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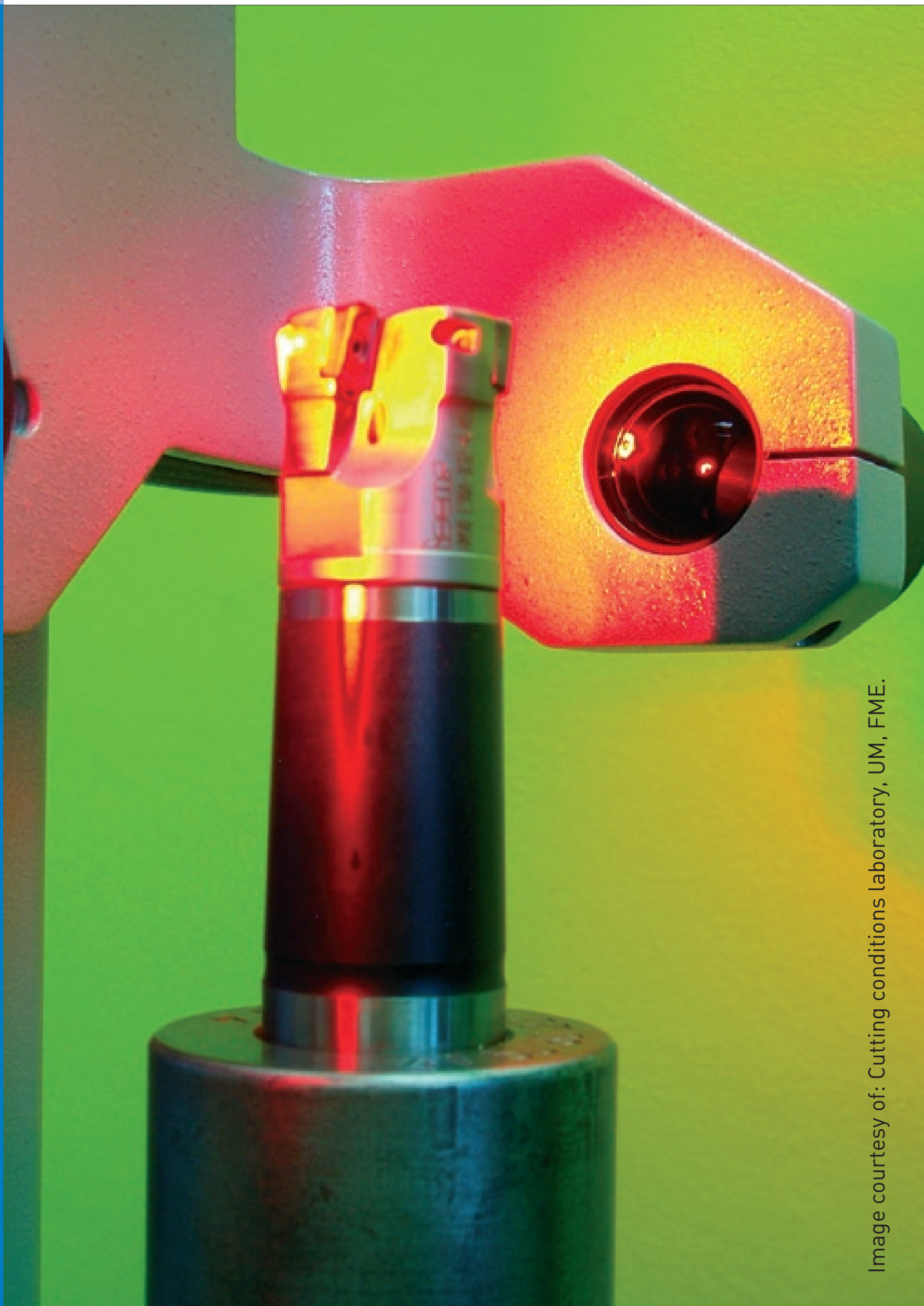

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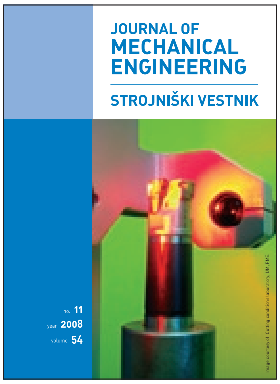

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Product Development Through Multi-Criteria Analysis

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The trend regarding the development of sanitary fittings is forecasted by the use of a developed model of multi-criteria analysis. In this analysis a multi-dimensional space is used, which enables the establishment of a time argument in comparison to product parameters. The establishment of product parameters is achieved by means of internal company information and market needs. In this way it is possible to establish an innovative environment for the development of new products.

This paper indicates various ways of dealing with product development, on the basis of which the method of multi-criteria analysis for establishing future trends in product development is acquired.

Keywords: sanitary fittings, product development, multi criteria analysis, multi-dimensional space

0 INTRODUCTION

The key moment of any company's strengths lies within essential and sustainable continuous development. Modern companies require constant investment into development. The development of the equipment for product development is also very wide, while the use of such equipment is still not as widespread as it should be [1]. As a line of business, product development has played an important role in production engineering by researches within the global industry experience[2], design and analysis [3] and [4], product design [5] to [8] and creativity used in product development [9].

On the other hand, product development also includes research within the market with regard to customer needs [10], [6] and [11], product positioning and segmentation [7] and [12], product forecasting [13] to [15] and test marketing [16]. A number of applications, marked by different views, led to a deeper understanding of how to join and use the information regarding customers and product engineering in designing, testing, starting and managing new products. To further disclose the contents, methods and applications of the above, more integrative views and papers on the topic of product development were published [17]. The production and engineering precision, combined with the marketing approach, both of which were focused on customer needs and production capability, proved very successful. In parallel with the development of established equipment, researchers discovered the correlation of new product success by establishing the communication between marketing and production engineering as the most important elements necessary for success [2], [5], [10], [19] and [20]. Organisation processing equipment as are, for example, teams functioning via network [14], quality function development (QFD) and distribution [21], were all developed with the purpose of establishing a closer link between production engineering decision-making and customer needs [22]. New challenges and opportunities are reflected in global markets, global competitiveness, the global spread of engineering knowledge and with communication technologies. The use of multi-criteria analysis with product development represents a new challenge and an opportunity in design research and new product forecasting [23] and [24].

1 THEORETICAL BACKGROUND

In the last decade companies were focused on new product development on the basis of satisfying customer needs. Researchers in the field of marketing were convinced that understanding customer needs and improving the transfer of these needs to product manufacturers was the key to success.

The Kaizen method for continuous improvement helped enhance the understanding of quality in product development with improved reliability [25], with statistical-qualitative control [26], modified experimental design [20] and design for production [27] to [29]. Engineers were certain that a product of higher quality was the key to success [30].

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Both marketing and production engineering recognised that the time from conception to implementation was of key importance. The awards for the early entrants were excellent, while production engineering went through great losses by working overtime and delays. Customer satisfaction and the time from conception to marketing became the warranty for success and profit.

Both the economic and academic worlds realised that successful product development is a closely related process, which can bypass many compromises. Customer satisfaction, the time from conception to marketing and cost reduction through complete control and quality management are also important factors. However, none of them has been recognised as a warranty for success.

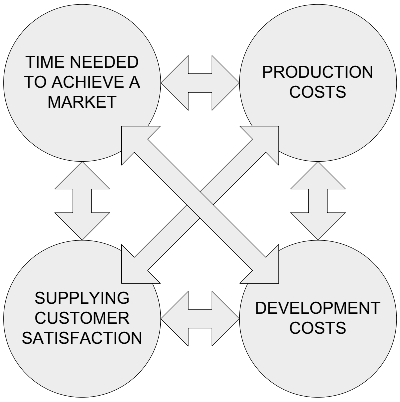

Fig. 1. *Alternatives and connections in new product development* [16]

Under unchanged conditions a product will prove profitable if it supplies customers with greater satisfaction, is among the leading products in the market, and has low production and development costs. Fig. 1 puts forward researches carried out in the field of equipment and product development methods. These researches should ensure that companies are directed towards new fields by taking into account all the strategic aims presented in Fig. 1. The concept of joint or common dealing of product parameters is included in the conjoint product analysis [13] and [31].

Researches must prove that various perspectives with all the effective new fields of development are of key importance. If a closer look is taken at only two of the numerous aims in the development of a new product, effectiveness proves the most essential. QFD can represent the most effective way of supplying customer satisfaction by means of improved communication and coordinating the efforts of the various parties involved in the process of product development. At the same time it is necessary to stress that certain equipment might prove inefficient in saving time in the process from conception to implementation and thus increase development costs.

Most companies see product development as a process of conception and implementation and connect it with production engineering, marketing, production and organisation development. Fig. 2 shows the process that takes place from conception to implementation [16]. It is a set of strengths that influence product development and shed light on opportunities for researches regarding product development.

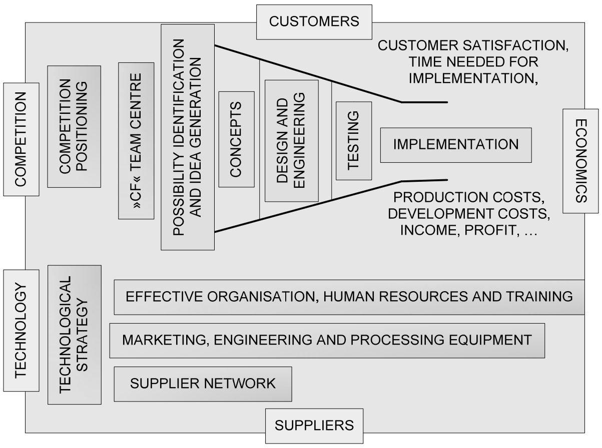

Fig. 2. *Product development: from cognition to implementation*

Instead of choosing a 3-year planning cycle it is advisable for companies to adopt a development plan which is checked on a monthly or even weekly basis. For example, a company should have a strategy for dealing with technology and with implementing methods for understanding opportunities that are to be offered to customers by means of offered products, as well as with recognising where demands and expectations are not being fulfilled. Here it is just as important to know how the competition will respond, while the supplier's chain helps and is involved in the development in order to fulfil customer demands.

Perspectives of marketing, production engineering, designing and manufacturing must be integrated for the needs of product development and show themselves as the basic network of a functional team that supports an effective organisation.

Human resources are important for the inclusion of needs for context and culture organisation understanding, as well as the need for developing human capabilities through training, information technology, and communication on the part of practice. Marketing, engineering and processing equipment enable the process of development from its conception to its implementation and support this process in being effective.

Product development, as shown at the funnel neck in Fig. 2, shows a normal - traditional view, according to which product development generates itself through idea conception and develops further into a number of potential products that are potentially realised. Within the neck presented in Fig. 2a method is adopted - steps of opportunities, identification and idea formation, concept development and choice, detailed selection of design and engineering, testing and implementation [8]. Although the context and individual companies use a slightly different description of the steps, the description of product development in the form of development steps remains more or less the same.

The basic idea of management is that it is less expensive to establish product suitability in the early rather than in later steps, and that every following step might improve the product and its positioning and thus increase its success in the market. Mathematic examples show that such a step process, which is best presented in the form of key steps, proves to be the most efficient in decreasing costs [1].

The neck in Fig. 2 also tries to show the concept of management flow by means of parallel projects that are moving through the funnel neck. However, in the steps, and in the assessment of the work carried out in each step, there is no connection between individual steps, which remains one of the greatest weaknesses of the step process. On the other hand, in the process of continuing product development in the multi-dimensional method this moment of weakness is smaller.

Often the best strategy for companies is to have a suitable number of parallel projects, since it is in this way possible to implement the project that shows the most profitable future. Fig.2 does not show clearly enough the importance of the real product development process characteristics, since certain steps are often expedited and left out.

For example, with advanced methods, as are user's and same-time design, it is possible to test the design concept already in the early steps of designing and engineering, or to, for example, present ideas already in the concept phase more effectively. Moreover, Fig. 2 does not explicitly include (co-)circumstances of the nature of the whole process [32]. Nowadays many companies use a spiral instead of line development process, since in the former products or concepts move through numerous narrower and narrower steps.

The essential difference between the neck and spiral processes is that the latter is more suitable for higher expectations in the form of a repeating return in the parallel direction through the neck of the shown funnel and leads to improvement. An interesting challenge for research would be to make a comparison of input data in the spiral and the funnel form of the process. Here could be compared which circumstances influence one or the other form of development and which is more suitable.

The process of multi-criteria product analysis also includes product platforms. It has been recognised in numerous industry branches and companies that it is far more effective to develop products in platforms. In the field of sanitary fittings a platform carries a very specific name – family. From the point of view of customers these platforms supply companies with the possibility of adapting to customer demands and market needs [4], [17], [27] and [33].

On the right side of Fig. 2, where the process from conception to implementation is presented, an increasing trend in the direction of conventional product development is shown. When the process is exposed to various circumstances, as are functionality, teams and suppliers, the process itself becomes more dispersed and the product involved consequently more complex. This then leads to a greater need for balancing in the controlling of top management by means of their increased and stressed own engagements in the role of connecting within functional teams. To achieve such balance companies turn to a metrical approach, in which teams are measured on the basis of strategic indicators, as are customer satisfaction and the time needed for implementation, as well as production and development costs. The enumerated parameters are followed-up in the analysis covered within this article. If the ratio of these parameters is correct, then these teams can perform in the best possible way and with the greatest short- and long-term enthusiasm, and it is only in this way that the accepted decisions will lead to the best short- and long-term profits [34].

2 METHODOLOGY

The conceptual model with data capture and information flow is shown in Fig. 3. The data are collected from the market with a data collecting form and the data flows into the data collector together with the technological company capabilities (internal data). The combined data are processed in the model, and in this way the model anticipates trends on the basis of individual parameters as well as the common trend. The possibility of development determination also depends on the body's centre of gravity which is time-dependent. Possible feedback connections are also shown on the conceptual Fig. 3 and serve as corrections or modifications to the model.

3 MODEL OF MULTI-CRITERIA ANALYSIS FOR PRODUCT DEVELOPMENT ASSISTANCE

The idea about multi-dimensional analysis of product acceptability in the market was born from watching two-dimensional graphs showing the dependence of the dependent variable from the independent one. The independent variable represents time, the dependent one is derived from the observed and most representative parameters – e.g. prices, sale quantities, input into development on individual product, costs of manufacturing. Because of the incapability of demonstrating individual parameters on one graph the concept or model is presented, which could eliminate that weakness.

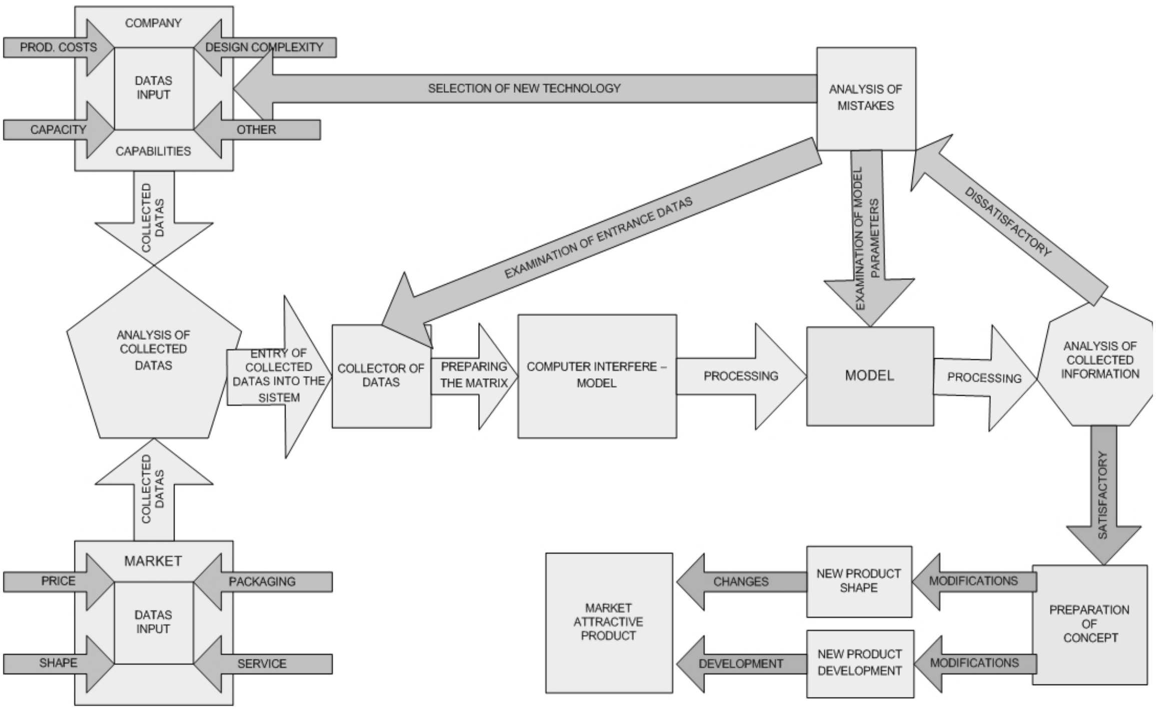

Fig. 3. *Conceptual scheme of product development*

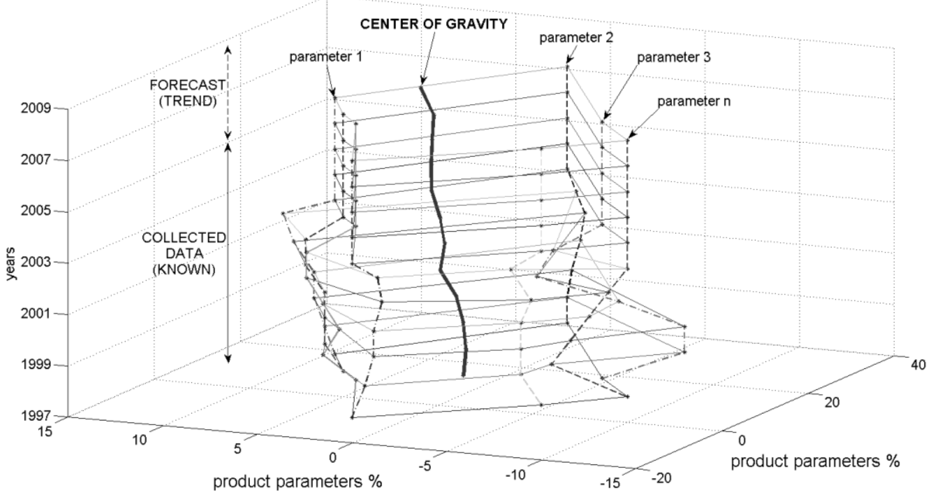

Fig. 4. *Outline scheme of the model*

Due to longer non-changeability of products and technology in the branch most of the products observed remained the same in that time or changed minimally (e.g. sanitary fittings, handles of sanitary armatures and packaging changed [35]), which is an additional confirmation of the model`s results. The calculated trend on the basis of the gravity centre is represented graphically and mathematically and applies for future years.

The transition from Cartesian coordinates to polar coordinates is given by the following Equations (1), (2) and (3). In Equation (4) we calculate the uniform distribution of the horizontal axes of observed parameters around time – central axis. This uniform way of distribution of product parameters does not emphasise only one parameter but that all parameters are equivalent Equation (6).

The representative parameters acquired from the company are evenly distributed on the circle arch of 360° with the centre in coordinate origin. The angle according to Equation (1) belongs to each parameter; parameter *n* means the number of representative parameters.

$$\varphi_k = {360^0}/{n} \cdot (n-k) \; ; \qquad k = 0,1,2 \ldots n-1 \tag{1}$$

The percentage value of an individual parameter with belonging angle (Equation (1)) is converted to Cartesian coordinates upon Equations (2) and (3). On the coordinate axis "z" an independent variable time is shown or the period of watching (e.g. from 1997 to 2007).

$$x_k(\%) = Par_k(\%)\cos\varphi_k \tag{2}$$

$$y_k(\%) = Par_k(\%)\sin\varphi_k \tag{3}$$

Each parameter is represented in the form of a point, with three parameters used for representation of the results in three-dimensional space, where parameter *m* is the number of years observed.

$$Par_{k_{kart}}(\%) = (x_k, y_k, z_m) \tag{4}$$

Presentation of results with a polar way of data demonstration is improved since it shows the trend and not just information. The centre of gravity of the surface shape enclosed by polar coordinates of observed parameters is calculated upon Equations (5) to (9). The shape contains a set of n-triangles and the sum of the *n*-centers of the mass of those triangles is the mass centre of one observed time parameter [35].

$$S_i = \frac{1}{2}\begin{vmatrix} x_k & y_k & 1 \\ x_{k+1} & y_{k+1} & 1 \\ x_0 & y_0 & 1 \end{vmatrix}; \quad (x_0, y_0) = (0,0) \tag{5}$$

$$x_m = \frac{\sum_{i=1,k=0}^{n,n-1} S_i x_k}{\sum_{i=1}^{n} S_i} \tag{6}$$

$$y_m = \frac{\sum_{i=1,k=0}^{n,n-1} S_i y_k}{\sum_{i=1}^{n} S_i} \quad (7)$$

An algorithm draws and calculates polar coordinates for individual periods between the year *m-1* and the adjacent variable, and the year *m+1* and the adjacent variable. The year is selected as a time argument typical for the branch since the product and technology changes are relatively slow.

The representation of the centre of mass in a polar way Equation (8) to (10) provides complete information related to an individual time period.

$$T_{pol_m} = \rho_m e^{j\gamma_m} \quad (8)$$

$$\rho_m = \sqrt{{x_m}^2 + {y_m}^2} \quad (9)$$

$$\gamma_m = tg^{-1}\left({y_m}/{x_m} \right) \quad (10)$$

Time as the only independent variable is represented by the central axis in the graph, which is the result of model visualization. The displacement of dependent variables on time shows their importance and development upon time parameter.

There is an arbitrary number of dependent variables in the model. They are configured in the circle around time in the form of uniform distribution. For the purpose of this investigation a model is prepared where data is uniformly distributed.

In the observed changing of the trend it has been ascertained that linear accommodation is inaccurate.

These are higher order curves that are genomically imposed and on the bases of polynomial curves and Fourier rows (harmonic analysis) in Equation (11) they form a trend for each parameter separately (curve accommodation is higher than 95%)

$$s_n(x) = \frac{a_0}{2} + a_1 \cos\frac{2\pi x}{T} + a_2 \cos 2\frac{2\pi x}{T} + ... + \frac{a_n}{2}\cos n\frac{2\pi x}{T} + ...$$
$$+ b_1 \sin\frac{2\pi x}{T} + b_2 \sin 2\frac{2\pi x}{T} + ... + b_{n-1}\sin(n-1)\frac{2\pi x}{T} \quad (11)$$

3.1 The Use of a model in the Example of Sanitary Fittings

There is practically no research to be found on the topic of development of sanitary fittings products. The field of survey is from the production engineering point of view, which is interesting due to the complexity of the product. It is pre-supposed that sanitary fittings represent generic products which are intended for a wider range of users.

The sample on which the first model of multi-dimensional analysis is prepared with the intention of product development covers eight time-dependent variables of sanitary fittings. The products observed were sanitary fittings of middle-price range in Slovenia. The price and quality range was assumed on the basis of expert opinions from the branch of sanitary fittings production and from the branch of sanitary fittings suppliers. The number of the chosen sanitary fittings representatives comprises 95% of the observed range, that is the sixteen most representative products of the middle-priced range of recognised European trade marks that were, and still are, present in the Slovenian market. The price range of up to 110 EUR, for which certain marketing and production rules are applicable, is a so-called premium range. The characteristics that were observed in the chosen sanitary fittings were the following: price, shape, packaging, service, production costs, capacity, design complexity, and unclear influences given under the column other.

The questionnaire that was carried out in the market and among the Slovenian producers of sanitary fittings showed the information represented in Table 1. The key moment belongs to 'product' and 'product characteristics'. On the basis of this key moment the carrying out of the analysis covered the most important parameters of the product in each time period for the observed group of sanitary fittings (herein parameters). These parameters do not change through time intervals. The concept of the information analysis is based on the observation of the product in each of the given time periods. However, trend forecasting for future time intervals is based on statistical analysis by means of an approximate function that is designed as development simulation. The information that was not gained empirically is subject to the joint evaluation of experts in the field of sanitary fittings. In 1997 the characteristics of the product in the market were the following: 30% of its value was represented by price, 10% of the overall product was represented by the importance of its design, 5% was represented by its packaging, 5% by service, 20% by production costs, 10% by capacity, 10% by design complexity and 10% by other characteristics. The total of the observed and covered parameters lies in the centre of a polygonal form of the observed characteristics.

In 1998 the same market and the same product were analysed. However, the latter included new characteristics this time. This paper represents the same number of variables for each year, with the intention of showing the functionality of the system.

The established algorithm was modelled in the Matlab programme version 7.6.0.324. This programme enables easy and transparent recording of algorithms. By means of Matlab computing language, which contains a number of other functions for three-dimensional presentations of objects, three-dimensional programming was also performed.

4 RESULTS AND PREPARATION

The established model has eleven years' worth of recognised parameters (Table 1), which develop partly independently from one another. Even though the reviewed parameters do not have much in common, they represent one product and development path within one time determinant. The combination of market data and strategic know-how of the company are thus presented in a graphically simple, transparent manner and within a mathematically ascertainable system. Polynomial interpolation and extrapolation allow the adjusted trend to offer values of individual monitored parameters based on a set time-frame. In polynomial interpolation, we find the polynomial which corresponds to function f at given points.

If we are presented with N points, we require a polynomial at N-1, so that the set polynomial is uniform. Some functions may be interpolated well by using polynomials, while others pose more difficulty. Calculation of polynomial interpolation is carried out by using Neville's algorithm. The trend determined in such a way will confirm future parameter values with a probability higher than 2 sigma. These values, moreover, represent changes in product development throughout future time-frames.

There is an indication of which way the product will lean towards and which parameters will be emphasised. This will give designers of new products in the company guidelines for development, which will not be limited solely by the market, but also by the company. The combination of the company's internal – economic arguments and external data obtained from the market, is presented as key in the literature [6], [10], [27] and [35].

Table 1. *Information gathered from the market and company*

Time (years)	Observed parameters								
	Market information				Manufacturer information				
	Price	Shape	Packaging	Service	Production costs	Capacity	Design complexity	Other	Total
1997	30	10	5	5	20	10	10	10	100
1998	30	11	6	7	17	8	6	15	100
1999	31	12	6	6	15	8	7	15	100
2000	33	12	6	7	15	8	8	11	100
2001	34	14	7	8	13	9	9	6	100
2002	32	15	6	7	14	7	8	11	100
2003	34	16	4	6	12	8	9	11	100
2004	36	18	4	4	11	7	10	10	100
2005	37	19	3	3	11	7	7	13	100
2006	38	19	2	3	10	8	6	14	100
2007	43	17	2	2	12	8	8	8	100

The observed model shows the aggregate variable to be the centre of gravity. Analysis of data in the future allows linear review or quadratic review of the trend, including an arbitrary form of establishing a trend based on lines of respective independent variables.

The common trend of spatial lines allows for analysis of a common product development trend. It depends on the respective field whether data from the market or from the company is more important. When the model is ideal, all dependent variables may be presented arbitrarily at optional angles, and further broken down into their dependent variables. When reviewing independent variables this may be done in a classical circle diagram.

The system is limited by the values of the dependent parameters of the product, which represent the limit value. This limit value is the limit which the company is not allowed to surpass in a respective product development in considering the model, as doing so would impair its competitiveness, which must be monitored with regard to all parameters of the product. In this part the model looks to the finite elements analysis, where outer limits are recommended for development and establishment of individual product parameters - summarised according to [22].

Fig. 5 shows the "skeleton" multidimensional graph of product development. Limits to the system are set uniformly with boundary lines of observed parameters. The central axis is represented by the centre of gravity, which is the aggregate variable, and indicates a trend, which is presented in greater detail in Fig. 6 and Fig. 7.

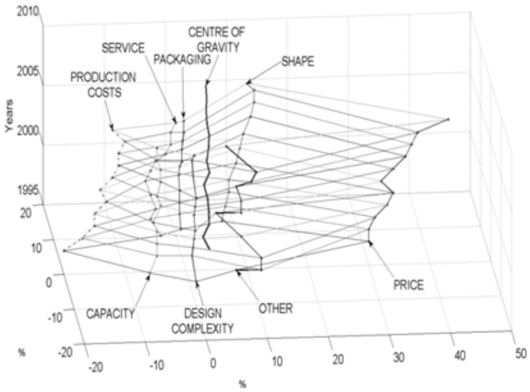

Fig. 5. *Overview of links between individual product parameters and the aggregate variable – the centre of gravity*

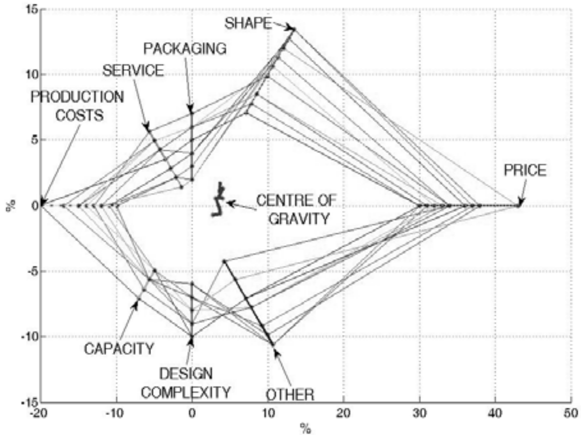

Fig. 6. *The ground plan of the graph shows deviation of the centre of gravity to the desired product parameters*

Fig. 6 shows a view of the polar graph through various time-frames. The centre of the graph is the point of time with coordinates T (0, 0, 1997). The whole display otherwise presents the development of individual product parameters and their mathematically ascertained trend.

The polar diagram shows shifts in the gravitational centre from 1997 until 2010 – Fig. 6 and 7. The path travelled by the aggregate parameter, comes from the direction of different characteristics, which substantially mean unchartered territory for the product in the direction of the product design.

These data are appropriate and also logical considering that the industry is an unknown variable. Development departments in the company will thus have a goal to design an armature that will be interesting and demanding from a design point of view. The direction of development would be further improved by conducting an analysis of the sense of design and thus obtain the desired values. It is presumed that the product design in the observed class will summarise the features of design in the higher class, which generally dictate the direction of development of lower and less demanding products in terms of quality. They would also discover whether they are able to achieve the desired market design with the given technology and production costs, which would give the model a moment of strategic decision-making with regard to product development.

Fig. 8 gives us the opportunity to observe a multidimensional curve, which is defined by the absolute value of the angle of aggregate indicator of the trend of the centre. These curves show a linear trend which, in the coming years, moves the centre of the observed products towards the importance of product design.

5 CONCLUSION

Life cycles of technologies, products and processes are becoming ever shorter, so technological foresight is a very important aspect of their planning. In a time when foretelling the development of products is difficult and the price of error as steep as it is, the article offers a solution for the development of products through multidimensional analysis. An alternative manner of product development, it is based on a simple premise that an individual product in a certain time consists of separate parameters, which make a whole.

The presented concept can be developed and adjusted towards all dimensions of modern forecasting of the development of middle range sanitary faucet products, which will, through time, show a deviation from the orientation towards unexplored elements towards product design.

