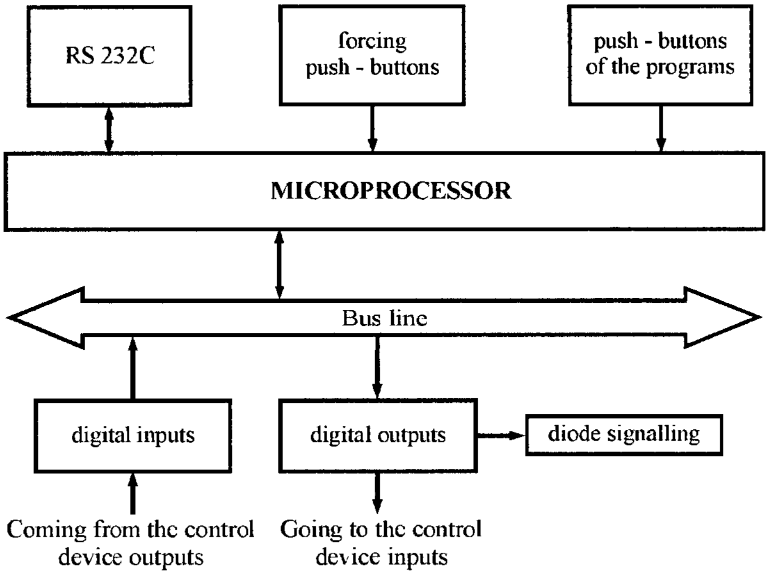


Fig. 1. Discrete objects simulator

The most important element of the system is the microprocessor controlling the whole simulator. The device uses Atmel 89S8252 microprocessor.

The next block is a digital inputs block. It draws the output signals from the controller and sends them to the processor. The digital input block consists of one or several 74 HCT373 or 74 HCT374 sets and transoptors.

The digital output block sends signals from the microprocessor to the controller inputs. It consists of one or several 74 HCT373 or 74 HCT374 sets and transistors. This block also consists of LED diodes signalling the state of the simulator outputs.

The block of starting the controlling program push-buttons and the one of the forcing push-buttons can come in two versions. In the first version the number of inputs and outputs is limited to 8. In the second version the number of inputs and outputs is theoretically unlimited. Besides, in the second version the system was fitted out with a logical set controlling the readout and entries of the input and output signals.

The communication of the processor with the computer takes place through the MAX 232 integrated circuit. This circuit together with an adequate transmission reports forms a serial communication port of RS 232C standard. Through the port the computer can modify or enter new stimulating programmes to the microprocessor memory and control the state of the simulator outputs.

Fig. 2 presents a simplified scheme of the discrete processes simulator adapted to operate a controller of maximum both 8 inputs and 8 outputs.

At strictly definite intervals of time the processor reads the information about the states of the signals entering the simulator, that is the information about the states of the output signals from the controller.

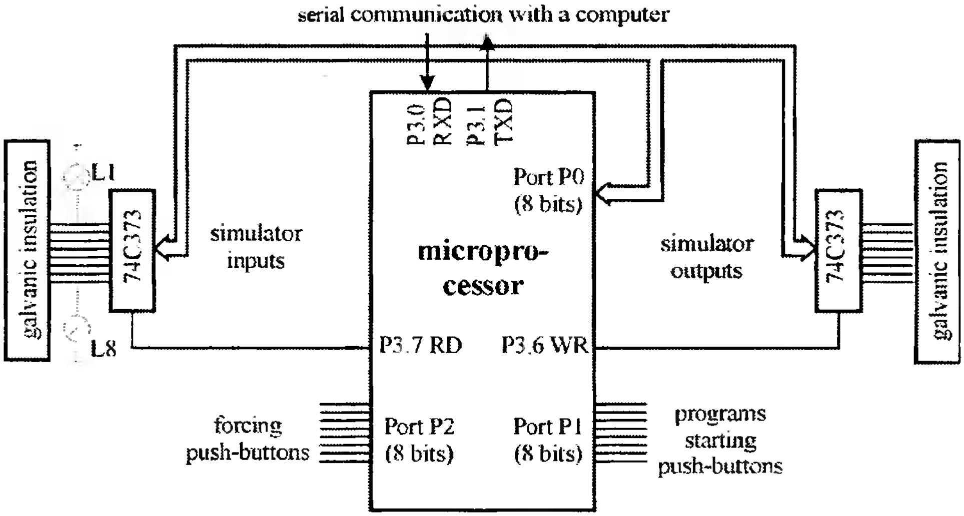


Fig. 2. Simplified electronic scheme of the discrete processes simulator of 8 inputs and 8 outputs

3. STAND FOR DISCRETE PROCESSES SIMULATION

A stand for discrete processes simulation consists of 3 basic elements: a discrete processes simulator (1), a computer (2), a controller (3) and cables connecting the devices. The computer performs a double role; programming the controller and simulating the processes in real time with the use of the simulator as well as sending the controlling programmes to the discrete processes simulator.

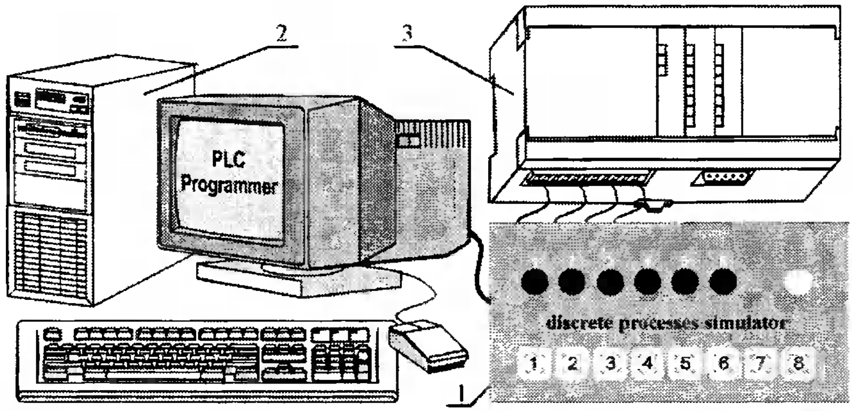


Fig. 3. Stand for discrete processes simulating

The connection between the simulator and the testing device is presented in Fig. 4. The output signals from the simulator are, at the same time, input signals to the PLC controller, while the PLC' output signals are, at the same time, the input signals to the simulator.

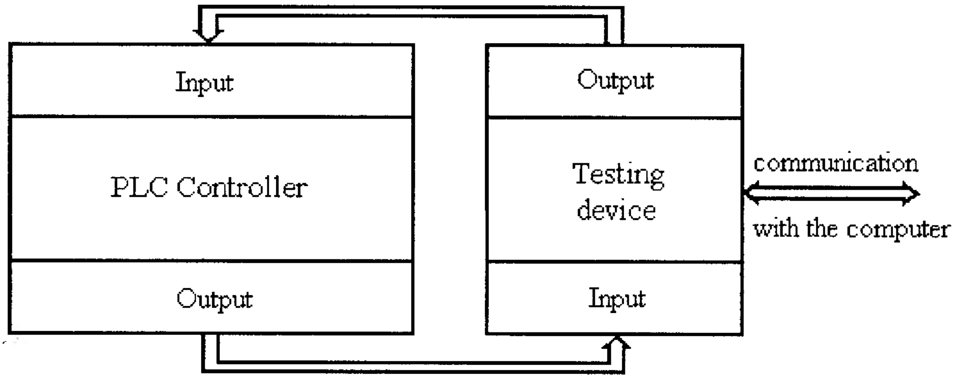


Fig. 4. Connection of the simulator with the PLC controller

4. CONCEPT OF THE SIMULATOR OPERATION PROGRAMME

The simulator operation programme is constructed to make the operation possibly easy. It allows for a remote change in the states of inputs and outputs in the simulator as well as to create and send the software for the automatic process simulation to the simulator. The algorithm of the program with the manual outputs forcing is shown on Fig. 5a. Figure 5b presents the algorithm of the programme during the automatic simulation.

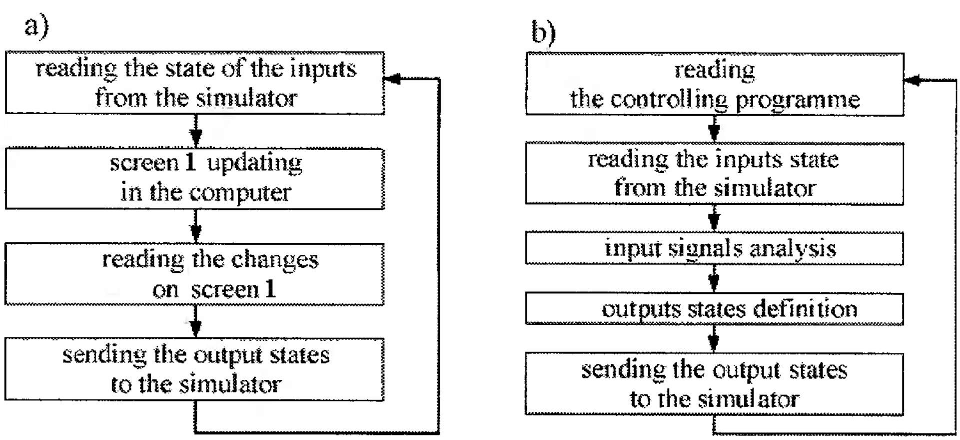


Fig. 5. Algorithms of simulator programmes: a) with the manual outputs forcing, b) with process simulation

5. EXAMPLE OF TESTING THE CONTROLLING PROGRAMME FOR TWO-LIQUID DOSING AND MIXING

An example process showing the concept of the discrete processes stimulator is mixing and dosing two liquids. A functional diagram of the process is presented in Fig. 6.

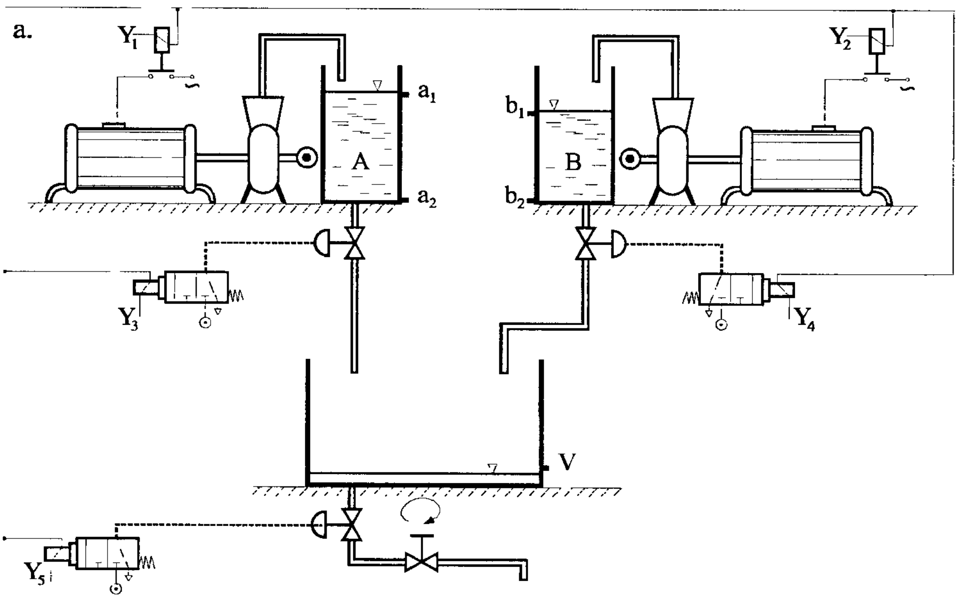


Fig. 6. Mixing and dosing two liquids: a functional diagram

There are two stages in one cycle:

Stage 1

- A liquid dosing
  - input signals: W0 = 1 (the main switch), a2 = 0, Y3 = 0;
  - the output signal: Y1 = 1.

Stage 2

- B liquid dosing
  - input signals: W0 = 1, b2 = 0, Y4 = 0;
  - output signal: Y2 = 1.

  A and B liquids dosing is independent of each other. After achieving the predefined levels a1 = 1, b1 = 1, the controlling signals will be, respectively, Y1 = 0, Y2 = 0.

Stage 3

- Supplying the mixer with liquid A
  - input signals: W0 = 1, a1 = 1;
  - output signals: Y3 = 1, Y4 = 0, Y5 = 0.

Stage 4

- Supplying the mixer with liquid B
  - input signals: W0 = 1, b1 = 1, a2 = 0;
  - output signals: Y3 = 0, Y4 = 1, Y5 = 0.

Stage 5

- Preparing A+B mixture – 10-minute state (mixing starts when Y4 = 1)
  - the input signals: W0 = 1, a2 = 0, Y3 = 0;
  - the output signals: Y6 = 1.

Stage 6
- state after 10 minutes
  – input signals: W0 = 1, a2 = 0, b2 = 0;
  – output signals: Y5 = 1, Y6 = 0.

The process runs correctly if the controller provides adequate changes in signals Y1, Y2, Y3, Y4, Y5, Y6, depending on the state of the output signals of the process W0, V, a1, a2, b1, b2. Successive stages and their states are as follows:

Stage 1
- A and B liquids dosing (where Y3 = 0 and Y4 = 0)
  – output signals: W0 = 1 (the main switch), a2 = 0 and b2 = 0;
  – after output signal Y1 = 1, a2 = 1 signal has appeared, time counter starts, after 15 seconds signal a1 =1;
  – after the output signal Y2 = 1, b2 = 1 signal has appeared, time counter starts, after 10 seconds signal b1 = 1.

  Stage 2 stars upon the controlling signals being, respectively, Y1 = 0, Y2 = 0.

Stage 2
- Supplying the mixer with liquid A (where Y1 = 0)
  – output signals: W0 = 1, a1 = 1;
  – after the output signal Y3 = 1, a1 = 0, V = 1 signal has appeared, time counter starts, after 7 seconds signal a2 = 0.

Stage 3
- Supplying the mixer with liquid B (where Y2 = 0 and Y3 = 0)
  – output signals: W0 = 1, b1 = 1, a2 = 0;
  – after the output signal Y4 = 1, b1 = 0 signal has appeared, time counter starts, after 20 seconds signal b2 = 0.

Stage 4
- Preparing A+B mixture; the simulator does not change its states

Stage 5
- Empting container C (where Y6 = 0)
  – output signals: W0 = 1, a2 = 0, b2 = 0;
  – after the output signal Y5 = 1, time counter starts, after 40 seconds signal V = 0.

The course of the process following the above stages will be ensured by the controlling programme developed entered to the controller. The testing device is to verify the correctness of the programme. To do so, the controller is not connected to the controlled system but to the tested device. The device is programmed in the processor language or in Turbo Pascal. To programme in Turbo Pascal, a especial language has been developed which aids the compilation, converting the program into processor language.

REFERENCES

[1] Microcontroller Data Book, 1999. Atmel Corporation.

[2] Gajewski P., Turczyński J., 1990. Układy scalone CMOS. WKŁ Warszawa.

[3] Marcinek A., 1995. Turbo Pascal 7.0 z elementami programowania. Nakom Poznań.

[4] Starecki T., 1996. Mikrokontrolery jednoukładowe rodziny 51. Nozomi Warszawa.

Józef Flizikowski
Ali Makhief Al-Zubiedy
University of Technology and Agriculture
Department of Food and Environment Protection Machines
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz
Marek Macko
University of Bydgoszcz
Faculty of Mathematics, Technology and Natural Sciences
Chodkiewicza 30, 85-064 Bydgoszcz

GRINDERS PROCESSORS CONSTRUCTION

Summary: This paper contains practical fundamentals of both design and milling process innovations, making use of the analogy between a granule and a machine element which treats granules as a part of grinder design. An eco-balance method of plastic refuses technology machines analysis was applied. Intelligent grinding as the results of research potential studies, actively controlled towards: mathematical description of general or selected machine operation, influencing machine environment of plastic in both active and passive manner have also been described; whereas quality, as reliability estimator, means the distance between the real system response and the response of the design model.

Keywords: plastic recycling mechanics, intelligent grinder design, the environment

1. INTRODUCTION

In the intelligent grinder machines construction processing, the attention was paid to the range of stresses and strains but also efficiency. The specific form of cross-section of elements causes large non-dilatational strains in the test specimens. Investigating the efficiency there is an additional machine design problem to be solved, based on instantaneous transformation of the charge, the energy carrier, into the processed element. This transformation is connected with the principal objectives of grinding: transfer of the grinding loads through the shredded material and maintenance, and even improvement of its processing and constructional properties.

Department of Food and Environment Protection Machines at the University of Technology and Agriculture in Bydgoszcz conducts intensive research into plastic grinder design and grinding processing to describe the identification, representation, formalization, implementation and testing, as part of engineering intelligent granule milling [3, 4, 5, 9].

2. MATERIAL AND METHODOLOGY

The theory of intelligent grinder design is made up of descriptions, models, rules and principles of plastic environment machines design, which can be reduced to the following criteria [1, 4, 5]:

- *optimal load* – the necessity to guard against harmful impact of machines on plastic, which not might be suitable for technology, environment and the design itself;
- *optimal material* – special requirements in relation to internal structure of working elements of a grinder as well as their machining;
- *optimal stability* – the necessity to ensure high standard of hygiene facility during operation of the machine, high peculiarity of some machining operation, which are very difficult to stabilize, mechanize or even, to automate; the necessity to measure, monitor and control polymer features, previously processed in machines;
- *optimal relations of related quantities* – loads – distortions – stress, maintenance of high smoothness, efficiency, continuity of technological operations, traditions – progress, innovations, 'novelties' for plastic markets.

The foundation of machine design and manufacturing process planning in production of polymer raw materials is the knowledge about physical quantities of those substances. It concerns different groups of features, such as, physical, chemical, biological, and generally: technological. Supposing that the ground element, during grinding process, becomes an element of the machine, it becomes subject to design criteria. Polymer raw materials, semi-manufactured products and final products are environmentally active.

Problem identification: design of a grinder. The rules mentioned were presented in a nearly hierarchical way. They form basis for plastic machine design, building and operating. Mathematical model of grinding is the mathematical description of relations between input and output with a necessary degree of simplification. Generally, the function of the research object (using characteristics H_u and constructions features C_k) is:

$$\{H_u\}: H_N = f\{C_k\},\ H_m = f\{C_k\},\ H_e = f\{C_k\},\ H_q = f\{C_k\} \tag{1}$$

where:

N_u	– power demand:	$H_N = f(C_k)$,
W_u	– mass efficiency:	$H_m = f(C_k)$,
$e_R, \eta, E_T, M, \omega, v, n$	– energy indicators:	$H_e = f(C_k)$,
λ, q	– product quality:	$H_q = f(C_k)$.

It is aimed at, by the rule, to minimizing or maximizing selected grinding characteristics with intelligent design. A detailed form of the intelligent grinding, research object is (for quality function) as follows (particular features of grinder design are given in brackets: dimensions, speeds, circular pitches, number of holes and gaps, Fig. 1):

$$H_q = f\left(d,\ d_r, \omega, t_o, t_r, l_t, l_o, l_{rz}, s_i\right) \tag{2}$$

Knowledge representation: The following items were used while modelling [3-5]:

- work potential equation,
- design feature matrices of a power unit and multi-disc unit,
- functions of peculiar and general research objects.

The work potential equation of plastic grinding, within a period (t_0, T), is:

$$P_d(T) = P_d(t_o) - \int_{t_0}^{T} p_d^E(t)dt - \int_{t_0}^{T} p_d^s(t)dt - \int_{t_0}^{T} p_d^o(t)dt \tag{3}$$

where:

- $P_d(t_o)$ – initial work potential,
- $p_d^E(t)$ – flux density of effectively used potential,
- $p_d^s(t)$ – flux density of wasted potential,
- $p_d^o(t)$ – flux density of recreated potential (or obtained from the environment).

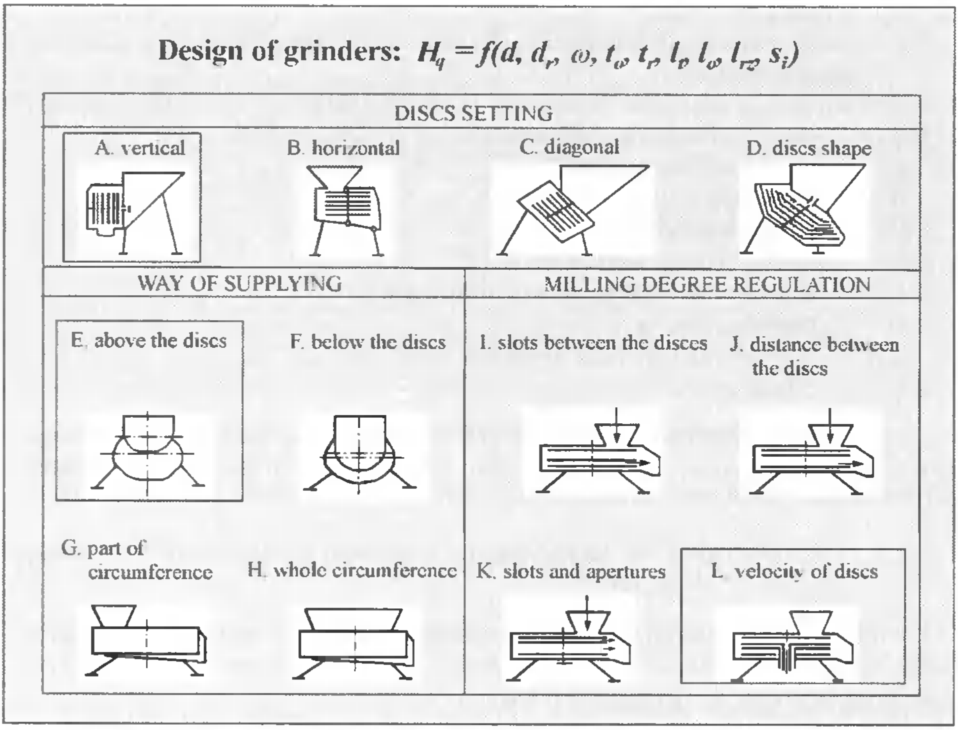


Fig. 1. Design of grinders and elements of a plastic grinder unit with features C_K

Taking into account polymer recycle, as energy-material grinding, the following is obtained:

$$P_{em}(T) = P_{em}(t_o) - \int_{t_0}^{T} p_{em}^E(t)dt - \int_{t_0}^{T} p_{em}^s(t)dt - \int_{t_0}^{T} p_{em}^o(t)dt \tag{4}$$

where:

- $P_{em}(t_o)$ – initial energy-material potential of grinding,
- $p_{em}^E(t)$ – flux density of effectively used energy-material potential,
- $p_{em}^s(t)$ – flux density of wasted energy-material potential,

$p^{o}_{em}(t)$ – flux density of energy-material recreated potential (or only retrieved from the environment).

Knowledge formalization: Quality function Q and technological estimators are used as a formalization field to assess the model of research object, its intelligent grinder design quality and grinding efficiency, as a measure of the difference between signals of the model and the real object:

$$Q = \|y^* - y\| \tag{5}$$

where:

y^* – real system response (characteristics H_u and constructions features C_k, e.g. grinding - process),

y – model response (characteristics H_u and constructions features C_k, e.g. quasi-shear phenomenon).

Technological – intelligent estimators: The estimation makes use of the analysis of the function extreme (of operating characteristic) of grinding process:

e_R - power efficiency function. – ,
W – mass output of the process, kg·h^{-1},
N_e – power demand, kW,
E_T – specific energy consumption, J·g^{-1},
λ – degree of fineness (product dimensions), mm,
M – torques, N·m,
ω, n, v – angular, rotational and linear velocities, rad·s^{-1}, s^{-1}, m·s^{-1},
η – efficiency, –.

The polymers usefulness conditions are met by process parameters and design features, which maximize: efficiency function, output, degree of fineness for (equation (6)):

$$\{C_k^* \in \phi\} : \left\{ \bigwedge_{C_k \in \phi} H_u(c_k) < H_u(c_k^*) \right\} \text{ for: } H_u\text{: } e_R, W_u. \tag{6}$$

While minimizing of power demand, specific energy consumption, dissipation of energy, torque, angular, linear and rotational velocity – (as a measure of usefulness) can be obtained by proper design features (equation (7)):

$$\{C_k^* \in \phi\} : \left\{ \bigwedge_{C_k \in \phi} H_u(c_k) > H_u(c_k^*) \right\} \text{ for: } H_u\text{: } N_u, v_{..}, n \tag{7}$$

where:

C_k^* - solution to the problem,

Φ – intelligently permissible area of grinding vector or design features C_k^*,

H_u – operating characteristics.

Knowledge implementation: Detailed indicators of intelligent grinding of plastic pipe refuses were also used (Fig. 2):

- specific energy consumption,
- performance and efficiency of the process.

Specific energy consumption: While modelling, there were used such quantities like description of energy consumption (p_e *(t)*) compared to the amount of output granule in a given period of time (p_{e-m} *(t)*), i.e. specific energy consumption.

Knowledge implementation:		
Specific energy consumption E_{JM}: $E_{JM} = \frac{\dot{N}}{\dot{G}}$	Specific energy consumption: $E_{JO} = \frac{\dot{N}}{\dot{W}}$	Dedicated consumption: $E_{Rq} = \frac{N}{W_{f_q}}$
Performance-efficiency model: $\Delta e_R = \frac{K}{N_E}$	Numerator and the denominator: $\Delta e_R = \frac{(\Delta)E_{pp}}{(\Delta)E_{R\lambda(F)}}$	Efficiency model: $\eta_{q-\acute{s}} = \frac{E_{q-\acute{s}(f)}}{E_{q-\acute{s}(m)}}$
$e_{RP} = \frac{(\eta_{q-\acute{s}} - \eta_o) \cdot E_{brutto} \cdot \eta_s \cdot \eta_p}{(k_j \cdot v_r + \tau_{q-\acute{s}} \cdot F_{q-\acute{s}} + \varepsilon \cdot F_R^{'} \cdot v_r^2) \cdot M_k \cdot v_r \cdot t}$		

Fig. 2. Knowledge implementation: detailed indicators of grinder processing

Specific energy consumption E_{JM} was defined generally as a relation of power $\dot{N}$ to mass rate of ground plastic discharge $\dot{G}$ (mass flux of the final product) [4]:

$$E_{JM} = \frac{\dot{N}}{\dot{G}} \tag{8}$$

The power was compared to the volume flow rate of the final product ($\dot{W}$) and the result was a variety of specific energy consumption:

$$E_{JO} = \frac{\dot{N}}{\dot{W}} \tag{9}$$

E_{JM} is called specific energy mass consumption, whereas E_{JO} means specific energy volume consumption. This model is not very useful for grinding. While specific energy consumption decreases, watt-hour efficiency of the process increases. The usefulness was measured by the energy consumption for required processing dimension (e.g. 80% of granules fractions with an average dimension of 4.3-4.8 mm, dedicated consumption) E_{Rq}:

$$E_{Rq} = \frac{N}{W_{f_q}} \tag{10}$$

where:

N – power used for grinding, W,

W_{fq} – output, measured by the amount of ground granules with desirable, dimensions of fractions (f_q = 4.3-4.8 mm), kg·s^{-1}.

Performance and efficiency: the performance-efficiency model was adopted as follows:

$$\Delta e_R = \frac{K}{N_E} \tag{11}$$

where:

Δe_R – increase in grinding power efficiency, –,

K – grinding power benefits, kJ·kg^{-1},

N_E – grinding power input, kJ·kg^{-1},

in which the numerator and the denominator are described as:

$$\Delta e_R = \frac{(\Delta)E_{pp}}{(\Delta)E_{R\lambda(F)}} \tag{12}$$

where:

E_{pp} – workability energy, kJ·kg^{-1},

$E_{R\lambda}$ – grinding energy (phenomenon), e.g. to obtain the product with 4.3-4.8 mm granule fraction in 80% of mass, kJ·kg^{-1}.

The efficiency model is described by the relation between machine energy and phenomenon conditions:

$$\eta_{q-\acute{s}} = \frac{E_{q-\acute{s}(f)}}{E_{q-\acute{s}(m)}} \tag{13}$$

where:

$\eta_{q-\acute{s}}$ – quasi-shear efficiency, –,

$E_{q-\acute{s}\,(f)}$ – quasi-shear energy in phenomenon conditions (testing machine, static research), kJ·kg^{-1},

$E_{q-\acute{s}\,(m)}$ – quasi-shear in real conditions (machine-specific grinding unit), kJ·kg^{-1}.

To assess the power efficiency of quasi-shearing of granule plastic, for technology purposes, we have to use the following indicator:

$$e_{RP} = \frac{(\eta_{q-\acute{s}} - \eta_o)\cdot E_{brutto}\cdot \eta_s \cdot \eta_p}{(k_j \cdot v_r + \tau_{q-\acute{s}} \cdot F_{q-\acute{s}} + \varepsilon \cdot F_R^{'} \cdot v_r^2)\cdot M_k \cdot v_r \cdot t} \tag{14}$$

where:

$\eta_{q-\acute{s}}$ – part of granule with dimensions of fractions (f_q = 4.3-4.8 mm) in the grinding product, –,

η_o – part of granule with dimensions of fractions (f_q = 4.3-4.8 mm) in the entire plastic, –,

E_{gross} – energy included in the processed granule, PE_LD E_{gross} = 46.5 MJ·kg^{-1}, kJ·kg^{-1},

η_s η_p – efficiency of the power transmission system of the grinder (motor and transmission), –,

k_j – idle run resistance coefficient, kg·s^{-1}.

v_r – speed of cutting edge quasi-shear elements, $m \cdot s^{-1}$,
$\tau_{q\text{-}\acute{s}}$ – quasi-shear stress of plastic, $N \cdot m^{-2}$,
$F_{q\text{-}\acute{s}}$ – temporary section of quasi-shear of plastic or its pieces, m^2,
F_R' – secondary reaction section of quasi-shear, m^2,
ε – factor of proportionality, $N \cdot s^2 \cdot m^{-4}$,
M_k – mass-trial multiplication indicator, –.

3. KNOWLEDGE TESTING – RESULTS AND DISCUSSION

The cutting edge of the grinding (cutting) tool sinks in and cuts, and at the same time acts as a wedge, which exerts pressure with its surfaces on a plastic. Quasi-shear in the disc grinder shows that exactly this pressure has an influence on plastic grinding process. It is assumed that ground granule is dismembered from the rest of total along certain line (the so-called: parting line). We deal with shear or quasi-shear, depending on the force appliance, resultant of quasi-shear in relation to the parting line. The normal component causes compression or tension stresses, whereas the tangent component – shear. Due to the fact that both tension and compression strength of a plastics are twice (or more) as big as shear strength, it is also sheared along the surface under the reduced stresses.

Some results of scientific research of multi-disc grinding process of plastic with optimal grinding unit are shown in Fig. 3.

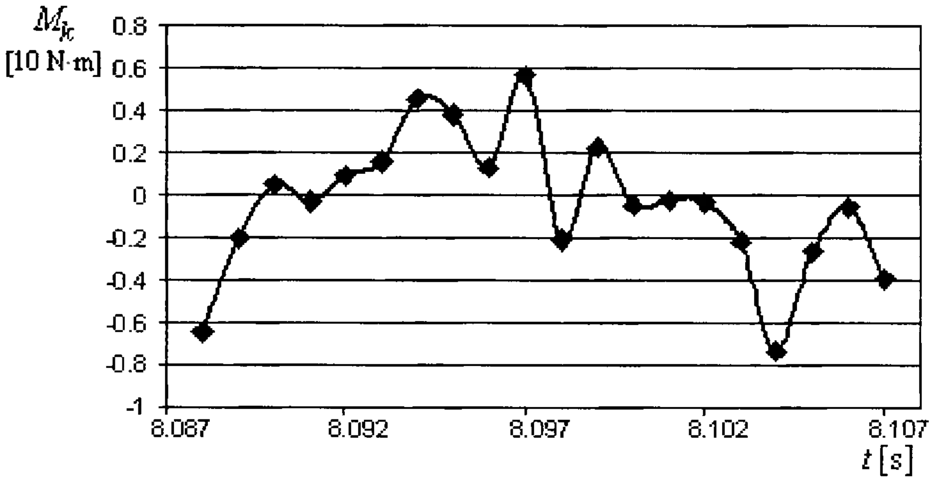


Fig. 3. Changes of torque as a time function ($H_e = f(C_k)$) for single-cycle disintegration. Material PE_LD – pipes Ø = 32 mm

The diagram indicates the irregularity in single cycle of sample material disintegration. This is an effect of deformation and much depend on the shape and properties of the material. The graphs determine the variety range of plastic grinding efficiency and specific grinding energy consumption with for to the gap between discs.

The main research determined the influence of the speed between discs on specific energy consumption, irregularity of work and power demand.

The multi-criteria analysis, based on models (2) – (14), makes an assumption that design features meet specific indicators (criteria) [1-8] (Table 1). To obtain sub-optimal conditions of plastic grinding unit design, it is necessary to take a different quality of recycled plastic into account. A set of design features (Table 1), to optimise grinder design condition (6) and (7) were derived based on of the fulfilment of criteria, estimators verifying user-environment models of mechanical processing.

The design solution of multi-disc grinding unit (for raw material and other recycled materials) has been verified based on grinder process tests carried out on the grinders during their low-volume production. The solution presented was awarded the first prize at the World Trade of Innovations, Scientific Research and Technology in Brussels in 1998 (Fig. 4).

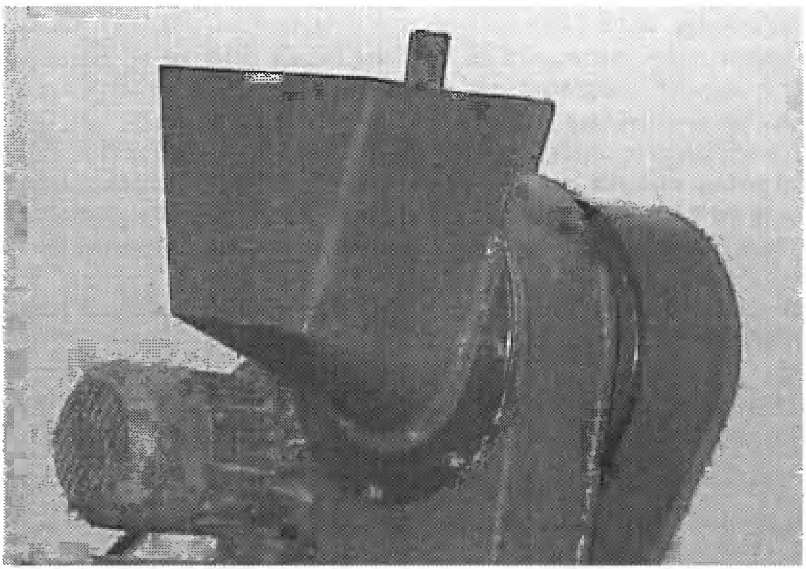


Fig. 4. Multi-disc grinder: number of discs $l_t = 7$

To obtain the intelligently postulated very high efficiency state during the control of variable features in the "material – machine – process – grinding aim" system, firstly, it is very important to take advantage of the process possibilities, secondly, of the material features change possibilities and thirdly, of the design feature change in the grinder.

The grinding effectiveness can be assessed at least from two points of view: indicators and potentials. Efficiency indicators are related to efficacy, i.e. smooth realisation of the aim function needed; economy, as a model broadened with socio-environmental aspects; informativeness, as approaching the absolute ideal (model); and durability, as relations between specific and extreme durability.

Table 1. Design features (construction features C_k) of multi-disc unit (*AEL* – Fig. 1) which fulfil optimisation criteria (characteristics H_u)

Multi-disc unit	$C_k \in \Phi$ – research area	$C_k^* \in \Phi$ – solution
1. External discs diameter	D_t = (430-500) mm	D^*_t = 500 mm
2. Holes diameters	d = (15-180) mm	d^* = (15-180) mm
3. Hole spacing diameter	d_r = (200-400) mm	d^*_r = (200-400) mm

4. Hole edge angles	γ = (60-120)°	γ = (60-75)°
5. Roughness	R_a = 10 μm	R^*_a = 10 μm
6. Circular and radial pitch	$\left.\begin{array}{l} t_o \\ t_r \end{array}\right\}$ acc. to hole spacing	$\left.\begin{array}{l} t_o \\ t_r \end{array}\right\}$ acc. to hole spacing
7. Number of discs	l_t = 1-9	l^*_t = 5 or 7
8. Number of holes in the first disc	l_o = 5-35	l^*_o = 9 or 11
9. Number of hole lines in one disc	l_{rz} = 1-3	l^*_{rz} = 2
10. Gap between discs	s_i = (0.01-3.1) mm	s^*_i = (0.01-0.1) mm

Out off all plastic grinders design solutions, multi-edge grinders are most preferred, especially multi-hole grinders whose general shape and design features of grinding area can be determined empirically.

Recycled materials engineering progress requires monitoring, measurement and scientific description of a growing number of physical and mechanical qualities of raw materials in order to design machines and plan technological processes properly.

4. CONCLUSIONS

Designing plastic processing machines depend on the progress in plastic engineering and even in human life [2, 4].

Intelligent mechanical engineering of plastic grinder and grinding will concern the application of achievements of mechanics and other sciences in growing, processing, storage, transport, serving and disposal of plastic.

Innovations (rapid change into a higher level of technology development) have played a crucial role in various areas of plastic production and processing.

Another important task of plastic intelligent grinding engineering is to minimise environmentally harmful effects of intense production by processing friendly products, as it is impossible to stop automation, mechanisation and chemicalisation of plastic processing suddenly.

This paper covers selected aspects of relations between grinders construction, mechanical engineering of plastic grinders, building and operation of machines, mechanics, chemistry, production and processing in the environment.

A progress in grinders design, material, plastic and energy processing, as a basic area of activity, will probably develop the same as mutual relations between: the level of technology and the plastic perpendicular on the environmental diagonal.

REFERENCES

[1] Wróbel J., 1994. Technika komputerowa dla mechaników. PWN Warszawa.

[2] Flizikowski J., Flizikowski A., Macko M., 2001. The computer aided design of functional system of mill for biological materials. IMACS/IFAC – Fourth International Symposium on Mathematical Modelling and Simulation in Agricultural and Bio-Industries VI, Haifa, Israel.

[3] Dietrych J., 1985. System i konstrukcja. PWN Warszawa.

[4] Flizikowski J., 1998. Projektowanie środowiskowe maszyn. Wyd. Uczeln. ATR w Bydgoszczy.
[5] Flizikowski J., Bieliński K., 2000. Projektowanie środowiskowych procesorów energii. Wyd. Uczeln. ATR w Bydgoszczy.
[6] Johansson A., 1997. Czysta technologia. WNT Warszawa.
[7] Pahl M.H., 1994. Umwelt und Energie. Universitaet-GH. WUZ Paderborn.
[8] Kocańda S., Szala J., 1985. Podstawy obliczeń zmęczeniowych. PWN Warszawa.
[9] Mulawka J.J., 1998. Systemy ekspertowe. WNT Warszawa.

Henryk Holka

University of Technology and Agriculture
Department of Applied Mechanics
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

SEMI-ACTIVE CONTROL OF VIBRATION BY THE APPLICATION OF ELECTROMAGNETIC FIELD

Summary: The paper consists of two basic parts. The control concept was divided into active control and semi-active control. In the first part, the method of active vibration control was presented, and in the second part – the electrodynamic vibration absorber with non-linear stiffness and dumping. The procedure of identification of non-linear forces is given. The equations of motion were derived and the results were considered. The paper also includes a comparison of theoretical results with real vibration measured on a special stand.

Keywords: active control, semi-active vibration, electromagnetic force

1. INTRODUCTION

In numerous applications, a mass is isolated from vibration by interposing spring and damper between a mass and disturbance, Fig. 1.

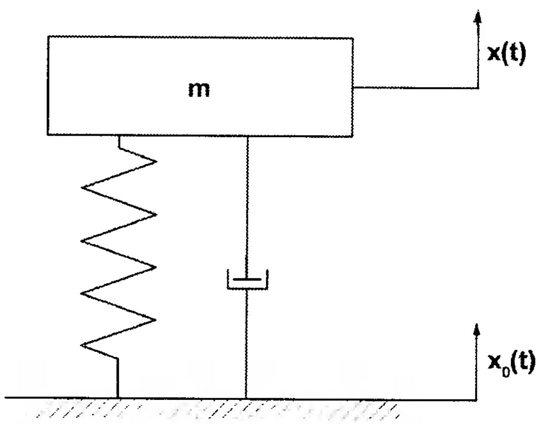


Fig. 1. Passive isolator

The conventional passive isolator, as it is known, has many defects.
The best solution is active system, Fig. 2. [1, 2].
The force $F(t)$ is generated by the actuator UA:

$$F(t) = W(i\omega)[x(t) - x_o(t)] \tag{1}$$

where:

$W(i\omega)$ is the unknown transfer function of the active vibration control system.

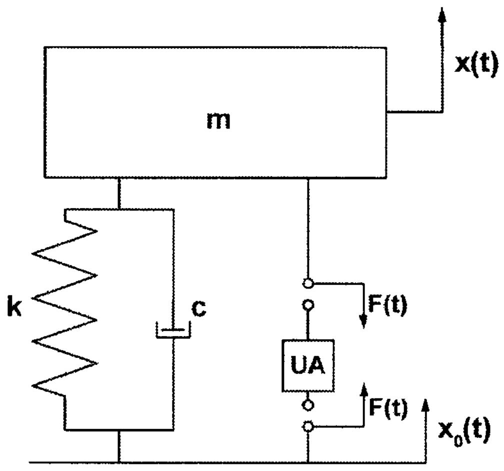


Fig. 2. Active isolator

Unfortunately, this system is quite complicated and rather expensive. For this reason very often we use the so-called semi-active method of control, Fig. 3.

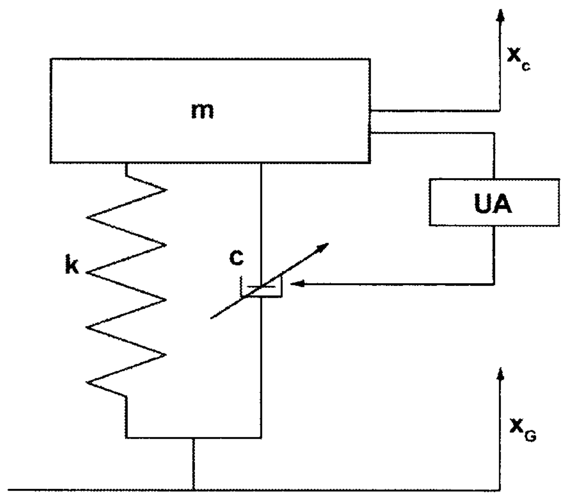


Fig. 3. Semi-active damper isolation

The velocity and acceleration of the isolated mass are measured. The damper is commanded to produce a force proportional to these semi-active signals [1].

Another example of such control is the dynamic absorber which follows the change in the spring stiffness, Fig. 4 [3, 4].

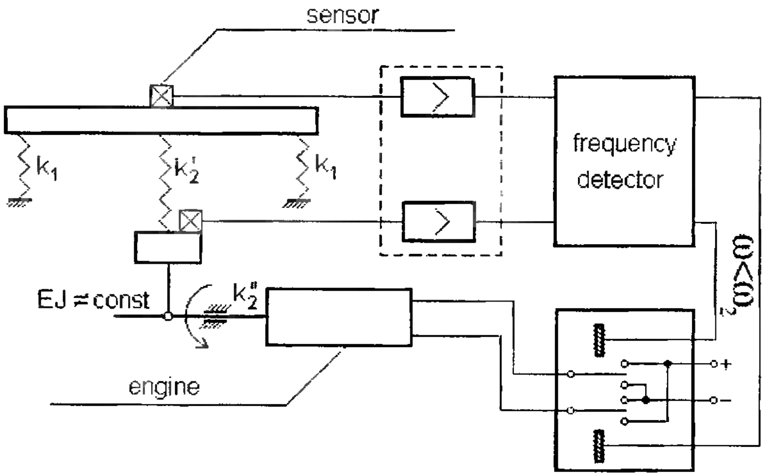


Fig. 4. Semi-active dynamic absorber

2. APPLICATION OF ELECTROMAGNETIC FORCE IN THE CONTROL OF VIBRATION

The dynamic absorber where the mass m_2 is represented by the movable bar inside the induction coil is presented in Fig. 5.

The spring and damping force of the coil depend on electromagnetic interaction. Since this relationships is very difficult to calculate. we introduce the mechanical interpretation.

The spring force:

$$P(x) = a_1 x + a_3 x^3 + a_5 x^5 \ldots \tag{2a}$$

The damping force:

$$P(\dot{x}) = c_1 x + c_3 x^3 + c_5 x^5 \ldots \tag{2b}$$

In this case the equation of motion of the absorber can be described as:

$$\begin{aligned} m_1\ddot{x}_1 + k_1x_1 + a_1(x_1 - x_2) + a_3(x_1 - x_2)^3 + c_1(\dot{x}_1 - \dot{x}_2) + c_3(\dot{x}_1 - \dot{x}_2)^3 &= P_0 \sin \omega t \\ m_2\ddot{x}_2 + a_1(x_2 - x_1) - a_3(x_2 - x_1)^3 + c_1(\dot{x}_2 - \dot{x}_1) + c_3(\dot{x}_2 - \dot{x}_1)^3 &= 0 \end{aligned} \tag{3}$$

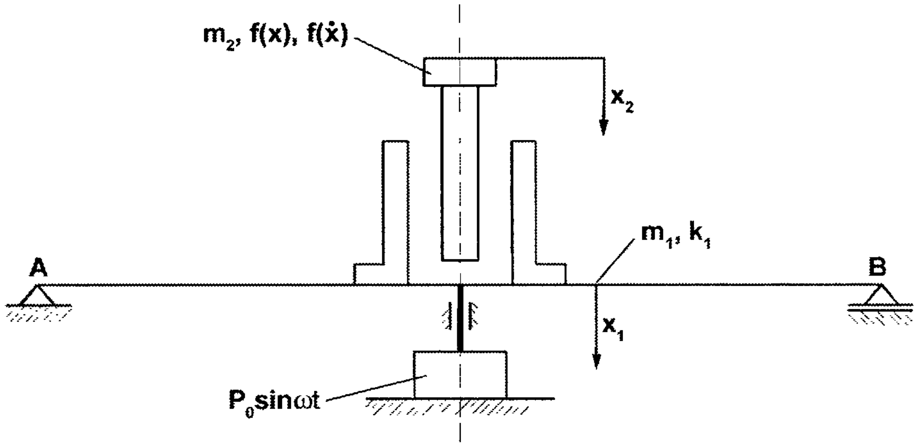


Fig. 5. Electrodynamic vibration absorber

As we can see, only the first two terms (2a, 2b) of the above equation were taken. The unknown terms a_1, a_3, c_1, and c_3 will be determined by experiment.

The equation of motion of mass m_2 can be written as:

$$m_2\ddot{x}_2 + c_1(\dot{x}_2 - \dot{x}_1) + c_3(\dot{x}_2 - \dot{x}_1)^3 + a_1(x_1 - x_2) + a_3(x_1 - x_2)^3 = 0 \tag{4}$$

Assuming stimulation:

$$x_1 = X_1 \cos \omega t \tag{5}$$

and response:

$$x_2 = A\cos \omega t + B\sin \omega t \tag{6}$$

where:

$$\begin{gathered} x_2^2 = A^2 + B^2 \\ A = x_2 \cos \varphi t \\ B = x_2 \sin \varphi t \end{gathered} \tag{7}$$

Substituting (4) and (5) into (3) and introduce x_1 and x_2 from the experiment, we finally obtain the unknown element "a" and "c".

Numerical calculations were carried out for the following values of parameters

$$\begin{array}{lll} m_1 = 0.362\,\text{kg} & m_2 = 0.150\,\text{kg} & k_1 = 700\,\text{N}\cdot\text{m}^{-1} \\ c_1 = 2.8\cdot 10^0 & c_3 = -3.72\cdot 10^0 & \\ a_1 = 5.68\cdot 10^2 & a_3 = -0{,}9\cdot 10^8 & \end{array}$$

The results of calculation are shown in Fig. 6.

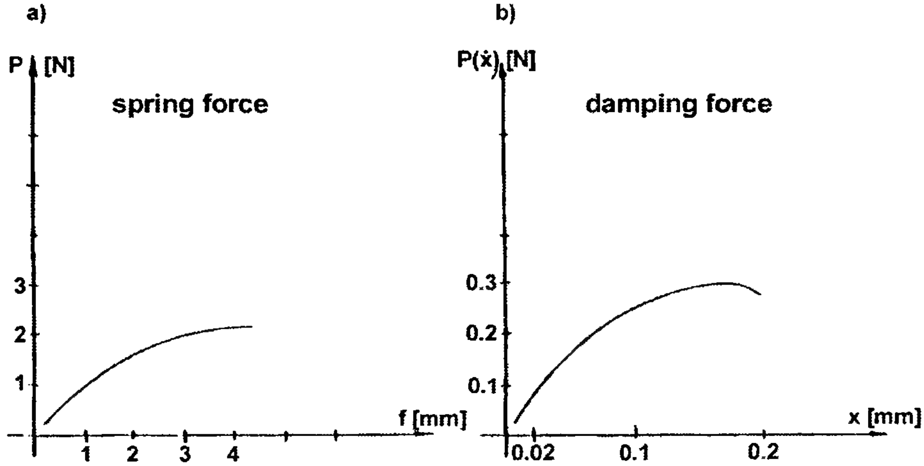


Fig. 6. Spring (a) and damping force (b)

The results of calculation of the electrodynamic absorber (Fig. 5) are presented in Fig. 7.