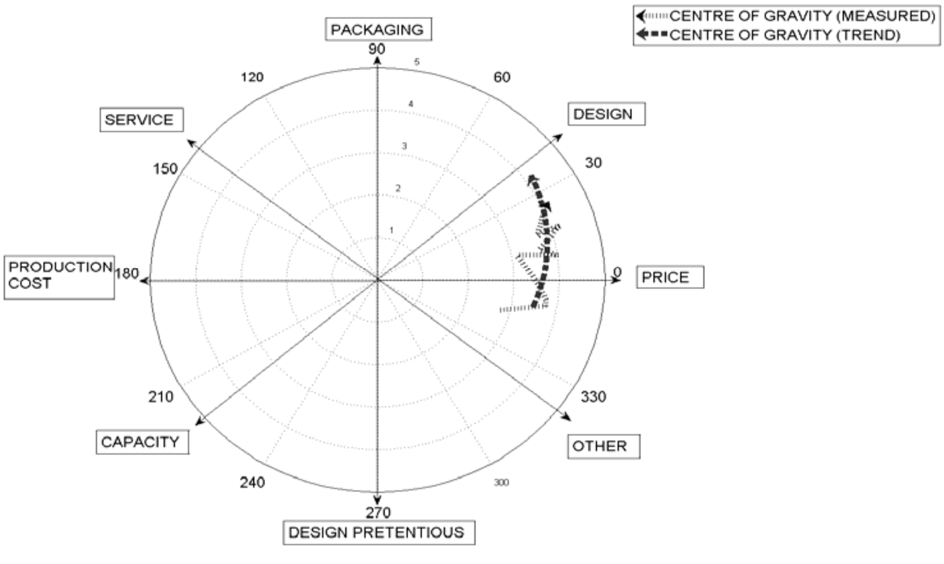

Fig. 7. *Polar graph of the movement of the centre in the observed years*

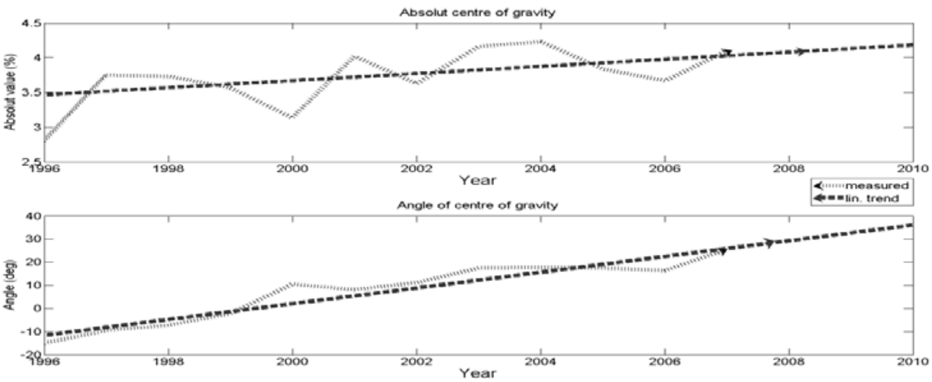

Fig. 8. *Variation of the absolute value and angle of the centre in the observed time interval*

Advanced options of the defined model are:

- The introduction of virtual reality into strategic product development, which would allow a multilayered and even spatial analysis of the outer limits of the system, which delineate the logical scope of development of a single product.
- A comparison of the development of two competing products through time, which would show the differences and similarities of products and highlight the advantages and disadvantages of an individual product through an analysis of 10 parameters.
- An opportunity to improve the visualization of the advantages and disadvantages in the business area the product is placed in.
- An opportunity to link the model directly with production and computer prototyping.
- Trend forecasting on the basis of extensive experience.
- An opportunity to analyse the internal characteristics of the company and gathered external data. The internal data gathered within a company and market research data allow simple and straightforward development of a concept of further company development, and enable the assessment of separate parameters through simulation. This is very important considering the fact that the limitations of production are equally or more important than market demand (high tech products), which enables us to enforce the claim calling for a technology "push" and marketing "pull".
- Computer models include a data entry interface which allows entry of data for instantaneous analysis in the model, thus effectively simulating whether further improvements remain reasonable [36].
- Analysis of separate parameters with the aid of approximation of existing movement by the movement of the aggregate central variable; a joint concept would provide more detailed data about product development as it would allow double simulation.
- An opportunity to analyse the shift of the aggregate variable of the body centre and its deviation towards individual dependent variables represents the quality of such an analysis.
- Another option is the representation of the "onion" product strategy – on a model where the basic demand for the product is fulfilled and its transfer into higher levels improves the product.
- Choosing shorter periods of time would not allow for such detailed data. The line between both time intervals can be an approximated value, which would indicate seasonal movement of product parameters.

The developed model of product design through multi-criteria analysis can be used in the development of virtually any mass produced product.

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Machining Process Optimization BY Colony Based Cooperative Search Technique

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Research of economics of multi-pass machining operations has significant practical importance. Non-traditional optimization techniques such genetic algorithms, neural networks and PSO optimization are increasingly used to solve optimization problems. This paper presents a new multi-objective optimization technique, based on ant colony optimization algorithm (ACO), to optimize the machining parameters in turning processes. Three conflicting objectives, production cost, operation time and cutting quality are simultaneously optimized. An objective function based on maximum profit in operation has been used. The proposed approach uses adaptive neuro-fuzzy inference system (ANFIS) system to represent the manufacturer objective function and an ant colony optimization algorithm (ACO) to obtain the optimal objective value. New evolutionary ACO is explained in detail. Also a comprehensive user-friendly software package has been developed to obtain the optimal cutting parameters using the proposed algorithm. An example has been presented to give a clear picture from the application of the system and its efficiency. The results are compared and analysed using methods of other researchers and handbook recommendations. The results indicate that the proposed ant colony paradigm is effective compared to other techniques carried out by other researchers.

Keywords: machining, turning, optimization, cutting parameters

0 INTRODUCTION

The selection of optimum cutting parameters is a very important issue for every machining process in order to enhance the quality of machining products, to reduce the machining costs and to increase the production rate. Due to machining costs of Numerical Control (NC) machines, there is an economic need to operate NC machines as efficiently as possible in order to obtain the required pay back. In workshop practice, cutting parameters are selected from machining databases or specialized handbooks, but they do not consider economic aspects of machining. The cutting conditions set by such practices are too far from optimum. Therefore, a mathematical approach has received much attention as a method for obtaining optimised machining parameters. For the optimisation of a machining process, either the minimum production time or the maximum profit rate is used as the objective function subject to the constraints. Optimization of cutting parameters is a difficult task [1], where the following aspects are required: knowledge of machining; empirical equations relating the tool life, forces, power, surface finish, etc., to develop realistic constrains; specification of machine tool capabilities; development of an effective optimization criterion; and knowledge of mathematical and numerical optimization techniques.

Optimization of machining parameters is complicated when a lot of constraints are included, so it is difficult for the non-deterministic methods to solve this problem. Conventional optimization techniques are useful for specific optimization problems and leaned to find local optimum solution. Consequently, non-traditional techniques were used in the optimization problem. Researchers [2] have done comparative analysis of conventional and non-conventional optimization techniques for CNC turning process. The optimization problem in turning has been solved by genetic Algorithms (GA), Tabu search (TS), simulated annealing (SA) and particle swarm optimisation (PSO) to obtain more accurate results [3]. Milfelner et al. [4] have described the multi objective technique of optimization of cutting conditions for turning process by means of the neural networks and particle swarm optimization (PSO) [5], taking into consideration the technological, economic

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and organization limitations. Further genetic GA and simulated annealing techniques have been applied to solve the continuous machining profile problem by [6]. They have shown that GA approach outperforms the simulated annealing based approach.

In this paper, a multi-objective optimization method, based on combination of ANFIS and ACO evolutionary algorithms, is proposed to obtain the optimum parameters in turning processes. The advantage with this approach is that it can be used for solving a diverse spectre of complex optimisation problems [7] and [8]. This paper also compares the results of ANFIS-ant colony algorithm with the GA and simulated annealing (SA). The results exhibit the efficiency of the ACO over other methods.

1 THE HYBRID ANFIS-ANTS APPROACH

The proposed approach consists of two main steps.

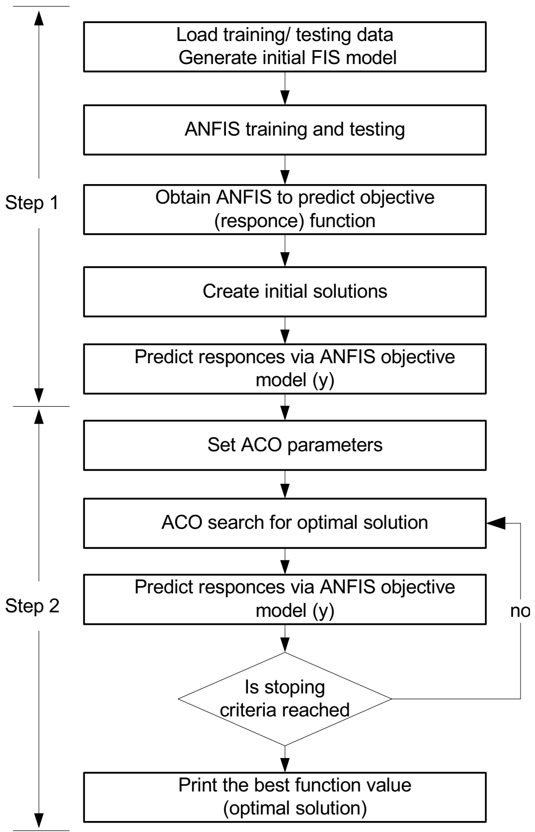

Fig.1. *Scheme of the proposed approach*

First, experimental data are prepared to train and test ANFIS system to represent the objective function (y). Finally, an ACO algorithm is utilized to obtain the optimum objective value. Figure 1 shows the flowchart of the approach.

Detail steps for optimization of cutting parameters by ANFIS-ants approach:

1. Entering of input data.
2. Generation of random cutting conditions-initial solutions.
3. Calculation of other values (P; F; MRR; C_p; T; R_a; T_p; y).
4. Preparation of data for training and testing of ANFIS.
5. Use of ANFIS model: The purpose of ANFIS is to predict the manufacturer's value function (y) in case of randomly selected cutting conditions.
6. Training and testing of ANFIS.
7. Optimization process: The cutting conditions where the function (y) has the maximum are the optimum cutting conditions. The extreme of the function (y). Since the function (y) is expressed with ANFIS, it means that the extreme of ANFIS is searched for.
8. Survey of optimum cutting conditions and the variables relevant to them.
9. Graphic representation of results and optimization statistic.

1.1. Machining Model Formulation

In CNC machine tools, the finished component is obtained through a number of rough passes and finish passes. The roughing operation is carried out to machine the part to a size that is slightly more than its desired size in preparation for the finish cut. The finish cut is called single-pass contour machining, which is machined along the profile contour. In this paper one roughing stage, and a finished stage are considered to machine the component from the bar stock.

The objective of this optimization is to determine the optimum machining parameters including cutting speed, feed rate and depth of cut in order to minimize the production cost (C_p) and to maximize production rate (represented by manufacturing time (T_p)) and cutting quality (R_a). The operation of turning is defined as a multi-objective optimization problem with limitation non-equations and with three conflicting objectives (production rate, operation cost, quality of machining). All the above-mentioned objectives are represented as a function of the cutting speed, feed rate and depth of cutting.

1.1.1 Production rate [9]

The production rate is measured as the entire time necessary for the manufacture of a product (T_p). It is the function of the metal removal rate (MRR) and of the tool life (T) [10];

$$T_p = T_s + V(1 + \frac{T_c}{T}) \Big/ MRR + T_i \quad (1)$$

where T_s, T_c, T_i and V are the tool set-up time, the tool change time, the time during which the tool does not cut and the volume of the removed metal. In some operations the T_s, T_c, T_i and V are constants so that T_p is the function of MRR and T. The metal removal rate is expressed as:

$$MRR = 1000 \cdot v \cdot f \cdot a \quad (2)$$

1.1.2 The Cost function [9]

The unit production cost, C_p, for turning operations can be divided into three basic cost elements: the tool cost and tool replacement cost (C_t), cutting cost by actual time in cut (C_l) and overhead cost C_0, T is tool life.

The formula for calculating the above cost is used as given by [9].

Finally, by using the above mathematical manipulations, the unit production cost ($/piece) can be obtained as:

$$C_p = T_p\left(C_t/T + C_l + C_0\right) \quad (3)$$

1.1.3 Cutting quality [9]

The most important criterion for the assessment of the surface quality is roughness calculated according to:

$$R_a = k\, v^{x_1} f^{x_2} a^{x_3} \quad (4)$$

where x_1, x_2, x_3 and k are the constants relevant to a specific tool-workpiece combination.

1.1.4 Cutting condition constraints

The practical constraints imposed during the roughing and finishing operations are stated as follows [9].

Parameter bounds. The available range of cutting speed, feed rate and depth of cut are expressed in terms of lower and upper bounds. The bounds on feed rate and depth of cut is setup for the safety of the operator. The parameter bound values and constants are: $v_{min} \le v \le v_{max}$, $f_{min} \le f \le f_{max}$, $a_{min} \le a \le a_{max}$.

Tool-life constraint. The constraint on the tool life is taken as $T_{min} \le T \le T_{max.}$

Power constraint. The power required during the cutting operation should not exceed the available power of the machine tool. The power is given as:

$$P = \frac{k_f f_r^{\mu} d_r^{\nu} v_r}{6120\eta} , \quad (5)$$

where k_f , μ and ν are the constants pertaining to specific tool-work piece combination and η is the power efficiency. The limitations of the power and cutting force are equal to: $P(v, f, a) \le P_{max}$

In order to ensure the evaluation of mutual influences and the effects between the objectives and to be able to obtain an overall survey of the manufacturer's value system the multi-attribute function of the manufacturer (y) is determined. The cutting parameter optimization problem is formulated as the following multi-objective optimization problem: min T_p (v, f, a), min C_p (v, f, a), min R_a (v, f, a).

$$y = 0.42e^{(-0.22\mathrm{Tp})} + 0.17e^{(-0,26\mathrm{Ra})} + \frac{0.05}{\left(1 + 1.22T_p C_p R_a\right)} \quad (6)$$

A multiattribute value function is defined as a real-valued function that assigns a real value to each multiattribute alternative, such that more preferable alternative is associated with a larger value index than less preferable alternative.

1.2 Objective Function Modelling

First step uses an ANFIS to model the response (manufacturer's implicit multiattribute) function (y). The variables of this problem are velocity, feed rate and depth of cut, which can have any continuous value subject to the limits available. The ANFIS system needs three inputs for three parameters: cutting speed (v), feedrate (f) and depth of cutting (a). The output from the system is a real value (y). The relationship between the cutting parameters and manufacturer objective function is first captured via a neural network and is subsequently reflected in linguistic form with the help of a fuzzy logic based algorithm. Algorithm uses training examples as input and constructs the fuzzy if–then rules and the membership functions of the fuzzy sets involved in these rules as output.

Figure 2 shows the fuzzy rule architecture of ANFIS when triangular membership function is adopted. The architectures shown in Figure 2 consist of 32 fuzzy rules. During training in ANFIS, 140 sets of experimental data were used to conduct 400 cycles of training. ANFIS has proved to be an excellent universal approximator of non-linear functions. If it is capable to represent the manufacturer's implicit multiattribute function.

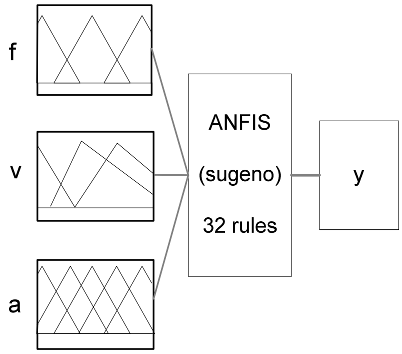

Fig. 2. *Fuzzy rule architecture of the triangular membership function*

Using a given input/output data set, the ANFIS method constructs a fuzzy inference system (FIS) whose membership function parameters are tuned using either a backpropagation algorithm alone, or in combination with a least squares type of method. This allows fuzzy systems to learn from the data they are modeling. FIS structure is a network-type structure similar to that of a neural network, which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs. ANFIS applies two techniques in updating parameters. For premise parameters that define membership functions, ANFIS employs gradient descent to fine-tune them. For consequent parameters that define the coefficients of each output equations, ANFIS uses the least-squares method to identify them. This approach is thus called Hybrid Learning method since it combines the gradient descent method and the least-squares method.

ANFIS modeling process starts by:

1. Obtaining a data set (input-output data pairs) and dividing it into training and checking data sets.
2. Finding the initial premise parameters for the membership functions by equally spacing each of the membership functions
3. Determining a threshold value for the error between the actual and desired output.
4. Finding the consequent parameters by using the least-squares method.
5. Calculating an error for each data pair. If this error is larger than the threshold value, update the premise parameters using the gradient decent method as the following ($Q_{next}=Q_{nov}+\eta_d$, where Q is a parameter that minimizes the error, η the learning rate, and d is a direction vector).
6. The process is terminated when the error becomes less than the threshold value. Then the checking data set is used to compare the model with actual system. A lower threshold value is used if the model does not represent the system.

After training the estimator, its performance was tested under various cutting conditions. Test data sets collected from a wide range of cutting conditions in turning were applied to the estimator for evaluating objective function (y). The performance of this method turned out to be satisfactory for estimating of objective function (y), within a 2% mean error.

Once a multi-attribute value function is assessed and validated the ANFIS is used to decipher the manufacturer's overall preference and the multi-objective optimization problem will be reduced to a single objective maximization problem as follows:

$$\max_{v,f,a} y\left[T_p(v,f,a),\, C_p(v,f,a), R_a(v,f,a)\right] \qquad (7)$$

2 ANT COLONY OPTIMIZATION-ACO

ACO is a non-traditional optimization technique in which the main idea underlying it is that of a parallelizing search over several constructive computational threads, all based on a dynamic memory structure incorporating information on the effectiveness of previously obtained results and in which the behavior of each single agent is inspired by the behaviour of real ants.

Special insects like ants, termites, and bees that live in a colony are capable of solving their daily complex life problems. These behaviours which are seen in a special group of insects are called swarm intelligence. Swarm intelligence techniques focus on the group's behaviour and study the decartelized reactions of group agents with each other and with the environment. The swarm intelligence system includes a mixture of simple local behaviours for creating a complicated general behaviour and there is no central control in it. Ants have the ability to deposit pheromone on the ground and to follow, in probability, pheromone previously deposited by other ants. By depositing this chemical substance, the ants leave a trace on their paths. By detecting this trace, the other ants of the colony can follow the path discovered by other ants to find food. For finding the shortest way to get food, these ants can always follow the pheromone trails. This cooperative search behaviour of real ants inspired the new computational paradigm for optimizing real life systems and it is suited for solving large scale optimization problem.

The first ACO algorithm, called ant system (AS) has been applied to the travelling salesman problem (TSP). Dorigo [7] proposed an ACO methodology for machining parameters optimization in a multi-pass turning model, which originally was developed by [8]. Recently, a modified ACO was presented as an effective global optimization procedure by introducing bi-level search procedure called local and global search. The important aspect in ACO is that the artificial ants select the solution.

2.1 ACO Algorithm of Process Optimization

The proposed continuous ACO for optimization of cutting conditions in multi-pass turning is shown as scheme in Figure 3. The distribution of ants is shown in Figure 4.

Initial solution. An initial solution of N will consist of 160 randomly generated solutions, with values that lie in the range of allowable cutting speed, depth of cut and feedrate. The 160 solutions are then sorted in ascending order with respect to the objective function.

The regions pertaining to minimum production cost are referred to as superior solutions, while regions pertaining to the maximum production cost are referred to as inferior solutions.

Distribution of ants. The total numbers of ants, A, is 80, which is half of N and is distributed as 72 for global (G) and 8 for local search (L).

An ACO utilizes bi-level procedures which include local and global searches.

Local search: With a local search, the L local ants select L regions from N regions and move in search of better fitness. Here L is 6, and L solutions are selected as per the current pheromone trail value. Local search ants select a region L with a probability $P_i(t) = \tau_i(t) / \sum \tau_k(t)$, where i is the region index and t_i(k) is the pheromone trail on region i at time t. After selecting the destination the ant moves through a short distance (finite random increment 0.005).

Updating the pheromone trail value of new solution in local search. If the fitness is improved, the new solutions are updated to the current region. Correspondingly the regions position vector is updated. The variables of this problem are cutting speed, feedrate, depth of cut, all of which can have any continuous value subject to the limits imposed. The objective functions are calculated for each solution. In the continuous algorithm, the pheromone values are decreased after each iteration by:

$$\tau_i(t+1) = \rho \cdot \tau_i(t) \tag{8}$$

where ρ is the evaporation rate which is assumed to be 0.2 on a trial basis and τ_i(t) is the trail associated with solution at time t.

Global search. Using global search, global ants create G new regions by replacing the inferior solutions of the existing solutions.

The following three operations are performed on the randomly generated initial solution: (a) Random walk or cross over –90% of the solutions (randomly chosen) in the inferior solutions are replaced with randomly selected superior solutions; (b) Mutation – the process where by randomly adding or subtracting a value is done to each variable of the newly created solutions in the inferior region with a mutation probability; and (c) Trial diffusion – applied to inferior solutions that were not considered during random walk and mutation stages.

A global search is done sequentially by crossover, mutation and trial diffusion operations. The subsequent values of the variables of the child are set to the corresponding value of a randomly chosen parent with a crossover probability (0.75). Mutation operation adds or subtracts a value to/from each variable with mutation probability. The mutation step size is the same as the above distance $\Delta(T,R)$. After selecting the destination, the ant moves through a short distance ($\Delta(T,R) = R(1-r^{10(1-T)})$, where R is maximum search radius, r is a random number from [0,1], T is the total number of iterations of the algorithm.

Performing an ACO, ants are repeatedly sent to trail solutions in order to optimize the objective value. The total number of ants (denoted by A) is set as half the total number of trail solutions (denoted by S).

Trail diffusion. Here, two parents are selected at random from the parents region. The child can have:

1. the value of the corresponding variable of the first parent;
2. the value of the corresponding variable of the second parent; or
3. a combination arrived from the weighted average of the above $X(\text{child}) = \alpha\, x(\text{parent } 1) + [1-\alpha]x$ (parent 2), where α is a uniform random number in the range [0,1]. The probability of selecting the 3rd option is set equal to the mutation probability 0.75, and the probability of selecting the 1st and 2nd options is allotted a probability of 0.2.

Updating of pheromone trail value of new solution in global search. After the global search, the pheromone trail value of the new solutions is updated proportionally to the improvement in the objective value.

Sort the regions according to the function value. New solutions will be obtained after the global and local search. The solutions will also have the new pheromone trail values. The solutions are sorted in ascending order of the objective values and the best objective value is stored. The process is repeated for a specified number of iterations.

The ACO algorithm:

Step 1. Set parameter values including: S, A, ρ, τ_0, P_c, P_m, T, R, and bounds of each control factor.

Step 2. Create S trail solutions (v, f, a). Estimate the objective value of the trail solutions through the ANFIS model (y).

Step 3. Set the initial pheromone value of all trails.

Step 4. Repeat steps 6 to 8 until the stopping criteria has reached.

Step 5. Send L ants to the selected trail solutions for local search.

Step 6. If the solution is improved, move the ants to the new solution and update the pheromone value.

Step 7. Send G ants to global trails and generate their offspring by crossover and mutation.

Step 8. Evaporate pheromone for all trails.

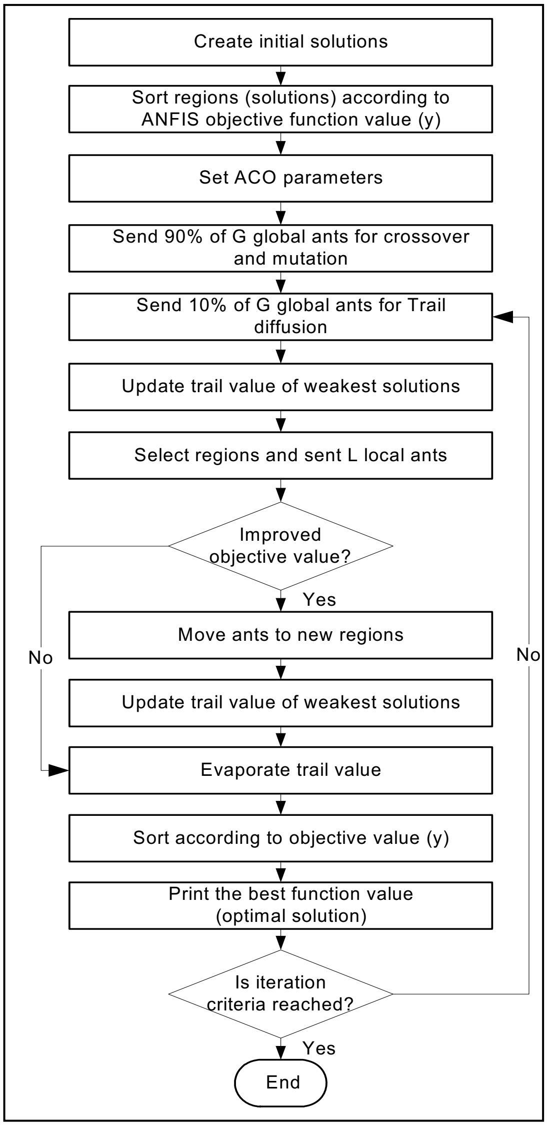

Fig. 3. *Scheme of the ACO algorithm*

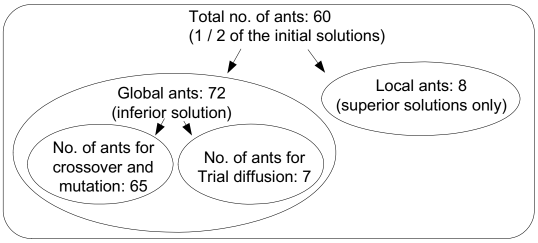

Fig. 4. *Distribution of search points (ants) in ACO algorithm*

3 COMPUTATIONAL RESULTS AND DISCUSSION

The ant colony optimization method combined with ANFIS prediction system was tested on the CNC lathe GF02. The work piece material is mild steel (Ck45) and the tool material has a carbide tip. The task is to find optimum cutting conditions for the process of turning with minimum costs.

Proposed ACO approach was compared with three non-traditional techniques (GA, SA and PSO). The results obtained from four techniques are given in Table 1. All the parameters and constraint sets are the same in all four cases. There is a total of 4 constraints. The proposed model is run on a PC 586 compatible computer using the Matlab language. The results revelled that the proposed method significantly outperforms the GA and SA approach. The proposed approach found an optimum solution of 12.461 for as low as 1 to 18 runs the genetic-based approach require as much as 1 to 500 runs to find an solution of 14.661.

This means that the proposed approach has 16.02% improvement over the solution found by GA approach and 23.08% over SA approach.

Moreover, the simulated annealing approach (SA/PS) of [14] also generated an inferior solution of 17.24 for as much as 901 to 1000 runs which means that the optimum solution of ACO algorithm has an improvement of 23.6%. It is observed that PSO has outperformed all other algorithms [16]. Next ACO, SA and GA are ranked according to costs obtained from algorithms. The costs obtained and optimum machining conditions are shown in Table 1. From the results, it is clear that the proposed ACO approach significantly outperforms the other two methods, such as GA and SA. Clearly, the ACO approach provides a sufficiently approximation to the true optimum solution.

4 CONCLUSION

In this paper, non-conventional optimization techniques ACO has been studied for the optimization of machining parameters in turning operations. The hybrid ANFIS-ants integrates neural network, fuzzy logic and continuous ant colony optimization to model the machining system and to optimize machining process. ACO algorithm is completely generalized and problem independent so that can be easily modified to optimize this turning operation under various economic criteria. It can obtain a near-optimum solution in an extremely large solution space within a reasonable computation time. The algorithm can also be

Table 1. *Comparison of results for ANFIS-ACO, GA, LP and PSO approach*

No.	Algorithm	Constraint set	Runs	Optimum solution v_{opt} [m/min]	f_{opt} [mm/rev]	a_{opt} [mm]	C_p [$]	Average optimiz. time [s]
1	PSO [11, 12]	tool-life; cutting force- power [13]; surface roughness;	1 to 25 1 to 150	101.211 103.377	0.231 0.217	0.44 0.51	12.461 **12.235**	3 7
2	Proposed ANFIS-ACO	tool-life; cutting force- power; surface roughness;	1 to 25 1 to 150	95.1926 97.433	0.3793 0.2934	0.84 0.89	12.423 **12.314**	2 6
3	SA [14]	tool-life; cutting force- power; surface roughness;	1 to 1000 1 to 1400	112.852 108.464	0.194 0.221	0.46 0.41	**16.152** 16.171	12 11
4	GA [15]	tool-life; cutting force- power; surface roughness;	1 to 150 1 to 500	102.165 98.122	0.039 0.313	1.268 0.612	18.394 **14.661**	7 9

extended to other machining problems such as milling operations. The results of the proposed approach are compared with results of three non-traditional techniques (GA, SA and PSO). Among the four algorithms, PSO outperforms all other algorithms.

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Radio Frequency Identification Technology Application in Disassembly Systems

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This paper presents the results of developing a model of RFID technology application in disassembly systems as a solution for a problem of rapid arrival of numerous products at a waste dump. During the process of disassembly and dismantling the basic components, they should be redirected to the disassembly systems for renewal, reprocessing and recycling. An integral part of the WEEE (Waste Electrical and Electronic Equipment) directive is the product take back strategy, which supports the endeavor to recycling as efficient as possible. System processes, like disassembly, make it possible to selectively separate the renewable, non-recycling and dangerous components from those which are recyclable. Appropriately planned process of disassembly, together with recycling and waste disposal, can help to efficiently manage the products during their life cycle. In order for something to be achieved, proper strategies should be considered. The collection of data about all kinds of flows of products, materials, parts/subassemblies and dangerous components/materials are necessary at the end of the life cycle. By applying RFID (Radio Frequency Identification) technologies to the systems for refining the outdated product, the management of all the above mentioned flows can be improved. Information gathered in this way is reliable, precise and dynamic. They could provide optimum management with products that have come to the end of their work lifetime.

Keywords: radio frequency identification technology, end of life cycle, disassembly systems

0 INTRODUCTION

Contemporary production conditions demand the application of distributed production concept, because there is an enormous pressure on the manufacturers to comply with market changes and continuous shortening of the product life cycle [9]. Virtual Manufacturing Systems (VMS) are currently more and more indispensable for obtaining the information about future properties and the state of manufacturing in any production company [8], and a help for dealing with the problem of dynamic changes and shortening of the product life cycle. RFID technology could be appropriate solution for problems regarding automatic identification and data acquisition. Information gathered in this way could be crucial for designing and functioning of VMS and Virtual Disassembly System (VDS).

There is a need for finding a good solution for a problem of production of certain types of products and their disposal into the waste dumps, in order to reduce and control the quantity of such waste, because the waste is being made in ever-increasing quantities. According to some researches, quantity of electrical appliances being used in every household is about 3.3 tones for one citizen per life time of which: large household appliances 69%, small household appliances 8%, information technology and telecommunications equipment 7%, consumer equipment 13%, lighting equipment < 1%, electrical and electronic tools 2%, toys, leisure and sports equipment < 1%, monitoring and control instruments < 1% [7]. Having this in mind, production systems for the processing of such waste are designed and put into use.

Disassembly is just one of the processes in the life cycle of a product [8] and lately it has attracted a lot of attention, considering its key role in reassembling and recycling of products. This is due to ecological and economical reasons. The echological side of the problem is seen in ending numerous products at waste dumps and in depletion of non-renewable natural riches. The economical side of the problem of disassembly is seen in the need for a design of the disassembly system in a way that the value of the disassembly process result is grater then the resources invested for its proper functioning [4].

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The end result of the disassembly is frequently changing, depending on the state of the product, especially when we realize that we are talking about technologically outdated products.

Strategies for managing products at the end of their life cycles, the problem of shaping the production system to refine the products at the end of the life cycle and using of RFID technology are presented in this paper work. Other similar researches have been done in this field [10] and [11]. This approach of using RFID technology is rather new and it is a challenge for a research.

1 STRATEGIES FOR PRODUCTS AT THE END OF THE LIFE CYCLE

First step in designing disassembly system process is to consider possible end of life strategies for products. Strategies for products at the end of a life cycle represent methodes, which are used to conduct the general direction of products, and only suggestions are given for the management of a product at the end of a life cycle. Studies related with the strategies of the products end of a life cycle are numerous [4] and [5]. The most accepted, and in its character, the most comprehensive classification of the products end of a life cycle is [1]:

1. re-use of used products,
2. reconstruction of used products,
3. usage of already used products for spare parts,
4. recycling with disassembly,
5. recycling without disassembly,
6. dumping of the used products.

Re-use of already used products is a strategy that organizes the return of discarded products which are still in function. If such an interest exists, already used products are sold in the market.

Reconstruction of used products is applied due to modernize or to upgrade their performances. The purpose of this strategy is to attain a product, which is in quality less or very similar to the quality of the new products. The quality of the reconstructed products depends on the determined depth of disassembly. If a product is disassembled to the level of parts and a control and a replacement of all parts is conducted, the used products are brought to a high level of quality, required for the new products.

Also, it is possible to conduct the modernization of products, by replacing certain modules with contemporary ones, after applying the disassembly.

Appliance of already exploited products for spare parts is being frequently used. In certain companies, out of date products are being collected in an organized manner. The purpose of this strategy is to take a relatively small part of sub modules from a used product and use them for the above mentioned strategy, or for another purpose, and the rest will be used for material recycling.

Recycling with disassembly is a strategy used for separating parts made of different material, before its conversion in the process of disassembly. The purpose of this strategy is to use the materials from the used products and parts, by separating them in the procedure of disassembly into the component parts and with appropriate selection, depending on the determined type of material. These materials can then be used in the production of original or some other products.

Recycling without disassembly is a procedure, which is used to compact and compress the product and then crush it and sort it by type of material.

Disposal is, from the ecological point of view, the most inconvenient strategy for disposing products on the waste dumps. Having the above mentioned strategies in mind, it is necessary to design an appropriate production system.

2 STRATEGY SELECTION FOR PRODUCT AT THE END OF THE LIFE CYCLE

The production system for product processing at the end of life cycle has a quite complex structure, since there is a need for more then one technologicaly different subsystem like [4]:

1. disassembly,
2. reassembly,
3. recycling,
4. waste incineration,
5. hazardous waste storage,
6. waste storage.

The choice of strategies for reconstruction of used products (2), usage of already used products for spare parts (3) and recycling with disassembly (4) are made according with the both momentary product condition and suggestions taken from the database for particular product. A production system for product processing, according with chosen strategies for product management at the end of the life cycle, is shown in the Figure 1. [4].

In the most general case, if for the given product (p_i), all three potential strategies are chosen as possible, which comprise the need for disassembly (strategies 2, 3 and 4), then the production system for processing of such products contains in itself all the elements as in the previous figure. In case we choose only the strategy number 4, then a subsystem for repair does not exist.

When choosing strategies 3 and 4, a subsystem for repair possibly exists. Depending on the type of product and the type of repair, the repair subsystem does not have to be specially separated. It is important to notice that in the procedure of the product disassembly, during the parts selection, a flow of materials must be planed for the parts that are headed for reassembly. In other words, it is often very possible to conduct, in a same place, within one subsystem where the disassembly is conducted, a second assembly of the product. A subsystem is being shaped for disassembly/reassembly, with a developed procedure for disassembly, selection of parts/subsystems and then, the reassembly of the required elements. In this case, a line for disassembly and a line for reassembly (assembly) are completely overlapping.

3 PRODUCT DISASSEMBLY PROCESS

Disassembly can be defined as a process of separating a product into its basic parts or subsystems, including the analysis on the condition of products and the selection of dismantled parts [4]. That is always an assembly of operations, which are conducted on technological systems for disassembly with the help of certain tools and fixtures.

In the disassembly, the operation procedure is accomplished according to an adequate technological procedure, which is designated for every work place in particular. The procedure implies, in the most general case, the following [4]:

- accomplishing operation with the help of appropriate tools and fixtures,
- analysis of the state and the diagnosis of the disassembled components (part/subsystem),
- selection of the disassembled components (part/subsystem) according to previously accomplished analysis of the condition and the diagnosis.

Basic problems in designing and working processes of disassembly systems are in a component selection phase. It is a result of a lack of information about products, and different product condition arrived in disassembly system. That is the reason for expansion of product design documentation with another document - scenario for component selection (Table 1).

Managing EOL products according to strategies (S) 2, 3 and 4 bacis material flow

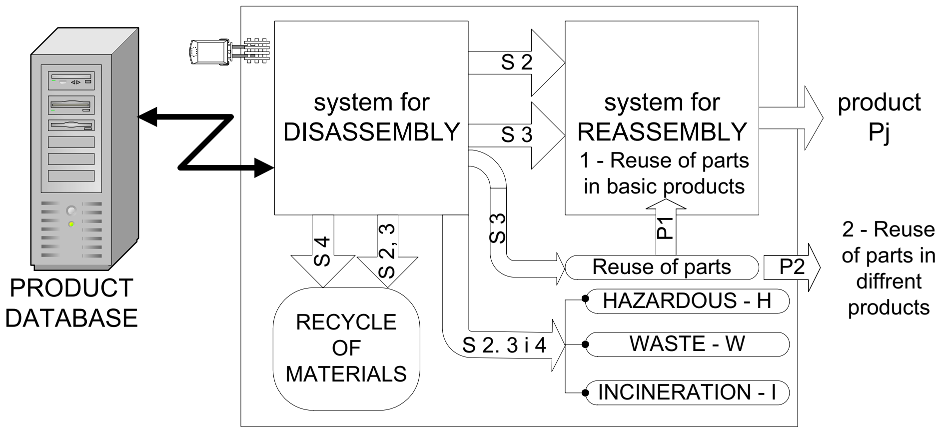

Fig. 1. *Production system for processing the products at the end of the life cycle*

In essence, we distinguish the next possibilities for the selection of components after the process of disassembly:

- dangerous components – materials (*H* (hazard)),
- material recycling (*R*),
- reusable (*P*),
- finishing (*D*),
- incinerate (*I* (incineration)),
- waste disposal (*W* (waste)).

Scenario for component selection is important document not only in designing disassembly system process, but later when system is functioning. It enables dynamic correction of variant component selection (parts/ subassemblies). There are many possible selection alternatives for some components (Table 1.). The reason is that products arrive in disassembly system in different conditions. It is important to emphasize that not all parts are necessary to pass through the phases of condition analysis and diagnosis. This can be applied in the case when in a selection scenario (procedure) for the disassembled part it is not foreseen to have more possible variants of selection, but only one (e.g. recycling). In this case, right after the process of disassembly, a selection of the components is accomplished according to the previously determined scenario.

4 IMPLEMENTATION OF RFID TECHNOLOGY IN A (SUB) SYSTEM FOR DISASSEMBLY

In the (sub) systems of disassembly, we often find obstacles for different reasons. One of them is a problem of a lack of any kind of information regarding the newly arrived products for processing (disassembly) and their distribution, after the operation, from specific work places [3]. Before and after conducting certain disassembly operations, information are crucial for efficient and effective decision making and for general management of the work processes.

Improvement of the quality of transferring information for conducting certain operations of disassembly, and then for the analysis of the state, diagnosis and selection of the disassembled components into appropriate flows, is one of the steps for general improvement of the processes for managing products at the end of the life cycle.

With the aim of faster distribution of real time information to according information flow nodes, it is necessary to use RFID technologies.

4.1. RFID Technologies

Radio Frequency IDentification (RFID) is a technology that enables automatic reading of multiple objects at the same time, without the need for individual scanning. The tag keeps in itself an Electronic Product Code (EPC) of every object that is read with the help of a remote reader.

EPC is a 96-bit numerical code written on a "smart tags" memory chip, which is fixed to individual products and physical objects. In this way, AUTO ID makes the dynamical acquisition of data possible, and products identification is located in every product with a unique print [2].

Table 1. *Component selection scenario*

Possible strategies for product:										
Part ID	Modul ID	Pcs	Disassem-bly level	......	Possible variants of selection after disassembly					
					H hazard	R recycle	P1/2 reuse	D remanuf.	I inciner.	W waste
				...						
				...						

In every mentioned phase of the work process it is possible to upgrade the process by applying the RFID technologies, because of the advantages compare to other identification technologies.

Tasks that needs to be performed in disassembly system are complex and they involve not only disassembly proces but later analysis and diagnosys of component condition and their selection in adequate material/component flows. Decision about material/component variant selection is made according to the established diagnosis and suggested component/material variant selection obtained form the disassembly documentation database accordig with the RFID product identification i.e. document named Component selection scenario (Fig 2.)

Problems are mostly noted in [4]:

- providing instructions for performing technological processes of disassembly,
- selection process of disassembled components (parts/ subsystems / materials),
- divergence – dissipation of the material flows is obvious and especially characteristic for the disassembly processes; controling the flows and the quantity in the material warehouse for disassembled components (parts / subsystems / materials).

In these parts of information flows it is possible to apply RFID technologies with the goal of: gathering real time data, improving the quality and the availability of certain types of information needed for not only disassembly process but also for the selection of disassembled parts and reassembly process.

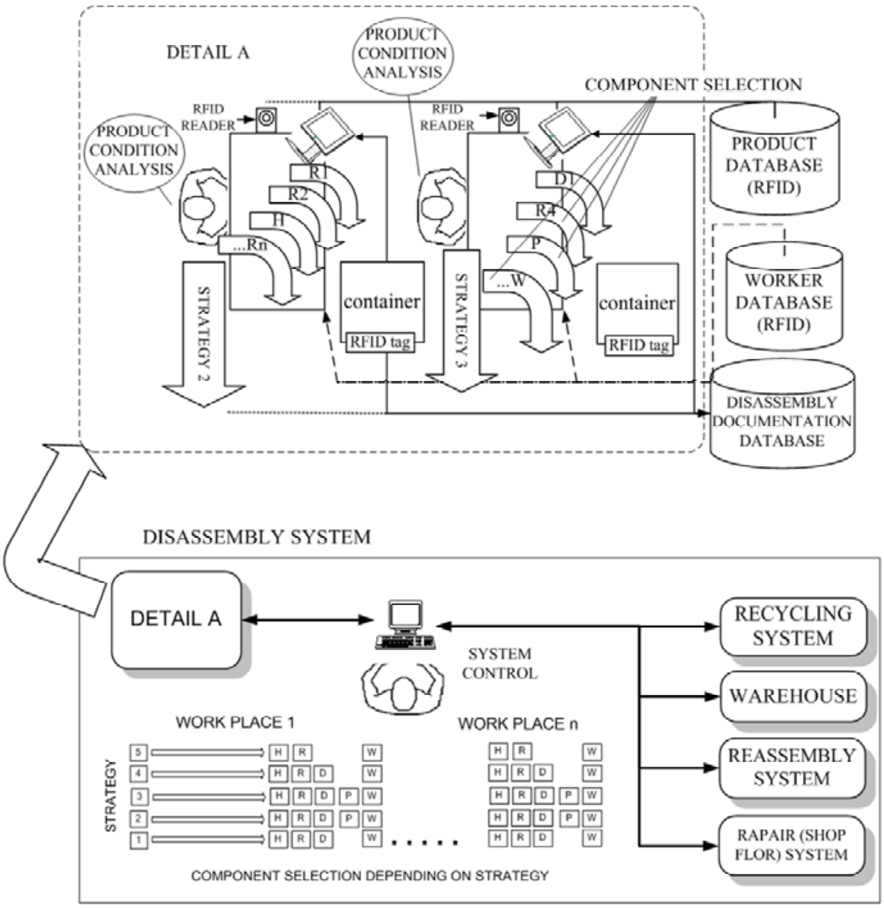

Fig. 2. *Material flows during the processing of an electric motor*

4.2. A Model of RFID Technology Application in the Disassembly Subsystem

When designing a disassembly system one of the problems arising is the way of gathering information from products meant to be disassembled. Various technologies for automatic identification can be applied like barcode and others but we have developed a model of RFID technology application in the disassembly subsystem.

The model presented in this paper is a starting point of a research project conceived at the Institute for Industrial Systems in Novi Sad (Republic of Serbia). The concept of implementation of RFID technology in a disassembly process, applied in Laboratory for Assembly and Disassembly Systems at the Institute for Industrial Systems, is shown in Fig. 3.

In the control station (1) one of the possible strategies (strategies for reconstruction of used products (2), usage of already used products for spare parts (3) and recycling with disassembly 4) is being selected for the product that has to be disassembled. After selection, RFID transponder (tag) is being put on the base part of the product (3) which corresponds to the class and type of the product, for which the strategy has been chosen, with its EPC. After that, the product is being put on the assembly line and then moves to the processing phase. In the work station, the RFID tag reader (2) reads an EPC and uploads set of instructions from the database for the technological procedure of disassembly, in the form of a visual presentation on the monitor in front of the worker. Instructions are in a step by step form. They are activated by taking appropriate types of tools, and after returning them to their station, the next step is activated.

Another possibility is putting tags on tools and checking usage of tools with the help of RFID reader (6). If the worker takes by mistake different tool the system alerts with the adequate massage. If a task is being executed without tools, initiation of the next instruction is done manually.

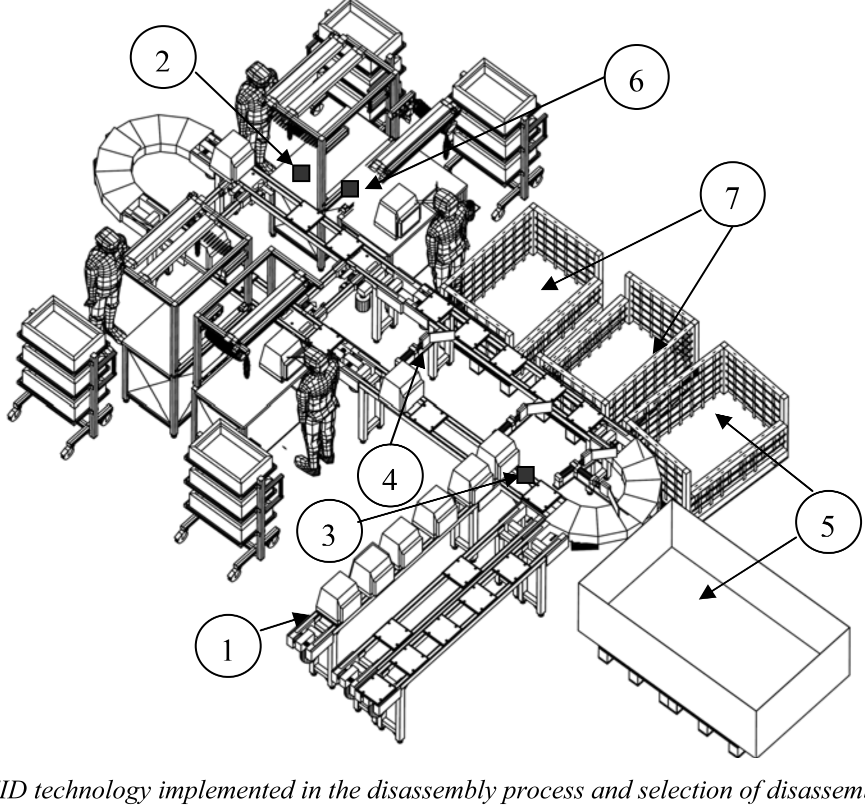

Fig. 3. *RFID technology implemented in the disassembly process and selection of disassembled parts of the products*

After the operation (set of operations) designated for that work station is completed, the set of instructions ends. The product is afterwards placed on the assembly line, and then on some of the other work stations. After reading its signal from the RFID tag, the identification of the object for that work place is being performed. If the object is supposed to be processed in that work station, the signal light flashes and the worker pick the object from the assembly line. After that the process is continued as in the previous operation with a set of instructions designed for that work place and for that product. If all the work stations are busy, the object is circling on the assembly line until the moment some of them are free. The tag has to be on the base part all the time. The base part is the last that leaves the disassembly process.

If some component (part or subassembly) can be used again according to strategy for usage of already used products for spare parts, after disassembly, then an appropriate tag is put on that component at momentary work station. The tag carries in itself an EPC that corresponds to the component on which it is being put. By placing the component with a tag on the assembly line, it is transported to the warehouse for later use.

Products, for which strategy for reconstruction of used products is selected, are moving all the time, from one phase to another, together with all the disassembled parts in the appropriate transport unit (e.g. a palette or a box – so-called kit). After completing all of the disassembly operations (required for executing reconstruction of the appropriate degree), the whole palette with all its disassembled components is being redirected to the overall subsystem, that is, toward the preparation warehouse for the product reconstruction.

Secondary materials, meaning materials that are going to be recycled, are being directed to adequate containers for the secondary material with the help of sensors which can recognize different types of materials, and the help of actuators (4), which push them into adequate containers. On each of the containers (5 for recycling, 7 for further disassembly processing) there is a tag-transponder, which corresponds to the type of material for which the container is designated.

Analyzing previous system with manual data acquisition and installed RFID system we came to the conclusion that overall time that product spends on disassembly line (from it's arrival to control station till putting it into containers) has been decreased for more than 17% (Table 2., Fig. 4.). It is important to mention that quantity of disassembled products is not big enough to provide fully valid statistically model of the impact of RFID technology on disassembly processes, since research was conducted in laboratory conditions.

This kind of concept enables a complete control of all material flows in the disassembly process. Also, it could be possible to track the number of parts in a warehouse and types of material and material quantity for recycling and for waste dumps.

One of the basic problems in the disassembly system is designing and organizing a disassembly system for different types of products.

Table 2. *Experimental results*

Average time for disassem. (min/piece)	$\bar{t}_1$	$\bar{t}_2$	$\bar{t}_3$	$\bar{t}_4$	$\bar{t}_5$	$\bar{t}_6$	$\bar{t}_7$	$\bar{t}_8$	$\bar{t}_9$	$\bar{t}_{10}$	$\bar{t}_{11}$	$\bar{t}_{12}$	$\bar{t}_{13}$	$\bar{t}_{14}$	$\bar{t}_{15}$	$\bar{t}_{16}$	$\bar{t}_{17}$	$\bar{t}_{18}$	$\bar{t}_{19}$	$\bar{t}_{20}$	$\sum \bar{t}_{ii}$
Manual disassembly	5.5	5.2	6.5	6.9	7.5	6.2	8.2	9.7	8.0	7.8	5.1	5.3	9.5	9.0	8.4	8.2	5.0	5.3	7.0	9.0	143.3
Disassembly with RFID use	6.3	6.2	5.0	4.9	5.0	9.0	5.2	5.9	7.2	6.2	5.3	5.4	7.6	6.8	7.7	4.9	5.1	5.0	8.6	4.8	122.1
Model-type of monitor disassembled	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	
Σt_{ii} (manual disassembly) > Σt_{ii} (disassembly using RFID) (laboratory conditions conclusion: 17% shorter time - by using RFID)																					

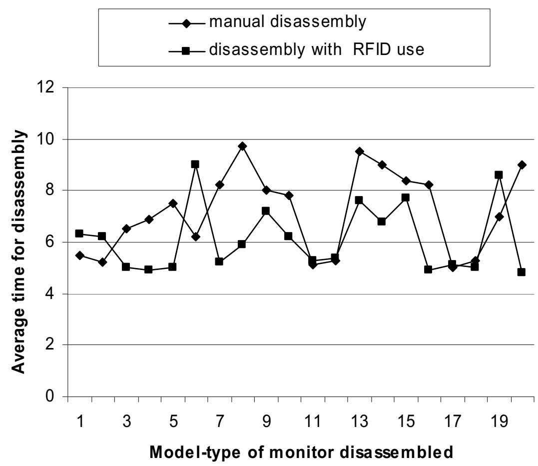

Fig. 4. *Average time for manual disassembly comparing to disassembly with RFID technology*

It is uncommon to organize a disassembly system for only one type of product, unless this way of the systems functioning is strategically planed.A suggested system design has a higher degree of flexibility in the sense of possibilities to process different types of products including different variants of the same product.

Savings in time and space required for the selection of components (parts / subsystems / materials) are also noticeable.

5 CONCLUSİON

The RFID technology has not been in wider usage in production, assembly and disassembly processes for various reasons. Some of them are: the popularity of the barcode, higher expenses due to RFID tags, privacy and security measures, lack of consensus on standards. However, some things are changing (e.g. the limited possibilities of barcodes in different conditions are being noticed, the tag prices are falling...) and slowly, the advantages of the RFID technology are being noticeable.

By implementing of RFID technology in the disassembly process it would be possible to quickly gather necessary information for the disassembly process, basically about the structure and the composition of the materials in the product. This information is necessary to define the technological procedure of disassembly completely and without any difficulties. Also, there can be integrated information about date of the production, so the system can be able to decide about later usage of the product in reassembling. All the products of the older generation, which currently arrive to the disassembly subsystems, carry with them exactly this problem – the lack of information.

The benefits arriving with the use of the RFID technologies are multiple. As stated above, the possibilities of supervision, control and data acquisition in real time for the whole process is upgraded by using the RFID technology.

The model of RFID technology in the disassembly process presented in this paper is a starting point of a research project conceived at the Institute for Industrial Systems in Novi Sad. It is important to mention that quantity of disassembled products used in this research is not big enough to provide fully valid statistically model of the impact of RFID technology on disassembly processes, since research was conducted in laboratory conditions. For a valid statistical model it would be necessary to implement it in manufacturing site. There is another challenge for overcoming problems with high level of electrical noise coming from many electrical devices in manufacturing site which interfere with the writing and reading of RFID tags that could be tested when the model is implemented in manufacturing site.

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Flexibility and Complexity of Effective Enterprises

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The aim of this research was to give contribution to the efforts that are being made to develop the procedures of structural designing of industrial systems - highly effective enterprises. For that purpose, this paper analyses the conditions and possibilities that would enable those structures to adapt to changes in the surroundings - flexibility and management adequacy of organizational structures - by lowering the degree of complexity. Special focus is given to Mass Customization - tailoring the production to the needs and preferences of the customer. This requires high flexibility of a system as this is what determines the costs in this type of production.

The original contributions of this paper are the definitions and determination of the measures of the two most important characteristics of an enterprise - complexity and flexibility, and establishing their interdependence. While in the great body of literature complexity is measured by size (number of structural elements), this paper observes the complexity degree as comprising a number of interrelationships between the elements of a structure, beside the number of elements. Flexibility of the structures of an enterprise consists of three interdependent components: technological component, capacity component and flexibility of flows.

Keywords: production systems, enterprise system, organizational structure, enterprise flexibility, system complexity

1 INTRODUCTION AND LITERATURE OVERVIEW

Flexibility, structure of a system, complexity and customer-oriented production are terms used when considering trends in the development of the realistic requirements of the market [1] and predicting their further development. Flexibility can be defined as the ability of a system to quickly adapt to new circumstances [2] and [3]. It is the ability of a system to respond to changes as quickly as possible and at minimum cost and effort [4]. It is a well-known fact that production costs are reduced with the increase of products produced all the way to the minimum defined by basic costs [5]. Therefore, the term optimum number of products is introduced as an important parameter in observing the relation between the costs and the capacity of the production structures - the relation that involves the estimate of a system's flexibility. The increase of flexibility degree of a system has a negative effect because of its increased complexity, the result of which are limitations in the effective realization of processes in the system.

During the past twenty years, complexity theory has been regarded as an epitome of a completely new way of understanding nature. It has introduced and delineated adaptive systems (species, animals, plants, viruses etc.) as interactive networks of agents and tried to determine the behaviour within the networks [6] to [8].

A special view on a quality of enterprise's production structures involves approaches for its design by using simulation methods. Corresponding methods and techniques as tools for analyzing key performance indicators of production systems are described in [9] to [13].

As a result of the most recent researches into flexibility, mass customization can be seen as a response of flexible structures of a system to unpredictable changes in the surroundings. A model used here was the one that examines the relationships between the unpredictability of the surroundings, production flexibility and work results. Still, the idea of mass customization cannot give a complete answer to the question of production of a large number of various products which would satisfy the criteria of effectiveness, efficiency, and concerning the customer, the criterion of acceptable price [14] and [15].

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Literature on mass customization has mainly focused on two areas: 1) the factors influencing companies to shift from mass production to mass customization [16] and 2) the implementation of mass customization [17]. Few authors have written about the success of customer-oriented mass production and this within the research of the markets [18] and [19]. Considering the efforts of some authors to determine a favourable relation and methodology and thereby solve the problems of flexible structures with low enough degree of complexity which can offer tailor-made products, it can be concluded that each of the mentioned components should be dealt separately with the introduction of common limit functions [20].

2 FLEXIBILITY AND COMPLEXITY OF ENTERPRISES

2.1. Production Structures' Flexibility

Earlier researches on the production structures of industrial systems conducted at the IISE *(Institute of Industrial Systems Engineering, Novi Sad, Serbia)* [21] formed the basis for the development of (Fig. 1) effective enterprises: 1) change of the flow designing approach - individual to group and 2) change of the structure designing approach - process to product.

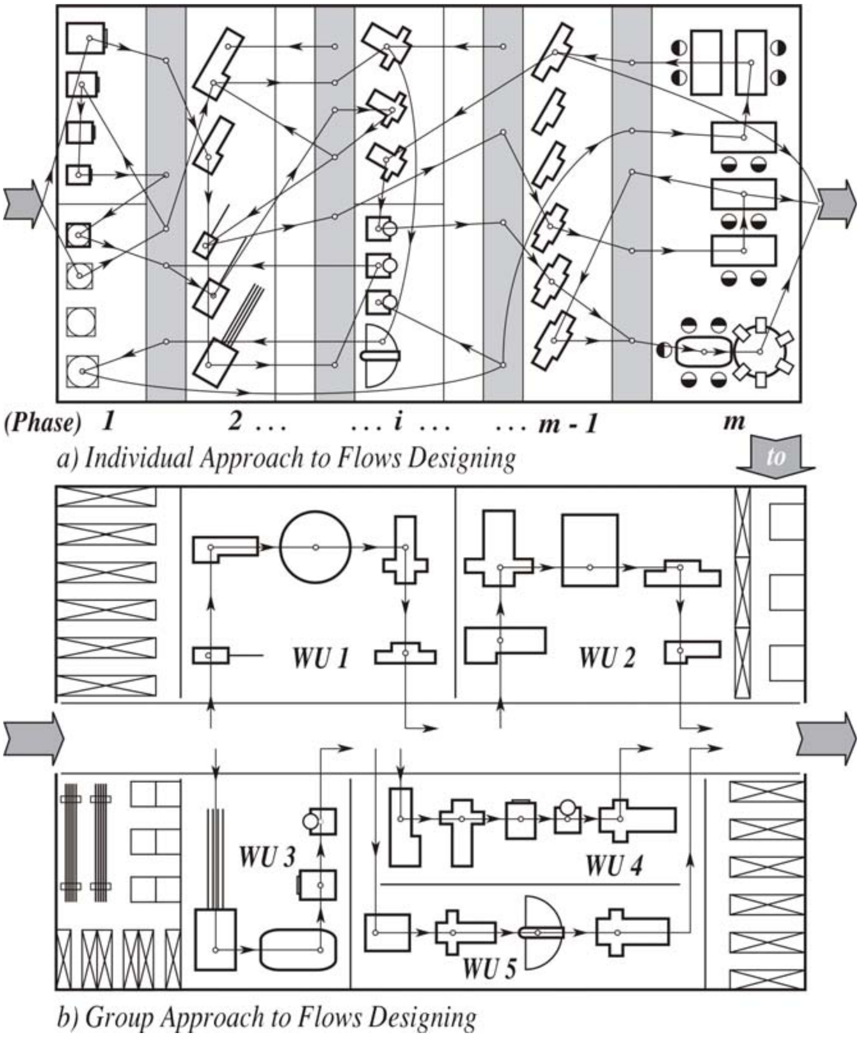


Fig. 1. *The basic changes in approaches for production structures designing*

The result of the mentioned changes in the approach is the creation of the Working Unit, the basic module of an effective enterprise - designated as ***WU*** in Fig. 1. Working Unit is defined as part of the production structure of an enterprise capable to carry out a certain task which is part of the work programme, should conditions of adequate space, technological equipment and the required structure of employees be met. Working Unit has the following characteristics:

- it is independent of the other parts of the system's structure concerning the human resources and technical capacity,
- it is responsible for completion of part of a programme, concerning the amount, quality and deadlines and
- it is suitable for process automation.

According to above definition, Working Unit (WU) is a concept, in literature well known as *Production Cell*, but with defined differences. It is a part of enterprise's production structure (for machining or assembling) that is maximum independent from all other production structure parts in sense of its ability and capability for making *groups of similar working objects*. Therefore, *Production Cell* holds high flexibility level and it is enabled to all production operations demanded by each group of similar working objects for which it has been previously installed.

Similarity of working objects is providing conditions for high degree or total automation of processes for the *Production Cell*. Working Unit has all characteristics of *Production Cell* but beside its executive (production) independence it has to have an organizational and controlling independence too, which means its total responsibility for quantity, quality, and delivery terms of similar working objects, and also for organizing and managing of processes. So we can say that *Production Cell* can be Working Unit if its competence is not limited just on production functions but also on planning, controlling, and processes improvement.

Flexibility has been defined in specific researches [22] to [24] as one of the basic characteristics of production structures that is of vital importance.

2.2. Organization Structures' Complexity

Functional structure of an enterprise consists of a group of *functions* of the enterprise (Fig. 2) [21] which are determined by the needs of going on a mission and achieving the goals of the enterprise. The project of organizational structures, based on the project of production structures, determines the structure of the other functions of an enterprise: *Top management, marketing, development, commerce, financing, administration* and *logistics*.

3 THE PRODUCTION STRUCTURES FLEXIBILITY - RESPONSE ON CHANGES

The ability of enterprises to adapt to changes in the surroundings and to the disorders in the work process is their extremely important characteristic called *flexibility* [22] to [27].

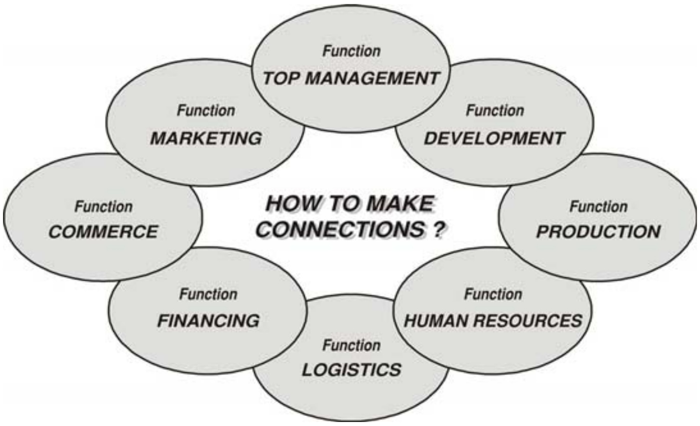


Fig. 2. *Enterprise's Functional structure*

Considering the characteristics of enterprise structures and the character of changes, three components of flexibility can be defined:

- characteristics of elements - *technological flexibility*,
- capacity of system elements - *capacity flexibility*,
- dependability of system flows - *flexibility of flows*.

The degree of flexibility is a measure of structure flexibility.

It is defined as the likelihood of a system to successfully adapt to changes in the surroundings and to the current needs of the work process. Accordingly, it is possible to determine the components of flexibility [2] and [3] and their measures (Fig. 3).

3.1. Technological Flexibility

Technological flexibility is determined by the parameters of technological system elements and by the characteristics of the work object. The measure of technological flexibility of a system 's structures [28] to [29] (Fig. 3a) is represented by the likelihood with which the given element of a structure, within the certain installed parameters, will accept a group of work objects on which part of the work should be done in accordance with the projected technological procedures.

3.2. Capacity Flexibility

Capacity flexibility is determined by the ability of elements, parts of the structure and the entire system to do that amount of work that is necessary for manufacturing the projected amount of the work object. The measure of capacity flexibility [28] to [30] is determined by (non)existence of capacity reserve as represented in Fig. 3b):

$$f_k{}^i = \frac{K_{eu}{}^i - K_{ep}{}^i}{K_{eu}{}^i} = 1 - \frac{K_{ep}{}^i}{K_{eu}{}^i} \tag{1}$$

where f_k^i is the degree of capacity of flexibility of a workplace "i" in the system *(i =1,2...m)*, $K_{eu}{}^i$ - installed and $K_{ep}{}^i$ - required capacity of that workplace.