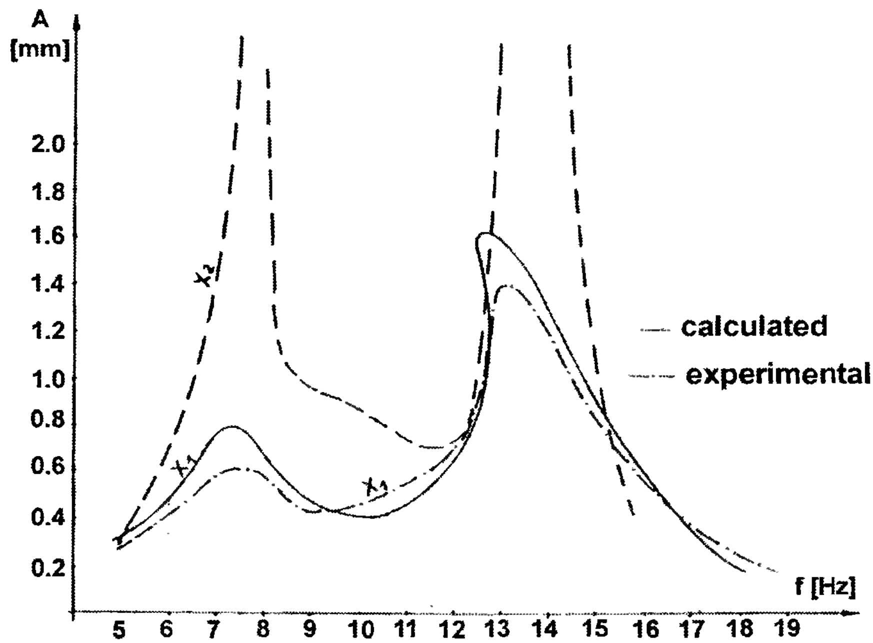


Fig. 7. Amplitude of x_1 and x_2 motions

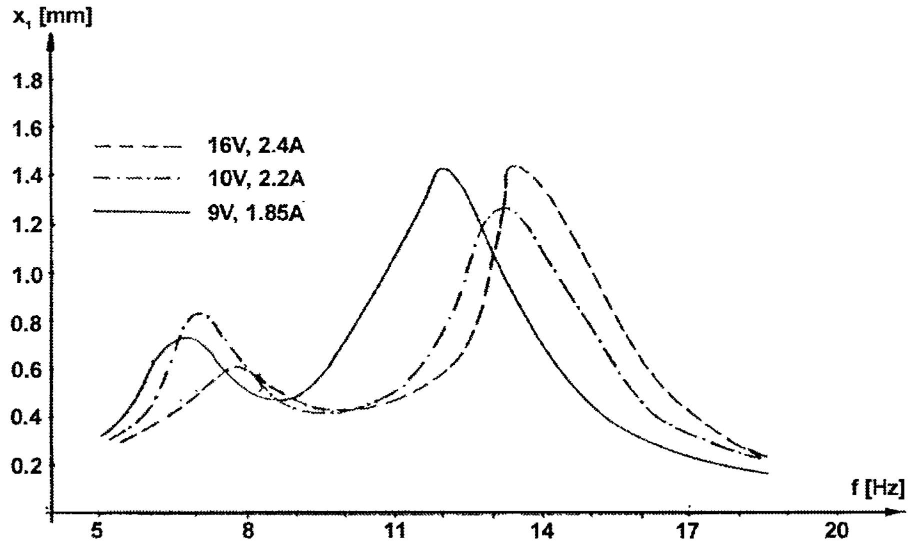


Fig. 8. Amplitude of mass motion m_1 as functions $f(Hz)$ for different values of electric current in the coil

3. CONCLUSIONS

1. The results of the analysis have shown a complete agreement between theoretical and experimental investigations.
2. The spring and damping force of the induction coil can be very easily changed by changing the voltage in the coil. which gives a large potential of applying electromagnetic field in the control of vibration.
3. Electromagnetic field can be used in the semi-active suspension systems.

REFERENCES

[1] Crosby M.J., 1973. The Active Damper a New Concept for Shock and Vibration Control. Shock and Vibration Bulletin 43.

[2] Michałowski S., 1994. Aktywne układy w konstrukcji maszyn roboczych. Politechnika Krakowska, Monografie 171.

[3] Holka H., 1979. A Dynamic Vibration Damper with an Active Frequency Tuning. Fifth World Congress on IFToMM, Montreal.

[4] Holka H., 1984. The Dynamic Vibration Absorber for the Main System with Two Degrees of Freedom. International Symposium on IFToMM. Tokyo.

[5] Burrows C.R. (ed.), 1994. The Active Control of Vibration. Mech. Eng. Pub. Ltd London.

Tomasz Piątkowski
University of Technology and Agriculture
Division of Postal Technology
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

Janusz Sempruch
University of Technology and Agriculture
Department of Control and Machinery Design
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

KINEMATIC STRUCTURES AND PHYSICAL MODELS OF NONPREHENSILE POSITIONING DEVICES

Summary: The paper deals with the problem of the unit loads manipulation by means of the nonprehensile devices and presents basic theoretical guidelines assumed while designing the manipulator pushing sequences. Solutions are offered which include manipulation actions to address different tasks given before the manipulation process, types of manipulator actuators and load dislocation methods.

Keywords: unit loads, manipulation process, pushing sequence

1. INTRODUCTION

The paper is a part of the project realised at the University of Technology and Agriculture in Bydgoszcz with the participation of two departments: Department of Control and Machinery Design (Mechanical Engineering Faculty) and Division of Postal Technology (Telecommunications and Electrical Engineering Faculty). The project is connected with a development of universal dynamic models of sorting and positioning unit load devices. The models are to aid designing of the unit loads sorting and positioning devices, depending on conditions and requirements of manipulation process and physical properties of the unit loads. The coverage of the project mentioned can be presented in a graphic form as a diagram of model connections (Fig. 1). According to the diagram dynamic model of the manipulation process depends on three types of input data: properties of the loads manipulated (unit mass, dimensions, frictional properties, susceptibility to damage, etc.), process intensity (flow intensity, loads dislocation velocity), kind of manipulation process which can refer either to sorting or positioning. The types of data determine the complexity of model (according to the diagram, model features), in which the load can be treated as material point, flat or spatial body, as rigid or viscous-elastic body. The data also determine what physical phenomena, and in what way, should be taken into consideration (for instance sliding dry friction, oblique impact). The authors' past studies concern modelling of dynamic phenomena that occur in automatic sorting process of the load steam with active fences mounted above the conveyor belt. The research has been concluded with doctoral dissertation and a number of papers e.g. [14, 15].

The present paper deals with modelling of positioning process, i.e. object manipulation process limited to one horizontal plane, which is to position the objects finally in a strictly defined way with nonprehensile manipulators (i.e. devices that do not grasp the objects manipulated, but affect them with the an adequately designed impact or strike sequence) [1, 2, 4, 7, 10, 14]. The devices can be made e.g. in the form of active arms (fences) in swinging motion with one degree of freedom or sequence of passive fences mounted above the conveyor belt surface at a given angle to the load stream.

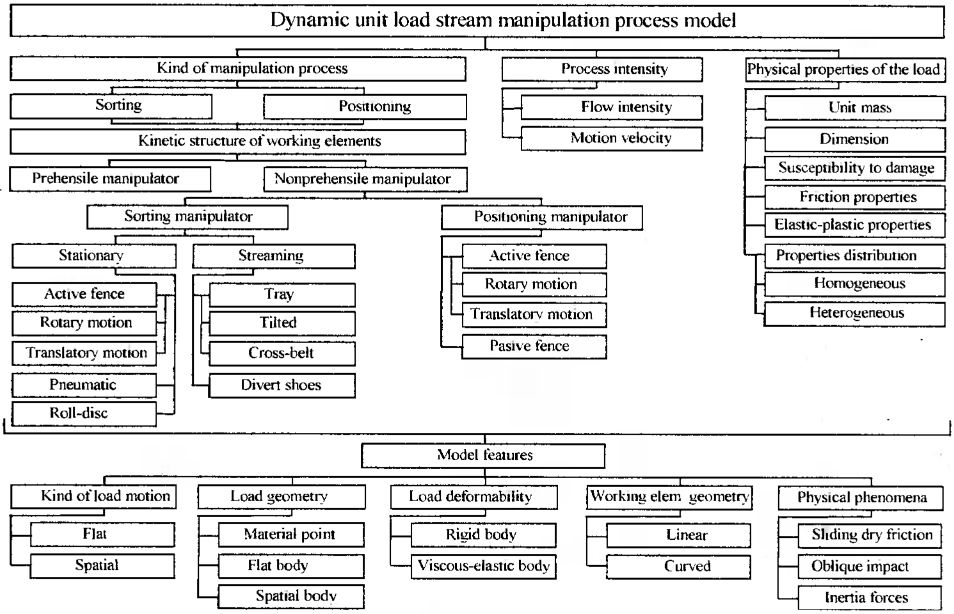


Fig. 1. Diagram of model connections

Despite their simplicity the devices can manipulate the objects that have a great spectrum of shapes, dimensions and mass. Before the positioning process the loads can be freely oriented and situated without any influence on their unique final position accuracy. The application of devices which do not grasp the objects manipulated shows a surprising effect. No rigid joint between the actuator and the object manipulated makes it possible for the object to have a much more complex kinematics than the actuator itself. Nonprehensile devices realize manipulating activities by using gravity, friction and geometric constraints of the object.

The aim of the paper is an analysis of scientific publications available concerning the manipulation process modelling of the unit load stream with nonprehensile devices and focus on problems which are often neglected.

2. LITERATURE STUDY

2.1. Basics of the Push Sequence Design

Scientific papers available today dealing with the problem of the object manipulation by means of nonprehensile devices (e.g. [1, 2, 4, 5, 6, 8]) reduce the necessary theoretical analysis while designing manipulator working motions to the quasi-static issues based on the undeformable bodies. The authors of these papers limit their research to considerations in which the inertial forces acting on the object (i.e. product of the object mass and acceleration forcing its motion) are negligibly small in relation to the friction forces.

The remaining assumptions of the physical manipulation process models:

- object geometry and its gravity centre are known,
- three-dimensional object is taken as flat two-dimensional geometric figure in the shape of convex polygon (in orthographic projection on the plane of object motion),
- fences have sufficient length to span the object,
- support and pushing forces comply with Coulomb's law,
- friction coefficient between the load and the surface in contact with the object is uniform,
- friction forces in translatory motion that appear between the object and contact surface can be reduced to one resultant force acting on a fixed point (does not depend on sliding direction), friction centre, is oriented opposite to velocity of the object motion [9],
- some manipulation techniques assume that between the fence and the load exists slide without friction forces and other techniques assume infinite forces that prevent load from sliding along the fence,
- pushing continues until the object stops rotating and settles in a stable equilibrium position.

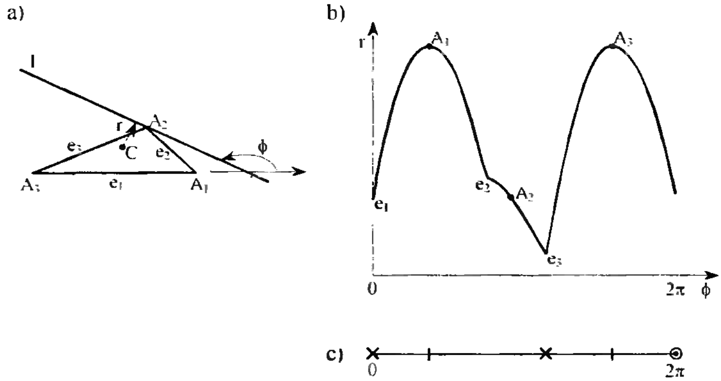


Fig. 2. Assignment of the object geometry features: a) object examined, b) chart of radius function, c) chart of push function

The object behavior as a result of the fence action on its edge is connected with the properties of this edge; it depends on whether the edge is stable or unstable. According to [1, 2, 4], the edge is stable if, while pressing the fence, the load does not change its rotary position, and it is unstable if the object, rotates. Designing indispensable manipulation actions of the fence and their reaction direction is realized so as to lead the load from any initial position into a unique final position (in relation to the stable edge chosen) based on the knowledge of the load geometry that is enclosed in the push function (Fig. 2c). The push function projects positions of the object stable equilibrium (signs x) and unstable (signs in the form of vertical line). If the force direction of the fence reaction on the load is perpendicular to the fence arm (i.e. when the force friction between the load and the fence is neglected), the push function can be simply calculated by means of the object radius function (Fig. 2b). The chart of radius function is created through rolling reference line l round the load shape (Fig. 2a) and representation of the radius length r in a rectangular co-ordinate system Orφ (Fig. 2b). Radius r is led from reference point C in the direction perpendicular to line l. If the reference point is the friction centre and the reference line is the fence frontal surface, then the local minimum of the radius chart determine the stable edge of the load. The corner of the load subjected to the fence action causes rotation of the load so as to reach the local minimum (Fig. 3). Every local minimum designates orientation of the load in which it is in stable equilibrium (according to the fence pressed) and each maximum designates unstable equilibrium. More detailed relations occurring between the load and the fence are presented in the next chapter.

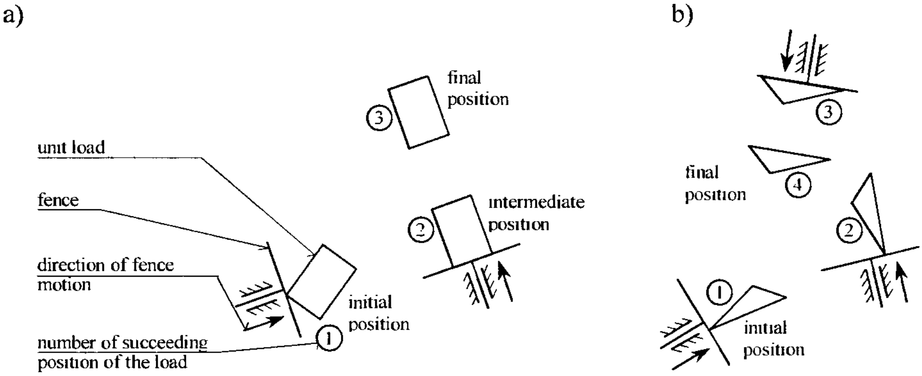


Fig. 3. Chart of working motions of the fence that dislocates unit load: a) rectangular, b) triangular

2.2. Examples of Object Manipulation Techniques by Pushing

2.2.1. Manipulators with Active Fences

The load manipulation process based on giving specific translatory and (or) angle position usually requires a series of fence working motions. The object destination intended reached by a single fence action can take place in exceptional load arrangements.

In Fig. 4 an example of driving the load to an exactly established position through a number of intermediate positions is presented. The object dislocation is realized by means of the fence with deflection working motion mounted above the conveyor belt (moving with a fixed linear velocity v) [1]. The desirable position (from any initial position) is obtained as a result of properly planned push sequence of the fence alternated with the free object drift along the conveyor. The selection of the fence actions follows the initial position data of an object approaching and its geometry read and processed by the manipulator system measurement equipped with a video camera. The essential assumption of this solution is no slip between the object and the fence.

Another variant is a solution which requires only a detection sensor recognizing object presence in the manipulator work zone (e. g. light barrier) to start the fence working motion (Fig. 5, [1]). The manipulation process is realized as a result of single information about the type of the manipulated object. The fence working cycles are worked out so as to (common for every object of a given type) permit an efficient object manipulation in any of its initial pose. The main assumption is the frictionless slip between the object and the fence. The fence manipulation activities begin with the object interception by the fence and its location at the end of the fence limited by a bumper. The object motion along the fence (until the fence end) is realized through the fence deflection consistently with the belt velocity motion.

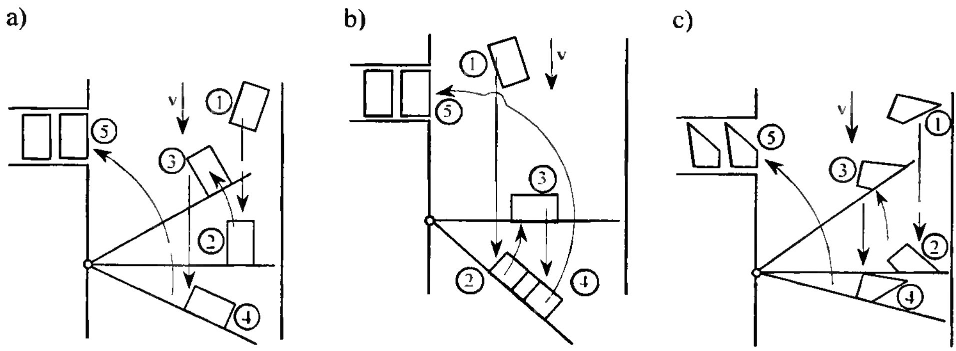


Fig. 4. Physical model of the manipulator with rotary arm with one degree of freedom [1]: a), b) rectangular load, c) asymmetrical quadrangle load

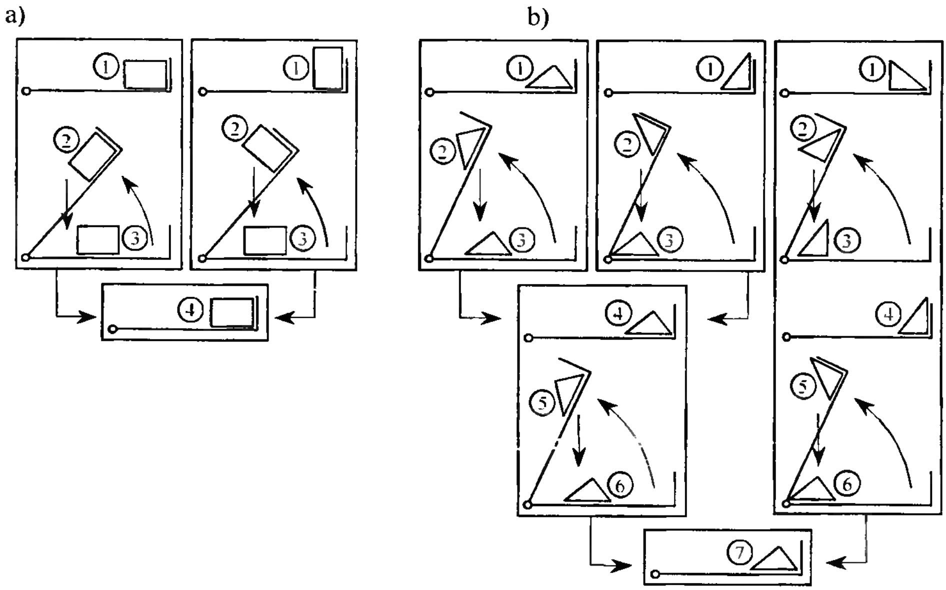


Fig. 5. Examples of the active fence push sequence for the loads [1]: a) rectangular, b) triangular: loads from any initial position get specific final position

2.2.2. Manipulators with the Passive Fences

A change in the object orientation (and its position) can be also obtained through an application of a sequence of the passive fences located diagonally along the conveyor belt surface (motionless fixed arms, Fig. 6 [3]).

The objects reach the desired location (from any initial) due to the effect of fences without any sensor application. The conveyor belt motion makes the object resting on the belt rub against the fences so that the fences acting on the objects realize a suitably planned push sequence. The object slip along the fence arranges it against one of the stable edges. Upon leaving the fence, the object is parallel (this edge that has contacted the fence recently) to the conveyor axis. The fences, which act in the following way, make the object turn in a suitable direction.

AKADEMII TECHNICZNO-ROLNICZEJ Biblioteka GŁÓWNA w Bydgoszczy

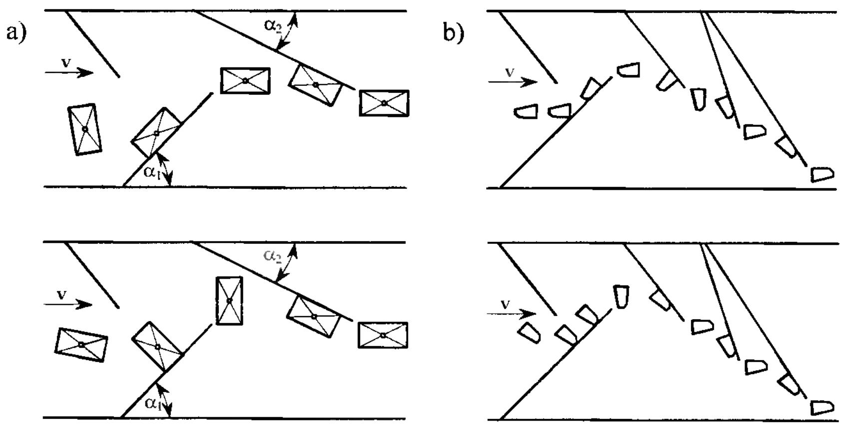


Fig. 6. Examples of the passive fences sequence manipulating the unit loads stream [3]: a) rectangular, b) pentagonal; the loads independently of the initial position get specific final position

The object process manipulation in more than one plane can be conducted by means of passive fences sequence and cascades placed one above the other bearing surfaces inclined to the level of the bearing surface, Fig. 7 [4]. The objects sliding over the bearing surface also rub against the fence so that the object is affected by pushes from two perpendicular directions: the bearing surface and the fence. It is assumed that the object stabilizes its position at first according to the bearing surface, and next, according to passive fences attached to this surface. During the fences actions, the object rests on the wall that was designated before the object came into contact with the fence. The rest wall change is realized as a result of the object transition from one bearing surface to the next.

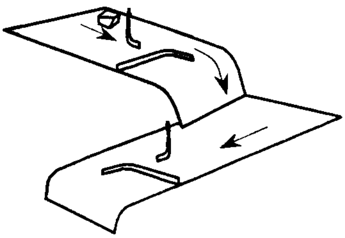


Fig. 7. Example of cascades located passive fences that manipulate the unit loads stream in two plates [4]

Manipulators that are built based on a passive fences sequence and during their work do not require any sensors and they are designed for objects with specific geometric features (Figs. 6, 7). The knowledge about the object geometry and feasible scenario of the load dislocation is hidden in the structure of the device. These devices during their exploitation can operate the objects that are described by the same push function. The objects with different characteristics and a different final position require manipulator rebuilding. The object manipulation techniques that use active fences (Fig. 5) dislocate the object according to programmable (by control system of the manipulator) push sequence. The change of the object geometry is not connected with a need of arm change but only with the change in their motion program.

3. REMARKS CONCERNING THE MODELS OF THE MANIPULATION PROCESS

The authors of the paper have experiences connected with investigation of the object manipulation process that consists in loads stream separation – sorting of the unit loads stream (Fig. 8 [12, 13, 14]). The process is characterised by a big similarity to the above examples of the loads process positioning, with one exception – the sorting process is realised in one working cycle of the fence (for the individual object) and positioning process, usually as a result of multiple fence working motions. The experiences show that the modelling assumption of no effect of inertial force is too much simplified; the assumption seriously limits the theoretical model simulation results conclusions. Based on the model we cannot assess properly the effect of the manipulation process parameters (i.e. load dislocation velocity, fence motion velocity) on the behaviour of the loads manipulated: i.e. their patch motion, strike results between the load and the fence, load damage causes, manipulator construction load level.

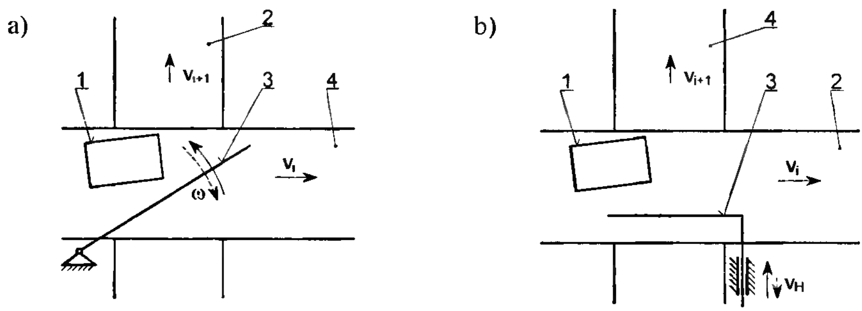


Fig. 8. Physical models of the active fences used in sorting process of the unit loads stream: a) deflection motion fence, b) translatory motion fence: 1 – load, 2 and 4 – conveyor belts, 3 – fence, v_i – linear velocity, ω – angular velocity

Another essential manipulation process model assumption which seriously limits its applicability to decision-making about the kinetic manipulator structure is neglecting the friction forces between the load and the fence sliding or assuming no sliding. So perfect work cases are extremely rare. The frictional forces between the load and the manipulator fence [11] has a big influence on the characteristics of the object push function. These forces (i.e. friction coefficient: $0 < \mu_2 < \infty$) shift the object balance positions (with the value of an angle friction) and in some cases lead to a loss of the stable edges. As a result of these modifications, the object push function has totally new properties; a change in the object reaction to the fence effecting. By considering the friction (between the load and the fence), the manipulator with a totally new kinetic structure should be designed for a new push function.

On the basis of the authors' preliminary research, for the object manipulation with a passive fences system, the loads leaving each of the fence do not position themselves (the edge that has been in contact with the fence recently) parallel to the conveyor belt axis, as it is assumed e.g. in the paper [3]. After the loads leave the fences, they do not assume parallel position; they are rotated in relation to the axis of the belt. The load rotation depends on the object shape, the load motion velocity, angle of the fence position, friction property of the fence and can even assume the value above 20°. During designing of the manipulator push sequence this fact should be also taken into consideration.

4. FINAL COMMENTS

The technique of object nonprehensile manipulation based on performing push sequence allows for the complex kinematics object motion in one plane. The objects of any initial position can be brought to the final position against the designated edge of the object in a fully controlled way. An important progress that contributes to the new quality in the range of nonprehensile object manipulation is speeding up this process (by increasing the fence velocity action and the loads transporting velocity). This approach makes it necessary to consider the object motion in dynamic approach. An increase in the motion parameters in the object manipulation process requires research order to find solutions which would consider the object susceptibility to mechanical damage.

REFERENCES

[1] Akella S., Huang W.H., Lynch K.M., Mason M.T., 2000. Parts Feeding on a Conveyor with a One Joint Robot. Algorithmica 26, Springer-Verlag, 313-344.
[2] Akella S., Mason M.T., 1998. Posing Polygonal Objects in the Plane by Pushing. The International Journal of Robotics Research 17, 70-88.
[3] Berretty R.P., Goldberg K.Y., Overmars M.H., Stappen A.F., 1998. Computing fence designs for orienting parts. Computational Geometry 10, Elsevier Science, 249-262.
[4] Berretty R.P., Overmars M.H., Stappen A.F., 2002. Orienting Polyhedral Parts by Pushing. Computational Geometry 21, Elsevier Science, 21-38.
[5] Cutkosky M.R., Wright P.K., 1986. Friction Stability and the Design of Robot Fingers. The International Journal of Robotics Research 5, 20-37.
[6] Erdmann M.A., 1994. On a Representation of Friction in Configuration Space. The International Journal of Robotics Research 13, 240-271.
[7] Goldberg K.Y., 1993. Orienting Polygonal Parts without Sensors. Algorithmica 10, Springer-Verlag, 201-225.
[8] Kao I., Cutkosky M.R., 1992. Quasistatic Manipulation with Compliance and Sliding. The International Journal of Robotics Research 11, 20-40.
[9] Mason M.T., 1986. Mechanics and Planning of Manipulator Pushing Operations. The International Journal of Robotics Research 5, 53-71.
[10] Mason M.T., 1999. Progress in Nonprehensile Manipulation. The International Journal of Robotics Research 18, 1129-1141.
[11] Piątkowski T., Sempruch J., 2002. Analysis of the Manipulation Process of the Unit Loads. Technical University of Lodz, Mechanics and Mechanical Engineering, Problems of Working Machines Development 6, 187-194.
[12] Piątkowski T., Sempruch J., 2002. Bezier's Curve in Modeling of Scraper's Arm Geometry. [In:] Tarnowski W., Kiczkowiak T. (eds.), Polyoptimisation and Computer Aided Design. WNT Warszawa, 183-190.
[13] Piątkowski T., Sempruch J., 2002. Physical Models of the Unit Loads Stream Sorting Process. [In:] Sempruch J. (ed.), Development in Control and Machinery Design. Wyd. Uczeln. ATR w Bydgoszczy, 65-70.
[14] Piątkowski T., Sempruch J., 2002. Sorting Process of Load Units – Dynamic Model of Scraping Process. The Archive of Mechanical Engineering 49.
[15] Piątkowski T., Sempruch J., 1999. Model and Analysis of Selected Features of Scraping Process. 10th World Congress on the Theory of Machines and Mechanisms. Oulu, 59-167.

Michal Styp-Rekowski
University of Technology and Agriculture
Division of Machine-tools and Robots
Prof. S. Kaliskiego 7, 85-796 Bydgoszcz

FORMATION OF FUNCTIONAL PRODUCTS FEATURES IN PARTICULAR SPHERES OF ENGINEER'S ACTIVITY

Summary: In this paper the analysis shows possible products features decision-making in the following spheres of engineer's activity: designing, production and using. As functional features of both individual elements and whole machines are limited by design features, we can discover a possible influence on functional features almost in all the domains of engineer's activity.
The range of possibilities differs in the individual phases: the possibilities are mainly a costs function. ISO documents which refer to quality standard implementation state that changes in designing are 10-times more effective than those introduced during experimental verification of prototype and 1000-times, than those introduced in the operating process.
This paper presents an attempt at identifying possible effects on functional features at particular stages of the existing real product cycle. An example of rolling pairs has been considered, which confirms the results of literature reports.

Keywords: engineer's activity, functional product features, existing product cycle

1. IDENTIFICATION OF PARTIAL PROBLEMS, DEFINING NOTIONS

To address the subject of the present paper, the main issues have been defined which are as follows:

- engineer's activity,
- cycle of product existence,
- its functional features.

Generally, they are well-known notions but sometimes differently understood and to make the present considerations clear and unambiguous, the notions have been defined and discussed.

1.1. Engineer's Activity

Engineer's activity, with some simplifications, can be referred to us solving all technical problems resulting from current needs. It is an essential feature of this activity to consider its wide surrounding, including the results of the activity, see Fig. 1.

Constructing a highway to satisfy the need of fast movement of people and commodities can be a spectacular example which justifies the necessity of such a wide meaning of engineer's activity. The highway generates a new need of creating its whole infrastructure, which comprises not only petrol stations, catering facilities, sanitary facilities but also a network of local collision-free roads. Developing the highway, one should consider also its influence on the environment (noise, fumes, fuel vapours etc), as well as the opposite influence – of the environment on the highway (wild life in forests and fields adjacent to the road may disturb the traffic).

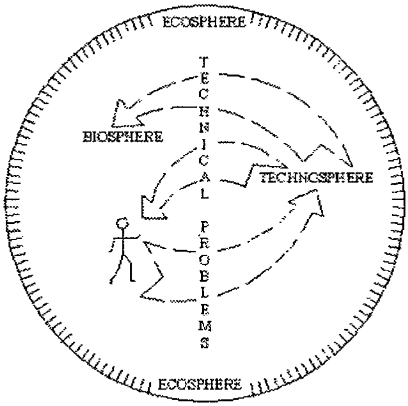


Fig. 1. Essence of engineer's activity [4]

The example presented is far from machinery engineering domain but it concerns all of the society, it includes also a wide spectrum of aspects to be considered in every field of engineer's activity and therefore it has been quoted here.

Engineer's activity is based on the essential knowledge of the subject, using skills acquired, showing a proper attitude [6]. The most essential elements, which condition the activity, are presented in Fig. 2.

The range of indispensable essential knowledge of the subject, in its particular domains, changes depending on the problem to be solved and, therefore the best results are obtained in engineer's activity realized in teams made up of depending on the needs.

The skills in Fig. 2 create a general one which can be referred to as *skill of creative thinking and working*. Out of the elements attitude, a special attention must be paid to the last two. The first of them, *ecological consciousness* should trigger a pursuit of a maximum reduction in the actions degrading the environment, not only for moral reasons, but also technological and legal ones (ISO 14000 standards). What is interesting and worth of popularising is the view that '*No technological process generates wastes; apart from the end product, also by-products are generated, which at times (according to the state of the art) one does not know how to process into supplies being a source of wealth*' [1]. Such an attitude ensures proper relations between technosphere and biosphere.

The second element of the attitudes: *pursuit of knowledge updating and broadening as well as improvements of skills* is also very essential. The progress which is observed practically in all the fields of science makes it that, without this element of attitude, creative engineer's activity is simply impossible. A great deal of indispensable knowledge makes it also that to meet the needs, one should get to know the most effective methods of learning. '*The illiterate of the future will be the man who does not know how to learn to learn*' [3] seems very accurate.

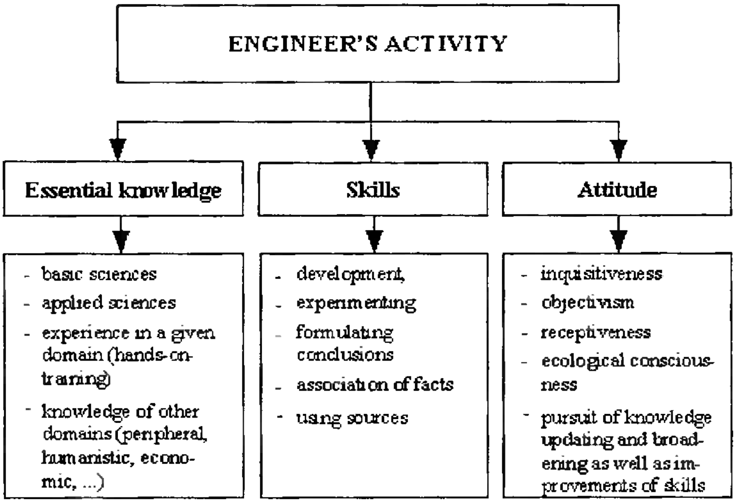


Fig. 2. Elements of engineer's activity

1.2. Cycle of Product Life

The *product life cycle,* the second issue discussed, comprises the following stages:

- developing (the so-called valuating),
- designing,
- production,
- operation,
- utilisation.

Developing is a logical function of the attitude of the project creator to the need. The results of developing, at the next stage, *designing*, are the base to determine this attitude to the product. *Production* is the stage of the product life in which it materializes as a result of technological processes. The end product begins thee next stage of its life, *operation*, namely the process of use in accordance with its purpose and with indispensable services. The stage lasts until a total wear of the product. Then begins the last stage, *utilization*, in which the product is made possibly least burdensome for the environment, in the most useful way for the user. This stage, until recently completely marginalized, is becoming more and more important.

1.3. Functional Features of the Product

The third issue considered are *functional features of the product.* For machines, they will be mainly their performance. The basic criterion to be considered are the needs and expectations of the user. However one should remember that a given machine will be operated in a given environment and under defined conditions. These factors should limit the definition of functional features selected by a choice of the following design features (DF) [4]:

- material,
- geometrical,
- dynamic.

Material design features (MDF) define the internal structure of the material used to produce a given end product and geometrical design features (GDF) define its external structure. Dynamic design features (DDF) define the states of the product caused during production (processing and assembly).

2. RELATIONS BETWEEN THE ISSUES IDENTIFIED

To estimate the potential of developing functional features of the product, in particular spheres of engineer's activity, it is necessary to define mutual relations among respective stages of the product life cycle, as well as to identify the activities which can affect functional features of the product.

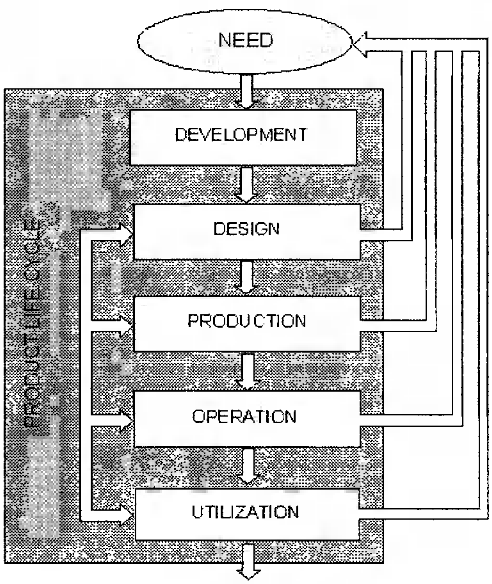


Fig. 3. Product life cycle stages and their mutual relations

2.1. Engineer's Activity and Product Life Cycle

Engineer's activity takes place in spheres marked directly by respective stages of the product life cycle. The relations among respective stages of the product life cycle, which is also among respective spheres of the activity, are given in Fig. 3.

Respective stages follow one after another and each next one is a result of the previous stage. Among them there are interactions which, in each of them, make it possible to verify and potentially correct actions in the previous stages.

2.2. Possibilities of Affecting Functional Features of the Product in Respective Stages of the Product Life Cycle

It is possible to decide about design features of the product at the following stages: development, designing, production and operation. As functional features of both respective elements and the whole products are defined by design features, one can, therefore, claim that a possibility of affecting functional features exists in almost all domains of engineer's activity.

The range of these possibilities differs, however, a cross phases and they are mainly costs function. The range of possibilities differs in the individual phases; the possibilities are mainly a costs function. ISO documents which refer to quality standard implementation state that changes in designing are 10-times more effective than those introduced during experimental verification of prototype and 1000-times, than those introduced in the operating process. These observations are confirmed in publications, e.g. [8].

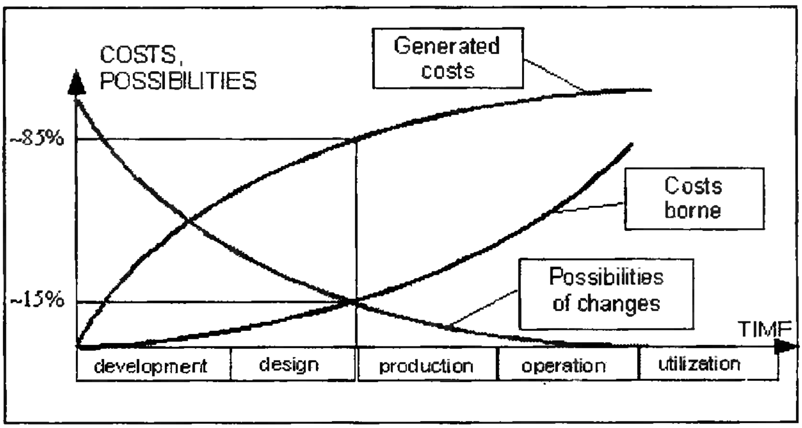


Fig. 4. Costs and possibilities of changes in the next stages of product life cycle [8]

In this paper qualitative relations among the factors discussed have been introduced in Fig. 4. The graphic representations show that development and design stages consume only up to 15% of the total costs of satisfying the need. At the same time at these stages, decision are taken which account for about 85% of the costs indispensable for the realization of the whole task. The figures show also that at every stage of the product life cycle, the possibilities of introducing are smaller.

The above statements can justify a special interest in the two first stages of the cycle (development and design) of the persons educating engineers. Numerous papers and books e.g. [2, 4, 6, 7, 8, 10] are a tangible evidence here.

The answer to the question, being the title of the paper [7]: '*Design engineering: art, science or craft?*' is the essence of the actions discussed in the spheres – they are all in one. One should remember about it in the process of educating engineers, as the main executors of engineer's activity.

2.3. Engineer's Activity and Functional Features of the Product

Developing functional features of the product can take place in the following cases:

- to give expected features to the new products,
- modification of the present features,
- changes in functional features, e.g. due to a change in the products application.

The first case is most frequent and for that reason it is covered in more detail. It is discussed with an example of rolling bearings.

At the first two stages (*development* and *design*) by a selection of all the three design features: geometrical, material, and dynamic, it is possible to influence the functional features of the products developed. As for rolling bearings, an adequate GDF selection of their elements (including a definition of their proper mutual relations) allows for a decrease in motion resistances, as well as an increase in durability due to a decrease in the intensity of wear [9]. A result of an adequate selection of MDF, which is mainly a selection of the material (depending on the function to be served), is a costs reduction by, e.g. an increase in durability, reduction in services and repairs. At those stages of engineer's activity the third feature (DDF) can be directly affected, e.g. by ensuring the initial stress control in the bearing or indirectly – by a selection of material which would guarantee, with the foreseen technology, the best operational features of the surface layer (SL) in loaded element zones (mainly for tensions in SL).

At the *production* stage, it is possible only to influence dynamic selection DF. The method of inducing initial stress (DDF), as well as its value, are followed at the second stage, and while producing the whole machine (in assembly), it is only possible to control its value. The geometrical and material features assumed have been, in fact, already determined.

While producing, the material structure, mainly in surface layer, and also on MDF, can be affected only by changing the technological process. In that way it is also possible to affect DDF, e.g. polishing grind wheel results in SL positive tensions (stretching) and the tape – the negative ones (squeezing). As for rolling bearings, the sign of tensions in SL is a very essential feature affecting their durability considerably.

The effects are observed at the fourth stage, *operation*. Ensuring proper conditions guarantees long, failure-free operation. An adequate diagnostic during operation allows for possibly fast reaction and prevents from the effects of extensive breakdown. It is possible to affect the course of inevitable wear with a material and dynamic design feature (e.g. lubricating, checks and control of internal load) at the stage of operation.

The last stage, *utilization*, at the present state of social development is comparatively essential to those presented earlier. At that stage of product life there is neither a possibility nor a need anymore to influence the functional features of bearings, however this stage should be remembered about from beginning of product life, because the susceptibility to utilization is specified already from the development stage.

The two remaining cases of developing functional features are also interesting. My own experience, gained in the industry, shows cases of both [5].

The first one concerned a possibility of decrease in power consumption by calcium-silicate brick press. It was achieved due to polarising the pressed substance. The change, which decreased by over 30% the power consumption indispensable for the pressing process, maintaining its efficiency, was introduced at the machine operation stage. It was possible thanks to the know-how from the field only indirectly connected with machine engineering.

The second example concerned a change in the machine application method which requires a change in its functional features. As a result of economic transformation, the demand for construction material industry machines decreased considerably, which made the manufacturer search for new attractive products which it would be possible to produce under the plant conditions. The search was oriented at environment protection, as one of the directions. It was a good choice which was possible with a few changes only to adapt some machines to new applications. In jaw crushers it was enough to reduce the product granulation dimension range to apply them to glass waste recycling. They could be used without changes in utilization of ceramic construction wastes. In both examples the power consumption was reduced for a lower sufficient efficiency. In the first case introducing the change in functional features was possible at the development stage, while in second example – already during operation.

Similar changes were applied to screens. Another screened medium made it only necessary to cover the sieves with coating increasing resistance to corrosion.

The examples show also that the position of the company on the market depends not only on its production potential but at times also a skill of fast adaptation to the new needs.

The analysis show that the best results of developing and optimisation of functional features are obtained when decisions are taken at the stages of development and design, which is enhanced by methodological approach. The above justifies the aspirations to develop the methodology and guidelines which would ensure an adequate at possibly effective realization of the product life [2, 4, 10].

3. RECAPITULATION AND CONCLUSIONS

The considerations presented suggest that the three issues identified at the beginning of this paper are mutually related, see Fig. 5. It shows that each element discussed determines, to some extent, the other two. The quantitative relations depend mainly on the object considered.

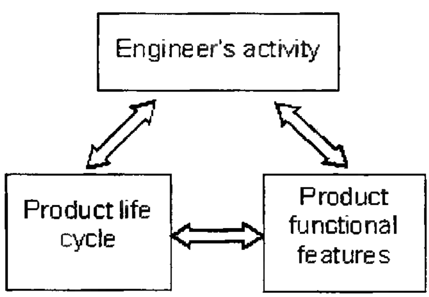


Fig. 5. Mutual relation among the issues analysed

The above-presented considerations concern one domain of engineer's activity, namely creative activity. The second one, engineer's reproductive activity, is also useful but as compared to the first one, it is clearly narrower and it requires from persons who realizes it much less knowledge and skills.

The considerations presented also allow for some generalizations which can be formed as the following conclusions:

1. Engineer's activity should be free from particularism, and its indispensable feature should be a wide approach to the technical problem being solved.
2. Developing functional features of the product takes place practically in every (except for utilization) sphere of engineer's activity. Possibilities of developing these features in particular spheres vary; the greatest at initial stages and the smallest at final stages.
3. Considering the range of developing or changes in functional features, as well as the cost of these actions, a special attention should be paid to development and design stages. At these stages of product life the possibilities are the greatest and the cost of implementing changes – the lowest.
4. It is not required every time a new need emerges to generate a full cycle of new product life. In many cases its respective stages can be skipped or at least minimized.

REFERENCES

[1] Bielski I., 1999. Ekologiczny wymiar współczesnego marketingu. Ekologia i Technika 3, 67-72.

[2] Branowski B., 1999. Metody twórczego rozwiązywania problemów inżynierskich. Wyd. Wielkopolskiej Korporacji Technicznej NOT Poznań.

[3] Cempel Cz., 2002. Superlearning – i co dalej? Referat wygłoszony na Seminarium Katedry Maszyn Roboczych i Pojazdów Wydziału Mechanicznego ATR w Bydgoszczy.

[4] Dietrych J., 1985. System i konstrukcja. WNT Warszawa.

[5] Kałędkowski J., Musiał J., Styp-Rekowski M., 1999. Techniczne i utylitarne aspekty recyrkulacji odpadów budowlanych. Mat. IX Międzynarodowej Konf. Nauk. Recyrkulacja w budowie maszyn, ATR Bydgoszcz, 231-236.

[6] Krick E.V., 1975. Wprowadzenie do techniki i projektowania technicznego. WNT Warszawa.

[7] Osiński Z., 1999. Konstruowanie: sztuka, nauka czy rzemiosło? Mat. XIX Sympozjonu PKM, t. 1, Zielona Góra – Świnoujście, 97-112.

[8] Rohatyński R., 1999. Projektowanie techniczne w inżynierii współbieżnej. Mat. XIX Sympozjonu PKM, t. 1, Zielona Góra – Świnoujście, 117-142.

[9] Styp-Rekowski M., Musiał J., 1997. Kształtowanie cech tribologicznych łożysk specjalnych na poszczególnych etapach działalności inżynierskiej. Tribologia 5-6, 921-928.

[10] Szala J., 1990. Podstawowe zagadnienia w konstruowaniu maszyn. Wyd. Uczeln. ATR w Bydgoszczy.

Dariusz Skibicki
Marcin Farbotko
University of Technology and Agriculture
Department of Control and Machinery Design
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

INTERNET-BASED TECHNICAL PROJECTS MANAGEMENT SYSTEM ALLOWING FOR TEAM-WORK IN DISPERSED ENVIRONMENT

Summary: The present papers covers conceptual presumptions and work of Internet application that supports the design-engineering process in the dispersed team. This system allows collecting, storage and accessing data of technical projects via the Internet, which makes it possible for projects participants to cooperate, while performing their tasks in a different time and place.

Keywords: CAD, Internet, design- engineering process, documents circulation

1. INTRODUCTION

At the beginning of the 80s a possibility of using computers to work together to support engineer work became a fact. Together with the first applications for designers the new notions, such as CAD, CAM and CAE, came into use. Nowadays there is a huge number of constantly-evolving computer programs beyond the shortcut CAx. Probably the most important change concerns the way of presenting the modeled artifacts. At the first stage of CAD, the first applications were used to create (it was indeed time-consuming although it required only bows and lines composition) two-dimensional drawings documents. Nowadays the applications are based on three-dimensional record of the structure. The information this kind of model contains can be used to create technical documents (drawings, lists of parts), calculations (e.g.: MES) and generating NC codes almost automatically.

The changes in most cases concern only individual design [1] process, namely: work of the single engineer in a separate (computer) work post, on a separate design task. In fact modern CAD programs allow team cooperation via the net, LAN in most cases. Besides CAx type programs support only part of design-engineering process, e.g. they concern only designer tasks that are apart of the structure shaping process. A great diversification and individualization of the CAD, CAM, and CAE program group can be still seen in data exchange between systems as well as from an organization (integration) of the design-engineering process point of view, communication in the design-engineering team, etc.

It is worth mentioning that there is a group of documents management dedicated programs, based on the Internet browser, e.g. Microsoft Project 2000 with the Internet extension: Microsoft Project Central. This application is dedicated to a wide group of users; it concerns the project management problem in general, and as such it becomes very difficult to tailor it to the needs of design-engineering process. The experience of the authors (2000-2001) shows a number of imperfections of this software, especially when updating database by both, administrator and user of the system. When there is no efficient technical support available, which refers to the period of 2000-2001 it must be considered as the problem that questions the idea of using the system mentioned.