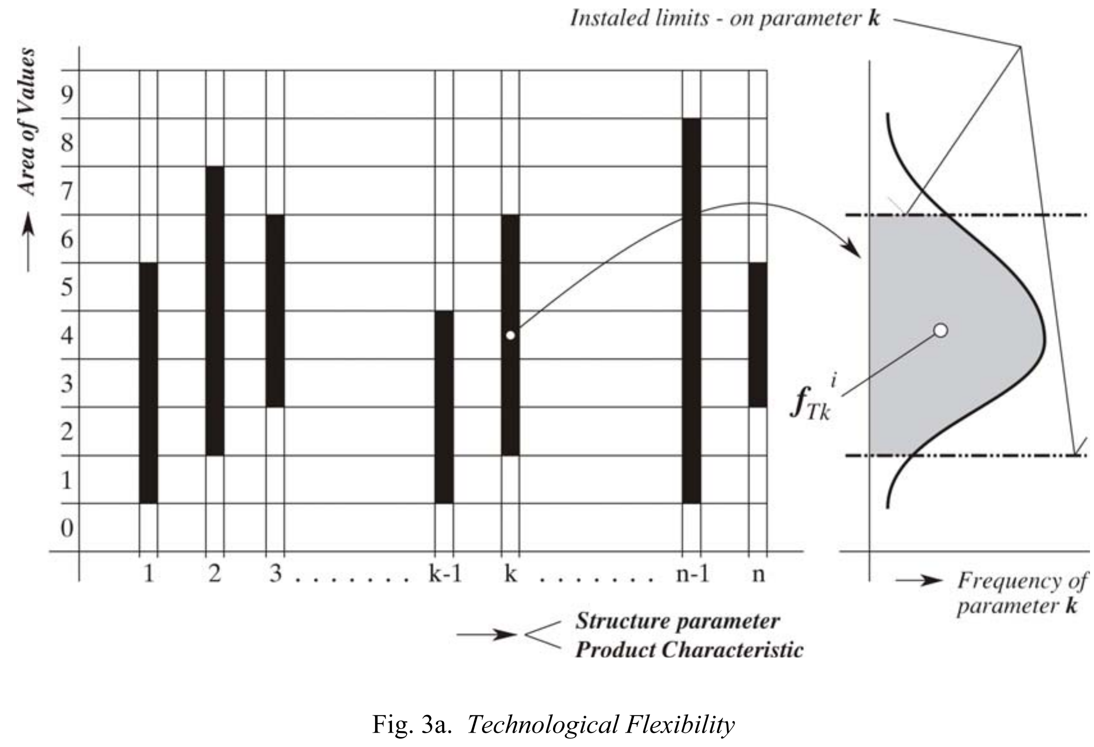


Fig. 3a. *Technological Flexibility*

3.3. Flexibility of Flows

Flows flexibility is determined by flows capacity (Fig. 3c), the relation between structure complexity degree (κ_p) and maximum complexity degree of the structure with a determined number of elements (κ_u):

$$f_p = \frac{\kappa_p}{\kappa_m} \tag{2}$$

Considerations of production structures flexibility indicate the existence of a close relationship between some components of flexibility in a way that:

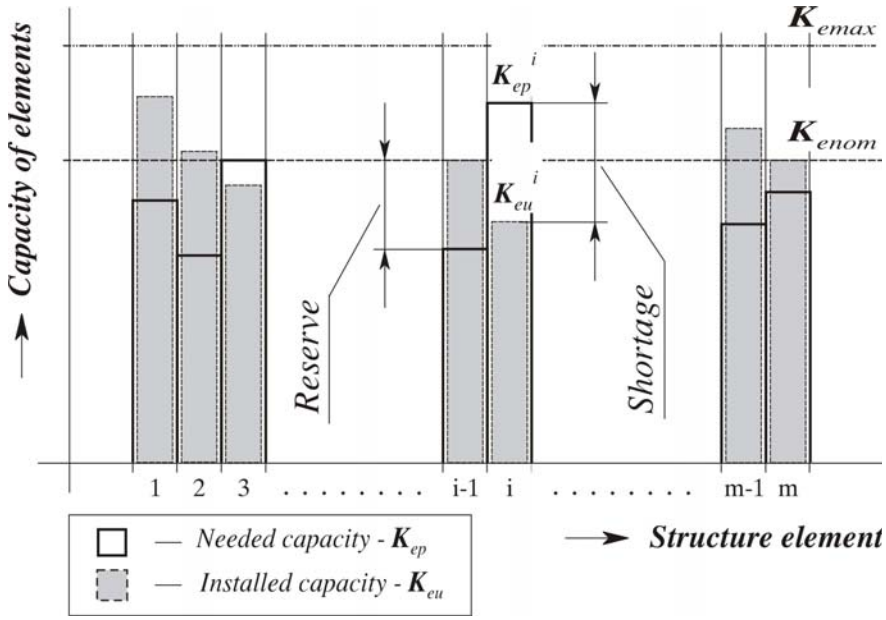


Fig. 3b. *Capacity Flexibility*

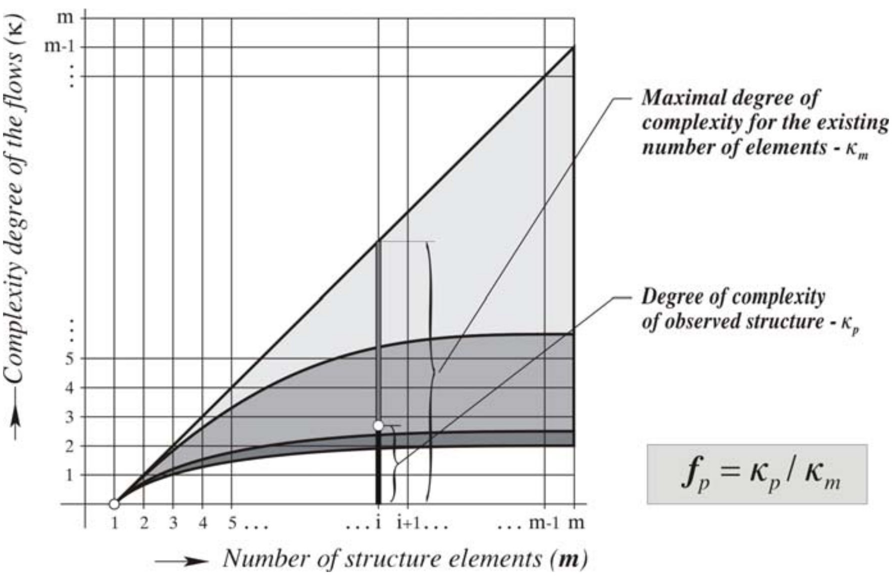


Fig. 3c. *Capacity Flexibility*

- parameters of structure elements, i.e. the value of technological flexibility degree and
- the value of the existing capacity and the reserve of the capacity, i.e. the value of capacity flexibility degree,

in the sense of compatibility between the technological and capacity flexibility in sections of flow, enable relationships between them, i.e. flows flexibility value.

Fig. 3 represents the basic dependability between components:

- *technological component* - on the work object characteristics and on the parameters of technological structures,
- *capacity component* - on the relation load-capacity, achieved in the process of design,
- *flexibility of flows* - on the complexity degree of flows, achieved in the process of design.

3.4. Research on the Technological Component of Production Structures Flexibility

Research into the value of the technological component of a system's structure in the conditions of implementation of the IISE - approach to design of production, organizational and control structures of industrial systems, points to significant possibilities for maintaining certain characteristics on the desired level.

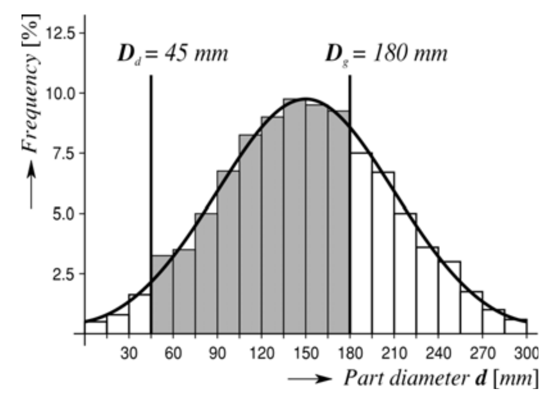
The main result of the research was the following [28] and [29]:

- Using the sample of 30 production programmes of real industrial systems, the technological component of flexibility was determined in the conditions: *STATE - individual approach* to flow designing and *process approach* to structure designing, and *PROJECT - group approach* to flow designing and *product approach* to structure designing. More than 10,000 work objects and 100 technological systems were analysed;
- In accordance with the definition presented in part 3.3 and presentation in Fig. 3, basic dimensions of parts were analysed and technological component of flexibility determined, taking into consideration the possibility of accepting the work object, as shown in Fig. 4.

Technological system:	**0250 UNIVERSAL LATHE**
Characteristic:	DIAMETER OF PARTS

BEFORE DESIGNING				**AFTER DESIGNING**			
Size of sample:	120	Distribution:	**NORMAL**	Size of sample:	75	Distribution:	**NORMAL**
Interval beginning:	0	$\mu_x(d)$	= 150.000	Interval beginning:	30	$\mu_x(d)$	= 120.000
Interval end:	300	$\sigma_x(d)$	= 70.863	Interval end:	210	$\sigma_x(d)$	= 28.336
Iinterval width:	15			Iinterval width:	15		

DISTRIBUTION DIAGRAM



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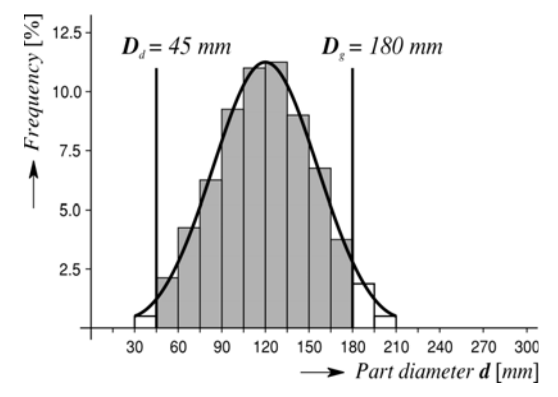

ACCOUNTING OF FLEXIBILITY			ACCOUNTING OF FLEXIBILITY		
$x_g(d) = 180$	$P_g(d) = 0.6628$	$f_{T,d}$ = **0.5934**	$x_g(d) = 180$	$P_g(d) = 0.9830$	$f_{T,d}$ = **0.9790**
$x_d(d) = 45$	$P_d(d) = 0.0694$		$x_d(d) = 45$	$P_d(d) = 0.0040$	

Fig. 4. *An example of results of Technological Flexibility research*

3.5. The Possibilities of Designing Flexible Production Structures

Research on the flexibility of production structures [29] has shown that when group approach is used in designing flows and object approach in designing production structures - the division of the system's structure into *working units* [21], as a result of the narrowing of the area of work object characteristics divergence in the working unit, variants of structure can be formed in the case of technological flexibility (Fig. 5) in which the technological component does not decrease in relation to state.

On the contrary, elements of structure - technological systems with an increased reserve for accepting and manufacturing the work object - occur in the greatest number of the observed cases.

4. THE DECREASE OF ORGANIZATIONAL STRUCTURES COMPLEXITY - A CONDITION FOR EFFECTIVE ENTERPRISE MANAGEMENT

4.1. Complexity - the Basic Characteristic of the Structure of an Enterprise

The basic goals of the process of enterprise structure development are: the ability to achieve a satisfactory (or set) *effects/investment* ratio and high control adequacy, which are conditioned by the increase of structures complexity - the most important inherent limit to the realization of an enterprise's effects.

4.1.1 The Definition

Complexity degree or variety of an enterprise's organizational structure [28], [29] and [31] denotes a variety of flows network in an enterprise, determined by the basic approach to the definition of structure complexity.

This approach is based on the number of elements and the number of connections ratio, using the equation:

$$S_s = \frac{\sum_{i=1}^{i=m} m_i}{m} \tag{4}$$

where:
m - the total number of organizational structure elements, $\boldsymbol{m_i}$ - number of organizational structure elements with a direct connection to element "***i***".

4.1.2 Connections in Organizational Structure

The structure of an enterprise, the structure of its functions and the basic structure of connections between parts of the organizational structure are determined [21] by the quality of approach and implemented design procedures.

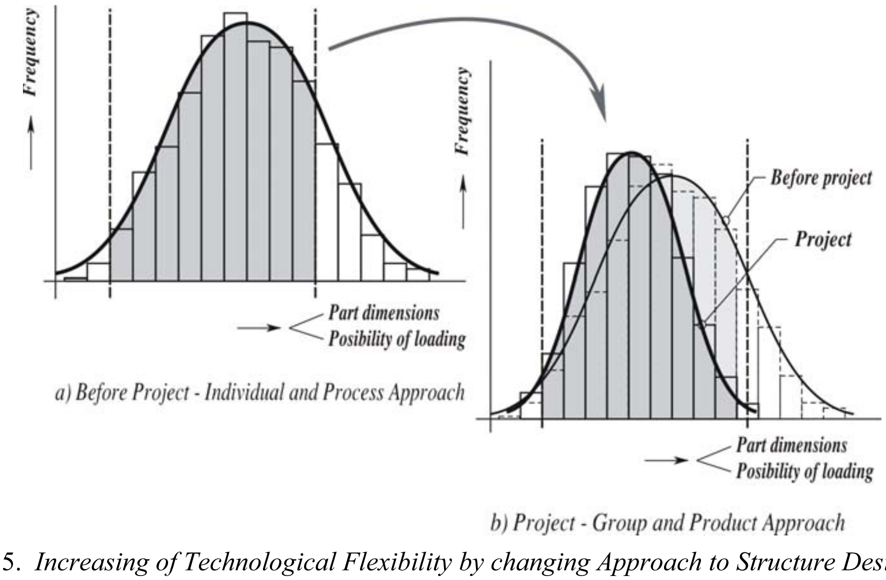

Fig. 5. *Increasing of Technological Flexibility by changing Approach to Structure Designing*

The basic structures of connections between parts of organizational structure are shown in Fig. 6.

4.1.3 The Number of Organizational Connections

Mutual connections are established between parts of organizational structure. These connections (Fig. 7) establish interdependency between the elements. The character of connections may be:

- Connections type: *major* ↔ *minor* and
- Mutual connections type: *minor* ↔ *minor*.

The position of elements in the structure, concerning the total numbers of hierarchy levels, the position of the observed element in relation to its minor and major elements, is of great importance when discussing organizational structure complexity.

The *major* ↔ *minor* ratio in organizational structure is determined by a number of hierarchy levels and management range where:

- *Hierarchy level* is part of organizational structure in vertical direction of connections, with one or more elements for defined working area (levels: enterprise, function, department, worker).
- *Management range* - ***r*** is the number of minor elements controlled by one major element.

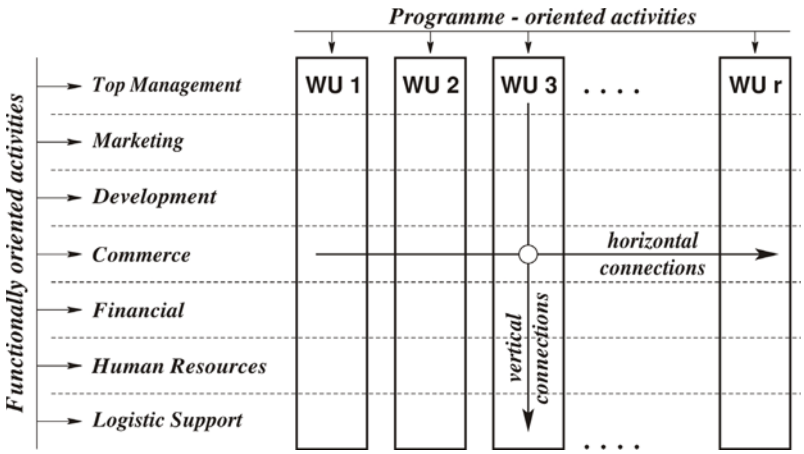

Fig. 6. *The Variety of Connections in Organizational Structure*

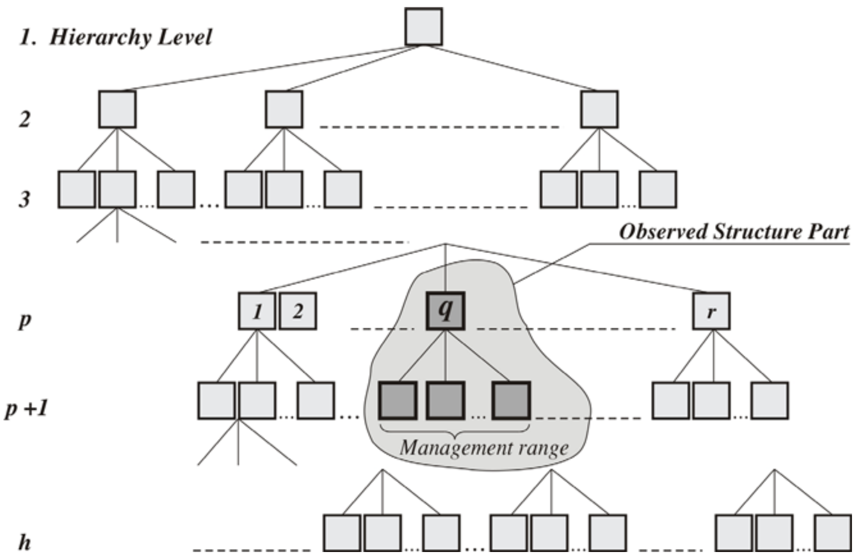

Fig. 7. *Determination of Number of Connections in Structure*

Management range determines the relationship between elements of two contiguous levels. Management range enables [21] the determination of the number of connections between the structure's elements in the observed part of the structure – $\boldsymbol{m}_i^q$, using the equation:

$$m_i^q = r\left(2^{r-1} + r - 1\right) \tag{5}$$

4.2. Complexity of Organizational Forms

With different cases of management range, the number of connections increases:

$\boldsymbol{r}$ = 4 (4 minors) → 44 conn.;
$\boldsymbol{r}$ = 5 (5 minors) → 100 conn.
$\boldsymbol{r}$ = 6 (6 minors) → 222 conn.;
$\boldsymbol{r}$ = 7 (7 minors) → 490 conn.

Using this definition, it is possible to determine the dependence complexity degree for organizational structure part between one major element and its minor elements and management range for different cases of organizational structure types (Fig. 8).

The types of organizational structures in Fig. 8 are the following [21] and [31]:

– *PROCESS TYPE of Organizational Structure* - centralistic, or functional organizational structure (Fig. 8a),
– *PRODUCT TYPE of Organizational Structure* - (non)centralistic, or divisional organizational structure (Fig. 8b),
– *PROJECT TYPE of Organizational Structure* - known as matrix organizational structure (Fig. 8c),
– *"ORCHESTRA" TYPE of Organizational Structure* - a fictitious form of organizational structure taken into consideration for comparison due to the lowest degree of complexity (Fig. 8d).

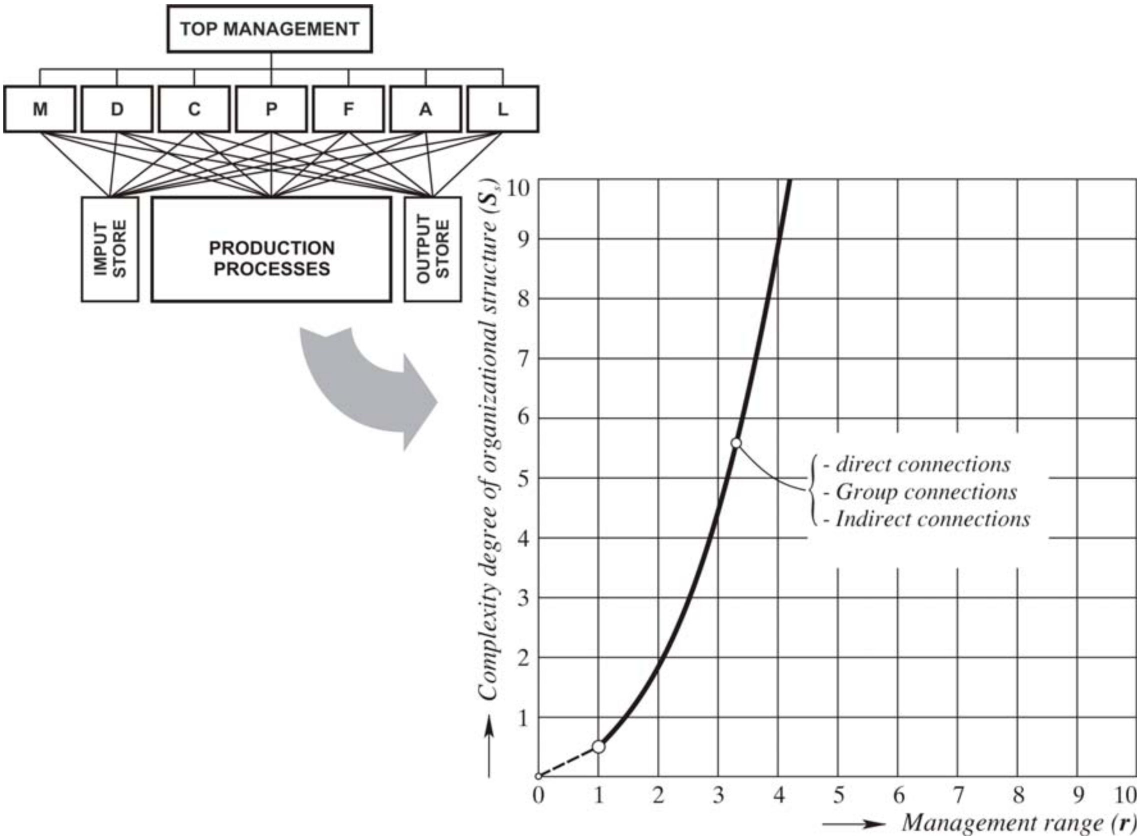

Fig. 8a. *PROCESS TYPE of Organizational Structure*

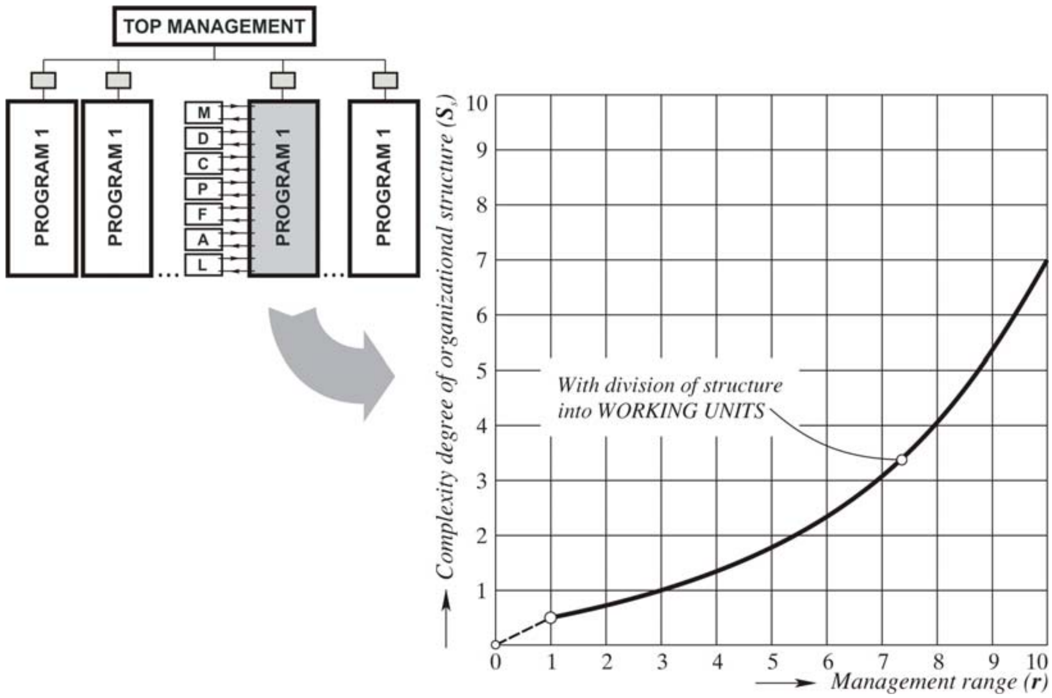

Fig. 8b. *PRODUCT TYPE of Organizational Structure*

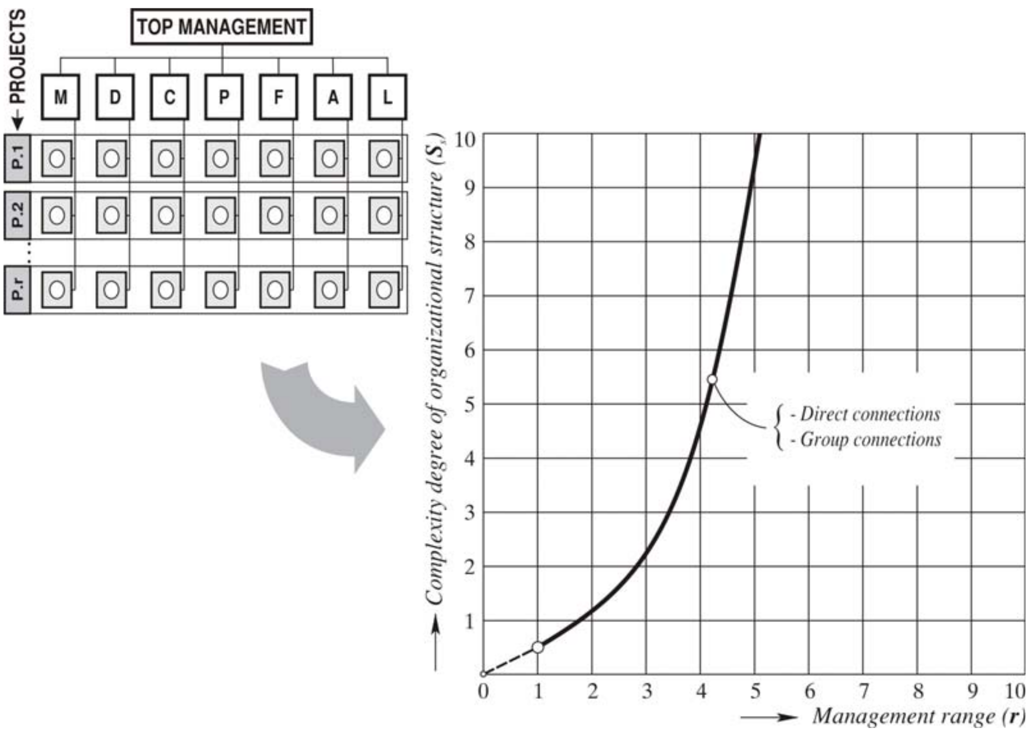

Fig. 8c. *PROJECT TYPE of Organizational Structure*

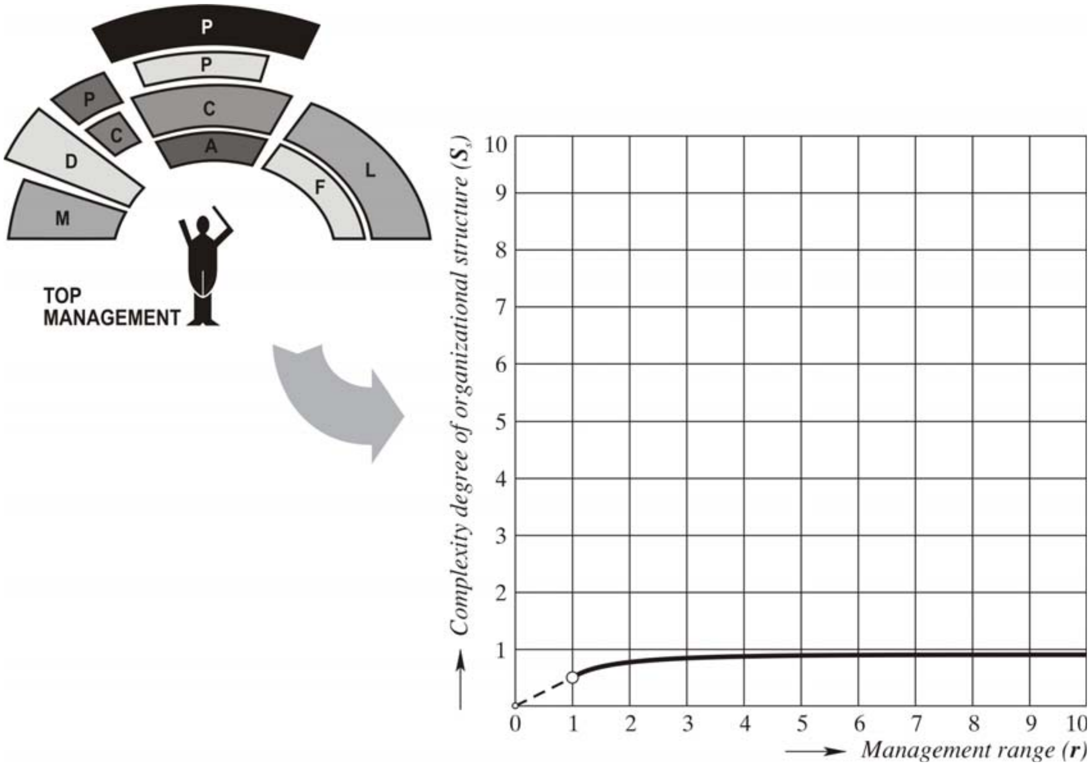

Fig. 8d. *"ORCHESTRA" TYPE of Organizational Structure*

4.3. Needs and Possibilities of Organizational Structures Simplification

Research on organizational structure characteristics in real industrial systems (enterprises) points to the necessity of eliminating all the installed limits for effective management of the work process, especially decreasing the complexity degree [28] and [29].

The possibilities of designing organizational structures with low degree of flows complexity, according to the given definition, various analyses and the presentation in Fig. 9, are reflected in the right choice of structure type. A detailed analysis of variants within a certain structure type is needed, however, with a special emphasis on the number of elements and their interrelations - the number of hierarchy levels and management range.

Research on the complexity degree of an enterprise's organizational structures shows that the complexity degree, beside the basic dependence on the number of elements and connections in a structure, is a consequence of the *quality* of the organizational structure *project*.

The quality of organizational structure project depends on:

a) Type-Variant of the Organizational Structure

The choice of the approach to organizational structure development - process, product, matrix or "orchestra" type results in the total number and specific character of connections between structure elements:

– *Process type* - a variant that demands direct, group and indirect connections between elements and results in high complexity degree,
– *Matrix type* - a variant that demands direct and group connections between elements and also results in high complexity degree,
– *Product type* - a variant that considers the installed principles of team work, demands group connections between elements and results in low complexity degree, and
– *Orchestra" type* - a variant with the lowest complexity degree, a theoretical variant - the goal in the process of organizational structure designing.

b) Management Range

Combined with a number of hierarchy levels, management range is a direct result of the process of organizational structure design because:

- Management range harmonizes the enterprise's functional activities and determines the number of structural parts on the first hierarchy level and their relationships, and
- Management range affects the design of structural parts, the total number of hierarchy levels and relationships between structural elements; most notably, management range makes a compromise between formal and informal organizational structure.

5 MASS CUSTOMIZATION

Mass customization basically refers to applied flexibility of business and production structures towards meeting the customer's requirements. As the demands of the market and development of their trends are more or less predictable (Fig. 10), the need for implementation of intelligent concepts is growing.

The period of value added time and total reconfiguration life cycle are getting shorter in time (Fig. 11). This is the crucial fact that introduces mass customization as a concept and flexibility as an answer in industrial systems.