Obviously, the complex systems, integrating work in large companies, such as I-DEAS, CATIA, has existed for quite a long time. Nevertheless, the authors pay attention to the needs of small and medium-size companies. However, as Wróbel [3] stresses, despite relatively high financial resources, for small and middle-size companies those systems are too expensive.

However, a development of telecommunications, computer networks and, particularly, the Internet and client-server applications makes it possible to create proper information channels between persons engaged in the project task [1] so it becomes possible to create computer systems which can respond to the needs of design-engineering process in a complex way, in small and medium-size enterprises.

The present paper is a description of the computer program that helps to go through the defined stages of the design-engineering process in dispersed work team [1]. The main scope of this work are information flows at each stage of the design process: structural (modeling the structure, selection of the structural features) and execution process (preparing technical and technological documents) [2].

The 'team' notion is provided [1] with the adjective 'dispersed', to stress a lack of limits concerning the distance between design-engineering process team members and differences in time of their work.

The system which is covered by this article has been developed by Faculty of Mechanical Engineering, the University of Technology and Agriculture in Bydgoszcz.

2. PRESUMPTIONS CONCERNING PROGRAM FUNCTIONS

It was assumed that systems described known as Projects Central Station need to offer the following functions and features:

1. It supports the flow of information on the project in the dispersed group of persons engaged in the process so it allows to: collect, store and access the information.
2. It presents information about the project in a given order as a tree which is the visualization of the project structure.
3. It treats design-engineering process as a time-evolving event. In practice it means that e.g. it allows to edit (change) the project structure, remembers the history of the project: it administrates versions of the documents and generates log (event register).
4. The scope of its work are design and execution phases: it can transform different kinds of documents and files.
5. It supports team work; it protects the documents from deleting (e.g. overwriting) information by other members of the team.
6. It notifies about events important for the user, shortening the time of response and rationalizing cooperation.

The system is based on the client-server architecture. It makes hardware and software basic layers, discussed in Section 4. The solutions of the database architecture for keeping the information are presented in Section 5. The work of the system and its utility is presented in Sections 6 and 7; the way the system collects and allows to access data.

3. CLIENT-SERVER ARCHITECTURE

To make collecting, storage and access to the information on the process possible from any work post and in any time, a computer system based on client-server architecture is proposed. The server is constantly connected to the Internet. The user requires the Internet connection (the temporary, e.g. by modem) and WWW browser is required.

Project data storage concerning on a server is possible through database server and properly designed structure of the database. Information storage and access is possible through WWW server, which is the element that joins database server with the user's computer, by means of active HTML pages (ASP). The WWW server transforms data stored in the database into HTML sites sent to the client's browser, and from HTML forms sent by the user, it collects data and stores it in the database.

Data files storage is executed in server folders of a suitable structure. Files transport to and from the server is ensured by FTP protocol.

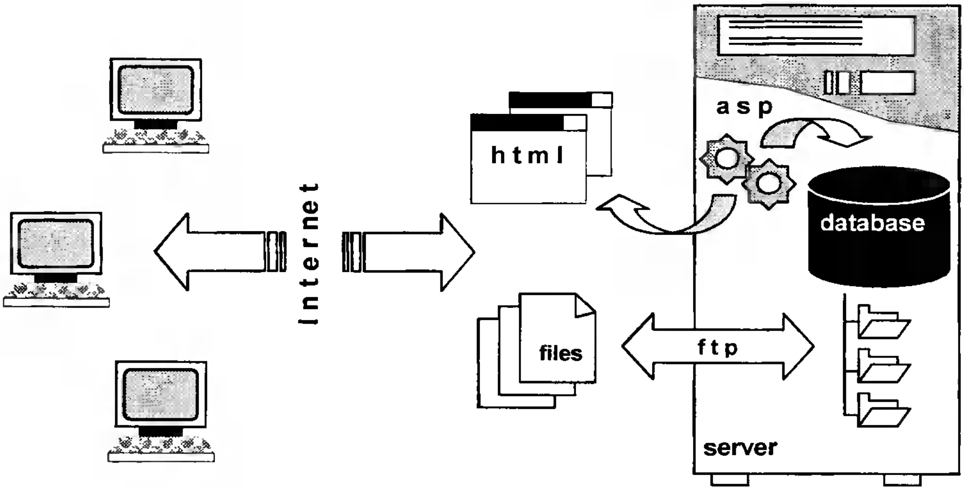


Fig. 1. System architecture

4. STORAGE AND PRESENTATION OF PROJECT INFORMATION

The project is understood by the system as a collection of elements linked to one another (Fig. 2). The elements are linked to one another in a special way, as each an element has to contain (except for project data) information about the space it occupies in the tree-structure of the project.

It is presumed that the structure of the project elements is the picture of the functional structure of the product designed (functions the products consist of) and that it will have a mounting character [2]. Therefore the project element can be only a part or combination of parts. The combination of parts is interpreted as a group of parts or other combinations of parts (Fig. 3). Each element stores only information concerning a superior element. It means that the part becomes a combination of parts, if there is the subordinate element in the project database.

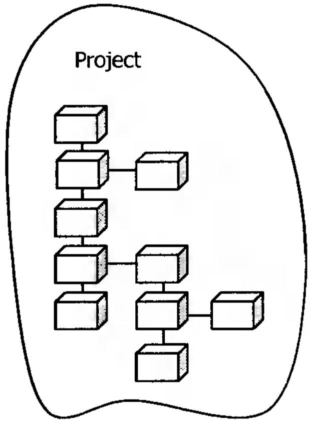


Fig. 2. Project as the collection of linked elements

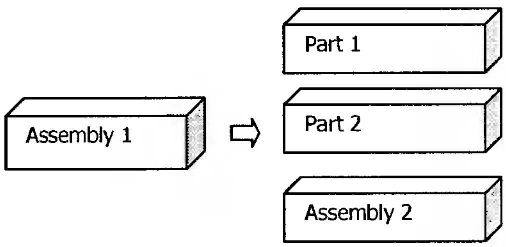


Fig 3. Structure of the combination of parts

The part is interpreted as the last, undividable element of the structure [2]. In this system the part can be interpreted as a container (folder) that stores elements linked to this part. Each document, except document file, stores in the database additional descriptive information, such as: author, date, material, standard, etc (Fig. 4).

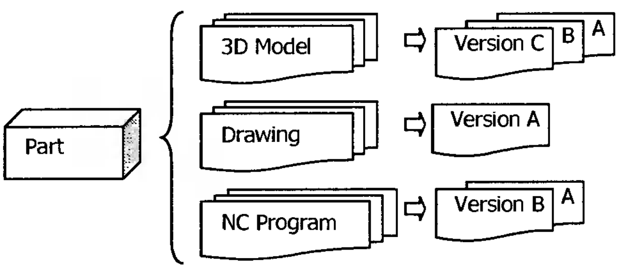


Fig. 4. Part structure

Each element (part or combination of parts) remembers all versions of its documents. The present (the active one) is always the last version of a given kind of the document.

Obviously each element can have a different collection of documents types, e.g. documents of the combination of parts differ from documents of the part as it does not store a certain kind of documents, CNC programs (Fig. 5).

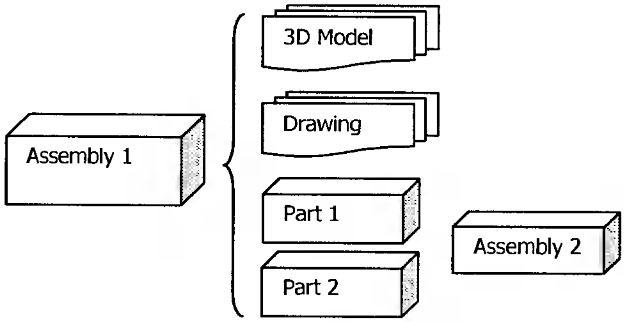


Fig. 5. Structure of the combination of parts

Elements defined in one project can appear in many other projects (Fig. 6.). It is possible to use other parts or combination of parts taken from the other projects. In this case in the tree-structure of the project the distinguished element, linked to the original element, appears.

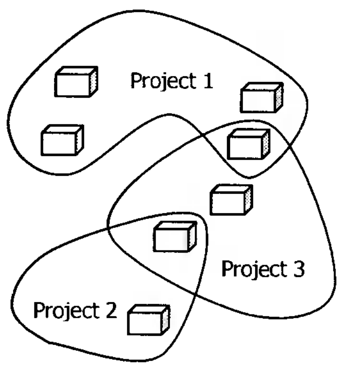


Fig. 6. Common parts of the projects

Elements can be also copied in the same project. They can appear many times in one project. Also in this case such an element is linked to the original element.

This multiple-use mechanism element are stored in elements library. The library is a group of ready elements, common and equal for other projects.

5. STRUCTURE OF DATABASE

The main element of database is two-dimensional table, whose specific structure allows recording complicated tree-structure of the project (Fig. 7). The difficulty in recording it results from the project having undefined number of elements directly or indirectly subordinate. The directly subordinate elements are all elements of the project which in a specified part of the structure appear as the original of the element. The indirectly subordinate elements are the elements which are copies of the elements existing in other parts of the tree-structure.

Each element of the project (combination of parts, part, document, etc.) is recorded in one record of the table, where each record has its own unique index. Index is an information that identifies each element explicitly. Additionally each record in the table has a field with index of the superior element. If the element is linked to any complete part of the tree-structure (combination of parts, part, etc.) except for index of the superior element, there is also index of original element in the separate field.

ID	Superior -ID	Name
1	0	AT_0010
2	1	AT_0011
3	0	AT_0012
4	0	AT_0013
5	4	AT_0014
6	4	AT_0015
7	4	AT_0016
8	6	AT_0017

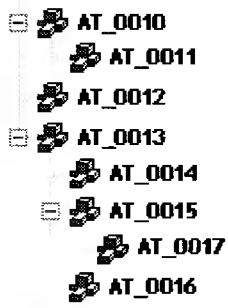


Fig. 7. Tree-structure: a) records in the table, b) shape

This kind of structure of the main table ensures a simple and plain structure and relatively less-complicated algorithm of data registration, mainly as the elements are recorded as the records of the identical structure (number and kind of fields). Registration of the new element at the optional level of the structure comes to specify the index of the superior element.

The flexibility of this solution is conductive to free modifying: moving single elements or all parts of the tree-structure, adding new elements etc., e.g. moving a part of a tree-structure by changing the index of the superior index into the new one in elements at the first level, the other internal ones of the part of the structure are still subordinate to the same elements.

However to obtain data and generate the tree-structure, it is necessary to use complicated algorithms that use recurrent functions.

Recurrent functions choose the data from the same two-dimension table in the following way: the single element data record (of the specified index) is read, then the set of records with superior index equal to the element index is taken. Subsequently for each of those elements next sets of records with equal superior indices are taken etc. In that way the loop of the algorithm that takes data from one record (which correspond to one element) is made a sufficient (unidentified) number of times, depending on the number of elements and structure of the tree.

6. ENTERING INFORMATION INTO THE SYSTEM

The main role while designing 'entering information to the system' function was to guarantee the fastest possible run of the process. The most important principle to achieve this goal was a confirmation that the information prepared once cannot be prepared once again in any other part of the system.

One has tried to define sources of information in computer-aided design-engineering process which are certain, that means that e.g. which exist always, which are always up-to-date. Two sources have been identified:

a) Drawing document file name.
b) Information in drawing files memory.

To use the information from the files name successfully (automatically), some principles concerning the file name format have been assumed. Document symbols should consist of classifying and identifying parts of the following syntax and contents:

a) Classifying part contains two pieces of information divided with underline: various numbers of signs defining the project and a letter that informs about the type of the document. Project'sName_A.
b) Identifying part of the file name consist of part identity and its version. Identity is a discretional unique 4-digit number. Document version is defined by the alphabet letter, for example 0123B.

Format of the file name appears as follows: Project'sName_A0123B.

By defining the roles for file name program, copying file to the Project Central Station, the file is automatically placed in the right place of the project tree-structure. If the program does not find the suitable place, it will create one, based on the information from the file name.

Copying the files to the Project Central Station offers many additional tools and conveniences, e.g.:

a) The user is notified about the danger of overwriting the file, if the file name like this already exists.
b) Copying, the user can make a new version of this document or to make a new version of the other document, which is linked to it.

The first case described above can take place when the file with drawing of the part contains solid model, and the designer wants the sketcher to prepare the next version of this file, with final drawing. The example of the situation when a new version can be needed is when solid model of the element is changing and one had to get somebody to prepare a new version of the CNC program, corresponding to the new model.

The system assumes also the use of the information from the drawing documents files. In those files optional, defined by the user, data can be recorded e.g.: author, date, material, standard signature etc. 'Combination of parts' files additionally have also information about files the combination is made of i.e.: the list of files names and other data saved in a single-element file. Creators of CAD programs give the opportunity to export from the optional drawing file all the information to an external file. Project Central Station takes those files and, according to the information in the file name, automatically:

a) Updates fields connected with the documents.
b) Changes the tree-structure of the project.

As the project gets more advanced, there is more information, specified up-to-date, the project tree-structure can easily get new branches with automatically-growing 'fruits'-documents (Fig. 8).

Obviously there is also a possibility of non-automatic editing field-elements of the tree, useful especially for the files which are not a drawing files of the project, which is those which do not contain the required information e.g.: bitmaps or CNC programs.

7. ACCESSING DATA

The first source of information about the project for the application user is, obviously, the tree-structure of the project itself. A hierarchic structure of a project is a background for the symbols of elements such as parts, documents, copies of combinations of parts and parts, library elements. Element name, element count in the combination of elements and description appear directly in the project tree-structure.

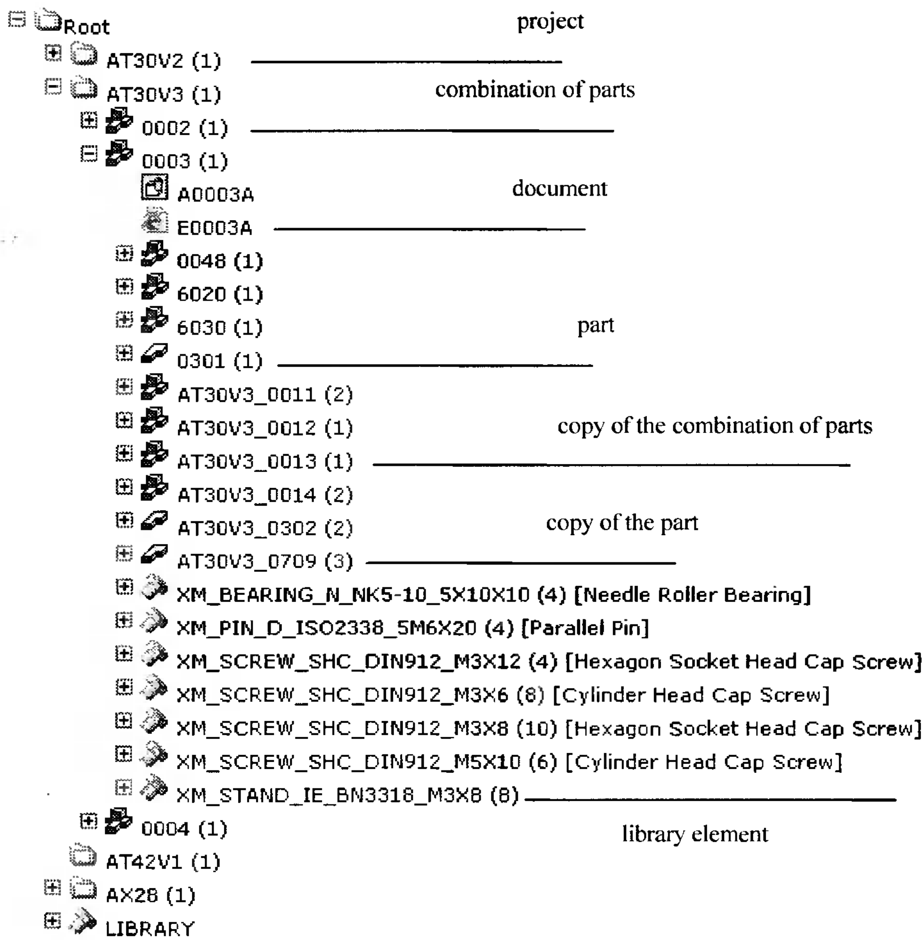


Fig. 8. Example of the project tree-structure

In addition, after pointing out the optional element, full information on the element appears in the dialog window (Fig. 9). Besides text information, if the previewing file is available, the file contents is also displayed.

To get full information about the project, the advanced reports are needed. Project Central Station is equipped with a reports creator. The user is able to create various reports, lists, comparisons. The question asked by the user is transformed into SQL language (language of database) and saved in a report form.

To use the report, one has to choose the report form (kind) and point out an optional part of the tree-structure of the project. Various lists are generated for all the branches and all the elements fitted on them, starting from the marked point, automatically e.g.: count of the pieces in the combination of parts, structural lists, material lists, report on project progress, report on working hours for team members, etc.

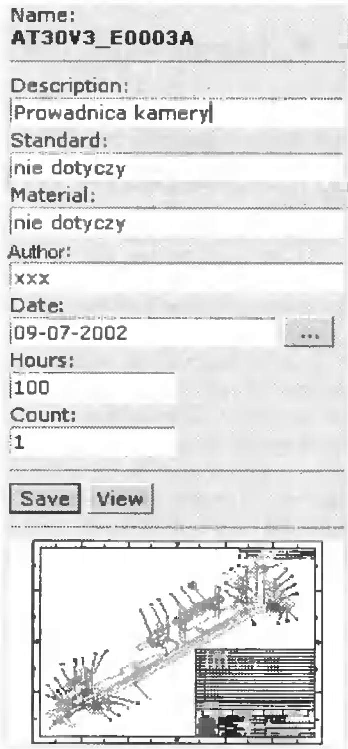


Fig. 9. Dialog window

Based on the lists of elements listed in the reports, it is possible to mark files to be to copied to the user's computer. Program collects files from projects it has found links to and from the library of elements. The program prepared in this way can be run on the user's computer. Furthermore, the user, while downloading the file, has a possibility to inform other users that the file is in the edition mode at the time. This information is being displayed as a graphic sign in a project tree-structure and in all the reports in which this file appears.

8. CONCLUSIONS

The system presented meets most requirements of documents management system for small and medium-size business listed by Wróbel [4]. The system has most functions of basic modules of the standard system: basic module (e.g. central database station, documents versions management, possibility of modeling the hierarchical structure of the project), CAD-serve module (e.g. linking drawings elements to data from database) and information transfer management module (e.g. visualization of information transfer).

The Central Project Station has been created as the response to the users' (designers' dispersed work team) needs and at present the application is being implemented. The program, supported by latest computer techniques, if still developed, can become an extremely useful tool in designer's work.

REFERENCES

[1] Praca zbiorowa pod red. W. Gospodarskiego, 1988. Projektoznawstwo. WNT Warszawa.
[2] Pahl G., Beitz W., 1984. Nauka konstruowania. WNT Warszawa.
[3] Wróbel J., 2002. Inżynierskie bazy danych i zarządzanie dokumentacją w małych i średnich przedsiębiorstwach, polioptymalizacja i komputerowe wspomaganie projektowania. WNT Warszawa.
[4] Wróbel J., 2001. Inżynierskie bazy danych dla małych przedsiębiorstw. Zesz. Nauk. Politech. Opolskiej, Mechanika 70, 29-41.

Wojciech Śliżewski
Technical High Schools in Suwalki
Lab of Mechatronics
Sejneńska 33, 16-400 Suwałki

MODELING OF HYBRID ASSEMBLY STANDS

Summary: Hybrid systems of assembly are constructed of complementary automatic stands and manual assembly stands. The configuration of such an assembly is to some extend a hybrid. Hybrid area modeling is based on determination of the configuration system. The assumption of simple division of the rectangle area of the system into two equal parts has been used for differentiation of manual activities from the automatic ones in the configuration system of the assembly process. The percentage of automatic assembly field in the whole hybrid process has been described as the level of hybridization of the assembly process. Fuzzy logic theory has been used for determination of optimal values of the assembly process at the assumed area of the hybrid. Simplification of project assumptions for hybrid assembly stands have been presented as well as the defined area and the level of hybrid and optimal parameters of a given assembly process.

Keywords: assembly, hybrid systems, mechatronic system

1. ASSEMBLY IN HYBRID SYSTEM

Hybrid systems of assembly of products or sets of products are constructed of complementary automatic stands and manual assembly. These systems fill the gap between the assembly processes which are fully manual and fully automatic. The assembly configuration may thus have a different structure, that is, it may be a hybrid to some degree [4]. This degree exists between hybrid border values, namely, the fully manual assembly and the automatic one (Fig. 1).

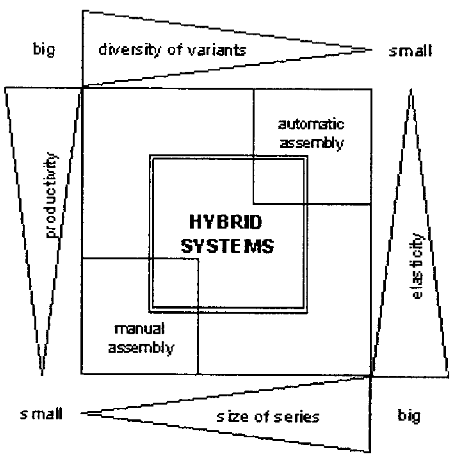


Fig. 1. Possible assembly configuration diagram [4]

As no hybrid scale exists the hybrid degree is rather difficult to define precisely. Finding the percentage of manual and automatic activities in the assembly process may offer some solution, however, the number of the activities cannot be compared exactly.

Analyzing the configuration presented in Fig. 1 it can be noted that the structure of the hybrid determines the structure of the parameters. These parameters are: productivity, size of series, diversity of variants, and elasticity.

The precise calculation of these parameters can be used to design of the assembly process hybrid scale. Marking the parameters with symbols coming from the first letters of their names, we can obtain set $H[p, ws, rn, e]$ which will be taken into consideration for hybrid area calculation.

2. HYBRID AREA MODELING

2.1. Reference System Construction

In the set of assembly structural parameters H there can be distinguished a couple of variables determining the manual assembly and a couple of variables describing automatic assembly. A growing diversity of variants rw and elasticity e indicates the assembly with growing share of manual activities in the process, shown in Fig. 2a. An increase in the remaining two parameters, that is, productivity p and series size ws, indicates the assembly with a growing share of automatic activities in the process, presented in Fig. 2b. Making a synthesis of the coordinate systems obtained through their overlaying, we obtain the form of an assembly process configuration system, presented in Fig. 2c.

The field of the obtained system has been divided into four zones with the help of a bold solid line, and was marked with letters (manual) M and (automatic) A. Letter markings indicate the assembly method that should be used in the process with its assumed configuration parameters. In case of the lower, left zone (manual assembly) and the upper right (automatic assembly), it is obvious to establish the assembly method. In turn, in the upper left and lower right zones the problem of the division of the manual process from the automatic one appears again. In these zones there should be introduced specified assumptions that will facilitate further modeling.

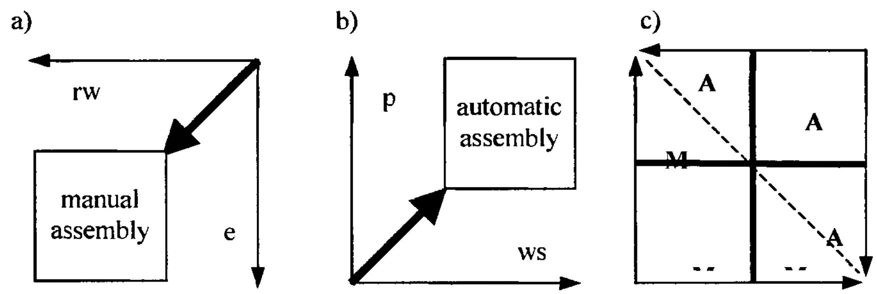


Fig. 2. Designing stages of the reference system: a) coordinates of the manual assembly. b) coordinates of the automatic assembly. c) process configuration system

2.2. Possibility of Using Fuzzy Logic

Since no precise borders between manual and automatic assembly exists, it would be advisable to make an attempt to solve the problem with the use of fuzzy logic laws. Fuzzy logic as a theory of fuzzy sets is an alternative for classic notions. It refers to logic, and to theory of sets being used for describing phenomena or poorly defined notions which are difficult to model by means of classic mathematical procedures. The basic idea of the fuzzy sets theory is a pursuit after reconstructing the man's thinking system that is based on a natural language, and that cannot be described in the traditional way. Algorithm of fuzzy concluding results from the functions it performs, namely: washing out, right concluding on the basis of fuzzy logic, and sharpening the set of rules. The fuzzy block involves transformation of input signals from the quantity domain into quality values represented by fuzzy sets by describing their attachment functions. In the right fuzzy concluding block, the output values are determined on the basis of inputs in the quality domain. The base of fuzzy rules represents qualitative knowledge about the system of implication expressions values connected by logical operators. The last block of fuzzy concluding algorithm is sharpening. In this block output signals of the system are transformed from the quality into he quantity domain. Sharpening operation makes it possible to determine quantitative invariable output value based on the quality set. One of the most frequently used methods of numerical output value determination is the center of gravity method [1].

2.3. Hybrid Area Field

A more simplified assumption for differentiating manual assembly from the automatic one is the division of the field of the assembly process configuration system into two parts along a diagonal joining the maximal values of parameters which determine the manual and automatic assembly. In Fig. 2c the diagonal was marked with a dashed line. Such a configuration system of the assembly process should include assembly parameters values of H set. Parameters become coordinates of the system and, as a whole, they form a variable of a record type $h = [p, ws, rw, e]$. The value of variable h placed on the axis of the configuration system yields certain points which, after being linked by straight lines, form vertices of a quadrangle, see Fig. 3.

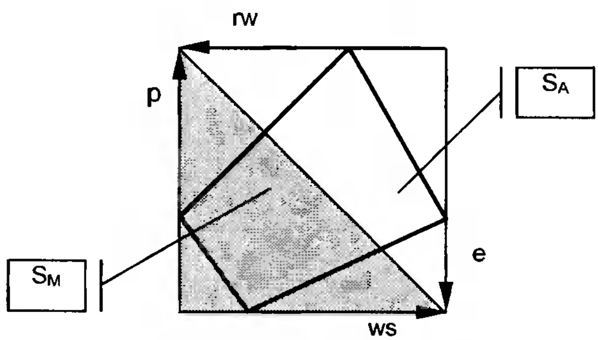


Fig. 3. Hybrid area at the assumed configuration of the assembly process: S_M – manual assembly field, S_A – the automatic assembly field, $S_M + S_A = S_H$ – the hybrid area field, ▬ hybrid area limit, ▒ manual activities zone, ☐ automatic activities zone

The quadrangle obtained shows the anticipated hybridization area with the assumed parameters of the assembly process. The darkened part concerns manual assembly, whereas the bright part may show the share of different values connected with organization and realization of the assembly process.

Applying the laws of fuzzy logic, for example, investment share or energy spent distributed proportionally on the parts of the manual and automatic assembly. Measurement of proportionality is the relation of the hybrid area field comprising the manual assembly field S_M or the automatic one S_A to the whole hybrid area field S_h.

2.4. Hybrid Scale Degree

Fig. 4 shows a hybrid scale system. The base consists of two vertical numerical axes of opposite senses. These axes are sides of a rectangle that is a scale net. The left axis is directed down and is assigned to the manual assembly, whereas the right axis is directed up and is assigned to the automatic assembly. These axes are scaled in % in the range from 0 to 100%. Zero points of the axis have been joined by a straight line. This line being a diagonal of a rectangular, divides it into two equal parts whose shapes are right-angled triangles. The basis of hybrid scale is the manual assembly whose participation is accepted as a reference point. Thus, the hybrid degree will be described by the automatic assembly share expressed in %, that is:

$$°H = U_{A\%} = \frac{S_A}{S_H} \cdot 100 \quad [\%]$$

where:

- $°H$ – hybrid degree in %,
- $U_{A\%}$ – automatic assembly participation in %.
- S_A – automatic assembly field,
- S_H – hybrid area field.

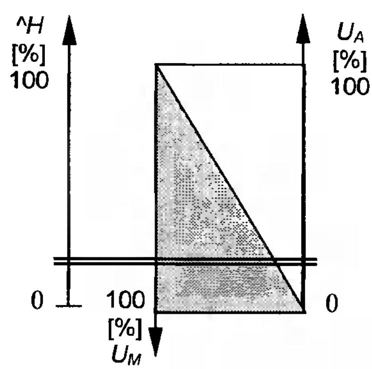


Fig. 4. System of the hybrid scale: ═══ the example hybrid degree

According to the above record the assembly that is almost fully manual, that is $\lim(°H \downarrow) = 0\%$, should be regarded as an assembly with low hybrid degree whereas almost fully automatic assembly, that is $\lim(°H \uparrow) = 100\%$, should be regarded as the one with high hybrid degree. To make the reading easier in the hybrid scale, an additional axis marked as hybrid degree has been drawn, and the scale net is used for graphic interpretation of the hybrid degree.

2.5. Hybrid Assembly Optimization

It should be said that the assembly structural parameters will be different from he theoretical assumptions, mainly due to technological possibilities of obtaining, for example, a very high elasticity of assembly alongside with high productivity. Thus, there should be introduced such criteria that will define the value of variable h at an assigned hybrid area. The value of the variable will be optimal.

$$x_o = \frac{S_1 \cdot x_1 + S_2 \cdot x_2}{S_H} \qquad y_o = \frac{S_1 \cdot y_1 + S_2 \cdot y_2}{S_H}$$

where:

$S_H = S_M + S_A = S_1 + S_2$ – hybrid area field,
S_M – manual assembly field,
S_A – automatic assembly field,
S_1 – the first figure field,
S_2 – the second figure field,
x_1, x_2, y_1, y_2 – coordinates of gravity centers of simple figures,
x_o, y_o – coordinates of gravity center O of the hybrid area in the system (x,y).

In the configuration system of the assembly process the point O determines an optimal value of a variable h marked as $h_o = [p_o, ws_o, rw_o, e_o]$ (Fig. 5).

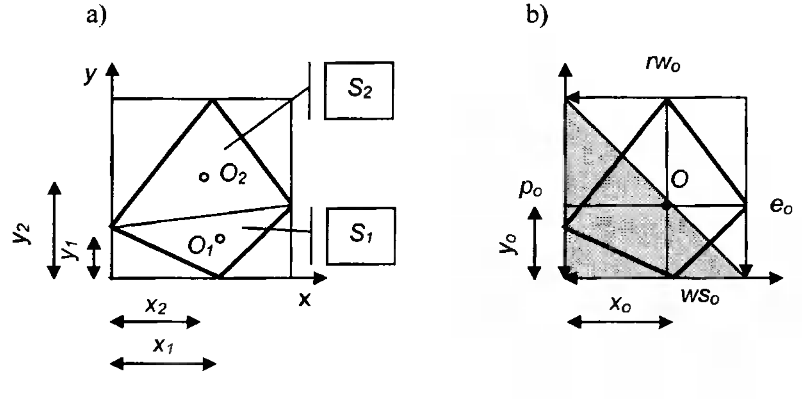


Fig. 5. Calculating the optimum point of the hybrid assembly: the simple figures of the hybrid area, the optimum structural parameters

3. HYBRID ASSEMBLY STANDS WITH MECHATRONIC SYSTEM

An analysis of hybrid assembly structural parameters dependencies enables the use of some simplifications in designing hybrid assembly stands. The point is that the direction of the project activities can be described explicitly. On the basis of the assigned values of these parameters, it can be said to what degree the assembly process has to be automated, and to what degree it should remain manual. The production process offers different solutions of hybrid assembly stands. Module assembly with mechatronic system and with simultaneous participation of the operator is a special case of such a stand (Fig. 6) [2, 3].

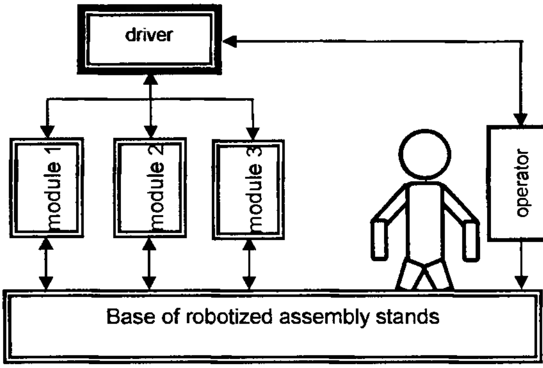


Fig. 6. Hybrid assembly stand with the mechatronic system

4. CONCLUSIONS

Assembly in the hybrid system consists of manual and automatic activities. Using a hybrid area model for the division of these activities makes it possible to calculate the hybrid degree and the optimal structural parameters for a given assembly process. The analysis of structural parameters dependencies enables us to use simplifications for hybrid assembly stands projects, indicating exactly the direction of project activities. In case of module assembly with the mechatronic system and with simultaneous participation of the operator, both these systems can complement each other in the operation area. However, they must be clearly divided in the decision-making, proportionally to the share in the hybrid area.

REFERENCES

[1] Ciszak O., Żurek J., 2001. Ustalanie kolejności montażu części i zespołów maszyn z wykorzystaniem logiki rozmytej. Technologia i Automatyzacja Montażu 2, OBR TEKOMA Warszawa.

[2] Śliżewski W., 2001. Struktura zrobotyzowanego stanowiska montażowego przewodów elektrycznych mocowanych łącznikami gwintowymi. Technologia i Automatyzacja Montażu 2, OBR TEKOMA Warszawa.

[3] Śliżewski W., Siemieniako F., 1998. Transformacja zasad procesu konstruowania do zasad tworzenia procesu sterowania. Zesz. Nauk. Politech. Białostockiej, Mechanika i Budowa Maszyn 20.

[4] Żurek J., Chruściel W., 2000. Hybrydowe systemy montażowe – uwagi dotyczące montażu ręcznego. Technologia i Automatyzacja Montażu 4, OBR TEKOMA Warszawa.

Aleksander Świtała
Dariusz Skibicki
Artur Cichański

University of Technology and Agriculture
Department of Machinery Design and Control
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

FATIGUE RESEARCH METHOD IN THE COMPLEX STRESS STATE CONDITIONS WITH THE USE OF RHOMBOID CROSS-SAMPLES ON A UNIAXIAL FATIGUE MACHINE

Summary: The paper presents a verification of the fatigue research method in the situation of a complex stress/strain state. Rhomboid samples and grips, which allow to obtain a biaxial load state on a uniaxial strength machine, have been proposed.

Keywords: multiaxial fatigue, rhomboid sample, testing methods

1. INTRODUCTION

Fatigue research in the situation of complex stress (strain) state is conducted with various samples and on different test stands. The complexity of stress (strain) states can be obtained through different ways of applying the load and through the sample forming.

The first group includes a great number of solutions, starting from multiaxial machines to adequately-tooled uniaxial ones. The samples used for tests are cylindrical samples, thin-walled tubular ones and cross-samples.

The possibility of realising complex strain (stress) states can be obtained in a relatively simple way (with uniaxial machine) using specially-formed samples. The samples applied are, for example, plate oval samples or rhomboid ones.

After having analysed the bibliography [1, 2, 3, 4, 5], a great number of methods used to test multiaxial fatigue can be noticed. However, most of them have one major drawback: they are expensive.

In the paper, one of the methods has been chosen based on the analysis of the contemporary multiaxial fatigue research methods. The method involves an uniaxial strength machine and rhomboid samples [9]. As well as the simplicity of the solution, it also offers a homogeneous distribution of strains on the large sample surface and an easy observation.

The method verification, involving testing the strain/stress distribution uniformity, is the main aim of this article.

2. ANALYSIS OF CONTEMPORARY RESEARCH METHODS OF MULTI-AXIAL FATIGUE

2.1. Cylindrical Sample Testing

One of the widely used methods of multiaxial fatigue testing assumes the use of a full cylindrical sample (Fig. 1). The shape samples usually undergo cyclic loading by an axial force and a torque. What is also applied is a simultaneous loading by a bending moment and torque. On the surface of the work part of the full cylindrical sample loaded with the torque and axial force. the stress state characterized by a constant amplitude of shear and normal stresses is achieved. In the case of loading the sample with the torque and bending moment, an additional gradient of stresses resulting from bending occurs.

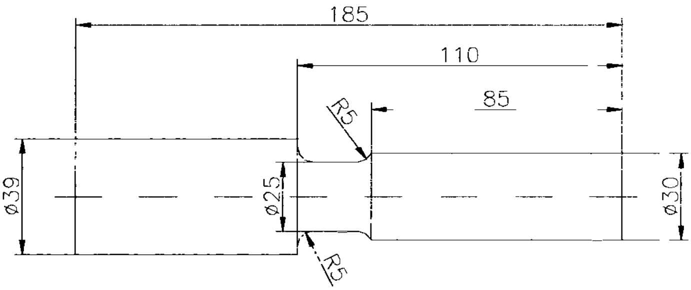


Fig. 1. Cylindrical sample [8]

Another way of acquiring in the sample shear and normal stresses resulting from bending is by applying a grip of a special design and uniaxial loads (Fig. 1). Under such conditions the loading on the test stand is distributed through a kinematical chain of the grip in such a way that for one extreme adjustment, the sample is bent, and for the other – it is twisted, while in the intermediate positions both bending and twisting occur. What can be concluded on the basis of how the load is applied is that there exists a possibility to control the relation of normal stresses to shear ones. However. they can change only synchronically in relation to each other.

2.2. Tubular Sample Testing

In the group of standard methods of biaxial fatigue testing the most often used are the methods assuming the use of a thin-walled tubular sample. This shape samples are tested in the conditions of cycle-changeable loads with an axial force and torque (Fig. 2) or with an axial force and the internal pressure (Fig. 3).

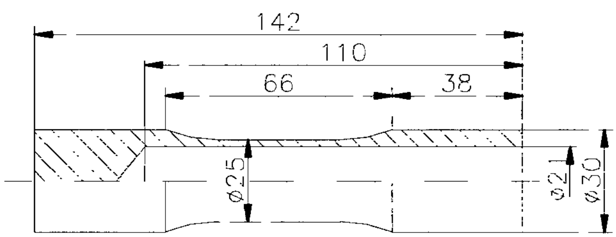


Fig. 2. Thin-walled tubular sample intended for the axial force and torque loading [4]

The stress state occurring in the work part of the sample that undergoes the axial force and torque loading is homogeneous (Fig. 2). The wall thickness (usually ≤ 2mm) is influenced both by the technological considerations and by the necessity to ensure the sample stability in the half-cycle compression. To decrease the little stress gradient in the transverse section of the sample loaded with the axial force and internal pressure, the wall thickness is agreed to be ≤ 0.7mm.

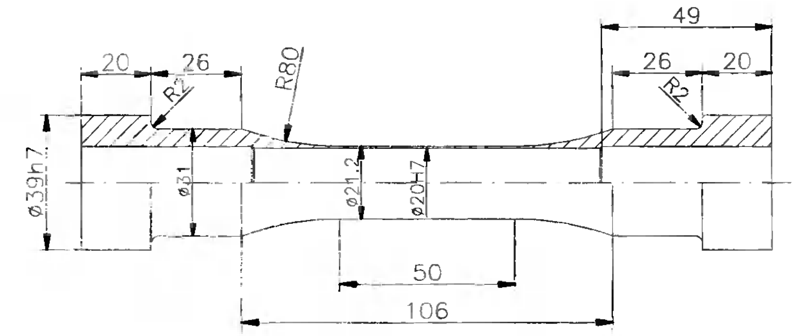


Fig. 3. Thin-walled tubular sample intended for the axial force and internal pressure loading [5]

2.3. Cross-Sample Testing

Methods employing the cross-samples (Fig. 4) are less commonly used for testing the biaxial fatigue. These samples are loaded with normal forces acting in two mutually vertical directions.

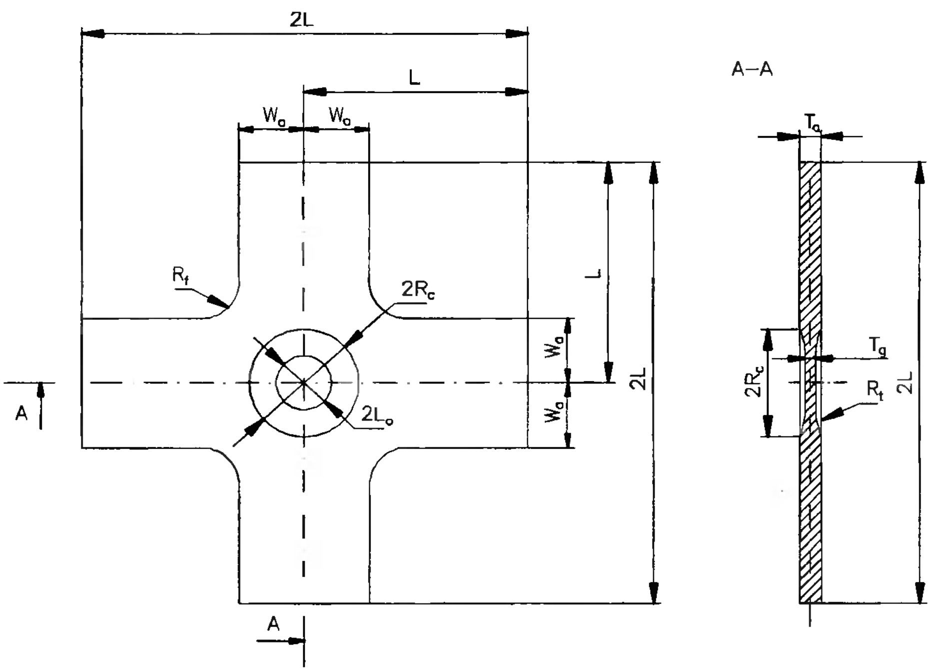
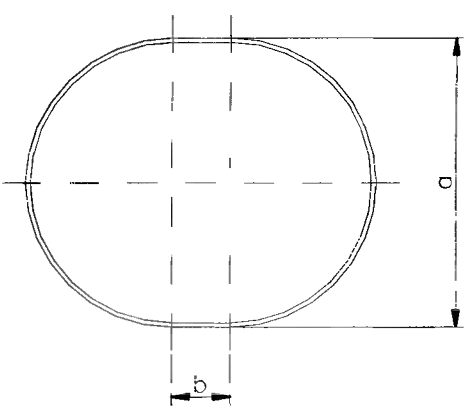


Fig. 4. Cross-sample [6]

A number of parameters influences the stress distribution in a cross-sample and the homogeneity of the strain fields obtained. The most important are (Fig. 4): width of the arms $2W_a$, outer overall dimension 2L, in-between-arm corner rounding radius R_f, central circular area radius Rc, transition radius R_t, arm thickness T_a, and relation of the arm thickness to the gauge part thickness T_a/T_g. Grooves decreasing the transverse rigidity are made to eliminate the interaction of both the load axis on each other in the grip parts of the sample. Apart from the parameters, the influence of the geometrical dimension quantity and the groove position on stress distribution should be considered for cross-samples with grooves. Experimental assigning the optimum geometrical shape is very difficult due to a considerable number of factors and their possible interaction. Therefore, the research is conducted with numerical methods. Another problem connected with employing the cross-samples is specifying the stresses caused in the sample by the load imposed to its arms. A certain solution to this problem may be offered by experimental designating the strains in the central part, omitting the influence of the in-between-arm corner rounding radius.

2.4. Flat Oval Sample Testing

An unconventional research method to test the fatigue behaviour of boiler drum walls loaded with variable pressure was suggested [8]. The method assumed the tests conducted on samples in the shape of oval plates. The change in the distribution of the main stresses realised is replaced with the change in sample geometrical dimensions. The sample dimensions and corresponding main strain distribution are presented in Fig. 5. For b = 0, the plate takes the shape of a circle.



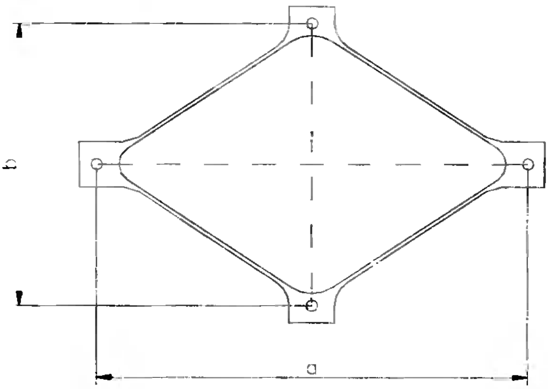
a	b	f_ε
127 mm	0 mm	1.0
	25.4 mm	0.75
	55.9 mm	0.5

Fig. 5. Flat oval sample [8]

During the tests, the samples were simple-supported in the perimeter. The biaxial stress state was obtained through applying on the plate surface pendulous-changeable pressure. The maximum measured pressure value did not alter for each of the cycle halves until several cycles before cracking. There was no possibility to observe the cracking initial moment as well as its development during the test due to specific loading, whose main point was applying pressure. To achieve this, the test was interrupted after each 10% of the expected durability and the sample was freed of the grip in order to control its surface. While running the tests with the use of flat oval samples, the plate deflection is controlled. At the stage of calibration, the deflection is connected with strains assigned by ten extensometers appropriately distributed on the plate. One of the weaknesses of these samples is their inhomogeneity of strain and stress distribution as only a restricted area in the sample central part is exposed to maximum strains and stresses.

2.5. Flat Rhomboid Sample Testing

Another paper [9] presents the methodology of tests using rhomboid plate samples. Sample loading resulted from a controlled displacement of a movable grip assembled along one sample diagonal in relation to unmovable grip assembled along the other sample diagonal. Also for these samples, geometrical dimensions define the distribution of the main stresses realised. The research described in [9] was carried out on three sample types, with different relations of diagonal length (Fig. 6).



a	b	f_σ
76 mm	38 mm	-0.25
	50 mm	-0.44
	76 mm	-1.00

Fig. 6. Flat rhomboid sample [9]

A unique feature of rhomboid samples is a homogeneous distribution of strains and stresses in a wide area of sample surface, which results from a rhomboid sample being possibly treated as a assembly of two bars of the same bending strength. The bars axis agree with the sample diagonals. As a result of the homogeneous distribution of strains and stresses on the sample surface, it is easy to control them, also when the relation of strains to stresses changes along with the cyclic change of material properties. The relation between strains and deflections assigned during calibration is valid as long as the assumption about the linear distribution of strains on the sample thickness is valid, the only value controlled during the test is the plate deflection.

2.6. Other Testing Methods Selected

Additionally to the standard testing sample shapes, the bibliography reports on biaxial stress state resulting from the geometrical shape of the sample of their own design. Another research [7] involved tests using three groups of samples, of different geometrical shapes. An example of a sample is shown in Fig. 7. The distribution of stresses occurring in the gauge part of the sample was modified through its thickness changes in the working part.

Due to the difficulties of analytical assigning the relations between the loading and the value of the stresses it generates in the gauge part of the sample, the distribution was appointed experimentally. A free-from-damage sample was exposed to a static loading of the value equal fatigue limit, and with the use of extensometric method, the stresses in the gauge base were defined. For a 2.5-milimetre-thick sample $f_\sigma = 0.57$, while for a sample b = 1.5 mm thick, $f_\sigma = 0.28$. The samples presented in Fig. 7 were tested in the conditions of pendulous tension-compression loadings.

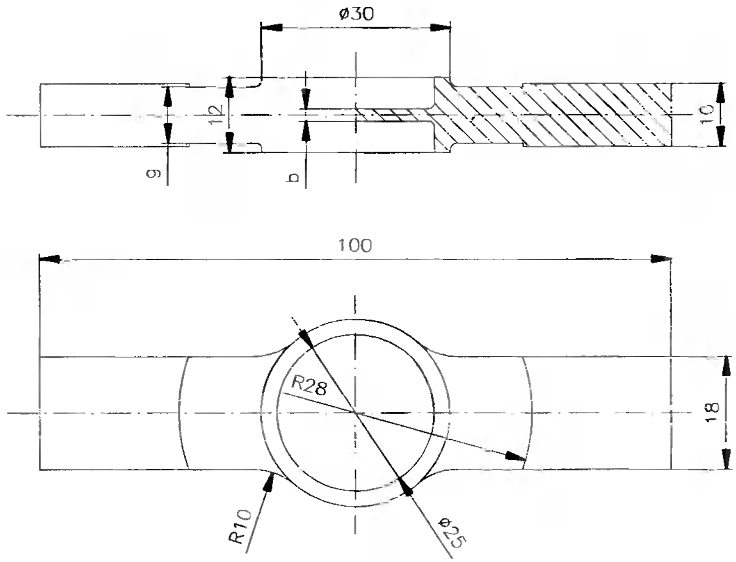


Fig. 7. Samples used for tests in work [7]

3. SUMMING UP THE ANALYSIS

The review of the methods selected for experimental biaxial fatigue testing indicates a great diversification of the research conditions as well as a variety of samples applied. Also, the most commonly used methods, assuming the realisation of two or more cycle-changeable load axis, are not standardised. There exist many methods assuming the application of cyclic simple loads, where the complex stress state results from the sample geometry.

A considerable limitation of the testing methods discussed under simple loads is the necessity of modifying the sample dimensions to alter the stresses proportions. Moreover, the methods do not allow testing the non-proportional fatigue. The greatest advantage is an availability of test stands and lower research costs in comparison to the methods assuming the realisation of two or more load axis.