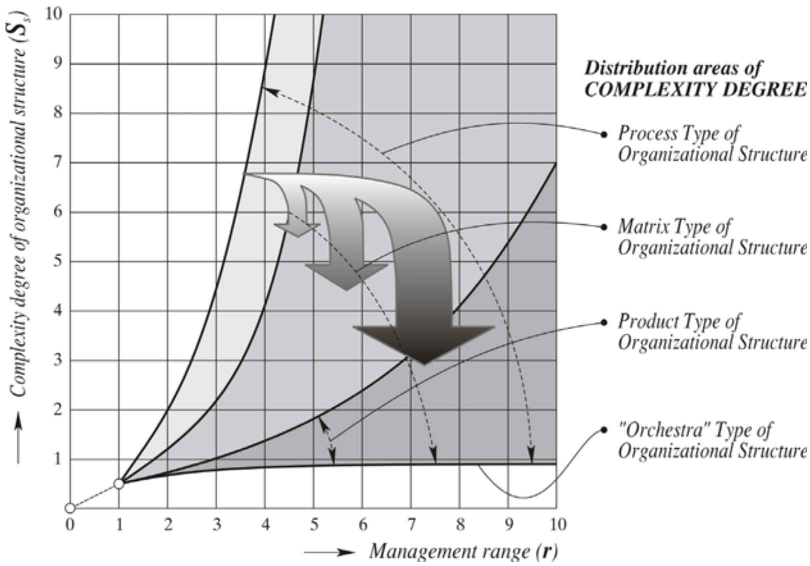

Fig. 9. *Simplification of Organizational Structures - Possibilities*

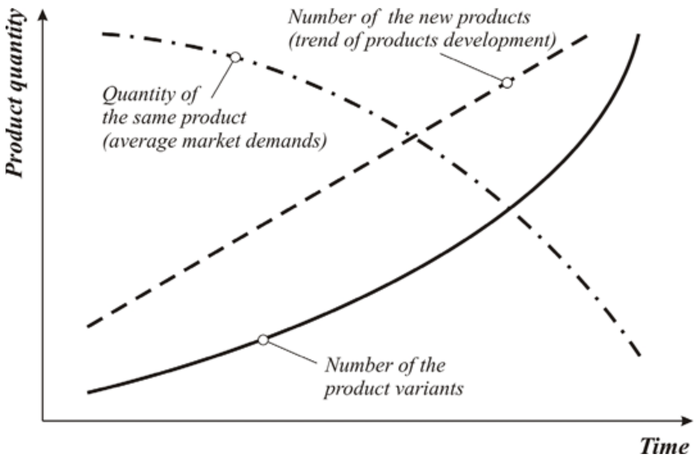

Fig.10. *Trends in market demands*

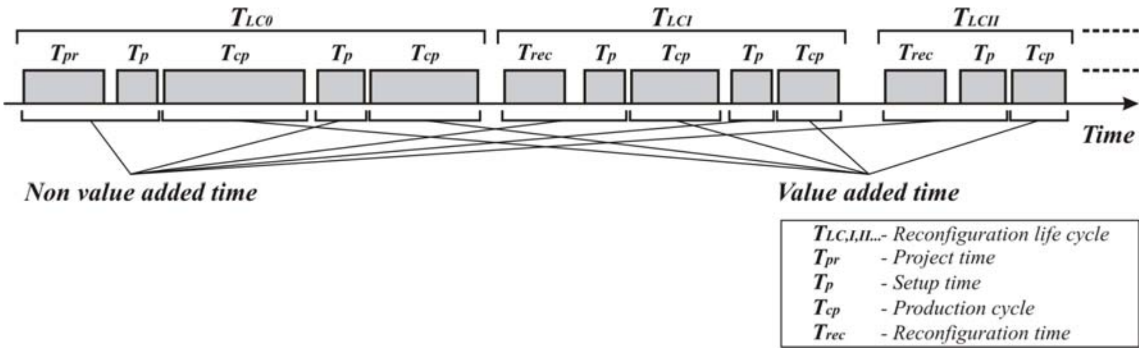

Fig. 11. *Reduction of added time period*

Mass customization is regarded as a strategy for firms to move closer to the customer. It combines elements of mass production and individualization. It can reduce the costs of a firm and increase its productivity. It is estimated that mass customization products have a potential to reach a market share of around 30%.

The implementation of a mass customization strategy requires a shift of the internal organization of a firm irrespective of whether the firm operated in the past as a mass producer or produced tailor-made individual solutions. Every staff member of the future mass customer - not only the staff responsible for production and assembly - must understand the principles of mass customization and their role in the customer-oriented production system. In comparison to the system of mass production, a much higher flow of information has to be processed and shared between the relevant function units. The implementation of a mass customization strategy thus requires, apart from new production equipment and the integration of information technologies, the definition of a new work organization with different roles and routines compared to the old system.

All this leads to a unified direction towards implementing flexibility as the only solution in structure planning and deployment.

6 CONCLUSION

Research on flexibility of production systems based on system approach indicates, as the example of technological component of flexibility shows, that the implementation of ***group approach*** in flow design and ***product approach*** in structure design create the necessary conditions for the design of *effective production structures*.

Systematically based and guided researches on organizational structure characteristics, as shown in this paper, indicate certain possibilities of generalizing the approach to establish the definition and determine *Enterprise's Complexity Degree*.

With this approach, a number of structural elements and a variety of relations between them are the basic parameters which define the complexity degree of organizational structure and simultaneously determine the complexity of an enterprise's information flows. Therefore, the complexity degree of organizational structure determined upon those parameters enables comparison of the designed structure variants using the quality defined as *Control Adequacy*.

The implementation of mass customization requires from industrial firms a reorganization of their internal structures and processes and additionally a more intensive collaboration with suppliers and customers. As the implementation of mass customization depends on the efficient interior communication processes and the willingness of workforce to learn and gain knowledge, as well as on the close collaboration with suppliers, service providers and customers, a cultural proximity between the involved parties smoothens the process of change.

Flexibility and complexity research results helped in defining and measures of key performances which are illustrating quality of enterprise's structure. In this way through different analyses the basics for quality evaluation and real enterprise's structure comparing had been set. However, characteristics of flexibility and complexity of enterprise's structure, how they are defined in this work, in furthers research could be used as criteria for analyzing and choosing the optimal variant in designing procedures of enterprises structure.

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Reliability and Efficacy of Identification Systems and Supply Chain Management[1]

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The processes of production and logistics often involve the requirement to reliably identify the individuals responsible for certain operational procedures (complaints, process audits, preventive-corrective actions due to non-conformance). The individuals in charge of these procedures usually have their own way of identity confirmation (signature, PIN codes, chip cards[2], biometric identifications, camera, etc.). It is thereby necessary to reduce the scope of information to the legally acceptable limit that insures personal integrity and confidentiality.

Because of the continuous optimization and automation of processes there is an increasing trend towards »simple identification systems« in the production and logistics processes. Biometry makes the identification process faster and simpler by using people's unique characteristics[3] without the need for any additional identification elements. However, it is necessary to research the reliability and efficacy parameters of this identification method in order to avoid unnecessary complications that could arise from selecting unsuitable technology.

Keywords: production processes, logistic processes, identification, automation, reliability, efficiency, biometry

0 INTRODUCTION

Production logistics must ensure an effective flow of material, tools and services during the whole production process and between companies. Solutions for traceability of products and people (identification and authentication) are very important parts of the production process. The entire production efficacy and final products quality depend on the organization and efficiency of the logistics process. The capability of a company to develop, exploit and retain its competitive position is the key for increasing company value [7].

Globalization dictates to the industrial management an effective, lean[5] manufacturing, downsizing and outsourcing. The requirements of modern times are development and the use of wireless technologies such as the mobile phone. The intent is to develop remote maintenance, remote servicing and remote diagnostics [8]. With the increasing use of new identification technologies, it is necessary to explore their reliability and efficacy in the logistics process.

The new identification systems are achieving extremely fast development in the last ten years with the evolution of microelectronics and it enables practical application in the branch of automation of logistics and production. It is necessary to research and justify every economic investment in these applications.

[1] Supply Chain Management (SCM); the process of planning, implementing, and controlling the operations of the supply chain as efficiently as possible. Supply Chain Management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption.

[2] Chip card (Smart card, Integrated Circuit card - ICC or Contact less RFID card) is defined as any pocket-sized card with embedded integrated circuits which can process information. This implies that it can receive input which is processed - by way of the ICC applications - and delivered as an output. There are two broad categories of ICCs. Memory cards contain only non-volatile memory storage components, and perhaps some specific security logic. Microprocessor cards contain volatile memory and microprocessor components.

[3] Characteristics; elements of unique personal identification (fingerprints, cornea, iris, DNK).

[4] Radio-frequency identification (RFID) is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. RFID tag is an object that can be applied to or incorporated into a product, animal, or person for the purpose of identification using radio waves. Some tags can be read from several meters away and beyond the line of sight of the reader. Most RFID tags contain at least two parts. One is an integrated circuit for storing and processing information, modulating and demodulating a (RF) signal, and other specialized functions.

[5] Lean manufacturing; Lean is essentially a business discipline that is built around obeying only the customer's demand signals (or "pull") and getting rid of waste everywhere in the supply chain, waste in overproduction as well as in inventory [9].

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The production process needs to be efficacious and carefully planned with the support of dynamic analysis and optimization tools (MS Visio, Process Simulator, etc.). In this paper the most important quantitative characteristics of reliability are explained. The authors also show the methodology for defining reliability and efficacy of identification systems in the process of production and logistics and provide experimental research of personal identification systems[6] based on reliability and efficacy parameters. Furthermore, an identification system of a real production-logistics system was upgraded based on automation and informatization.

In a comparative study based on wireless RFID and Biometric Identification Systems (see Figure 1.), the authors:

- show the availability and efficacy analyses in the processes of informatization and automation of production and logistics systems,
- extend reliability estimation of identification systems (RFID and biometric) based on significant reliability characteristics,
- research cost analysis of investment in an identification system,
- provide contribution to science by researching the process of production and logistics to ensure optimal procedures of automated identification.

A review of scientific databases shows that the area of assessing the reliability of identification systems in the process of production and logistics is not well explored. In modern production and logistics processes (automobile industry, aircraft-space industry, pharmacy, forensics, etc.) it is necessary to have a fast and reliable control over the flow of material and people.

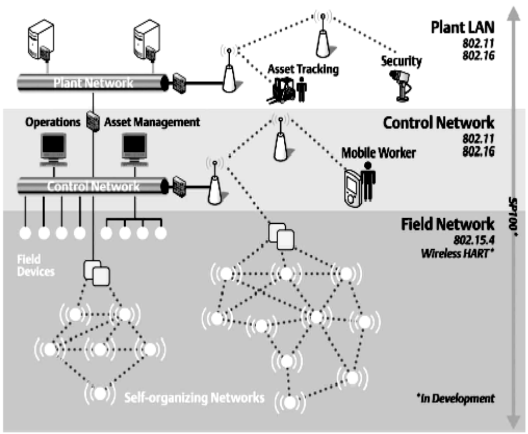

Fig. 1. *Self-organizing wireless network Identification technologies in the production logistic industry*

Companies such as army and automobile equipment suppliers can verify the serviceability of qualified parts. By using unique serial numbers of business events and transactions, connected to individual parts, it is possible to prevent any imitations or construction parts without warranty.

This paper deals with the systematical relations within identification systems. Statistical processing and conclusion forming were conducted using a tools for statistical treatment and reliability defining - Weibull++7. The aim of this research is improvement of the theoretical model, which will enable a better stability of identification in real dynamic systems. The theoretical research is followed by optimization including dynamic changes that can occur in the production-logistics process. Optimization as a function of automation will happen with linear programming[7] and numerical methods in order to minimize the production costs. Simultaneously, empirical data processing and development of a mathematical model take place.

[6] Personal Identification Systems; Recent events have heightened interest in implementing more secure personal identification (ID) systems to improve confidence in verifying the identity of individuals seeking access to physical or virtual locations in logistic process. A secure personal ID system must be designed to address government and business policy issues and individual privacy concerns. The ID system must be secure, provide fast and effective verification of an individual's identity, and protect the privacy of the individual's identity information.

[7] Linear programming; in mathematics, linear programming (LP) problems involve the optimization of a linear objective function, subject to linear equality and inequality constraints. More formally, given a polytope (for example, a polygon or a polyhedron), and a real-valued affine function.

1 DEFINING THE PROBLEM AND RESEARCH PARAMETERS

The availability of a production-logistic process is the probability that the system is functioning well at a given moment or is capable of functioning when used under certain circumstances. Reliability by definition is probability (capability) of the system to perform under stated conditions defined by function and time [4]. It is one of the most important characteristics of efficacy of identification systems and has an impact on safety and efficiency of the system. Increasing the system's reliability means less improper uses, higher safety, less repair procedures and shorter identification time and consequently causes higher system availability. Implementing higher reliability in early development phases and its assurance during the use of the identification system requires the knowledge of methods and techniques of reliability theory and their interactions.

Many different characteristics are used to measure the reliability of identification systems and their components. Some of them are connected to time functions; others represent average time functions. Which of these characteristic are relevant in specified cases depends on the set goals, selected method of analysis, and the availability of data.

Characteristics of reliability are based on mean time intervals to the occurrence of failure. Time to failure is a random magnitude and we will mark it with symbol ti. In this paper we give definitions and statistical estimations of basic reliability characteristics.

Reliability characteristics used in this research are:

- MTTF - mean time to failure
- MTBF - mean time between failures
- MTTR - mean time to repair
- *F(t)* - unreliability function
- $\lambda_{(t)}$- failure rate
- β - shape parameter
    a. β<1 temporary failure frequency $\lambda_{(t)}$ decreases (early period, system implementation)
    b. β=1 temporary failure frequency $\lambda_{(t)}$ is constant (normal system operation)
    c. β>1 temporary failure frequency $\lambda_{(t)}$ increases (exploitation, ageing)

The shape parameter (β) changes the configuration of the temporal distribution of operational failures.

1.1. Quantitative Reliability Characteristics

Unreliability function *F(t)* is defined by the equation:

$$F(t) = P(t_i \le t) \tag{1}$$

F(t) is therefore the probability of a system to become non-functional in the interval between 0 and *t*.

If we observe a number of systems or system components we can calculate the statistical estimation for the unreliability function by the equation:

$$\hat{F}(t) = \frac{N_0 - N(t)}{N_0} \tag{2}$$

$N_{(t)}$ - number of working/functional samples in the interval (0,t)

N_0 - number of samples at the start of observation at $t = 0$

Reliability function *R(t)* is complementary to unreliability function. We can define it using the equation:

$$R(t) = 1 - F(t) = P(t_t > t) \tag{3}$$

$R_{(t)}$ is the probability for a system or a component to become non-functional after a time period t. A statistical estimation of the reliability function we can define using the equation:

$$\hat{R}(t) = \frac{N(t)}{N_0} \tag{4}$$

The product of the time to failure function and dt is the probability of the system or its component to become non-functional in the interval (t, t+dt). We can calculate the function F(t) by differentiation of the unreliability function by time:

$$F(t) = \frac{dF(t)}{dt} \tag{5}$$

The statistical estimation for f(t) can be calculated with the equation:

$$\hat{f}(t) = \frac{N(t) - N(t + \Delta t)}{N_0 \cdot \Delta t} \quad (6)$$

where Δt is interval $(t, t + \Delta t)$.

Product of Failure rate $\lambda_{(t)}$ and dt is the conditional probability of a system/part of system to become non-functional in the interval (*t, t+dt*).

Momentary frequency of failure rate can be written as:

$$\lambda(t) = \frac{f(t)}{R(t)} \quad (7)$$

The statistical estimation for $\lambda_{(t)}$ is defined with the equation:

$$\hat{\lambda}(t) = \frac{N(t) - N(t + \Delta t)}{N(t) \cdot \Delta t} \quad (8)$$

For many systems or system parts the function $\lambda_{(t)}$ has a characteristic "bathtub" configuration (Figure 2.). The life cycle of systems can be divided into three periods: early damaging period, normal working period and ageing or exploitation period. $\lambda_{(t)}$ in first period decrease in second period $\lambda_{(t)}$ is constant and $\lambda_{(t)}$ growth in third period.

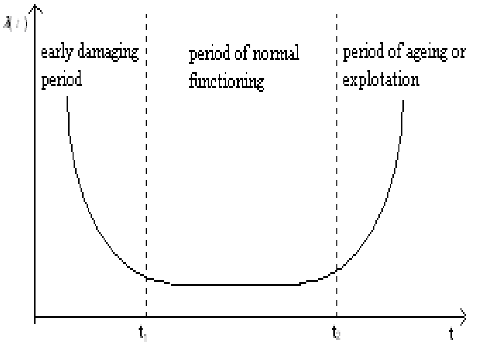

Fig. 2. *"Bathtub" curve* [4]

2 THE METHODOLOGY OF RESEARCHING THE RELIABILITY OF IDENTIFICATION SYSTEMS IN THE PRODUCTION-LOGISTIC PROCESS

2.1. Reliability of RFID Identification Systems

The research was conducted on Memory and Microprocessing identificators that can be installed onto the construction elements in the production-logistic process. Identification of persons in production-logistic processes is provided by biometric identificators which are unique to every person. Memory Identificators do not have a processor and therefore can not dynamically process data. Cards are designed to save the value or tokens for one time or continuous use.

Microprocessing identificators usually contain a processor, input-output unit and various kinds of data storage. They are able to dynamically process data. At the moment 8-, 16-, and 32-, bit processors are in use and have in average 16 to 32 Kb EEPROM and 3 Kb RAM. Input-output unit transmits 9.6 to 115 Kbits per second (only half duplex mode is possible). In terms of processor power they can be compared to the IBM-XT computer and cards with Crypto coprocessor in some function significantly exceed the 50 MHz 486 computer.

With adequate construction [1], the majority of operations and logs can be transferred from smart cards to PCs that have better working and process capabilities. For the cryptosystem RSA[8] with public keys, the recommended key length is 2000 bits. Adding components (e.g. coprocessor) increases the cost of cards and at the same time their reliability and safety are reduced. The conditions caused by the deficiency of data storage capacities or processing power can be improved with new technology (such as Cryptosystems with Elliptical Curves[9]).

[8] RSA; The mathematical details of the algorithm used in obtaining the public and private keys are available at the RSA Web site. Briefly, the algorithm involves multiplying two large prime numbers (a prime number is a number divisible only by that number and 1) and through additional operations deriving a set of two numbers that constitutes the public key and another set that is the private key.

[9] Elliptical curve cryptography (ECC) is a public key encryption technique based on elliptic curve theory that can be used to create faster, smaller, and more efficient cryptographic keys. ECC generates keys through the properties of the elliptic curve equation instead of the traditional method of generation as the product of very large prime numbers. The technology can be use in conjunction with most public key encryption methods, such as RSA.

They enable shorter safety keys and faster processing (with existing processor) and keep the same level of safety.

2.2. Reliability of Biometric Identification Systems

Definitions used in reliability calculation of biometric identification systems and terminology:

- FAR[10] is defined as the percentage of identification instances in which false acceptance occurs,
- FRR[11] is defined as the percentage of identification instances in which false rejection occurs,
- Mean time to failure (MTTF), mean time between failures (MTBF) and mean time to repair (MTTR),
- classification of failures,
- failures data bases.

In contrast to the classic methods of identification, in biometric methods probability needs to be considered. All sensors are subject to noise and errors. The largest problem is the development and implementation of a safe crypto algorithm. All limitations are summarized in the two terms: FRR and FAR. It a system is highly sensitive, the FAR value is low, but FRR is higher. In a system of low sensitivity the situation is reversed. Such us system accept almost everyone (FAR > FRR). It is therefore necessary to make compromise in the sensitivity of a system. It can also be regulated so that the FAR and FRR values are equal, the so-called EER (Equal Error Rate). Lower EER means a more accurate system. In application where the speed of identification is more important than safety (e.g. hotel rooms), the high FAR value can be allowed [3].

2.3. Identification and Verification (Authentication)

It often happens that we use the term identification when we talk about verification and vice versa. Identification is a term used for identifying a person based on their biometrical data. This mostly involves a database of biometric data with which the momentary information is compared until the most similar or same image is found. We search among N persons in the database so this way is called »1:N« or »One to many comparison«. With personal identification we look for a person's identity (e.g. name). In verification however, we ascertain if this is indeed the person they claim to be [6], so there is only one comparison (1:1). Since we know the person's name, we compare the data read by the sensor with the data stored in the database.

2.4. Fingerprint

Fingerprint recognition is the oldest form of all the biometric methods and they are secure from mutations. Fingerprint images are skin folders and furrows and have different details which can easily be read by a biometric module (Fig. 3.). Details are located on the end of furrows or on the joints of folders. The global images made by skin folders, furrows and details on a finger are different for each person and are therefore very adequate for recognizing a person. To recognize a fingerprint, approximately 100 bits are enough for detail searching methods, while high security systems store information in few Mbytes per image. We never store real fingerprints in the database. There is no possible way to recognize a person from the stored images without the use of special equipment. In correlation methods, the amount of data is higher.

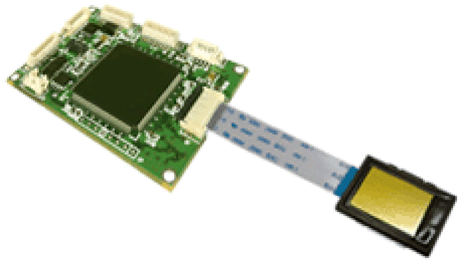

Fig.3. *Fingerprint Reader Module (Suprema Technical Manual, 2007)*

[10] AR (False Aceptance Rate); This can be expressed as a probability. For example, if FAR is 0.1 percent, it means that on average, one out of every 1000 impostors attempting to breach the system will be successful.

[11] FRR (False Recetion Rate); For example, if FRR is 0.05 percent, it means that on average, one out of every 2000 authorized persons attempting to access the system will not be recognized by that system.

3 RESULTS AND DISCUSSION

For the duration of research it is necessary to define reliability characteristics of RFID and biometric identification systems. Reliability characteristics of system components can be determined by testing, changing the functioning in the exploitation phases, catalogues and test reports or reference books (most known is the MIL HDBK 217[12]).

3.1. Reliability Parameters MTTF, MTBF of a RFID System Reader

$$\text{MTTF} = \int_0^\infty R(t)dt = \frac{1}{n}\sum_{i=1}^{n} t_i = 76.5 \text{ days}$$

$$\text{MTBF} = \int_0^\infty R(t)dt = \frac{1}{n}\sum_{i=1}^{n} t_i = 78.6 \text{ days}$$

The failures that were considered for defining MTTF, MTTR and MTBF (See Table 1.) of a RFID system are the following:

- Failures in Software operating (reader can not read RFID Tags).
- Failures in Hardware operating (RFID reader/antenna, impossible programming of RFID Tags or Microchips).

3.2. Reliability parameters MTTF, MTBF of Biometric Identification Reader

$$\text{MTTF} = \int_0^\infty R(t)dt = \frac{1}{n}\sum_{i=1}^{n} t_i = 88.8 \text{ days}$$

$$\text{MTBF} = \int_0^\infty R(t)dt = \frac{1}{n}\sum_{i=1}^{n} t_i = 90.1 \text{ days}$$

The failures that were considered for defining MTTF and MTBF of a Biometric system are following (See Table 2).

- Failures in Software operating (impossible read or recognition of fingerprint images)
- Failures in Hardware operating (Biometric Reader, PCBs[13]).
- Failures as a consequence of sensor operating: FAR, FRR.

3.3. Failure Rate *λ(t)* of RFID and Biometric Identification Systems

Reliability of the RFID module can be defined with the Failure Rate parameter $\lambda(t)$ in different periods:

- early damaging period,
- period of normal functioning,
- period of ageing or exploitation.

To define Failure Rate the Weibull model was used. It can also be used for models where $\lambda(t)$ can not be illustrated by constant or linear functions. The reliability parameters were defined using graphic method (Weibull++7 Software) and the results of the graphic methods are presented on the following figures:

- Reliability Function *R(t)* of RFID system by β=2.6535 (Fig. 4.).
- Failure rate *f(t)/R(t)* of RFID system by β=2.6535 (Fig. 5.).
- Reliability Function *R(t)* of BIOMETRIC system by β=2. 6024 (Fig.6.).
- Failure rate *f(t)/R(t)* of BIOMETRIC system by β=2. 6024 (Fig. 7.).

3.3.1 Times to failures (see Table 1) of RFID identification system samples and corresponding appraisal

Pairs $\left[t_i, \hat{F}(t_i)\right]$ (See Table 3.) were drawn in the probability web of a chosen (Weibull) probability distribution.

Times to failures and belonging point estimations (Fig .4.) shown during the ageing period or exploitation phase of RFID system β=2.6535 (β >1).

[12] MIL HDBK 217 [10]; this military standard is used to estimate the inherent reliability of electronic equipment and systems based on component failure data. It consists of two basic prediction methods: Parts-Count Analysis and Part-Stress Prediction. The general failure model in MIL-HDBK-217 and Bellcore TR-332 is the form: $\lambda_P = \lambda_b \pi_Q \pi_E \pi_A$ [11].

[13] PCB (Printed Circuit Board) is used to mechanically support and electrically connect electronic components using conductive pathways, or traces, etched from copper sheets laminated onto a non-conductive substrate. Alternative names are printed wiring board (PWB), and etched wiring board. A PCB populated with electronic components is a printed circuit assembly (PCA), also known as a printed circuit board assembly (PCBA).

Measured time parameters to terminal damage of the RFID system (t_i, i=1,2,3):

Table 1. *MTTF - MTTR - MTBF for RFID System*

Ser. no.	Time to Failure[1]	Time to Failure[2]	Time to Failure[3]	MTTF	Average value
22345	13	139	48	66.7	76.5
22359	27	106	42	58.3	
22346	54	106	58	72.7	
22347	54	110	83	82.3	
22348	72	96	73	80.3	
22349	90	82	88	86.7	
22360	116	28	93	79.0	
22375	87	29	115	77.0	
22381	51	40	145	78.7	
22387	60	36	155	83.7	
Ser. no.	Service procedure trial[1]	Service procedure trial[2]	Service procedure trial[3]	MTTR	Average value
22345	1	1	1	1.0	2.1
22359	1	1	1	1.0	
22346	2	3	2	2.3	
22347	2	0	3	1.7	
22348	5	3	7	5.0	
22349	1	1	1	1.0	
22360	4	1	2	2.3	
22375	4	2	1	2.3	
22381	4	3	4	3.7	
22387	1	0	1	0.7	
Ser. no.	Time to repeated start[1]	Time to repeated start[2]	Time to repeated start[3]	MTBF	Average value
22345	14	140	49	67.7	78.6
22359	28	107	43	59.3	
22346	56	109	60	75.0	
22347	56	110	86	84.0	
22348	77	99	80	85.3	
22349	91	83	89	87.7	
22360	120	29	95	81.3	
22375	91	31	116	79.3	
22381	55	43	149	82.3	
22387	61	36	156	84.3	

Measured time parameters to terminal damage of the biometric system (t_i, i=1,2,3):

Table 2. *MTTF - MTTR - MTBF fo BIOMETRIC System*

Ser. no.	Time to Failure[1]	Time to Failure[2]	Time to Failure[3]	MTTF	Average value
36365	53	89	88	76.7	88.8
36359	60	106	73	79.0	
36366	87	106	88	93.0	
36364	86	161	88	106.3	
36368	102	130	13	81.7	
36369	99	102	98	99.7	
36360	56	150	93	99.7	
36345	57	90	126	91.0	
36381	81	52	117	83.3	
36384	90	65	105	80.0	
Ser. no.	Service procedure trial[1]	Service procedure trial[2]	Service procedure trial[3]	MTTR	Average value
36365	1	1	1	1.0	1.2
36359	0	1	0	0.3	
36366	1	3	2	2.0	
36364	1	0	1	0.7	
36368	1	3	1	1.7	
36369	2	1	1	1.3	
36360	2	1	1	1.3	
36345	3	1	1	1.7	
36381	2	1	1	1.3	
36384	2	0	1	1.0	
Ser. no.	Time to repeated start[1]	Time to repeated start[2]	Time to repeated start[3]	MTBF	Average value
36365	56	90	89	77.7	90.1
36359	60	105	73	79.3	
36366	88	107	90	95.0	
36364	85	161	89	105.0	
36368	103	133	16	83.3	
36369	101	103	99	101.0	
36360	58	151	96	101.0	
36345	60	91	127	92.7	
36381	83	53	118	86.7	
36384	92	65	106	81.0	

3.3.1 Times to failures (see Table 1) of RFID identification system samples and corresponding appraisal

Pairs $\left[t_i, \hat{F}(t_i)\ \right]$ (See Table 3.) were drawn in the probability web of a chosen (Weibull) probability distribution.

Times to failures and belonging point estimations (Fig .4.) shown during the ageing period or exploitation phase of RFID system β=2.6535 (β >1).

Table 3. *Times to failures and belonging appraisal for RFID system*

Mean time to first failure (RFID)										
i	1	2	3	4	5	6	7	8	9	10
t_i	13	27	54	54	72	90	116	87	51	60
$\hat{F}(t)$	0.05	0.12	0.19	0.26	0.33	0.4	0.48	0.55	0.62	0.66

Mean time to second failure (RFID)										
i	1	2	3	4	5	6	7	8	9	10
t_i	139	106	106	110	96	82	28	29	40	36
$\hat{F}(t)$	0.05	0.12	0.19	0.26	0.33	0.4	0.48	0.55	0.62	0.66

Mean time to third failure (RFID)										
i	1	2	3	4	5	6	7	8	9	10
t_i	48	42	58	83	73	88	93	115	145	155
$\hat{F}(t)$	0.05	0.12	0.19	0.26	0.33	0.4	0.48	0.55	0.62	0.66

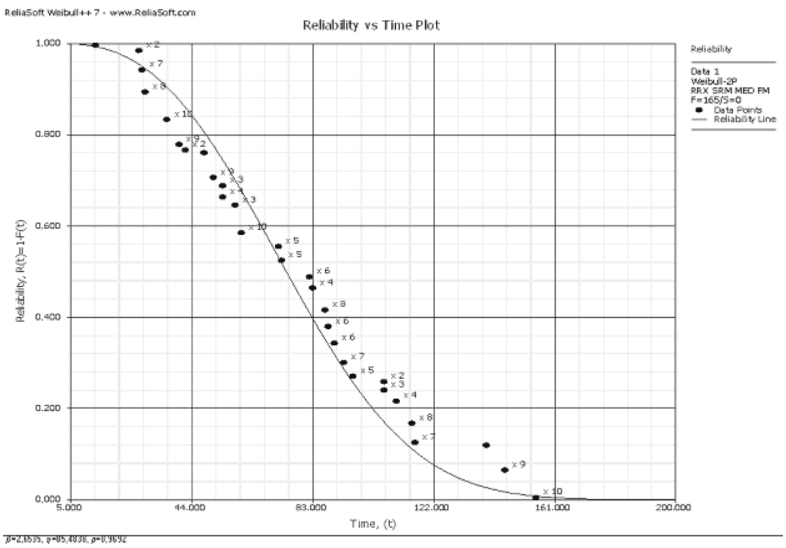

Fig. 4. *Reliability function of RFID system by ß=2.6535*

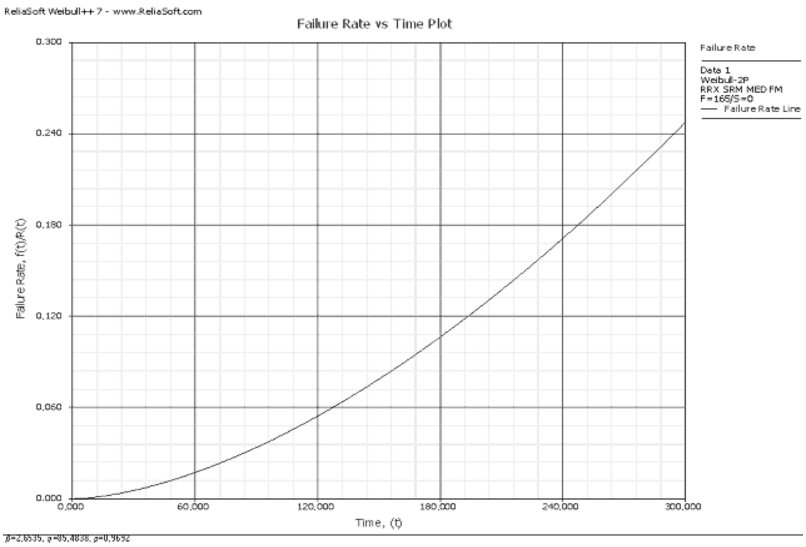

Fig.5. *Failure rate f(t)/R(t) of RFID system by ß=2.6535*

3.3.2 Times to failure (see Table 2.) of Biometric identification system samples and corresponding appraisal

Pairs $\left[t_i, \hat{F}(t_i)\right]$(Table 4.) were drawn in the probability web of a chosen (Weibull) probability distribution.