One way of testing under the simple load is cyclic flat plate sample bending. The best method in this group, due to the uniform stress distribution in the sample, is a method assuming the use of a rhomboid sample. The advantage of the method is an easy control of strains in the sample through a grip displacement measurement.

4. TESTING METHOD CHARACTERISTICS

The method suggested, due to specially-shaped samples subject to cycle-changeable uniaxial loads, enables us to achieve a biaxial state of strain (stress) on a uniaxial strength machine.

The sample is rhomboid in shape and can be treated as an assembly of two bars of equal bending strength. The bars axis overlap with the sample diagonals. The unique feature of this shape samples is the uniform strain and stress distribution in a wide area of the sample surface.

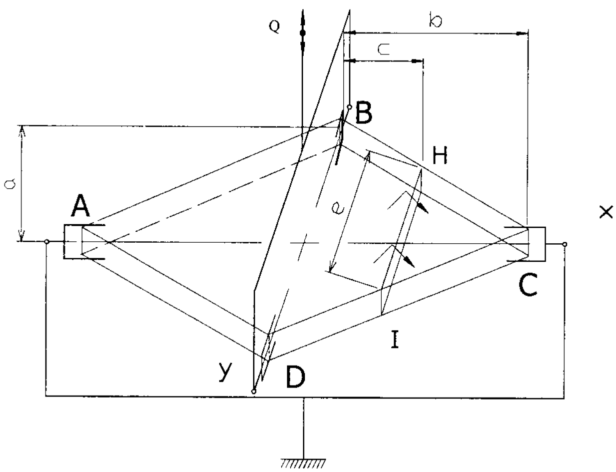


Fig. 8. Rhomboid sample dimensions and the way it is loaded

For the loading method presented in Fig. 8, (corners are joint fixed) the bending moment M_e referred to the length unit e is the load function Q and in distance c from BD axis:

$$M_e = \frac{Q}{4}(b-c)/e \tag{1}$$

where:

$\frac{Q}{4}$ – load working in a single corner,

b – half the AC segment length,

c – distance from BD axis,

e – HI segment length.

The length of HI segment is:

$$e = 2(b-c)(a/b) \tag{2}$$

where:

a – half the BD segment length.

Substituting the expression (2) into (1), an expression describing a rhomboid sample unitary moment is achieved:

$$M_e = \frac{1}{8}Q(b/a) \tag{3}$$

As it can be seen, M_e moment is independent of distance c from BD axis, and constant alongside the whole HI segment. What results from this is that it is constant on the whole sample surface (except the grip parts). On the basis of the moment constancy, it can be presumed that on the working part of the sample, there is a homogeneous flat stress state. The homogeneity of this state does not depend on the relation of sample diagonal lengths. The length relation affects only the main stress values.

The sample load will be caused by the movable grip displacement connected with one of the sample diagonals. It will generate a reaction in the corners appointing the other sample diagonal. connected with the unmoveable machine grip (Fig. 8).

The sample used and the stand design enable an application of various loads. By changing the relation between the sample diagonal lengths. it is possible to program the relations of the main stresses obtained. As for an even-armed sample. the stresses will equal in value:

$$\sigma_1 = \sigma_2 = \sigma = \frac{M_e \cdot e}{W} \tag{4}$$

where:

W – bending strength factor.

Following Fig. 7:

$$W = \frac{e \cdot g^2}{6} \tag{5}$$

where:

g – plate thickness.

And the stresses:

$$\sigma = 6M_e / g^2 \tag{6}$$

For a different axis length relation, the main stresses will depend on the relation of these lengths. Generally:

$$\sigma_{1,2} = 6(M_e)_{1,2} / g^2 \tag{7}$$

Substituting M_{e1} and M_{e2} moments values, the following is obtained:

$$\sigma_1 = \frac{1}{8} Q(b/a)/g^2 \,.\, \sigma_2 = \frac{1}{8} Q(a/b)/g^2 \tag{8}$$

The distribution of the main stresses f_σ, therefore, depends on lengths a and b:

$$f_\sigma = \frac{\sigma_1}{\sigma_2} = \left(\frac{b}{a}\right)^2 \tag{9}$$

5. TEST STAND PRESENTATION

In order to implement the research method, a device shown in Fig. 9 has been designed.

The device proposed constitutes the basis for the test stand, for diagram, see Fig. 10. It is composed of three fundamental parts: the fatigue machine, the device and the slotted line.

The sample is mounted in four mounting elements (Fig. 11) which, then, are placed in two grips, rotated in relation to each other by 90° in the machine axis. With this mounting, the sample is deprived of one freedom degree, i.e. in the direction of axis y. The device design allows mounting samples of different arm length relations.

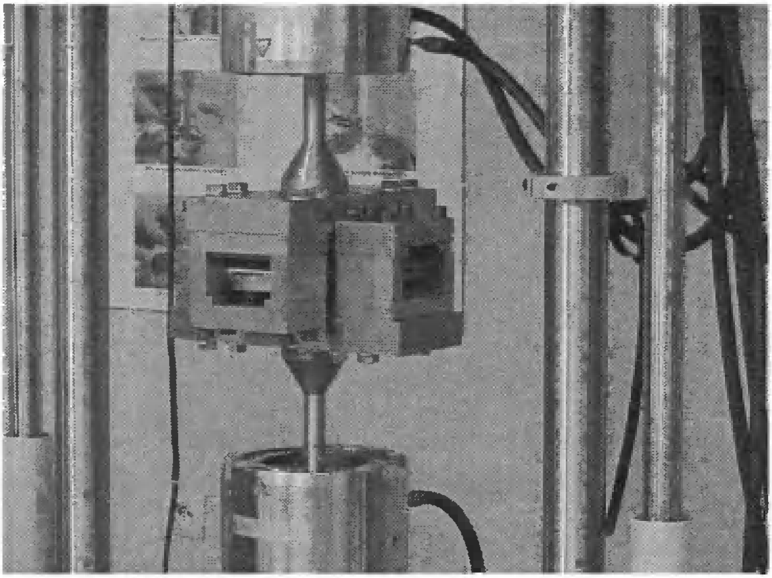


Fig. 9. Device mounted in the INSTRON machine jaws

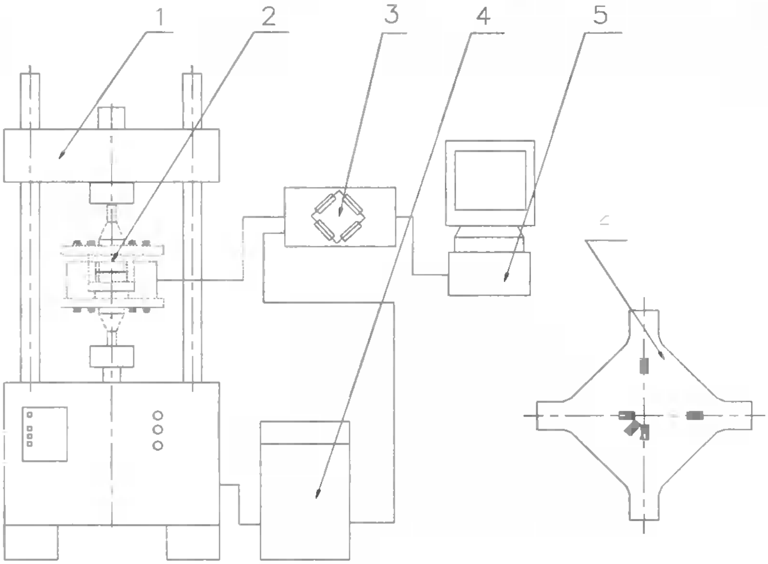


Fig. 10. Test stand diagram: 1 – fatigue research machine, 2 – device designed, 3 – bridge for sample strain measurement, 4 – machine controller, 5 – computer, 6 – sample with glued-on extensometers

The device is mounted in fatigue machine grips. The machine is directly controlled by controller (4), simultaneously collecting data about the piston displacement and the force. Using the analogue controller line, the information about the force and displacement is transmitted further to the analogue extensometric bridge inputs where, together with the information about the strains, it is transmitted to computer (5), playing the role of a recorder. The bridge used at this stage is a device by Vishay Measurement Group Mestechnik GmbH, together with the software.

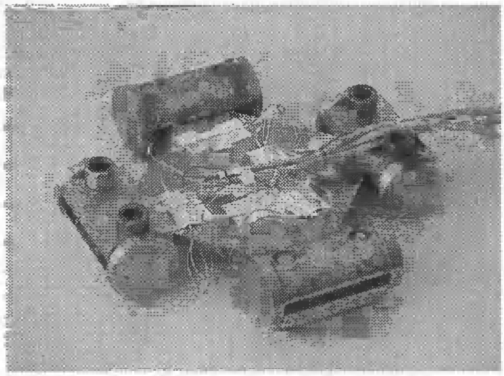


Fig. 11. Sample view with the glued-on extensometers and fixing elements mounted

6. EXPERIMENTAL VERIFICATION

The presented fatigue research method under the complex stress (strain) state requires an experimental verification.

It is necessary to confirm experimentally the assumptions about the stress distribution uniformity on the sample surfaces, which was possible with the extensometric measurements and MES analysis.

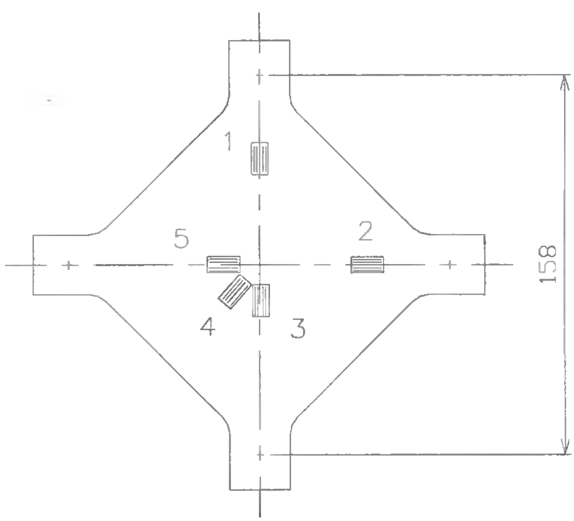


Fig. 12. Extensometer distribution on an even-armed sample

Ten extensometers were glued onto the sample (five on each side) in a half-bridge arrangement (Fig. 12). During the fatigue test, the strain values were recorded. The differences between the various extensometers records were defined.

The standard deviation of the differences in records picked up by extensometers working in the same axis (extensometers 2 and 5) equals 2.61%, with the average equivalent of 1.16%. while for the extensometers working in two perpendicular to each other directions, the deviation equals, respectively, 4.28%, with an average of 2.28%. the spectrum of the records deviations is shown in Fig. 13. Nearly 90% of the measurements fall within the 5% error margin. Based on the results, it was assumed that the strain (and, at the same time, stress) distribution is homogeneous.

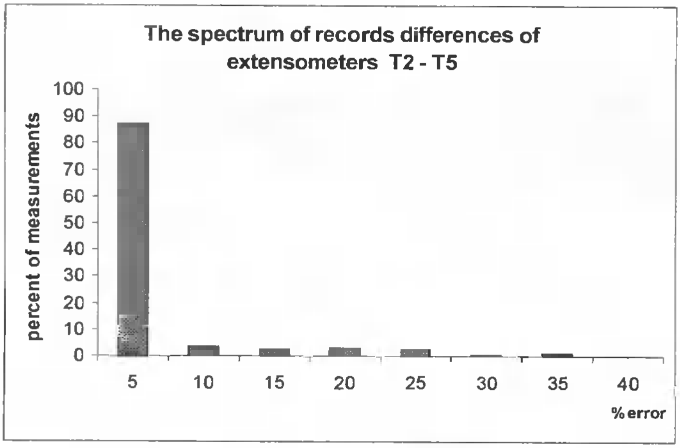


Fig. 13. Spectrum of differences recorded by extensometers (2 and 5) operating in one axis

The extensometric measurements allow measuring the strains only in selected points. The problem is to place them in certain significant for the fatigue process points, e.g. on the edges and in the notches of the sample. Therefore, the numerical analysis was conducted with the use of finite elements method.

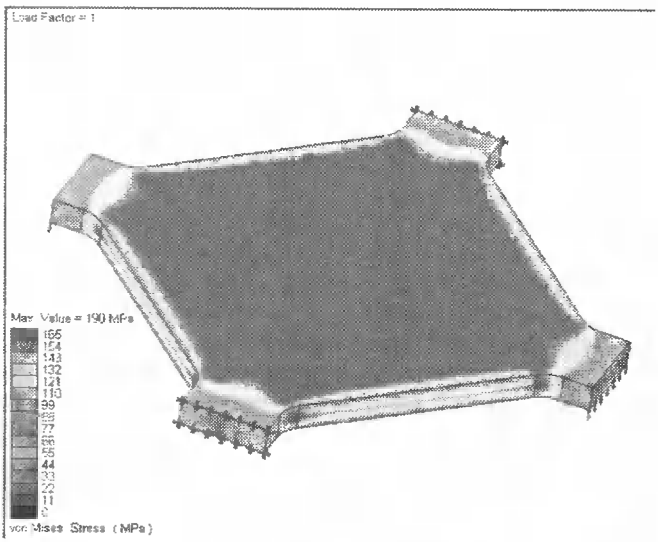


Fig. 14. Reduced (according to Huber) strain distribution in the sample

As a result of the analysis, a map of stresses (Fig. 14) was obtained. It shows, similarly to the extensometric measurements, that the surface stress distribution is homogeneous. Whereas on the sample side surface, in half of its thickness, high value stresses were discovered. The areas of these stresses overlap with the cracks on the samples used for the stress distribution research (Fig. 15). This unintended effect requires further analysis.

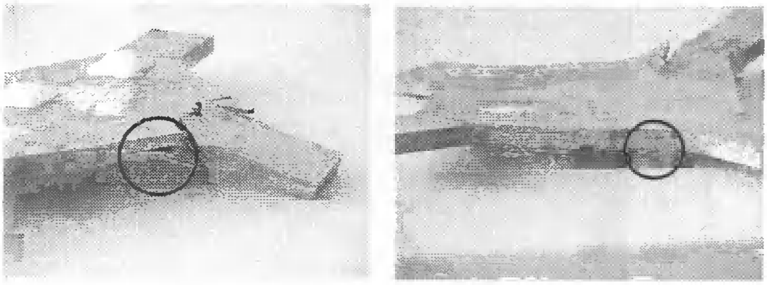


Fig. 15. Cracks seen on the sample side surfaces

7. CONCLUSIONS

The properties confirmed when investigating the strain and stress states which occurred on the sample surface as well as the simplicity of the method, make it very attractive. However, a further verification of its possible applications is needed.

The test results confirm the assumption about the homogeneous stress distribution on the sample working surface, however, the stresses noted on the side surfaces, having a significant influence on the results obtained, call for some additional research.

REFERENCES

[1] Bartolotta P.A., Kantzos P., Krause D.L., 1997. In-plane biaxial yield surface study of cast titanium aluminide (TiAl). Proceedings of the 5th International Conference on Biaxial/Mulitaxial Fatigue & Fracture, Vol. 2, Cracow – Poland, 389-402.

[2] Baum C., Ott W., Trautmann K.H., Buczynski A., Nowack H., 2001. Evaluation of the multiaxial crack initiation life prediction method EVICD for a modern tubes steel. Proceedings of the 6th International Conference on Biaxial/Multiaxial Fatigue & Fracture, Vol. 1, Lisboa – Portugal, 415-422.

[3] Blass J.J., Findley W.N., 1967. The influence of the intermediate principal stress on fatigue under triaxial stresses. Materials Research & Standards 7 (6), 254-261.

[4] Chen X., Xu S., Huang D., 1999. A critical plane-strain energy density criterion for multiaxial low-cycle fatigue life under non-proportional loading. Fatigue Fract. Enging. Mater. Struct. 22, 679-686.

[5] El.-Magd E., Mielke S., 1977. Dauerfestigkeit bei überlagerter zweiachsiger statischer Beanspruchung. Konstruktion 29, 253-257.

[6] Makinde A., Thibodeau L., Neale K.W., 1999. Development of an apparatus for biaxial testing using cruciform specimens. Experimental Mechanics 32 (2), 138-144.

[7] Sawert W., 1943. Verhalten der Baustähle bei wechseln der mehrachsiger Beanspruchung. Z. Ver. Deut. Ing. 87 (39/40), 609-615.

[8] Szewczuk J., Zamrik S.Y., Marin J., 1968. Low-cycle fatigue of 7075-T651 aluminum alloy in biaxial bending. Experimental Mechanics, 504-512.

[9] Zamrik S.Y., Ledger D.J., Dante C., 1997. Fatigue characteristics of thin titanium plates due to biaxial stress cycling. Proceedings of the 5th International Conference on Biaxial/Multiaxial Fatigue & Fracture, Vol. 2, Cracow – Poland, 167-187.

Sylwester Wawrzyniak
Kazimierz Peszyński

University of Technology and Agriculture
Department of Control and Machinery Design
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

INVESTIGATIONS OF TURBULENT PULSATION CHANGES AND MEAN VELOCITY DEPENDING ON FORCING FREQUENCY IN ANNULAR AXISYMMETRIC NOZZLE

Summary: The paper presents results of research of outlet jet from axisymmetric nozzle. In this jet turbulent pulsation was forced using loudspeaker membrane. Membrane oscillations were obtained with the pulsation generator and the air oscillations generated were superposed on the main flow. The relationship between turbulent pulsation and forcing frequency of membrane was analyzed.

Keywords: axisymmetric nozzle. turbulence. vibration damping. pulsation frequency

1. INTRODUCTION

Impinging jet applied in technological processes requires relatively high coefficients of heat or/and mass transfer. The factor which limits the transfer is the insulating layer near the object surface. It depends on fluid viscosity. The layer is the principal cause of heat resistance, since heat transmission is due to conduction, which is less efficient than due to convection. According to Stokes, the thickness of nonstationary border layer δ is:

$$\delta = 2 \cdot \sqrt{\nu \cdot t}$$

where:

ν – stands for coefficient of kinematics viscosity,

t – time.

As seen from the equation, the thickness of border layer depends on time which, in turn, depends on jet oscillations. Heat conduction depends on turbulent movement. Increasing turbulent pulsation in fluid probably increases transmission of heat through the border layer. The purpose of the present investigations was to test the relationship between pulsation superposed to the main stream and the turbulent pulsation of the main stream out of the nozzle. The main drawback of this solution is a complexity of the additional system activating periodic stream. The current progress in fluidic engineering offers a solution to the problem with a simple jet oscillator.

2. POSSIBILE USES OF AIR STREAM NOZZLES WITH INCREASED HEAT TRANSFER

Fig. 1 presents evolution of microprocessors. Since an increase in the number of transistors per microprocessor has been rapid over time, the ordinate is presented in logarithmic scale. Similarly power transmission grows rapidly per volume unit. So far no additional cooling systems have been used. Small fans have been used instead. However, if the present trend continues, it is most likely that power transmission in microprocessors will be close to power transmission in nuclear reactors, and therefore implementing an additional cooling will be indispensable.

Impinging jets used for cooling purposes are very efficient. However supplying the jets around microprocessor is extremely difficult. It would require the application of additional devices. Intensive investigations are then carried out which involve cooling by pulsating air streams (suction and blowing) as pulsation destroys the border layer. The new solution is to replace the traditional cooling systems available today.

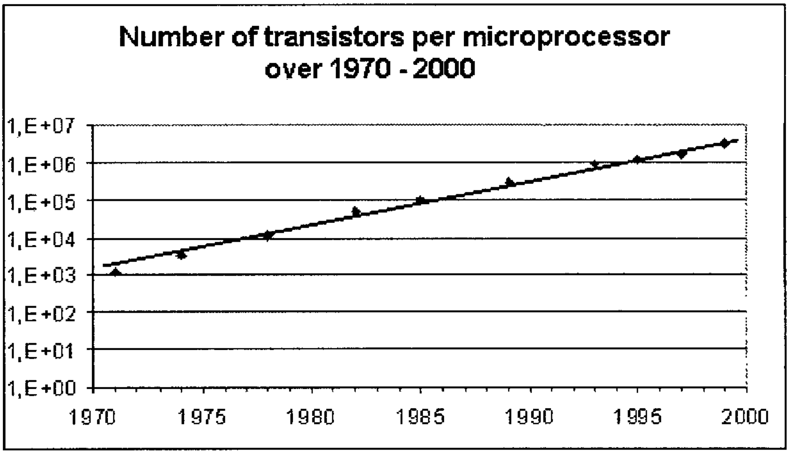


Fig. 1. Evolution of microprocessors in time

3. TEST STATION

Experimental research was made using a test station presented in Fig. 2.

The test station was air-supplied with a ventilator (5). Stream intensity is measured by measuring quadrants orifice (6) located on the supply pipeline. The pipeline inner diameter on both sides of the orifice is 46 mm. Maximum efficiency of the system is $0.063\,m^3 \cdot s^{-1}$, however having joined the nozzle tested (8), the efficiency decreases to $0.053\,m^3 \cdot s^{-1}$. The efficiency is controllable by throttling ventilator air-input with a rotational cover.

This type of control is not precise, however it does not generate additional resistance. A pressure drop on the orifice is recorded with a micromanometer (7) CMR-10A. It is equipped with an option indicating velocity in the supply pipeline and transmitting the data measured to the computer by a serial port RS 323.

The stream down the nozzle was tested. The anemometric system probe was placed on traverse device (1) whose motion is computer-controlled. The probe moves perpendicular to the axis of the nozzle (8). The pulsation superposed on the main stream was generated by the loudspeaker membrane (4) powered by the amplifier (3). The pulsation frequency was controlled by the frequency generator (2). Apart from controlling the pulsation frequency, it also allows for shaping control signals it generates.

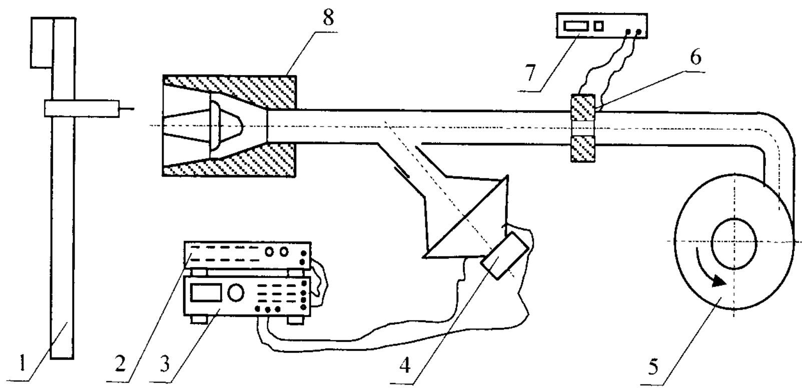


Fig. 2. Test station generating additional harmonic pulsation: 1 – traversing device, 2 – frequency generator, 3 – amplifier, 4 – loudspeaker membrane, 5 – ventilator, 6 – measurement quadrants orifice, 7 – micromanometer CMR-10A, 8 – nozzle tested

4. RESULTS OF THE MEASUREMENTS

At the first test stage, the pulsation generated by the loudspeaker membrane was measured without superposing on the main flow. The mean velocity distribution and absolute turbulence were tested. To do so, the test station was simplified. The loudspeaker was connected with the short pipe which coincided with the main pipeline diameter by conical pipe, (Fig. 3). The mean velocity distribution and absolute turbulence were tested for $x = 10\,\text{mm}$ downstream.

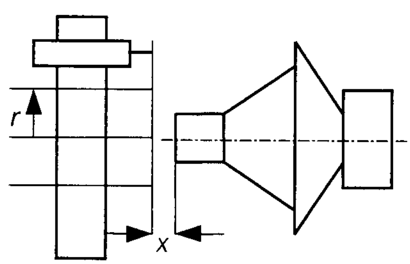


Fig. 3. Simplified test station for preliminary measurements

The measurements were made for two frequency ranges: 1 to 20 Hz (1 Hz step), and 1 to 70 Hz (10 Hz step). The probe traversed in the range $r = \pm 40\,\text{mm}$ off the symmetry axis of a the loudspeaker.

The results of preliminary measurements are shown in Figs 4 and 5. The diagrams show maximum absolute and mean absolute turbulence for the pulsation frequency range examined. The maximum turbulence was obtained for $f = 40\,\text{Hz}$ and maximum mean turbulence for $f = 30\,\text{Hz}$.

The preliminary measurements were followed by comprehensive measurements made with initial test stand to define the effect of the pulsation generated by the loudspeaker membrane on the main stream properties.