Table 4. Times to failures and corresponding appraisal for BIOMETRIC system

Mean time to first failure(BIOMETRIC)										
i	1	2	3	4	5	6	7	8	9	10
t_i	53	60	87	86	102	99	56	57	81	90
$\hat{F}(t)$	0.05	0.12	0.19	0.26	0.33	0.4	0.48	0.55	0.62	0.66

Mean time to second failure (BIOMETRIC)										
i	1	2	3	4	5	6	7	8	9	10
t_i	89	106	106	161	130	102	150	90	52	65
$\hat{F}(t)$	0.05	0.12	0.19	0.26	0.33	0.4	0.48	0.55	0.62	0.66

Mean time to third failure (BIOMETRIC)										
i	1	2	3	4	5	6	7	8	9	10
t_i	88	73	88	88	13	98	93	126	117	105
$\hat{F}(t)$	0.05	0.12	0.19	0.26	0.33	0.4	0.48	0.55	0.62	0.66

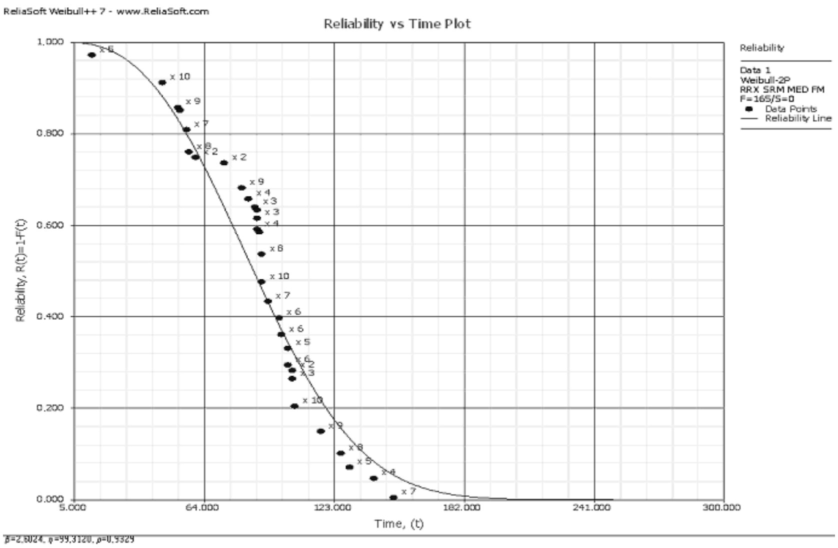

Fig. 6. *Reliability function R(t) of BIOMETRIC sytem by ß=2.6024*

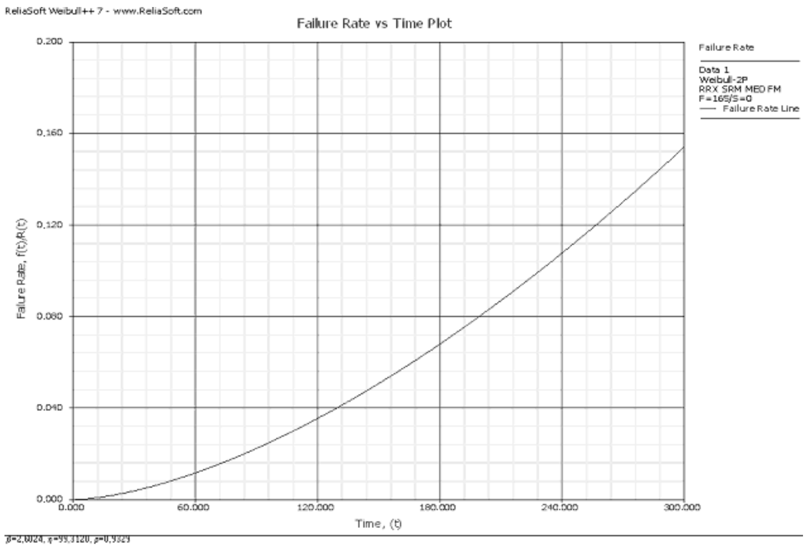

Fig. 7. *Failure rate f(t)/R(t) of BIOMETRIC system by ß=2.6024*

4 CONCLUSIONS

Biometric methods are becoming a very popular alternative to traditional identification systems in production-logistic processes where identification of people is necessary. Our research has shown that the ageing of biometric system begins later compared to RFID identification systems. The results indicate high availability the biometric identification systems and lower maintenance costs. There are many benefits to using biometric systems, such as no need for any additional identification elements. The use of biometric methods simplifies identification and increases reliability because biometric identification elements are not portable (fingerprints) and prevent non-authorized uses. Results of this research indicate the following:

1. better reliability of biometric systems regarding reliability parameters MTTF, MTBF and $\lambda(t)$;

- MTTF of biometric systems are improved by 12.3 days.
- MTBF of biometric systems are improved by 11.5 days.
- The most critical parameter of the RFID systems – λ(t), does not need to be considered in biometric systems. In a biometric system, there is no need for RFID cards or RFID tags for identification.

2. For biometric identification there is no need for RFID cards or tags which are the most critical parts in RFID Identification System. Experiments show that most cards fail within one year.
3. Time of servicing biometric readers is shorter than time of servicing RFID readers by an average of 1 day. This is a better result by 30% and consequently biometric systems have better availability.

4.1 Return of investment with optimizing production logistic

On the basis of the results of this research and customer feedback information, it can be concluded that the investment into automation of personal identification in the production-logistic processes is returned within 10 to15 months. The exact time depends on the degree of automation and the quantity of identification places). Of the many industrial branches these advantages and solutions will be a necessity for the pharmaceutical sector, where the processes must ensure safe distribution. Pharmaceutical companies have to deal with the problem of fake and altered medicaments (the estimated loss of is 75 billion dollars a year until 2010). According to predictions, biometric identification technology will reach vast rates of development. An indication of maturity of the biometric system is the amount of investments in the field. In the year 2002, the US government invested 16.63 million dollars into the biometric industry. The expected income of biometric industry in USA in 2007 was 153 million dollars. Expected growth of income between the years 2000 and 2007 is 67% [6].

5 SUMMARY AND FUTURE WORK

The usefulness of biometric systems is shown in production-logistic environment where personal identification is needed. From this research it is evident that the ageing period of biometric systems begins later compared to RFID (card identification) systems. The results also show that the availability of biometric identification systems is higher and therefore maintenance costs are lower. Functional and ergonomic advantages of biometry are clear because there is no need for any cards or other elements of identification in the production-logistic process. The use of biometric systems will make identification simple and at the same increase reliability due to non-transferability of identification elements (fingerprints) and prevent improper use. It can be expected that biometric technology will attain Slovenia in spite of doubts expressed by some institutions (office for personal data protection). Many open ethical questions arise, mostly on human personality, privacy and control. However researches such as this on reliability and availability unequivocally show that biometric technology has an advantage both in practical use and data safety.

Personal responsibility and accuracy in fields such as legislation, regulation adjustment, and production and supply chain management in global technical operations are more easily controlled using automated identification.

With the automation of identification there are also the possibilities of merging and comparing current process data with data from integral information systems (ERP, MRII, etc.) or other business applications.

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Mechanical and Metallurgical Properties of Aluminium and Copper Sheets Joined by Cold Pressure Welding

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Cold pressure welding is a special welding method that has been used in applications such as assembly of various parts at an increasing rate in recent years. In the present paper, cold pressure welding was applied to commercial purity aluminium and copper sheets as lap welding and a 150 metric ton hydraulic press was used for the process. As the surface roughness and the weld deformation ratia of aluminium sheets increased, tensile strength of the joints also increased. Purchased specimens with original roughness had the lowest weld deformation as-is and it was not possible to join these sheets at 30% weld deformations. Fatigue tests showed that joined sheets resisted against low fluctuating tensile stresses. Hardness increases due to local hardening at the interface as a result of cold deformation. Also EDX (Energy Dispersive X-ray) measurements clearly show that Al-Cu joints contain an intermetallic compound layer at the interface which does not affect the joint strength to a great extent. Results showed that the cold pressure welding technique in lap form resulted in strong Al-Al joints and the intermetallic layer formed in Al-Cu joints did not affect the joint strength to a great extent.

Keywords: cold pressure welding, metallography, mechanical properties, surface roughness, deformation ratio

0 INTRODUCTION

Cold pressure welding can be applied by bringing surfaces of virgin metal specimens into close contact. Cold pressure welding takes place due to the breakdown of the surface layers caused by bulk plastic deformation. It is a solid phase welding process that can be performed on a large number of possible metal combinations.

Cold pressure welding has particularly been applied within the last fifty years, due to the fact that the process can be carried out easily at room temperature without using complex and expensive equipment. Cold pressure welding also has the advantage of being applicable to metal pairs that cannot be joined with either melt welding methods or to those metal pairs that pose utmost difficulty with respect to melt welding.

Cold pressure welding is used to join aluminium cables, various types of kitchen furniture, electrolysis cells, and communication lines. It is also used to join wires and rods and in production of heat exchangers as coolers.

The important variables of the method are; surface preparation before processing, deformation, properties of the welding material or material pairs and pressure. Thus, one of the most important aspects of cold pressure welding is the properties of the surface before welding. The most commonly used method for surface preparation is cleaning the metal surfaces with a solving agent and brushing them with a wire brush. Wire brushing results in the formation of a hard brittle layer that prevents the metal from getting dirty (from grease, contaminant and oxide). It has been found that bonding occurs as a result of the cracking of this layer with the corresponding contact of metals [1]. Heating or chemical cleaning methods may also be applied. Deformation is the most important process variable. There is a minimum deformation – surface spread out or a reduction value for each material during cold pressure welding.

Mohamed et al. [2] investigated the mechanism of pressure welding in aluminium, copper, silver and gold. Bay [3] examined the bonding mechanism of cold pressure welding and mechanisms producing metallic bonds in cold welding [4]. Tabata et al. [5] investigated cold pressure welding of aluminium and copper by

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butt upsetting. Bond criterion in cold pressure welding of aluminium was examined [6]. Unal et al. [7] investigated the effects of process parameters on the welding strength in the cold pressure welding of aluminium. Altan et al. [8] obtained the surface roughness depending on welding strength in the cold pressure welding of aluminium. Li et al. [9] examined interfacial energy and the match of cold pressure welded Ag/Ni and Al/Cu. Li et al. [10] investigated the interfacial bonding state on different metals Ag, Ni in cold pressure welding. Krishna et al. [11] directed process parameter optimization to obtain high weld strength in the cold solid state in joining sintered steel and copper powder. Sahin et al. joined plastically deformed steels by friction welding [12]. Tylecote informed about pressure welding practice [13]. Sahin et al. investigated the application of cold pressure welding to aluminium and copper sheets [14]. Iordachescu et al. obtained the FEM Model of Butt Cold Welding [15]. Kim et al. described fabrication of organic light-emitting devices by low-pressure cold welding [16]. Okumura et al. developed the composite materials fabricated from multi-layered 5052 aluminium alloy foils and titanium foils by cold pressure welding [17]. A titanium-flake reinforced aluminium-matrix composite was prepared from multilayered foils by cold pressure welding [18]. Kim et al. investigated micro patterning of organic electronic devices by cold-welding [19]. Dariel et al. Studied acid-assisted consolidation of powder compacts [20]. Zhang et al. made a fractographic investigation of weld formation for cold welding [21]. Kuzin studied optimization of technological parameters for cold pressure welding of thin sheets of AD1M aluminium [22].

In the present paper, aluminium and copper sheets were joined by cold pressure welding, namely, lap welding. A 150 metric ton hydraulic press was used for the welding process. Before welding, a wire-brushing process was applied in order to prepare the aluminium and copper sheets, their roughness was determined using a surface roughness equipment and they were joined at different deformation ratia. The effects of deformation ratia and surface roughness on tensile strength of welded joints were investigated. Tensile tests and fatigue tests were carried out, hardness variations and micro-structures of the joints were examined. The joints were examined using EDX (Energy Dispersive X-ray) analysis in order to have an insight into the phases occurring during welding at the interface. Soundness of the joints was also investigated using non-destructive techniques radiographic inspection technique so as to evaluate the occurrence of defects.

1 COLD PRESSURE WELDING

1.1. Process Characteristics

Extent of deformation is one of the most important factors in cold pressure welding. Supposing that the basic parameter in cold pressure welding is the degree of deformation normally expressed as the reduction R or the surface expansion X of the bonding surface, plastic deformation of the metal pair is necessary in order to obtain a bonding.

In butt-welding, the experimentally measured extension (deformation) R is given by

$$R = \frac{A - A_0}{A_0} \tag{1}$$

where A_0 is the original cross – sectional area and A is the extended area after processing. True fractional metallic area revealed at a certain extension R is then:

$$\frac{\Delta A}{A} = \frac{R}{R+1} \tag{2}$$

This Equation, which is valid for butt cold pressure welding, is given by

$$R = \frac{h - h_0}{h_0} \tag{3}$$

for lap welding where h_0 is the original thickness of the sheet and h is the instantaneous thickness at deformation ratio R [2] and [3].

On the other hand, Equation 2 is also valid for lap welding. A specific threshold surface extension or reduction (minimum welding deformation) is required for bond establishment at the atomic level. This deformation depends on metal–metal pairs, joining shape and thickness and surface preparation. It should also be noted that welding strength increases as deformation increases. However, too many plastic deformations also cause a decrease in weld strength. Surface preparation before welding influences weld strength to a great extent. The most widely used surface pre-preparation technique is removing the grease and brushing with a wire brush. Nickel coating of metal surfaces before processing is known to produce effective results. Also, application of normal pressure on the welding surface affects weld strength in a positive manner [2], [3], [7] and [8].

1.2. Bond Formation Mechanism

Microstructural examination of SEM microphotographs was used to develop an understanding of the mechanisms underlying bond formation on the wire brushed surfaces. Wire brushing during mechanical surface preparation forms a hard and brittle surface film at metal surface which is referred to as the cover layer. Observations have shown that bond formation is carried out by means of the stages given in Fig. 1.

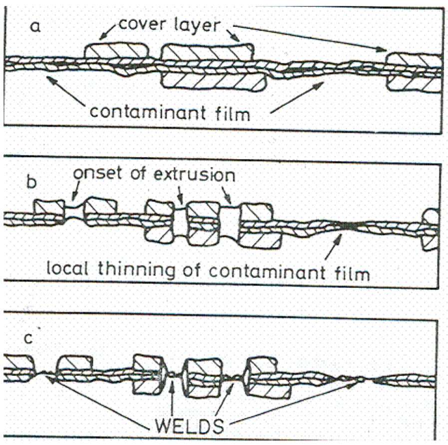


Fig. 1. *The bond formation mechanism in cold pressure welding [4]*

First the cover layer is fractured of by the effect of pressure (Fig. 1.a). Further increase in surface extension caused extrusion of metallic material through the crack in the cover layer (Fig.1.b). Finally, increase in deformation leads to real contact between metals resulting in the formation of a real bond (Fig. 1.c).

2 EXPERIMENTAL PROCEDURE

Aluminium and copper sheets (2.75 mm thickness) were joined using lap form of cold pressure welding. The properties of aluminium and copper materials used in the present study are given in Tables 1 and 2, respectively.

Table 1. *The chemical composition and the tensile strength of Aluminium material used in the experiments*

Chemical Composition	% 1.34 Fe, % 0.489 Si, % 0.439 Mg, % 0.913 Zn, % 0.107 Mn, % 0.0249 Cr, % 0.0135 Ti, % 0.005 Sn, % 0.0536 Pb, % 0.0179 Ni, % 0.003 Sb, % 1.12 Cu, % 95.47 Al
Tensile Strength	170 MPa
Surface Roughness	Arithmetical Average (Ra) = 0.30 µm

Table 2. *The chemical composition and the tensile strength of Copper material used in the experiments*

Chemical Composition	% 0.02920 Fe, % 0.00100 Si, % 0.00050 Mg, % 0.00100 Zn, % 0.00050 Mn, % 0.00100 S, % 0.00050 Bi, % 0.00108 Sn, % 0.00287 Pb, % 0.00596 Ni, % 0.00200 Sb, % 0.00230 P, % 0.00050 Al, % 99.95 Cu
Tensile Strength	360 MPa
Surface Roughness	Arithmetical Average (Ra) = 0.30 µm

The aluminium and copper sheets were 10x150 mm specimens and lap welding was applied in a single direction punch as shown in Fig. 2. Pressure needed for the process was applied using the 150 metric ton capacity press system (Figs. 2 and 3).

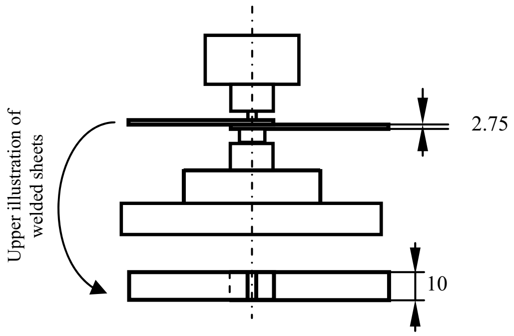


Fig. 2. *Schematic illustration of cold pressure welding*

Fig. 3. *The hydraulic press*

All parts used in the experiments were cleaned using acetone oil and then they were brushed using a wire brush. A 60 mm diameter rotating steel wire-brush was used. Test surfaces were brushed at 510 r.p.m. wire brush rotational speed. The arithmetical average of surface roughness of the sheets prepared was used to determine the effect of surface roughness on weld strength. PRAZIS – RUG-03 surface roughness equipment was used to measure the surface roughness (Fig. 4). Arithmetic average surface roughness was found as Ra = 1, 3, 5 µm.

Fig. 4. *The equipment for surface roughness measurement*

Surfaces prepared were subjected to cold pressure welding shortly after the preparation. The application of welding for 10 minutes affected the weld strength greatly. Increasing the welding time to over 10 minutes caused the weld strength to diminish to a great extent. Extent of deformation was measured by determining reduction (R) over the total thickness of welded parts.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Preparation of the Metal Sheets

Effect of deformation ratio and surface roughness on cold pressure welding of commercial purity aluminium and copper was investigated using deformation ratios of 30%, 45%, 50%, 60% (3.85 mm, 3 mm, 2.75 mm, 2.2 mm, respectively) and an arithmetic average surface roughness Ra = 1, 3, 5 µm. Surface roughness was provided by a revolving brush, and the sheets were wiped with acetone after brushing.

3.2. Tensile Test Results

Cold pressure welding in lap form was applied to wire brushed metal sheets at different deformation ratios. Tensile tests using an INSTRON 8501 dynamic testing machine were applied on the cold pressure welded sheets to determine their weld strengths. Acceptable weld strength was obtained at a surface roughness of Ra = 5 µm and 60% deformation ratio. It was not possible to join the purchased specimens having original surface roughness as-it-is at 30% weld deformation, the lowest extent of deformation used in the present study. Figure 5 shows the variation of weld strength with deformation for different surface roughness values, while Figure 6 shows the variation of weld strength with surface roughness at different extents of deformations.

Acceptable weld strength in the aluminium joints was obtained at 60% deformation ratio and 5 µm surface roughness (Figures 5 and 6). Therefore further experiments to join copper sheets together and to join aluminium sheets to the copper sheets were performed only at 60% deformation ratio and a surface roughness of 5 µm (Figs. 5 and 6).

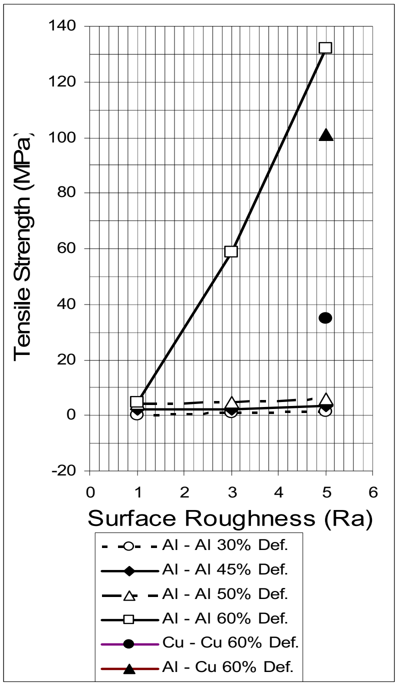


Fig. 5. *Relationship between tensile strength and surface roughness at different weld deformations*

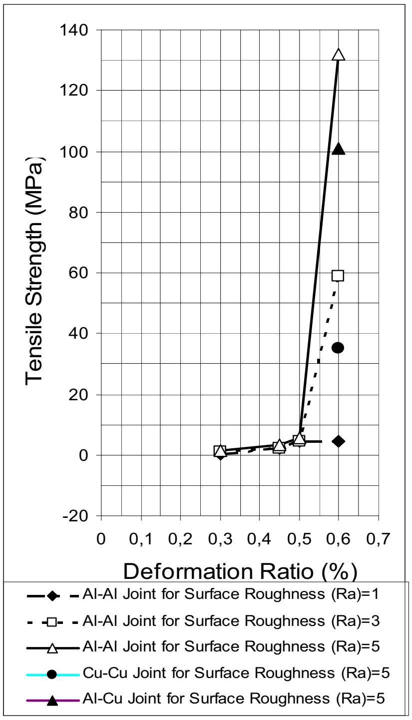


Fig. 6. *Relationship between tensile strength and weld deformation at different surface roughness*

The length of bond zones were found to increase with increasing deformation which further leads weld strength to increase. Weld strength also increases with surface roughness (Figs. 5 and 6).

3.3. Fatigue Test

Fatigue tests of cold-welded aluminium joints were conducted using an INSTRON 8501 hydraulic fatigue machine (Fig. 7). Tests were done at a frequency of 10 Hz Fatigue tests were applied to specimens that had the highest strength, namely to samples having a surface roughness of Ra = 5 µm and joined at 60% weld deformation. Dimensions of the specimens were set according to ASTM E-466 (Fig. 8).

Fig. 7. *INSTRON 8501 hydraulic fatigue machine*

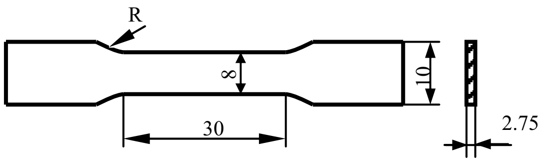


Fig. 8. *Dimensions of the specimens used in fatigue tests*

Welding interfaces were located in midsection of the fatigue specimen. Fatigue tests were conducted superimposing fluctuating tensile loads on a constant tensile load that can produce 40 MPa of tensile stress. When stress value in fatigue tests was increased, sheets joined were ruptured at the interface of the parts.

Fluctuating tensile stress amplitudes were varied between 10 MPa and 20 MPa and numbers of cycles to fracture were recorded. Sheets joined were capable of resisting fluctuating tensile stress (Fig. 9). Observations during fatigue tests showed that ruptures parts are usually detached from the welding interface. Joined sheets could not supply higher strength due to the defects (micro-cracks, inclusions or not fully bonded surfaces etc.) at the interface of the joints.

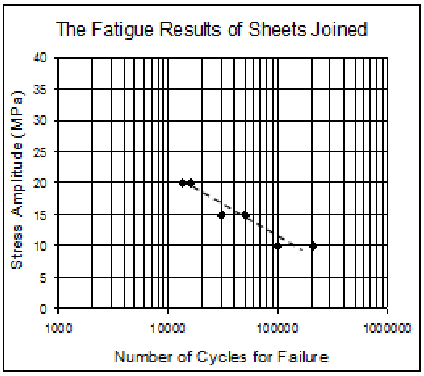


Fig. 9. *The fatigue test results,* σ_{mean} *= 20 MPa*

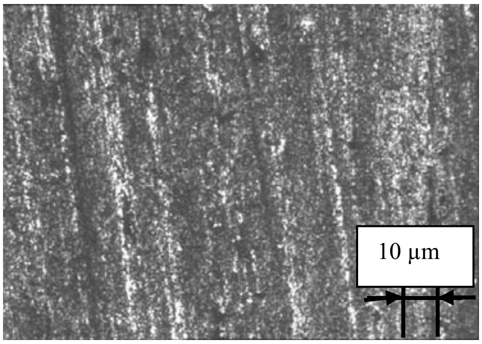


Fig. 11. *Microstructure at interface of joined aluminium parts having Ra = 5µm and 60% deformation*

3.4. Results of Microstructural Examinations

Optical microscopy was used to study the microstructure of the welded interface both for aluminium joints and aluminium to copper joints that have an average surface roughness of Ra = 5 µm and welded at a 60% deformation ratio after etched in picral (Figures 10 to 13).

The vertical scratches owing to brushing are clearly visible on the fragments of the cover layer (Figs. 11 to 13). Scratch-brushing was carried out in longitudinal direction parallel to the direction of deformation. Extended areas of bonding regions and un-bonded regions of the cover layer are confined to isolated regions. Therefore, the bond fracture is ductile and occurs after numerous local necking [3].

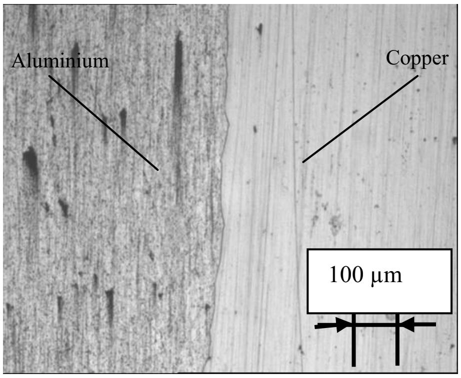


Fig. 12. *Microstructure at interface of welded aluminium to copper parts having Ra = 5µm and 60% deformation*

3.5. EDX Analysis of Joints

Scanning electron microscopy (SEM) and energy dispersive X-ray (EDX) analysis were performed to have an insight into the phases

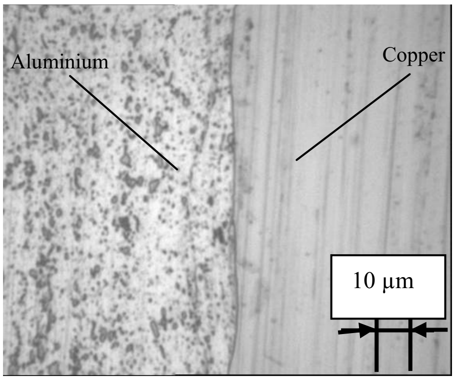


Fig. 13. *Microstructure at interface of welded aluminium to copper parts having Ra = 5µm and 60% deformation*

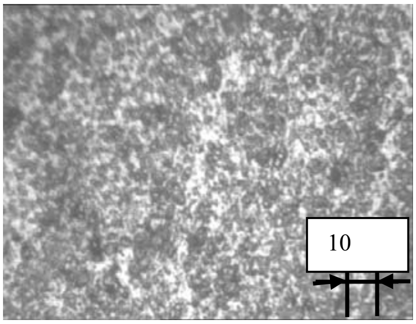


Fig. 10. *Microstructure of aluminium parts*

was utilized by means of software that allows piloting the beam and scanning along a surface or a line to obtain X-ray cartography or concentration profiles by elements, respectively.

Fig. 14 (a) shows EDX analysis points defined on the SEM microstructure at the interface region of the cold pressure welded Al-Al joints. Figure 14 (b) and (c) illustrate the EDX analysis results taken from point 3 of the SEM micrograph of the Al-Al joint and the respective EDS point analysis.

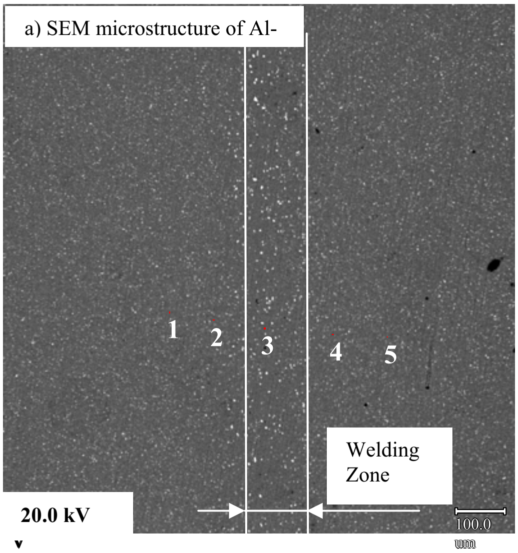


Fig. 14. a) *SEM microstructure of Al-Al joint*

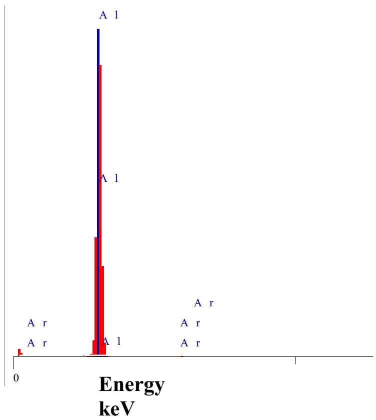


Fig. 14. b) *EDX analysis result taken from point 3 represented to SEM image*

Points	Elements	Line	Intensity (c/s)	Conclusion
1	Al Ar	Kα Kα	1852.48 28.12	96.940 wt. % 3.060 wt. % (100.000 wt. % Total)
2	Al Ar	Kα Kα	1537.79 17.99	97.614 wt. % 2.386 wt. % (100.000 wt. % Total)
3	Al Ar	Kα Kα	1404.12 14.93	97.824 wt. % 2.176 wt. % (100.000 wt. % Total)
4	Al Ar	Kα Kα	1378.65 19.41	97.151 wt. % 2.848 wt. % (100.000 wt. % Total)
5	Al	Kα	1495.16	100.000 wt. % (100.000 wt. % Total)

Fig. 14. c) *EDS point analysis results according to SEM microstructure*

Figure 15 (a) shows EDX analysis of the points defined on the SEM microstructure at the interface region of the cold pressure welded Al-Cu joints. Figures 15 (b), (c) and (d) illustrate the EDX analysis results of point 1 on the Al side, the point 3 on the Cu side of the SEM micrographs. The EDS results confirm that an intermetallic compound layer does not exist in Al-Al, whereas Al-Cu joints have an intermetallic compound such as Cu_3Al, Cu_4Al_3, CuAl and $CuAl_2$ which does not affect joint strength to a great extent [23] to [25]. This is well enough evidence that strong joints can be produced by cold pressure welding method.

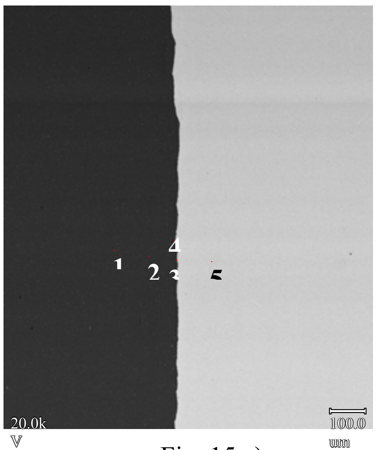
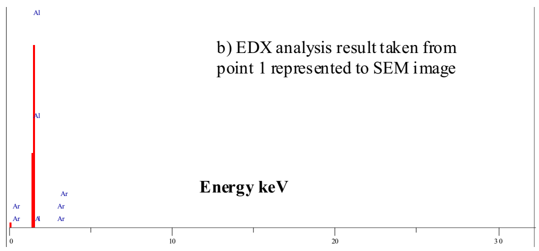
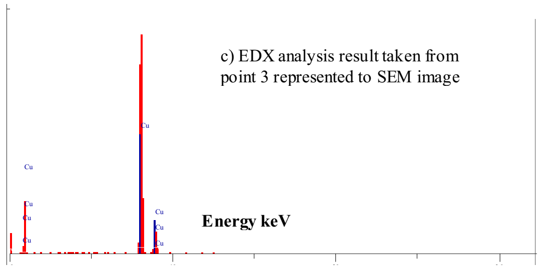


Fig. 15.a)





Points	Elements	Line	Intensity (c/s)	Conclusion
1	Al Ar	Kα Kα	1357.82 12.08	98.170 wt.% 1.830 wt.% (100.000 wt. % Total)
2	Al Ar	Kα Kα	1659.40 20.20	97.522 wt.% 2.478 wt.% (100.000 wt. % Total)
3	Cu	Kα	1134.00	100.000 wt. % (100.000 wt. % Total)
4	Cu	Kα	1188.01	100.000 wt. % (100.000 wt. % Total)
5	Cu	Kα	1205.98	100.000 wt. % (100.000 wt. % Total)

Fig. 15. *SEM microstructure of the cold pressure welded interface region between Al-Cu joints having Ra = 5µm and 60% deformation ratio and EDS analysis results*

3.6. Results of Hardness Examination

Hardness variations at the interface of joined parts were obtained by micro hardness tests under a load of 200 g. Measuring locations are given in Fig. 16. Hardness variations in vertical direction with respect to the weld-centre are shown in Fig. 17.

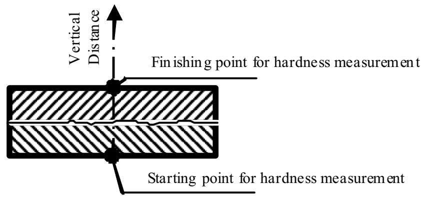


Fig. 16. *Hardness test orientations at cross-section of joined parts*

Hardness values are about the same at the interfaces of the parts having different surface oughness values and deformed at 60%. Hardness of aluminium material purchased is about 53 HV. Hardness of the joined parts is higher due to local hardening which is a result of cold deformation. The effect of the surface roughness on hardness variations is much less than that of the deformation ratio (Fig. 17). A similar result as to the increase in hardness due to local hardening is observed for the Al-Cu joint. Then, ductility is a mechanical property used to describe the extent to which materials can be deformed plastically without fracture. Aluminium is more ductile material than copper. It means that Al can be easily deformed according to Cu. Al sheet is plastically deformed in a greater extend than Cu when overall deformation ratio 60%. As a result, the hardness of a ductile material as aluminium is lower than that of less ductile material as copper [5] and [6].

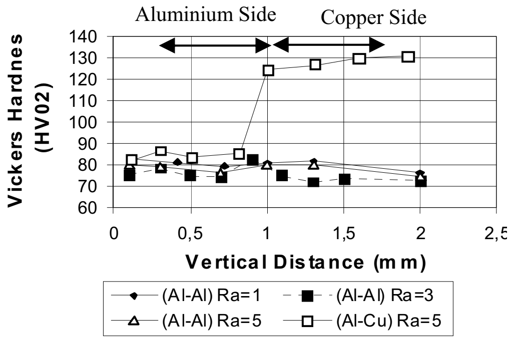


Fig. 17. *Hardness variations along the vertical direction*

3.7. Non-Destructive Evaluation by Radiographic Inspection

Inspection (NDI) is the examination of an object or material with technology that does not affect its future use. NDI can be used without destroying or damaging a product or material. Because it allows inspection without interfering with a product's final use, NDI provides an excellent balance between quality control and cost-effectiveness. NDI can and should be used in any phase of a product's design and manufacturing process, including materials selection, research and development, assembly, quality control and maintenance. Commonly used non-destructive inspection methods include liquid penetrant, magnetic particle, eddy current and radiographic inspection, ultrasonic inspection, tomography, and real-time radiography. Radiographic testing is one of the oldest methods of non-destructive testing and has been in use for approximately five decades. Radiography using X-rays is one of the NDT techniques used for imaging the joints to detect and locate defects. In the present study, Aluminium joints were evaluated by radiographic inspection using RIGAKU 200 kV test equipment. Figure 18 is an example of the radiographic patterns for an aluminium joint produced from sheets having a surface roughness of Ra = 5μm and welded at 60% deformation. As seen from the inspection figure, almost there are no defects in the joints. But, there can be very small weld defects (micro-cracks, inclusions or not fully bonded surfaces etc.) because the joined sheets do not resist against high static and dynamic loads.

Fig. 18. *An example from radiographic patterns used in this work*

3.8. Statistical Analysis of Data

The basis of this approach is the assumption of a simplified linear model for the optimization parameter η given by $\eta = \beta_0+\beta_1 x_1+\beta_2 x_2+\ldots\ldots$, where x_1, x_2... are the factors which η depends on and β_0, β_1, β_2..., etc, represent the 'true' values of the corresponding unknowns. From the results of an experiment comprising a finite number of trials, one can arrive at sample estimates of the coefficients, β, which are then usually fitted into a linear regression equation of the type $y=b_0+b_1x_1+b_2x_2+\ldots$, where y is the response function and the b_s are the "estimated" values of the β_s. In simple terms, each coefficient represents the influence of the corresponding factor on the quality of the tensile strength expressed by the optimization parameter [12] and [13]. Parameter optimization was carried out using factorial design of experiments. In the present study; aluminium specimens obtained by machining was chosen as an example model. Deformation ratio and pre-upsetting surface roughness were chosen as the two factors. Then, the tensile strength data were subjected to statistical analysis to understand the influence of individual effects of the factors. The other parameters were kept constant. Regression equation was obtained from this analysis. Correlation coefficient was also obtained from the statistical analysis. Experimental results are given in Table 3.

Table 3. *Experimental results*

Trial No	Surface Roughness of Parts (Ra-μm) x_1	Deformation Ratio (%) x_2	Tensile Strength of Joined Parts (MPa) y
1	1	0.30	0.192
2	1	0.45	2.021
3	1	0.50	4.362
4	1	0.60	4.590
5	3	0.30	0.974
6	3	0.45	2.267
7	3	0.50	4.650
8	3	0.60	58.700
9	5	0.30	1.527
10	5	0.45	3.410
11	5	0.50	5.810
12	5	0.60	132.100

Optimum estimates of regression coefficients were obtained using the Fisher method ratio. The resulting equation is also given here:

$$y = -94,739 + 8,230 \cdot x_1 + 191,204 \cdot x_2 \qquad (4)$$

The correlation coefficient using Eq. (4) is about 0.70 in respect of tensile strength. Therefore, it is quantitatively shown that the effects of deformation ratia and surface roughness on the tensile strength are very significant, as expected.

4 CONCLUSIONS

- Cold pressure welding of the commercial purity aluminium and copper in lap form was successfully applied to Al-Al and Al-Cu joints.
- As the surface roughness and the weld

deformation ratia of aluminium sheets increased, tensile strength of the joints also increased.
- Purchased specimens with original roughness had the lowest weld deformation as-it-is and it was not possible to join these sheets at 30% weld deformations. However, it was possible to join these specimens at deformation ratios greater than 70 %.
- Micrographs of specimens having a surface roughness of 5 µm and deformed at 60% deformation ratio clearly reveal bond formation at the interface of joined parts.
- Hardness values of joints are about the same at interfaces of sheets having different surface roughness and produced at equal deformation. Hardness results in Al-Cu joints are similar to those of aluminium joints. Hardness increases due to local hardening at the interface as a result of cold deformation.
- Fatigue tests showed that joined sheets resisted against low fluctuating tensile stresses.
- EDX measurements clearly show that Al-Cu joints contain an intermetallic compound layer at the interface which does not affect the joint strength to a great extent.
- Even if radiographic testing showed no defects at the welded joint, there could be very small weld defects since the joined sheets do not resist against high static and dynamic loads.
- Tensile strength of joined parts can be expressed in terms of the process parameters by regression equation obtained by statistical analysis.

5 NOMENCLATURE

X Surface expansion of bonding surface (%)
R Reduction (%)- Deformation Ratio
A_0 Original cross-sectional area (mm)
A Extended area after process (mm)
h_0 Original thickness of sheet (mm)
h Instantaneous thickness at deformation (mm)
R_a Surface roughness (µm)

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Safe Operation of Welded Structure with Cracks at Elevated Temperature

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The fatigue crack growth rate parameters and conditions for abrupt fracture of thick joint in steel at room and operating temperature were analysed. Fatigue cracks generated from sharp weld defects are initial cracks that grow through either the weld joint region or the base metal in accordance with Paris law. Service life of a welded structure depends on position and orientation of the existing sharp weld defect. Different pre-cracked specimens were used in this experimental investigation.

They were cut from the base and weld metals and heat-affected zone. In comparison with the base metal, weld joint region showed higher crack growth rate at operating and room temperatures. Fatigue crack growth rate was higher at operating temperature irrespective of the position. Reliability of structure with initial longitudinal cracks positioned in the heat-affected zone was lower than with initial transversal cracks located in the weld metal.

Keywords: welded structures, fatigue cracks, fracture toughness, proof test

0 INTRODUCTION

Weld defects arise in manufacture of welded structures. During normal operation of such structures, sharp defects in weld joint region act as sites from which fatigue cracks form and then grow. Cracks of critical size jeopardize structural integrity. Due to the complex nature of fusion welding and human factor, the size, location, type, and orientation of defects cannot be predicted. Only a thorough post- manufacture inspection of weld joints provides necessary information about the actual weld defect presence in welded structures.

The most jeopardizing type of sharp weld defects are two-dimensional defects oriented normal to the direction of fluctuating stress. Their direct effects on the strength of weld joints are treated as the effects of cracks (crack-like defects). Fracture mechanics is used to assess the severity of macroscopic two-dimensional defects in relation to design loading. There are some complex features that make thae application of fracture mechanics difficult such as residual stresses, interaction of cracks with weld geometry, material properties variations due to dissimilar weld and base metals and especially microstructural heterogeneities of weld joint region resulting from the welding thermal cycles.

Tensile welding residual stresses appearance and local material embrittlement are fundamental for various cracking phenomena of welds [1]. Interaction of stresses during structure operation and existing cracks often leads to unexpected weld joint fracture. Actually, cracks originating from sharp weld defects grow during service life of welded structures. They have to remain smaller than the critical crack size, otherwise, they will cause weld joint fracture in brittle or quasi-brittle manner. Disintegration of a welded structure is very likely if highly loaded weld joint collapses. A superior resistance of weld joint against the fatigue crack growth is of great importance for longer service lives of welded structures.

The resistance of metallic materials to fatigue crack growth and brittle fracture depends on the microstructure. Properties of the base metal (BM) meet requirements in standards. The weakest links are always weld joints consisting of heat-affected zone (HAZ) and weld metal (WM). Microstructure of both in as-welded condition

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results from chemical composition and welding thermal cycles.

Microstructure and properties of weld joint region can be analysed in details by using samples of materials cut from actual weld joints [2]. Alternative is an analysis performed with samples of materials with simulated microstructure. In this case, thermal conditions during welding have to be simulated either on samples of BM in order to prepare particular HAZ areas [3] or on samples of single-run WM in order to prepare particular multi-run WM areas [4]. Using combination of both, i.e. samples from weld joint and samples with simulated microstructure is an effective approach, too [5].

The experimental results of fracture toughness measurement and fatigue-crack growth rate measurement are shown and discussed in this paper from the leak-before-break concept point of view. Fracture properties of weld joint region and non-affected base metal were determined using the specimens machined from the samples of material cut from a real welded plate.

1 EXPERIMENTALS

1.1. Materials and Specimens

The steel used in this study is A-387 Gr. 11 Class 1 steel designed for operation at elevated temperatures. Its chemical composition and basic mechanical properties at room temperature are shown in Table 1 [6]. A 96 mm thick double-U shaped welded test coupon was available for the research. Root passes were deposited by metal manual arc welding (MMA) with coated electrode LINCOLN Sl 19G (AWS: E8018-B2), the rest of the weld-groove was filled at both sides by submerged arc welding (SAW) with wire LINCOLN LNS 150 and flux LINCOLN P230. Chemical compositions of both consumables are shown in Table 2. Basic mechanical properties for all-weld metals at room temperature are shown in Table 3 [6]. The WM is stronger than BM (overmatching).

Welding technology specification was prepared according to standard EN 288-3 [7]. Operating temperature is not specified in this standard. It is not required to test the behaviour of the weld joints at the operating temperature.

Weld joint with sharp initial weld defects in the WM and HAZ areas was evaluated in respect of the structure safe operation. The specimens for the fracture toughness assessment and fatigue crack growth rate measurement were machined from the welded test coupon as shown in Figure 1.

Three-point bend specimens (TPB) were used for fracture toughness testing at room temperature. Their shape and dimensions are shown in Figure 2. Due to specific design of the high-temperature chamber, the specimens looked like compact tensile specimens (CT) used for fracture toughness testing at operating temperature. Their shape and dimensions are also shown in Figure 2.

Table 1. *Chemical composition and basic mechanical properties of the steel*

C	Si	Mn	P	S	Cr	Mo	Yield stress	Tensile strength	Elongation	Impact energy
Mass. %							MPa		%	J
0.15	0.29	0.54	0.022	0.011	0.93	0.47	325	495	35	165

Table 2. *Chemical composition of filler metals*

Filler metal	C	Si	Mn	P	S	Cr	Mo
	Mass %						
LINCOLN Sl 19G	0.08	0.045	0.35	0.025	0.025	1.10	0.50
LINCOLN LNS 150	0.11	0.18	0.37	0.020	0.020	1.04	0.47

Table 3. *Mechanical properties of all-weld metals*

Filler metal	Yield stress	Tensile strength	Elongation	Impact energy
	MPa		%	J
LINCOLN Sl 19G	505	640	23	> 95
LINCOLN LNS 150	490	610	26	> 100

Bending specimens (B) were used for fatigue-crack growth-rate measurement. Their dimensions were 10×10×55 mm. The type of all specimens, their position, and orientation in the test coupon in relation to the weld axis is clearly indicated in Figure 1. The notches and cracks were located in the BM, WM and HAZ.

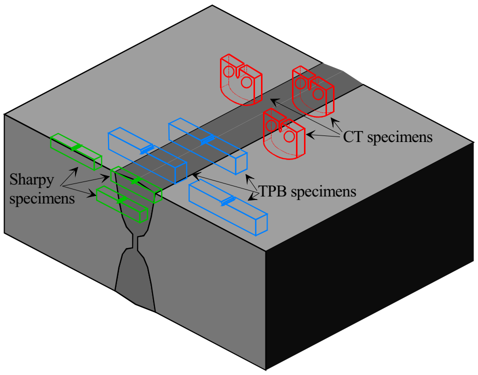

Fig. 1. *View of the welded test coupon with specimens sampling*

The values of J-integral were calculated from registered dependence of force versus load-point displacement just when unloading sequence started. The diagrams J – Δa were plotted using those values and corresponding crack increments. At first, a regression line was drawn in the linear section of each J – Δa diagram. J_{Ic}-value, critical J-integral, was obtained with intersecting J – Δa diagram and a parallel line to regression line. This line intersects x-axis at Δa = 0.15 mm. The diagrams J – Δa at room and operating temperature valid for the BM are shown in Figs. 3b and 4b, the diagrams valid for the WM in Figs. 5b and 6b, whereas the diagrams valid for the HAZ in Figs. 7b and 8b. Average values of determined J_{Ic}-values extracted from those diagrams are listed in Table 4 [10].

2 RESULTS

2.1. Fracture toughness

Fracture toughness was experimentally determined according to the standards [8] and [9]. Single-specimen method was used. Three specimens were notched and precracked in the BM, three in the WM and three in the HAZ. The specimens were loaded and successively partly unloaded at room temperature and at 540°C. The registered slope between force, F, and crack mouth opening displacement, δ (CMOD), in the course of specimen unloading enabled determination of the crack size, a, and every crack increment, Δa, respectively. The examples of diagrams F – δ plotted at room and operating temperature valid for the BM are shown in Figs. 3a and 4a, diagrams valid for the WM in Figs. 5a and 6a, whereas diagrams valid for the HAZ in Figs. 7a and 8a.

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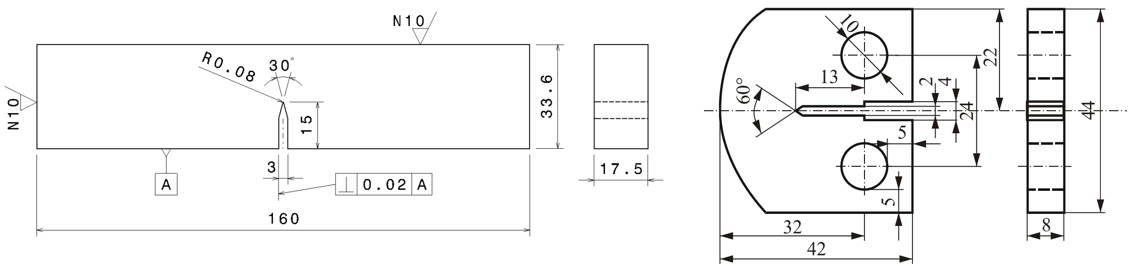


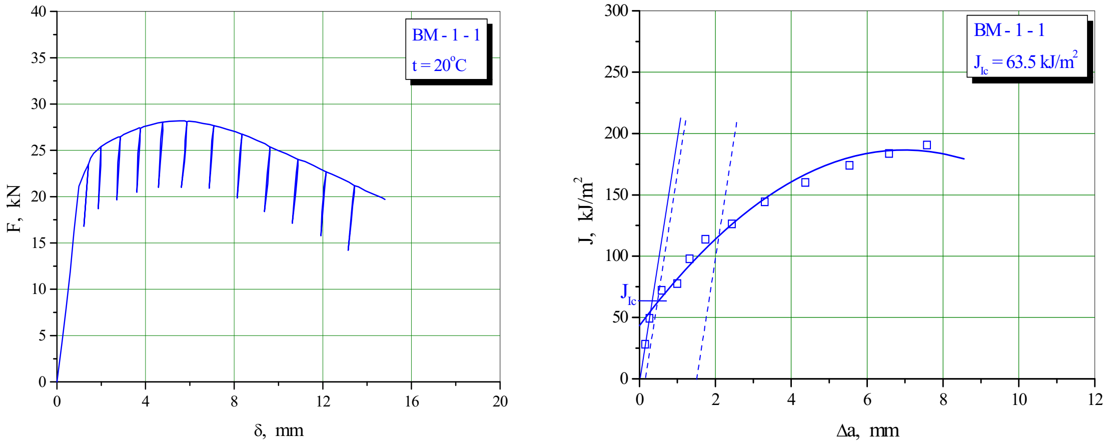
Fig. 2. *Fracture toughness specimens (TPB specimens above and "CT" specimens below)*

Average values of determined J_{Ic}-values extracted from those diagrams are listed in Table 4 [10].

In respect of fracture toughness the highest quality area of treated weld joint is WM whereas the lowest HAZ. Testing temperature does not change this fact.

Table 4. *Fracture toughness, J_{Ic}, plane-strain fracture toughness, K_{Ic}, threshold stress-intensity range and parameters of fatigue crack growth rate C and m*

Area	T, °C	J_{Ic}, kJ/m^2	K_{Ic}, MPa m$^{1/2}$	ΔK_{th}, MPa m$^{1/2}$	C, nm/cycle	m
BM	20	63.5	120.9	6.8	$4 \cdot 10^{-3}$	2.1
WM		81.3	133.7	6.8	$8 \cdot 10^{-4}$	2.8
HAZ		51.7	106.6	6.7	$2 \cdot 10^{-4}$	3,5
BM	540	43.4	88.4	5.9	$1 \cdot 10^{-3}$	3.0
WM		57.2	101.6	6.2	$5 \cdot 10^{-4}$	3.5
HAZ		38,9	83.7	6.1	$3 \cdot 10^{-4}$	3.9



a) b)

Fig. 3. *Diagrams F – δ and J – Δa for the BM at room temperature*

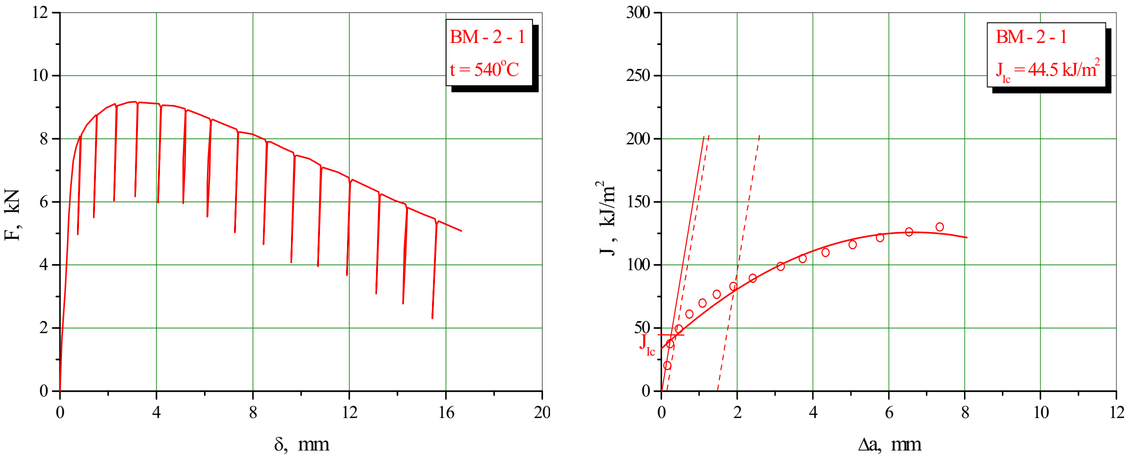


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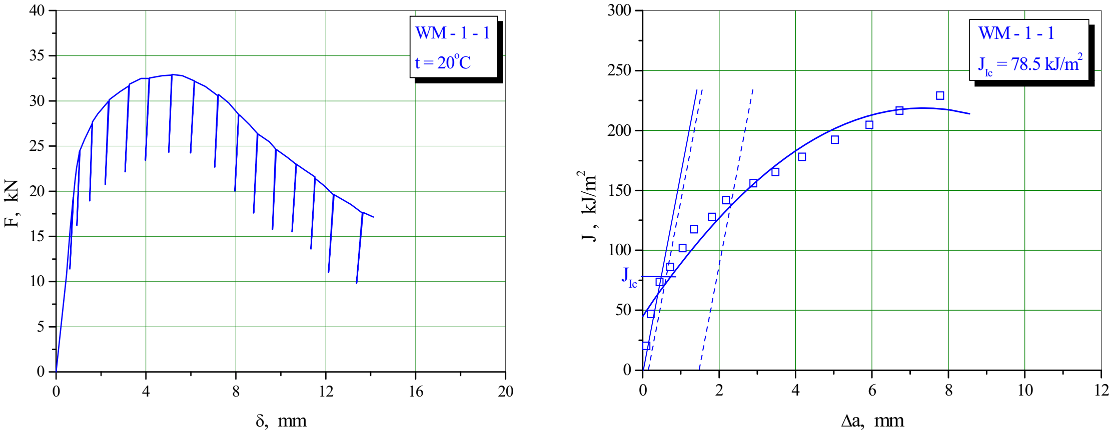
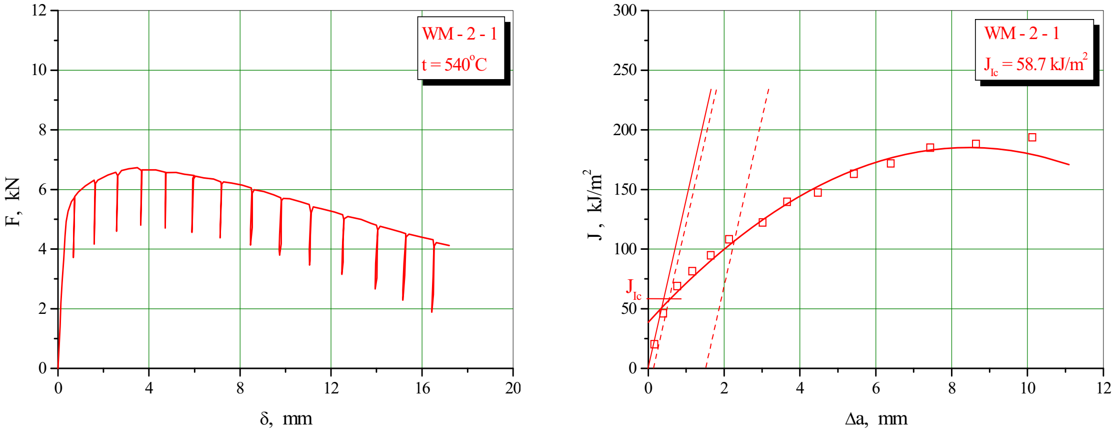
Fig. 4. *Diagrams F – δ and J – Δa for the BM at operating temperature*



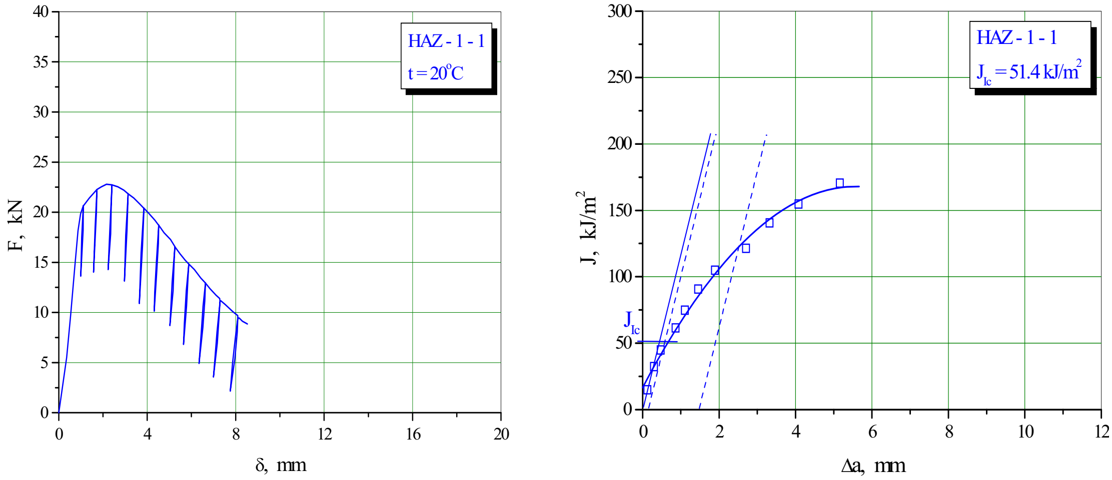
a) b)

Fig. 5. *Diagrams F – δ and J – Δa for the WM at room temperature*



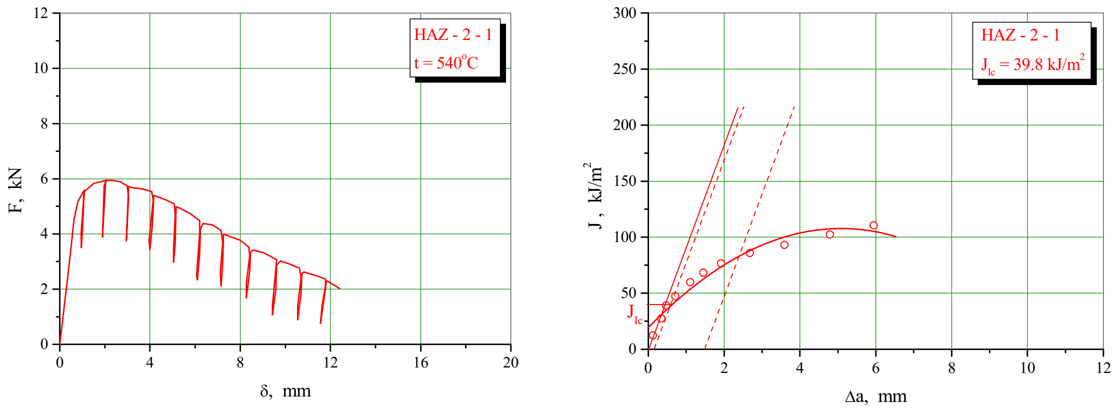
a b

Fig. 6. *Diagrams F – δ (a) and J – Δa (b) for the WM at operating temperature*



a b

Fig. 7. *Diagrams F – δ (a) and J – Δa (b) for the HAZ at room temperature*



a b

Fig. 8. *Diagrams F – δ (a) and J – Δa (b) for the HAZ at operating temperature*

2.2. Fatigue-crack growth-rate parameters

Fatigue-crack growth-rate parameters were experimentally determined according to the standard ASTM E 647 [11]. Charpy-size specimens were notched to a depth of 2 mm in the WM and HAZ areas and in the BM. They were bend-loaded in moment control at room temperature and at 540°C on a high-frequency resonant pulsator. Resistant foil-gauges were attached on the specimens in order to register crack size changes during oscillating loading (see Figure 9). In the course of successive small crack increments, the stress-intensity factor range, ΔK, was kept constant. Simultaneous corrections of loading moment were performed during fatigue crack growth. Fatigue crack growth rate, da/dN, was calculated as a quotient of crack increment, Δa, and number of cycles, N.

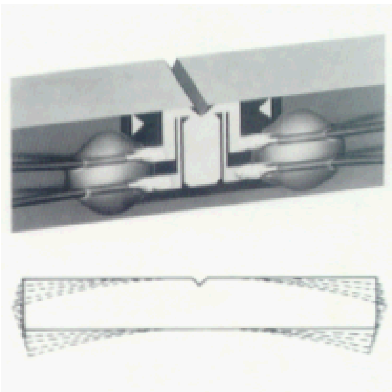


Fig. 9. *Specimen with firmly cemented crack size gauge with indicated bend-loading*

The fatigue crack growth rate rapidly decreased when ΔK when approaching the threshold stress-intensity factor range, ΔK_{th}. On the other side, when ΔK came up to K_c-value fatigue crack grew faster.

Experimental diagrams da/dN - ΔK represented in double-logarithmic scale at room temperature valid for the BM, WM, and HAZ are shown in Figure 10a and those at operating temperature in Figure 10b.

The linear portion of relationship between the fatigue crack growth rate and stress-intensity factor range is known as Paris law [12]:

$$\frac{da}{dN} = C \cdot (\Delta K)^m \qquad (1)$$

where constants C and m are material-dependent.

Fatigue-crack growth-rate parameters extracted from diagrams are listed in Table 4 [13].

3 EVALUATION OF TEST RESULTS

If mechanical properties are available, plane-strain fracture toughness, K_{Ic}, is indirectly determined from the J_{Ic}-values. The following expression is used:

$$K_{Ic} = \sqrt{\frac{J_{Ic} \cdot E}{1 - \nu^2}} \qquad (2)$$

where E is Young's modulus and ν Poisson's number.

Estimated value of E at temperature of 540°C is 82% of the same value at room temperature [14]. We took the same value of ν at room temperature and 540°C for the calculation of K_{Ic}-values given in Table 4.

Variations of K_{Ic} in the weld joint region in comparison with BM are extremely significant. Critical crack size, a_c, when weld joint fractures at a fixed stress level is strongly K_{Ic} dependent. By applying formula

$$K_{Ic} = \sigma \cdot Y(a)\sqrt{\pi \cdot a_c} \qquad (3)$$

Critical crack size is calculated as

$$a_c = \frac{1}{\pi} \cdot \left(\frac{K_{Ic}}{\sigma \cdot Y(a)} \right)^2 \qquad (4)$$

where Y(a) is shape factor and σ stress normal to the crack plane.

When fatigue crack grows in accordance with Paris law, stress-intensity factor range is greater than the threshold stress-intensity factor range, ΔK_{th}.

If the fatigue crack growth rate parameters C and m are available, the number of cycles to fracture, N, will be determined using Equation 1. The following expression has to be solved:

$$\int_{a_i}^{a_f} \frac{da}{Y(a) \cdot a^{\frac{m}{2}}} = C \cdot \pi^{\frac{m}{2}} \cdot (\sigma)^m \cdot \int_0^N dN \qquad (5)$$

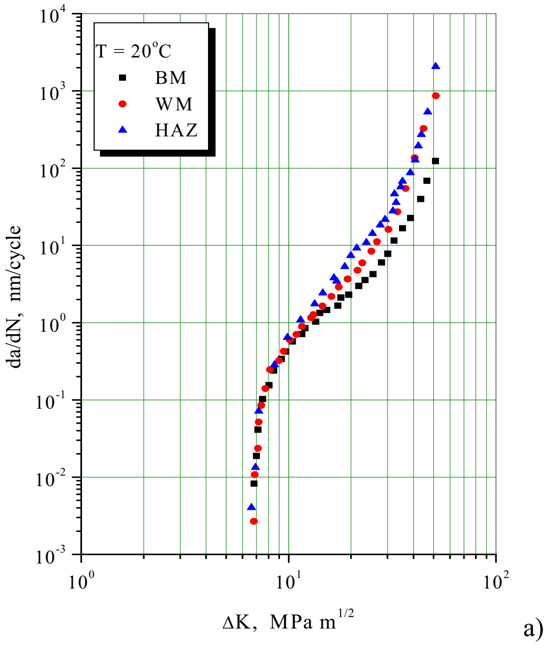
where a_i and a_f are initial and final crack size, respectively.

Shape factor of an infinite 96-mm thick wall with different types and sizes of cracks are [15]:

- Small half-elliptic surface crack with length-to-depth ratio 2.42 (Figure 11a): Y = 0.734
- Half-elliptic surface crack with length-to-depth ratio 2.83 penetrating half of the wall-thickness (Figure 11b): Y = 0.86
- Half-elliptic surface crack with length-to-depth ratio 4.2 approaching opposite wall surface (Figure 11c): Y = 1.234
- Through-thickness crack (Figure 11d): Y=1.

4 DISCUSSION WITH CONCLUSION

If during cyclic loading an existing crack, previously generated from a sharp weld defect, had grown to the size when anywhere along the crack contour stress-intensity factor attains plane strain fracture toughness, K_{Ic}-value, an abrupt fracture of weld joint would occur. This size is defined as the critical crack size. If size of fatigue crack attains the critical crack size, weld joint will fracture. The result can be a catastrophic disintegration of the whole structure.