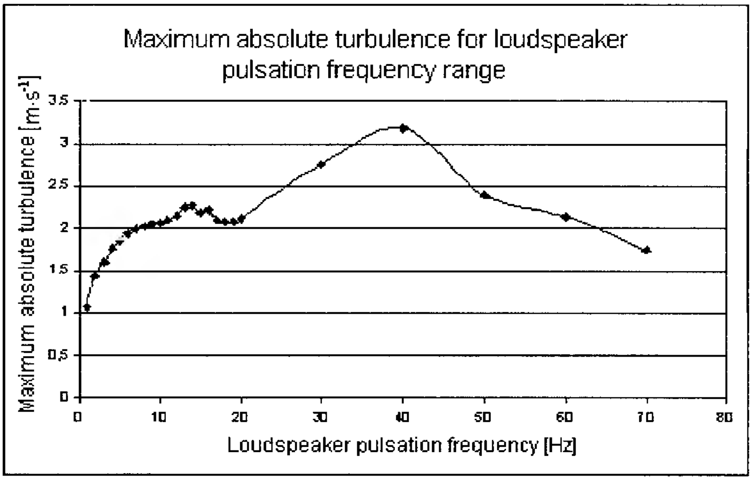


Fig. 4. Maximum turbulence for membrane pulsation frequency range

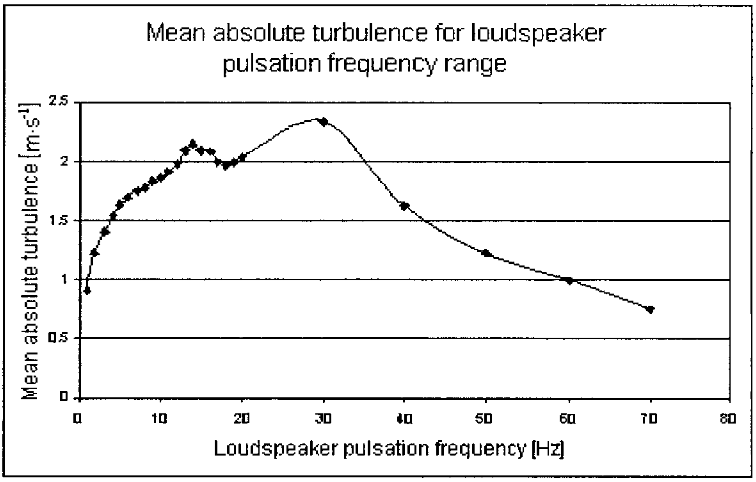


Fig. 5. Mean turbulence for membrane pulsation frequency range

Fig. 6 and Fig. 7 present the measurement results of velocity and turbulence distribution for a selected membrane pulsation frequency.

As we can see from the diagrams, the lowest turbulence values are obtained for $f = 1\,\mathrm{Hz}$, the highest peak values for $f = 40\,\mathrm{Hz}$, while the most steady distribution for $f = 14\,\mathrm{Hz}$.

Having connected the membrane with the ventilator-nozzle system, the effect of periodical force input on the behaviour and distribution of the mean main-stream velocity down the nozzle and absolute turbulence value was tested. The system presented in Fig. 2 included the following parameters: mean supply air velocity $v_m = 6\ \mathrm{m \cdot s^{-1}}$, distance of the probe from the end of the nozzle was $x = 60\,\mathrm{mm}$, and the measurement range of $r = \pm 100\,\mathrm{mm}$.

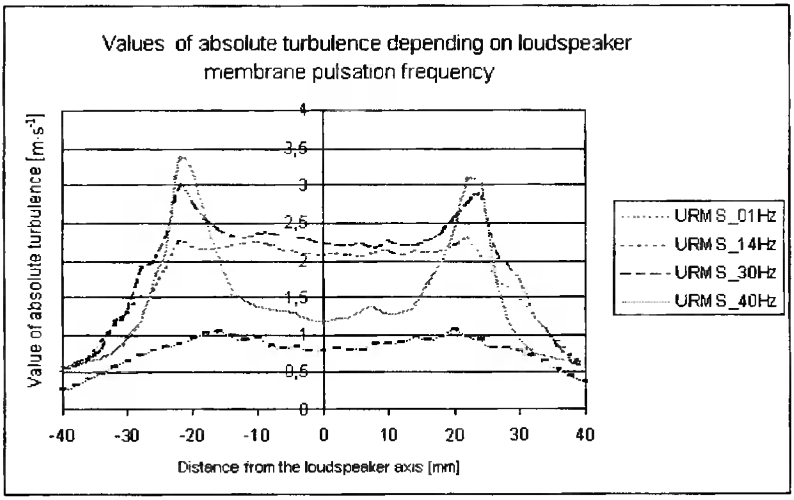


Fig. 6. Distribution of absolute turbulence depending on loudspeaker membrane pulsation frequency

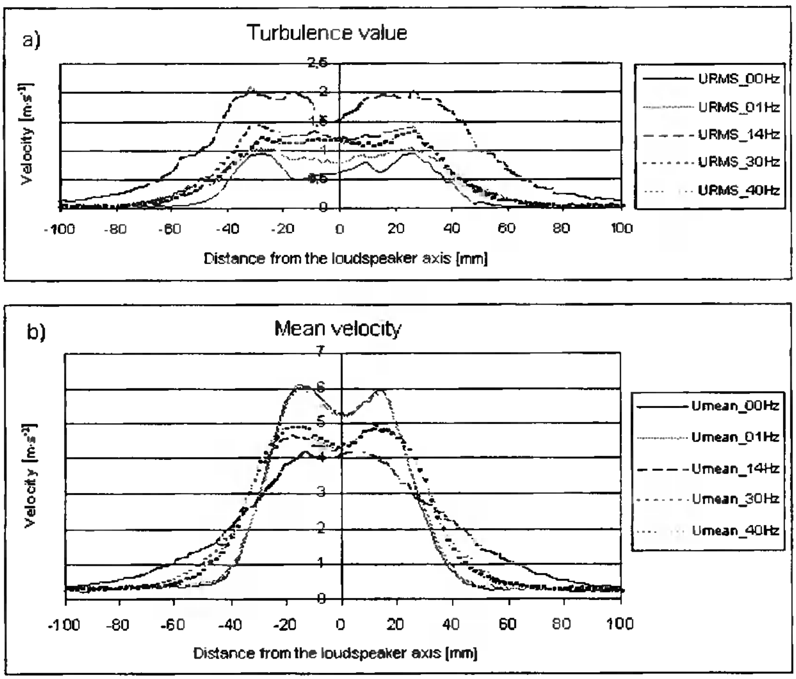


Fig. 7. Distribution of mean velocity and absolute turbulence downstream the nozzle: a) URMS – turbulence value, b) Umean – mean velocity

These measurements aimed at determining the influence of different distribution pulsation (Fig. 6) on pulsation value in the main stream down the nozzle.

5. DISCUSSION AND CONCLUSIONS

The preliminary loudspeaker membrane measurements aimed at determining the distribution of turbulence at connector pipe outlet. Fig. 4 shows changes in maximum turbulence depending on frequency for the total range of measurements. Having presented two measurement ranges in a form of one diagram, the local extremes of these changes are seen. The first extreme was obtained for $f = 14\,\mathrm{Hz}$ and the second for $f = 40\,\mathrm{Hz}$.

The mean value of turbulence and absolute turbulence downstream the connector pipe were a decisive factor when selecting the frequency of the next measurements. Based on mean turbulence and the lowest mean square deviation, the frequency was selected for researching the main stream of the nozzle. The distribution of the highest mean, the highest maximum and the lowest mean deviation (most steady along the probe traversing line) was chosen. For these frequency parameters and, for comparison, for the nozzle with / without pulsation of $f = 1\,\mathrm{Hz}$, the measurements were made with the membrane attached, Fig. 2.

Fig. 7 shows the results of measurements of the output velocity $v_m = 6\,\mathrm{m \cdot s^{-1}}$ for selected frequencies; changes in mean velocity and changes in absolute turbulence depending on forced input frequency. Maximum mean velocities were obtained for the main stream without pulsation and with pulsation of $f = 1\,\mathrm{Hz}$. The lowest velocity values were recorded for pulsation of $f = 30\,\mathrm{Hz}$ and $f = 40\,\mathrm{Hz}$. Interestingly, the least effect was observed for $f = 14\,\mathrm{Hz}$ which, however, resulted in the highest turbulence in the main flow. The lowest turbulence values were obtained for pulsation of $f = 1\,\mathrm{Hz}$ and without pulsation. For $f = 30\,\mathrm{Hz}$ and $f = 40\,\mathrm{Hz}$ no maximum turbulence was recorded in the flow. The highest pulsation in the main stream down the nozzle is noted for pulsation frequency which generates both high turbulence and steady-distribution turbulence throughout the cross-section of the connector pipe (Fig. 6 and Fig. 7).

REFERENCES

[1] Brunn H.H., 1995. Hot-wire anemometry. Principles and signal analysis. Oxford Univ. Press Oxford.

[2] Peszyński K., Kuszyński Z., Świtała A., 2000. Konstrukcja i badania aktywnie sterowanej dyszy strumieniowej do urządzeń technologicznych. X Międzynarodowa Konf. Nauk. Tech. X-ICMR '2000, 47-54.

[3] Tesař V., 1998. Excited Axisymmetric Impinging Flows. Proceedings of Engineering Mechanics '98, Czech Academy of Sciences, Vol. 4, 757-762.

[4] Wawrzyniak S., Peszyński K., 2000. Problematyka pomiaru prędkości miejscowych przy pomocy termoanemometru w urządzenia technologicznych. Międzynarodowa Konf. Nauk. Recyrkulacja w budowie maszyn, Bydgoszcz, 41-46.

[5] Wawrzyniak S., 2002. Wpływ częstotliwości sygnału sterującego na parametry wypływu strumienia głównego dyszy osiowosymetrycznej. Zesz. Nauk. ATR w Bydgoszczy, Mechanika 52, 137-143.

Ali Makhief Al-Zubiedy
Józef Flizikowski

University of Technology and Agriculture
Department of Food and Environment Protection Machines
Prof. S. Kaliskiego 7, 85–796 Bydgoszcz

MULTIPLE-DISC GRINDING UNIFORMITY MODEL

Summary: Uniformity of the crumbling-beater process and cutting mill is described a part by part due to a rather high process complexity. The aim of a new model. using new technical solutions and new computer aided calculations of energy process dynamics. allows for calculating the grinding process in a multiple disc cutting mill depending on the design properties and mill process.

Keywords: multiple-disc grinding, non-uniformity, efficiency. machines operation

1. INTRODUCTION

Optimizing the multiple-disc grinding design, a mathematical model of the effect of movement non-uniformity plays an important role. Detailed solutions of driving assembly factor in temporary and long time of changes in speed, torque and as a result power consumption.

Developing, designing, and operating machines, more and more attention is paid to environmental concerns [1, 2, 3, 4]. Crumbling polymer material, often as part of recycling, one must consider design properties.

2. METHODOLOGY OF RESEARCHES

2.1. Research Object Model

The power demand of multiple-disc crumbling is, similarly as in other solutions, very unequal. Between the successive crumbling stages dead movement occurs which allows for energy accumulation. Part of the supplied energy accumulates in multiple disc cutting mill due to a sufficient moment of inertia. Otherwise fly-wheel should be installed and as a result non-uniformity takes an acceptable form:

$$\delta = f(C_{R,x-y}, C_{kR}, P_T, Z-Z)$$

or (1)

$$\delta = f(\Pi, W, T; d_{me}, d_{max}, l_{zr}, e^{'}; n, \omega, G_n, t; E_R, \Delta\tau)$$

where:

$C_{R,x-y}$ – property of material crumbled, d_{me}, d_{max} – diameter on entry, l_{zr} – reduced dimension of the product of crumbling, $e^{'}$ – energy consumption per-unit, $C_{k,R}$ – design properties of crumbling assembly, Π – form of design, W – dimension, T – tolerance of elements, P_T – technological parameters, n – rotational speed, ω – angular velocity, G_n – geometrical tool parameters and of crumbling assembly, t – time; Z-Z – used environmental potential and emission of pollutants to the environment, E_R – value of potential energy – material received from the environment. ΔT – value of potential energy – material energy increases due to increasing temperature.

For the shaft moving at rotational speed n [min^{-1}], its average angular velocity equals nominal value:

$$\omega_{me} = \omega_{nom} = \frac{\pi n}{30} \tag{2}$$

Approximately one can assume [1-3, 7-8]:

$$\omega_{me} = \frac{\omega_{max} + \omega_{min}}{2} \tag{3}$$

With the above, one can define the coefficient of non–uniformity of machine movement [8]:

$$\delta_k = \frac{\omega_{max} - \omega_{min}}{\omega_{me}} \tag{4}$$

From equations (3) and (4) the following can be received:

$$\omega_{max} = \omega_{me}\left(1 + \frac{\delta_k}{2}\right), \quad \omega_{min} = \omega_{me}\left(1 - \frac{\delta_k}{2}\right) \tag{5}$$

That is to say:

$$\begin{aligned} \omega_{max}^2 &= \omega_{me}^2\left(1 + \frac{\delta_k}{2}\right)^2 \approx \omega_{me}^2(1 + \delta_k) \\ \omega_{min}^2 &= \omega_{me}^2\left(1 - \frac{\delta_k}{2}\right)^2 \approx \omega_{me}^2(1 - \delta_k) \end{aligned} \tag{6}$$

The value of energy accumulated in fly-wheel ΔL, which is the difference between the work really executed during cuts L_{cz} and the work executed by electric engine L_{sn} [2], which can be substituted to the equation:

$$\Delta L = L_{cz} - L_{sn} = \frac{B_{mk}(\omega_{max}^2 - \omega_{min}^2)}{2} \tag{7}$$

where:

B_{mk} – moment of inertia of machine together with fly-wheel:

$$B_{mk} = B_{mz} + B_k \tag{8}$$

B_k – moment of inertia of machine without the fly-wheel.

The work executed between points AB can be obtained from the following:

$$\Delta L = \int_A^B M_{zr}\, d\varphi = \int_A^B (M_{cz} - M_{sn})\, d\varphi \tag{9}$$

The work is the difference between the energy values due to the highest (ω_{max}) and the lowest (ω_{min}) angular velocity values. The work equals the area of field F_1 (Fig. 1). By introducing equations (6) and (8) to equation (7), we receive:

$$B_k = \frac{\Delta L}{\omega_{me}^2\ \delta_k} - B_{mz} \tag{10}$$

As the moment of inertia of cutting elements is negligibly low as compared to the moment of inertia of fly-wheel [9], equation (10) will assume the form:

$$B_k = \frac{\Delta L}{\omega_{me}^2\ \delta_k} \tag{11}$$

The real power demand is greater [2, 3, 6, 8, 9]:

$$N_s' = \frac{E}{t_o} \tag{12}$$

The energy used per piece cut of d_{me} diameter and length L while recycling allows for determining the energy consumption coefficient per unit for 1 m³ plastic materials e'. Hence

$$E = \frac{\pi\, d_{me}^2}{4} \cdot L \cdot e' \quad \text{[MJ]} \tag{13}$$

Time of cuts:

$$t_o' = \frac{L \cdot 10^3}{60 \cdot n \cdot z \cdot l_{zr}} \quad \text{[h]} \tag{14}$$

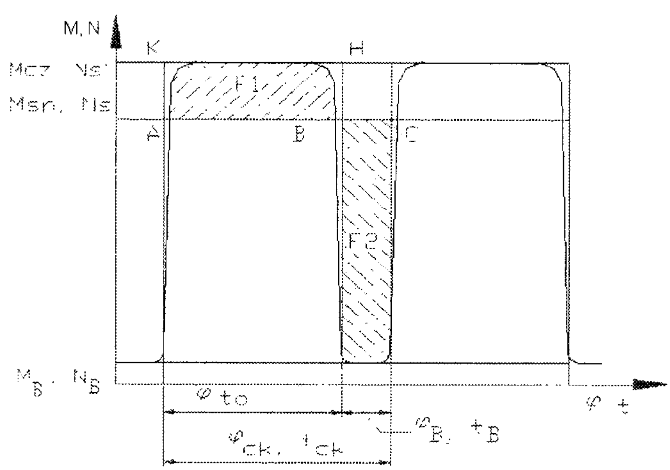


Fig. 1. Active resistances in pseudo-shearing cutting [2]

The real power demand while cutting to obtain recycled element d_{me} diameter can be calculated as:

$$N_s' = \frac{E}{t_o} = \frac{\pi\, d_{me}^2 \cdot L \cdot e'}{4} \cdot \frac{n \cdot z \cdot l_{zr} \cdot 60}{3.6 L \cdot 10^3} \quad \text{[kW]}$$

After transformation the following is received:

$$N'_s = \frac{60\,\pi\, d_{me}^2 \cdot e' \cdot z \cdot l_{zr} \cdot n}{14.4 \cdot 10^3} \quad \text{[kW]} \tag{15}$$

Without the fly-wheel the power demand would change from N' during cuts to the power of dead movement NB which occurs between pieces, see Fig. 1. The fly-wheel during dead movement t_B accumulates energy equal the area of field F_2. Areas F_1 and F_2 must be equal ($F_1 = F_2$). As a result, this power demand of the electric engine, remains constant, equal N_s, which makes it possible to enhance the engine operation conditions. Calculating, we assume with a little error, that the work executed by the fly-wheel during one cycle, i.e. cutting pieces, is equal to the area of the field of rectangle ABHK in Fig. 1. Hence

$$\Delta L = F_1 \cong F_{2\,ABHK}$$

Since

$$F_{2\,ABHK} = (N'_s - N_s) \cdot t_o$$

we can obtain:

$$\Delta L = (N'_s - N_s) \cdot t_o \quad \text{[kW·s]} \tag{16}$$

Substituting equation (16) to (11) we can receive:

$$B_k = \frac{(N'_s - N_s) \cdot t_o}{\omega_{me}^2 \cdot \delta_k} \tag{17}$$

After calculations, the following is obtained:

$$B_k = \frac{1020\,(N'_s - N_s) \cdot t_o}{\omega_{me}^2 \cdot \delta_k} \quad \text{[Nm·s}^2\text{]} \tag{18}$$

or

$$B_k = \frac{9.35 \cdot 10^4\,(N'_s - N_s) \cdot t_o}{n^2 \cdot \delta_k} \quad \text{[Nm·s}^2\text{]} \tag{19}$$

Substituting equation (15) to (19) we can receive:

$$B_k = \frac{9.35 \cdot 10^4 \cdot t_o}{n^2 \cdot \delta_k} \left[\frac{60 \cdot \pi \cdot d_{me}^2 \cdot e' \cdot z \cdot l_{zr} \cdot n}{14.4 \cdot 10^3} - N_s \right] \quad \text{[Nm·s}^2\text{]} \tag{20}$$

The calculated moment of inertia B_k of fly-wheel will ensure the stability of crumbling of pieces of an average d_{me} diameter by using a greater d_{max} diameter instead:

$$N''_s = \frac{60\pi \cdot d_{max}^2 \cdot e' \cdot z \cdot l_{zr} \cdot n}{14.4 \cdot 10^3} \quad \text{[kW]} \tag{21}$$

The electric engine then will work with surcharge defined bellow:

$$\left(N''_s - N'_s\right) = \frac{60\pi \cdot e' \cdot z \cdot l_{zr} \cdot n}{14.4 \cdot 10^3} \left(d_{max}^2 - d_{me}^2\right) \quad \text{[kW]} \tag{22}$$

If the moment of inertia B_t of the fly-wheel designed is greater then the calculated B_k, the surcharge of engine will be smaller and will be:

$$N''_s = \left(N_s + \frac{B_t \cdot \omega_{me}^2 \cdot \delta_k}{102 \cdot t_o} \right) \tag{23}$$

When analyzing in detail the fly-wheel inertia moment necessary in pseudo-shearing, additional periods of dead movements while pseudo-shearing of one piece should be considered. If the distance between the edges of cutting-tools holes is greater than d_{me} material diameter, then a break (of definite angle φ_p) occurs between the work of two successive cutters; hence dead movement. The pseudo-shearing angular distance can be calculated as:

$$\varphi_r = \frac{d_{me}}{R_m} \tag{24}$$

$$\varphi_p = \frac{2\pi}{z} - \varphi_r = \frac{2\pi}{z} - \frac{d_{me}}{R_m} \tag{25}$$

2.2. Theoretical Solution

For the needs of a detailed analysis of dynamic non-uniformity, a modified torque M_c and average torque value $(M_c)_{me}$ can be used, considering p_c – resistances of crumbling, Δl_i – unitary length of cut, r – radius, μ – friction coefficient, τ – angle of cut, Ψ – angle of tool working motion, z – number of tools; according to assumptions of equation (1), presented in paper [2]:

$$\delta_d = \frac{M_{cmax} - M_{cmin}}{(M_c)_{me}} = \frac{p_c \Delta l_{max} r\cos\tau(1+\mu tg\tau) - p_c \Delta l_{min} r\cos\tau(1+\mu tg\tau)}{\dfrac{z\int_{\varphi_p}^{\varphi_k} M_c(\Psi)\,d\Psi}{2\pi}} \tag{26}$$

Of course having considered non-uniformity, respective resistances of crumbling and friction conditions, the following is obtained:

$$\delta_d = \frac{A\Delta l_{\max} - A\Delta l_{\min}}{(M_c)_{me}} = \frac{A(\Delta l_{\max} - \Delta l_{\min})}{(M_c)_{me}} \tag{27}$$

The above equation can be used in measuring. The degree of dynamic non-uniformity, measured for arrangements of cutting assembly crumbling, is based on measurements lengths Δl_i in time; and of torque M_i. Under the conditions investigated also the value of constant A, for a specific multiple-disc considered, a selected kind of materials and process parameters can be determined.

The reports [2, 9] show that fly-wheel torque necessary in this instance case is ten times smaller, than this of the working disk. The previously calculated fly-wheel torque is sufficient to ensure the stability of movement.

3. CONCLUSIONS

The design features to obtain the highest possible uniformity of crumbling, which meet the criteria defined by equation (26), have been confirmed experimentally using the physical model developed in the Department of Food and Environment Protection Machines.

The solution presented was awarded a gold medal at the World Fair of Innovation, Scientific Researches and Technology in Brussels in 1998. The process of crumbling requires thermal stabilization due to heat transfer to the environment of the material crumbled during timely operation.

In the material – machine – process – crumbling environment system, to obtain a high uniformity, it is firstly necessary to use the possibility, secondly to change the properties of the material crumbled and, thirdly, to change the design features

Uniformity of crumbling is essential in terms of coefficients and of potentials. Coefficients of effectiveness are link to efficiency, namely the efficiency of fulfilling a given function.

Design solutions offer crumbling multiple-discs, which include, cutting-tools for which a mathematical model is proposed which consider both technological and environmental factors.

REFERENCES

[1] Flizikowski J., 1998. Projektowanie środowiskowe maszyn. Wyd. Uczeln. ATR w Bydgoszczy.

[2] Flizikowski J., 1998. Rozdrabnianie tworzyw sztucznych. Wyd. Uczeln. ATR w Bydgoszczy.

[3] Macko M., 2000. Wpływ cech konstrukcyjnych zespołu wielotarczowego na charakterystyki użytkowe procesu rozdrabniania rurowych recyklatów tworzyw sztucznych. ATR Bydgoszcz, praca doktorska.

[4] Flizikowski J., 2000. Konstrukcyjno-procesowa efektywność rozdrabniania nasion zbóż. Inżynieria Maszyn 15, 9-18.

[5] Bieliński K., Flizikowski J., 2000. Wspomaganie zarządzania mediami energo-materialnymi w technologiach spożywczych. Inżynieria Maszyn 15, 165-170.

[6] Flizikowski J., Peszyński K., Flizikowski A., Al-Zubiedy A.M., 2000. Analiza danych quasi-ścinania w metodyce środowiskowych rozwiązań konstrukcyjnych rozdrabniaczy. Inżynieria Maszyn 15, 235-238.

[7] Flizikowski J., Al-Zubiedy A.M., Flizikowski A., Tomporowski A., 2001. Nierównomierność rozdrabniania surowców i materiałów spożywczych. Cz. I i II. Inżynieria Maszyn 17, 35-50.

[8] Flizikowski J., 1984. Wpływ cech konstrukcyjnych na charakterystyki ruchowe bezstopniowej przekładni impulsowej. Politech. Gdańska, praca doktorska.

[9] Flizikowski J., Kikiewicz Z., Macko M., 2000. Cechy geometryczne krawędzi rozdrabniającej rurowe recyklaty tworzyw sztucznych. Inżynieria Maszyn 16, 73-80.

AKADEMII TECHNICZNO-ROLNICZEJ Biblioteka GŁÓWNA w Bydgoszczy

Biblioteka Główna ATR w Bydgoszczy
S 32868

ISBN 83-89334-80-1