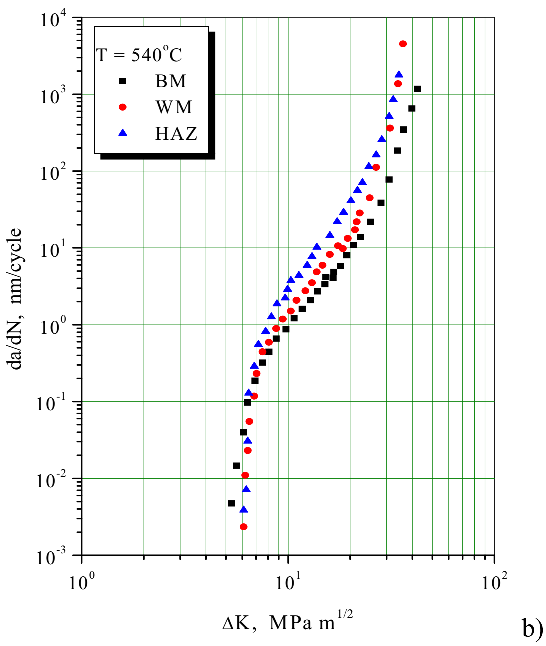


Fig. 10. *Diagrams da/dN - ΔK for the BM, WM, and HAZ at room temperature (a) and at 540°C (b)*

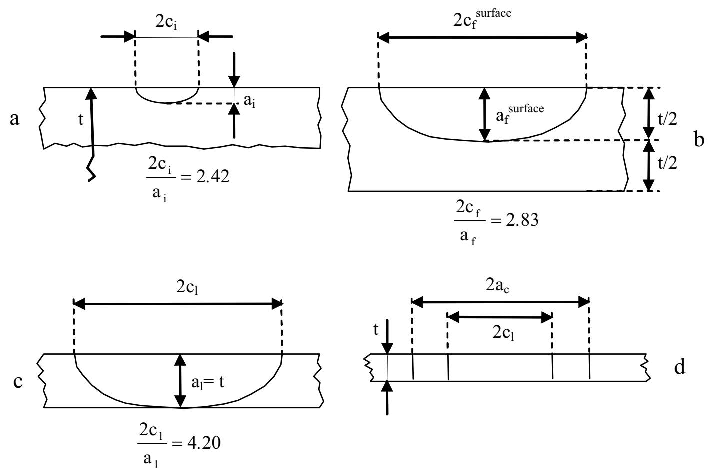


Fig. 11. *Four types of fatigue cracks: small initial half-elliptic surface crack a_i (a), final half-elliptic surface crack a_f (b), wall-penetrating crack when leakage starts a_l (c), critical and non-critical through-thickness cracks a_c, c_l (d)*

Assume that initial inner surface crack in the weld joint area is already a long crack. For the linear-elastic treatment, the depth of this crack, a_0, has to be much greater than the plastic zone size, r_y (Figure 11a).

$$a_i \geq 50 \cdot r_y \qquad (6)$$

Plastic zone ahead of the crack tip develops as the result of interaction between a crack and stress. Its size depends on the stress-intensity factor, K, material yield stress, R_p, and stress-field configuration.

$$r_y = \left(\frac{K}{R_p}\right)^2 \cdot \begin{cases} \dfrac{1}{2\pi} & \text{plane stress condition} \\ \dfrac{1}{6\pi} & \text{plane strain condition} \end{cases} \qquad (7)$$

Operating stress of the structure does not exceed 100 MPa. Inner surface crack 5 mm-deep fulfils the condition in Equation 6. Cracks of this size were found in the structure during regular in-service inspections. Therefore, those cracks grow in accordance with Paris law. Proof pressure test performed after in-service inspections led to the stress 100% higher than maximum operating stress.

It is great advantage to operate a pressure-plant designed based on leak-before-break. Fatigue-crack penetration through the wall can be manifested either by loss of pressure or by leakage. Thanks to those obvious indications, an operator is capable to prevent final fracture of the plant by shutting it down. Abrupt fracture of pressurized component could be jeopardizing for human lives and environment. Besides, a plant designed in accordance with leak-before-break concept allows periodical repairs or replacement of the damaged component.

The procedure is as follows:

1) Calculation of the through-thickness crack size which results in fracture, $a_c^{through}$ (subscript c denotes critical size for fracture).
2) Calculation of the depth of surface crack in an infinite thick wall which results in fracture, $a_c^{surface}$ infinite 96-mm thick wall
3) Comparison of the $a_c^{surface}$ with the wall thickness t. If $a_c^{surface}$ < t, crack will not penetrate the wall in a stable manner before fracture.
4) If $a_c^{surface}$ > t, the crack will penetrate the wall. Depth of crack approaching the opposite surface of the wall, a_l, is t, whereas its length $2c_l = 4.2 \times a_l$ (subscript l denotes the size for leakage to start).
5) The crack penetrating the wall grows further and becomes a through-thickness crack of length $2a = 2c_l^{surface}$.
6) If the critical crack size $a_c^{through} >> c_c^{surface}$, there is enough time to notice pressure loss or leakage.

Calculated size of part-through and through-thickness critical cracks in BM, WM, and HAZ are listed in Table 5. Sizes $a_c^{surface}$ are greater than wall thickness (t = 96 mm). Crack would certainly penetrate the wall before final fracture.

When crack would approach the opposite wall surface, its half-length on the inner surface would be c_l = 202 mm. This is not much less than critical through-thickness crack size under normal operating condition in the BM (249 mm) and especially in the HAZ (223 mm). Without any doubt, weld joint properties of this plant satisfy the leak-before-break concept, but its operating safety factor is a bit questionable.

Calculated critical sizes of the through-thickness crack in proof-test condition are listed in Table 5. They are much smaller than the half-length of the crack penetrating the wall. The possibility that the existing deep crack cannot be detected during in-service inspection after which proof-test should be performed may not be neglected. Crack size $a_c^{through}$ in proof-test condition could be crucial for further safe operation of the plant.

For higher reliability, it is beneficial to limit maximum allowable crack size rigorously, for instance, let the crack size be only one-half of the wall-thickness. Stress-intensity factor which is the result of this crack at proof stress is K = 67 MPa. This level of stress-intensity is lower than the plane-strain fracture toughness of BM, WM, and even HAZ. If during in-service inspections a careful effort were made to find all cracks on inner surface, safe operation of plant would be guaranteed.

Which cracks are more dangerous in the weld joint region - longitudinal cracks in the HAZ or transversal cracks in the WM? These cracks are often the result of hydrogen attack on hard areas of weld joints.

In terms of experimental data listed in Table 4, the cracks in the HAZ will grow faster than the cracks in the WM. Initial cracks in the HAZ could grow all the time through the material with the worst properties. Initial cracks in the WM grow at first in the WM, then go across HAZ, and continue outside the weld joint in the BM which properties are superior. Comparison of the number of cycles for an initial 5 mm-deep crack to grow to 50% of the final crack size (a = 24 mm) at room and operating temperatures is shown in Table 6. The basis is necessary number of cycles for crack growth in the HAZ at operating temperature.

Table 5. *Critical sizes of part-thickness and through-thickness cracks in normal operating and proof test conditions*

Area	T, °C	$a_c^{surface}$	c_l	$a_c^{through}$	$a_c^{through}$
		operating condition			proof-test condition
		mm			mm
BM	20	864	202	465	116
WM		1056	202	569	142
HAZ		671	202	362	90
BM	540	462	202	249	62
WM		610	202	329	82
HAZ		414	202	223	56

Table 6. *Time needed for the crack growth to half of the final crack size at operating temperature in relation to the time for growth in the weakest area of the weld joint region, i.e. HAZ*

Area	T, °C	N/N_0 operating condition
BM	20	51.8
WM		8.8
HAZ		4.5
BM	540	3.8
WM		1.8
HAZ		1

Quotients N/N_0 listed in Table 6 are additional safety factors for the safe structure operation. The most dangerous situation is the presence of longitudinal cracks in the HAZ, which grow through the HAZ under cyclic loading at temperature of 540°C.

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Strojniški vestnik - Journal of Mechanical Engineering 54(2008)11, SI 129
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Sprejeto: 25.09.2008

Razvoj izdelka s pomočjo večkriterijske analize

Tomaž Kostanjevec[1], Andrej Polajnar[1], Andrej Sarjaš[2]
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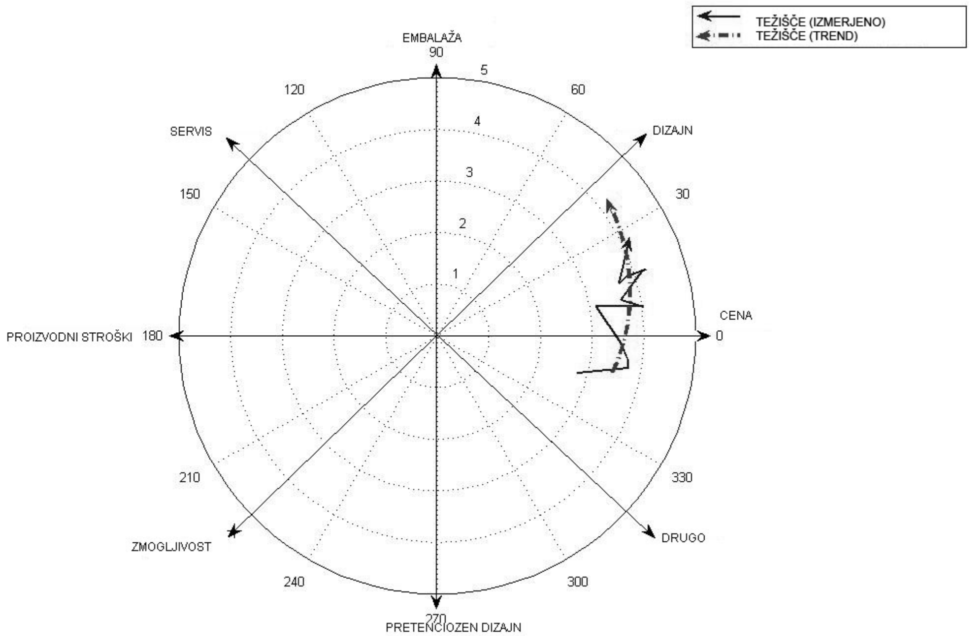
Pri razvoju sanitarnih armatur poskušamo z uporabo razvitega modela v večkriterijski analizi napovedati trend razvoja. V večkriterijski analizi pa uporabimo tudi večrazsežni prostor, ki nam omogoča določanje časovnega argumenta v primerjavi s parametri izdelka. V določanju parametrov izdelka sodelujeta podjetje z notranjimi informacijami in tržišče s svojimi zahtevami. V tem pogledu je mogoče vzpostaviti inovativno okolje v razvoju novih izdelkov.

Ta prispevek navaja različne pristope k razvoju izdelkov, na osnovi katerih je razvita metoda večkriterijske analize za ugotavljanje bodočega trenda razvoja izdelka.

Ključne besede: sanitarni izdelki, razvoj izdelkov, večkriterialne analize, večrazsežni prostor



Slika 7. *Polarni graf gibanja težišča v opazovanih letih*

*Naslov odgovornega avtorja: Univerza v Mariboru, Fakulteta elektrotehniko, računalništvo in informatiko Smetanova 17, Maribor, Slovenija, tomaz.kostanjevec@uni-mb.si

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)11, SI 130 Prejeto:04.09.2008
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Optimiranje postopka obdelave z na koloniji temelječo kooperativno iskalno tehniko

Uroš Županl - Franci Čuš
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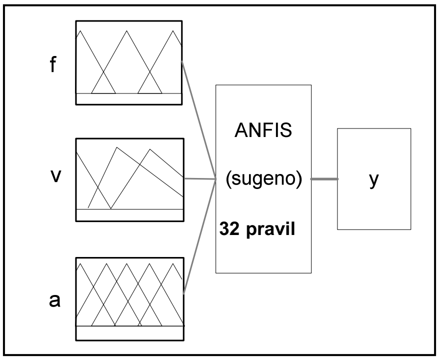
Preučevanje ekonomike pri opravilih obdelave z večimi prehodi ima pomembno praktično pomembnost. Ne-tradicionalne optimizacijske tehnike kot so genetski algoritmi, nevronske mreže in PSO optimizacija so vsepogosteje uporabljene pri reševanju optimizacijskih problemov. V prispevku je predstavljena več-ciljna optimizacijska tehnika, ki temelji na algoritmu kolonije mravelj (ACO) in je uporabljena pri optimiranju rezalnih parametrov pri postopkih struženja. S tehniko se simultano optimirajo naslednji trije nasprotujoči si ciljni dejavniki: stroški opravila, čas obdelave in kakovost površine. Za ciljno funkcijo je uporabljena funkcija, ki maksimira dobiček opravila. Predlagan pristop uporabi prilagodni nevro-mehki inferenčni sistem (ANFIS) za predstavitev ciljne funkcije proizvajalca in algoritem kolonije mravelj (ACO) za določitev optimalnih ciljnih vrednosti. Nova razvojna tehnika ACO je podrobno predstavljena. Razvit je obsežen uporabniku prijazen programski paket za določevanje optimalnih rezalnih parametrov z uporabo predlaganega algoritma. Na primeru je prikazana uporabnost sistema in njegova učinkovitost. Rezultate smo primerjali in analizirali z metodami drugih raziskovalcev in priporočili v katalogih. Rezultati nakazujejo, da je predlagana paradigma kolonije mravelj učinkovita v primerjavi s tehnikami drugih raziskovalcev.

Ključne besede: odrezavanje, struženje, optimiranje, rezalni parametri



Slika 2. Arhitektura mehkih pravil trikotne pripadnostne funkcije

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Uporaba tehnologije radiofrekvenčne identifikacije v sistemih za demontažo

Gordana Ostojić[1,*] - Milovan Lazarević[1] - Stevan Stankovski[1] - Ilija Ćosić[1] - Zoran Radosavljavić[2]
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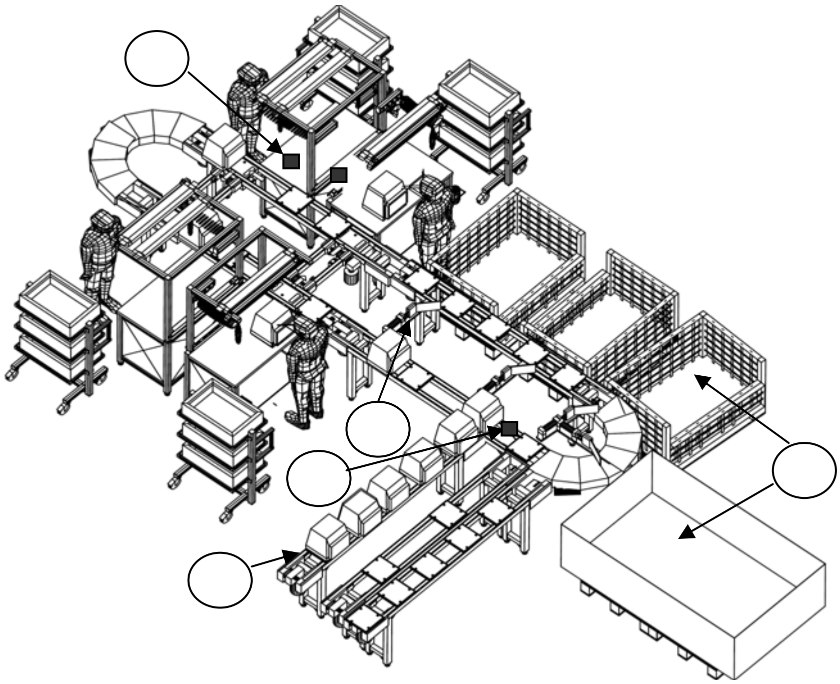
V prispevku so predstavljeni rezultati razvoja modela uporabe tehnologije adiofrekvenčne identifikacije v sistemih za demontažo kot rešitev za problem sprejema velike količine različnih izdelkov na odlagališče odpadkov. Osnovne komponente morajo biti v postopku razstavljanja in odstranjevanja usmerjene v sisteme za demontažo, kjer se opravita predelava za ponovno obdelavo in recikliranje. Sestavni del navodila OEEO (odpadna električna in elektronska oprema) je tudi strategija sprejemanja odpadnih izdelkov, ki podpira kar najbolj učinkovito recikliranje. Sistemski postopki kot je demontaža omogočajo selektivno ločevanje komponent, ki so obnovljive, jih ni mogoče reciklirati in so nevarne, od tistih, ki jih je mogoče reciklirati. Pravilno načrtovan postopek demontaže lahko skupaj z recikliranjem in odstranjevanjem odpadkov pomaga pri učinkovitem upravljanju z dobo trajanja izdelkov. Za doseganje ciljev so potrebne ustrezne strategije. Ob koncu dobe trajanja je nujno zbiranje podatkov o tokovih izdelkov, materialov, delov/sestavov in nevarnih komponent/materialov. Uporaba tehnologij RFID (radiofrekvenčna identifikacija) omogoča izboljšanje upravljanje z vsemi prej omenjenimi tokovi. Tako zbrane informacije so zanesljive, natančne in dinamične, zato lahko zagotavljajo optimalno upravljanje z izdelki, ki so na koncu dobe trajanja.

Ključne besede: tehnologija radiofrekvenčne identifikacije, konec dobe trajanja, demontažni sistemi



Slika 3. *Tehnologija radiofrekvenčne identifikacije, uporabljena v postopku demontaže in izbor demontiranih delov izdelkov*

*Naslov odgovornega avtorja: Univerza v Novem Sadu, Fakulteta tehniških znanosti, Trg Dositeja Obradovića 6, Novi Sad, Srbija, goca@uns.ns.ac.yu

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Sprejeto: 25.09.2008

Prilagodljivost in zapletenost učinkovitih podjetij

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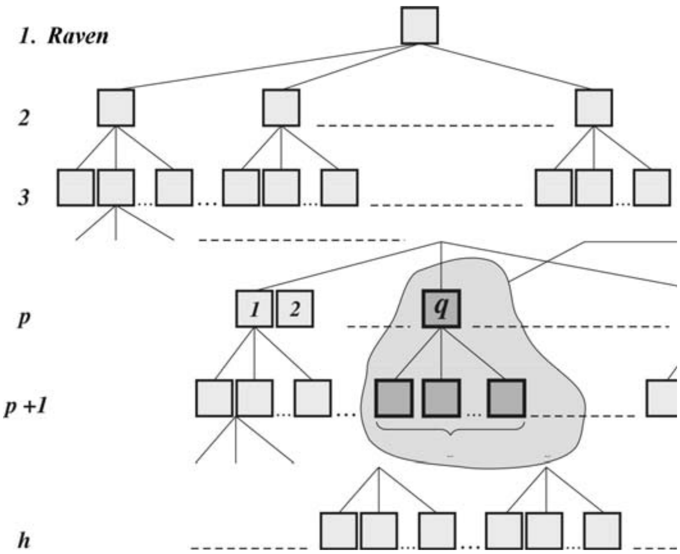
Cilj raziskave je bil dati prispevek prizadevanjem za razvoj postopkov snovanja strukture industrijskih sistemov – visokoučinkovitih podjetij. V spisu so analizirani pogoji in možnosti, ki tem strukturam omogočajo prilagajanje spremembam v okolju – prilagodljivost in ustreznost upravljanja organizacijskih struktur – z zmanjševanjem stopnje zapletenosti. Poseben poudarek je posvečen masovnemu prilagajanju po meri, torej prilagajanju proizvodnje potrebam in zahtevam kupcev. Za to je nujna visoka prilagodljivost sistema, saj prav ta določa stroške pri tovrstni proizvodnji.

Izvirni prispevek tega članka so definicije in določitve meril za dve najpomembnejši lastnosti podjetja, zapletenost in prilagodljivost, ter ugotavljanje njunih medsebojnih odvisnosti. Medtem ko se v literaturi zapletenost meri z velikostjo (številom strukturnih elementov), je stopnja zapletenosti v tem spisu obravnavana tudi kot število medsebojnih razmerij med elementi strukture. Prilagodljivost struktur podjetja vključuje tri medsebojno odvisne komponente: tehnološko komponento, sposobnost in prilagodljivost tokov.

Ključne besede: proizvodni sistemi, strukture podjetij, prilagodljivost, zapletenost



Slika 7. *Določitev števila povezav v strukturi*

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UDK 658.512 Sprejeto: 25.09.2008

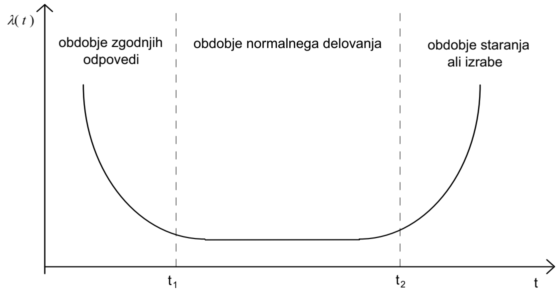
Zanesljivost ter učinkovitost razpoznavnih sistemov in Supply Chain Management[1]

Robert Brumnik - Zvone Balantič
Univerza v Mariboru, Fakulteta za organizacijske vede

V proizvodno-logističnih procesih se mnogokrat pojavijo zahteve po identifikaciji nosilnikov postopkov opravilnih dejavnosti (reklamacije, presoje postopkov, izvedeni preventivno-popravni ukrepi zaradi neskladnosti). Odgovorni nosilci teh dejavnosti so običajno ljudje, ki lahko svojo identiteto dokazujejo na različne načine (lastnoročni podpis, PIN kode, čipne kartice[2], biometrična razpoznava, kamere..).Ob tem pa se moramo v postopku omejiti na postopke zbiranja informacij, ki niso sporni s stališča človeške celovitosti in zaupnosti.

Zaradi neprestane optimizacije ter avtomatizacije postopkov, je trend uvedbe "enostavnih identifikacijskih sistemo" v proizvodno-logistične postopke vedno večji. Biometrija omogoča hitro ter enostavno izvedbo postopka osebne razpoznave v logističnem postopku na osnovi značilk[3], brez potrebnih dodatnih razpoznavnih elementov. Seveda pa je potrebno raziskati parametre zanesljivosti in učinkovitosti, v izogib nepredvidenim učinkom pri uvedbi obravnavanih tehnologij.

Ključne besede: proizvodni postopki, logistični postopki (RDIF[4]), sistemi ugotavljanja, avtomatizacija, zanesljivost, učinkovitost, biometrija



Slika 2. *Krivulja "kopalne kadi"*

[1] Supply Chain Management; Logistična veriga, ki zajema planiranje, uporabo ter nadzor vseh logističnih postopkov v podjetju ter pri dobaviteljih in kupcih. V osnovi se ti procesi nanašajo na oskrbo, proizvodnjo, razdelitev in vračanje ostankov in odpadkov.

[2] Čipne kartice (Pametne kartice, brezstične kartice - ICC ali RFID kartice); so plastične kartice žepne velikosti, z vgrajeno anteno in čipom za obdelavo podatkov. ICC kartice v splošnem delimo na dve kategoriji. Spominske kartice so lahko z vgrajenim breznapetostnim pomnilnikom in varnostno logiko. Mikroprocesorske kartice vsebujejo spominsko in mikroprocesorsko enoto.

[3] Značilke; elementi, na osnovi katerih lahko enolično prepoznamo človeka (prstni odtis, roženica, šarenica, DNK.).

[4] RFID identifikacija je avtomatska prepoznavna metoda , ki temelji na in brezkontaktni daljinski obdelavi podatkov, ki so shranjeni na RFID prepoznavku (tag). RFID prepoznavnik lahko vsadimo/namestimo v/na ljudi, živali ali ga namestimo na izdelek kjer nam služi za prepoznavo na osnovi radijskih valov. Nekatere RFID prepoznavke lahko preberemo z razdalje nekaj metrov, možnost branja pa je tudi iz za čelne črte RFID čitalca. Večina RFID prepoznavkov so sestavljeni iz dveh delov; integrirane enote za shranjevanje ter obdelavo podatkov in enote za modulacijo in demodulacijo RF signala .

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UDK 621.791.1

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Sprejeto: 25.09.2008

Mehanske in metalurške lastnosti aluminijeve in bakrene pločevine, spojene po postopku hladnega varjenja s pritiskom

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Hladno varjenje s pritiskom je poseben postopek varjenja, ki se zadnja leta vse bolj uporablja pri izvedbah kot je montaža raznih delov. V predstavljeni raziskavi je bil uporabljen postopek hladnega varjenja s pritiskom za izdelavo prekrovnega spoja aluminijeve in bakrene pločevine tržne čistoče v 150-tonski hidravlični stiskalnici. S povečevanjem površinske hrapavosti in deformacije zvarnih spojev aluminijeve pločevine se je povečala tudi natezna trdnost spojev. Kupljeni vzorci z izvirno hrapavostjo so imeli najmanjšo deformacijo zvarnega spoja in teh pločevin ni bilo mogoče spajati pri 30-odstotni deformaciji zvara. Utrujenostni preizkusi so pokazali, da so spojene pločevine odporne proti nateznim napetostim z majhno spremembo. Trdota se poveča zaradi lokalnega utrjevanja na stiku, ki je posledica hladnega deformiranja. Meritve EDX (energijsko disperzna rentgenska spektroskopija) jasno kažejo, da vsebujejo spoji Al-Cu na stiku plast spojine, ki pa ne vpliva v večji meri na trdnost spoja. Rezultati kažejo, da daje tehnika hladnega prekrovnega varjenja s pritiskom močan zvarni spoj Al-Al in da intermetalna plast v spojih Al-Cu ne vpliva v večji meri na trdnost spoja.

Ključne besede: hladno varjenje s pritiskom, metalografija, mehanske lastnosti, površinska hrapavost, deformacije

Slika 3. *Hidravlična stiskalnica*

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Varnost delovanja varjene konstrukcije z razpokami pri povišani temperaturi

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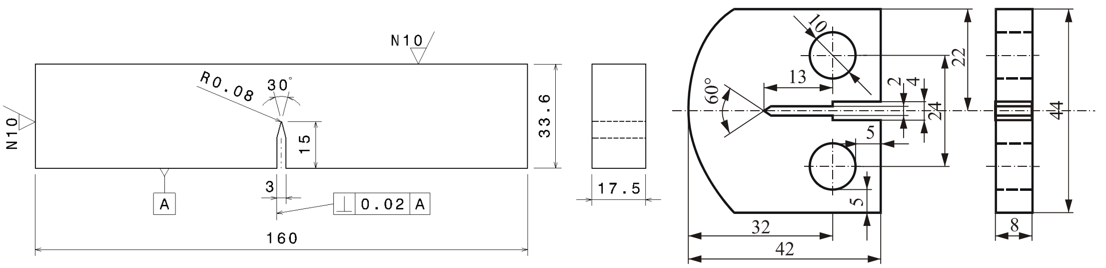
V prispevku so analizirani parametri hitrosti rasti razpok in pogoji za nenaden lom debelih zvarnih spojev jekla pri sobni in delovni temperaturi. Utrujenostne razpoke, ki nastanejo zaradi ostrih napak v zvaru, so začetne razpoke, ki v območju zvarnega spoja ali osnovnem materialu rastejo skladno s Parisovim zakonom. Doba trajanja varjene konstrukcije je odvisna od položaja in usmeritve obstoječih ostrih napak v zvaru. Pri eksperimentalni analizi so bili uporabljeni različni preizkušanci z vnaprej izdelanimi razpokami.

Preizkušanci so bili prerezani v območju osnovnega materiala, dodajnega materiala in toplotno vplivne cone. Hitrost rasti razpok v območju zvarnega spoja pri delovni in sobni temperaturi je večja kot pri osnovnem materialu. Hitrost rasti utrujenostnih razpok je bila pri delovni temperaturi večja ne glede na položaj. Zanesljivost konstrukcije z vzdolžnimi začetnimi razpokami v območju toplotno vplivne cone je bila manjša kot pri prečnih začetnih razpokah v osnovnem materialu.

Ključne besede: varjene konstrukcije, utrujenostne razpoke, lomna žilavost, preiskušanje



Slika 2: *Preizkusni vzorci lomne žilavosti*

[*]Naslov odgovornega avtorja: Inštitut ″GOŠA″, Beograd, Srbija, merib@neobee.net

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Navodila avtorjem

Članki so v Strojniškem vestniku od leta 2008 objavljeni samo v angleškem jeziku s slovenskim naslovom, povzetkom ter sliko s podnaslovom v dodatku. Avtorji so v celoti odgovorni za jezikovno lektoriranje članka. V kolikor recenzent oceni, da jezik ni dovolj kakovosten, lahko uredništvo zahteva ponovno lektoriranje usposobljenega lektorja ter potrdilo o opravljenem lektoriranju.

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- besedilo članka,
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- seznam literature in
- podatke o avtorjih, odgovornega avtorja in njegov polni naslov.

Članki naj bodo kratki in naj obsegajo približno 8-12 strani.

Člankom so lahko priložene tudi dodatne računalniške simulacije ali predstavitve, pripravljene v primerni obliki, ki bodo bralcem dostopne na spletni strani revije.

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Članek naj bo napisan v naslednji obliki:

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- Literatura, ki mora biti v besedilu oštevilčena zaporedno in označena z oglatimi oklepaji [1] ter na koncu članka zbrana v seznamu literature.

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Besedilo članka naj bo pripravljeno v urejevalniku Microsoft Word. Članek nam dostavite v elektronski obliki (lahko po elektronski pošti). Ne uporabljajte urejevalnika LaTeX, saj program, s katerim pripravljamo Strojniški vestnik, ne uporablja njegovega formata. Enačbe naj bodo v besedilu postavljene v ločene vrstice in na desnem robu označene s tekočo številko v okroglih oklepajih.

Enote in okrajšave

V besedilu, preglednicah in slikah uporabljajte le standardne označbe in okrajšave SI. Simbole fizikalnih veličin v besedilu pišite poševno (kurzivno), (npr. v, T, n itn.). Simbole enot, ki sestojijo iz črk, pa pokončno (npr. ms-1, K, min, mm itn.).Vse okrajšave naj bodo, ko se prvič pojavijo, napisane v celoti, npr. časovno spremenljiva geometrija (ČSG). Vse veličine morajo biti navedene, ko se prvič pojavijo, v besedilu ali za enačbo.

Slike

Slike morajo biti zaporedno oštevilčene in označene, v besedilu in podnaslovu, kot sl. 1, sl. 2 itn. Posnete naj bodo v ločljivosti, primerni za tisk, v kateremkoli od razširjenih formatov, npr. BMP, JPG, GIF. Diagrami in risbe morajo biti pripravljeni v vektorskem formatu, npr. CDR, AI.

Vse slike morajo biti pripravljene v črno-beli tehniki, brez obrob okoli slik in na beli podlagi. Ločeno pošljite vse slike v izvirni obliki.

Pri označevanju osi v diagramih, kadar je le mogoče, uporabite označbe veličin (npr. t, v, m itn.). V diagramih z več krivuljami, mora biti vsaka krivulja označena. Pomen oznake mora biti pojasnjen v podnapisu slike.

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Preglednice morajo biti zaporedno oštevilčene in označene, v besedilu in podnaslovu, kot preglednica 1, preglednica 2 itn. K fizikalnim veličinam, npr. t (pisano poševno), pripišite enote (pisano pokončno) v oglatih oklepajih.

Seznam literature

Vsa literatura mora biti navedena v seznamu na koncu članka v prikazani obliki po vrsti za revije, zbornike in knjige:

[1] Wagner, A., Bajsić, I., Fajdiga, M. Measurement of the surface-temperature field in a fog lamp using resistance-based temperature detectors. Strojniški vestnik – Journal of Mechanical Engineering, February 2004, vol. 50, no. 2, p. 72-79.

[2] Boguslawski L. Influence of pressure fluctuations distribution on local heat transfer on flat surface impinged by turbulent free jet. Proceedings of International Thermal Science Seminar II, Bled, June 13.-16., 2004.

[3] Muhs, D. et al. Roloff/Matek mechanical elements, 16th ed. Wiesbaden: Vieweg Verlag, 2003. 791 p. Translation of: Roloff/Matek Maschinenelemente. (v nemščini) ISBN 3-528-07028-5

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