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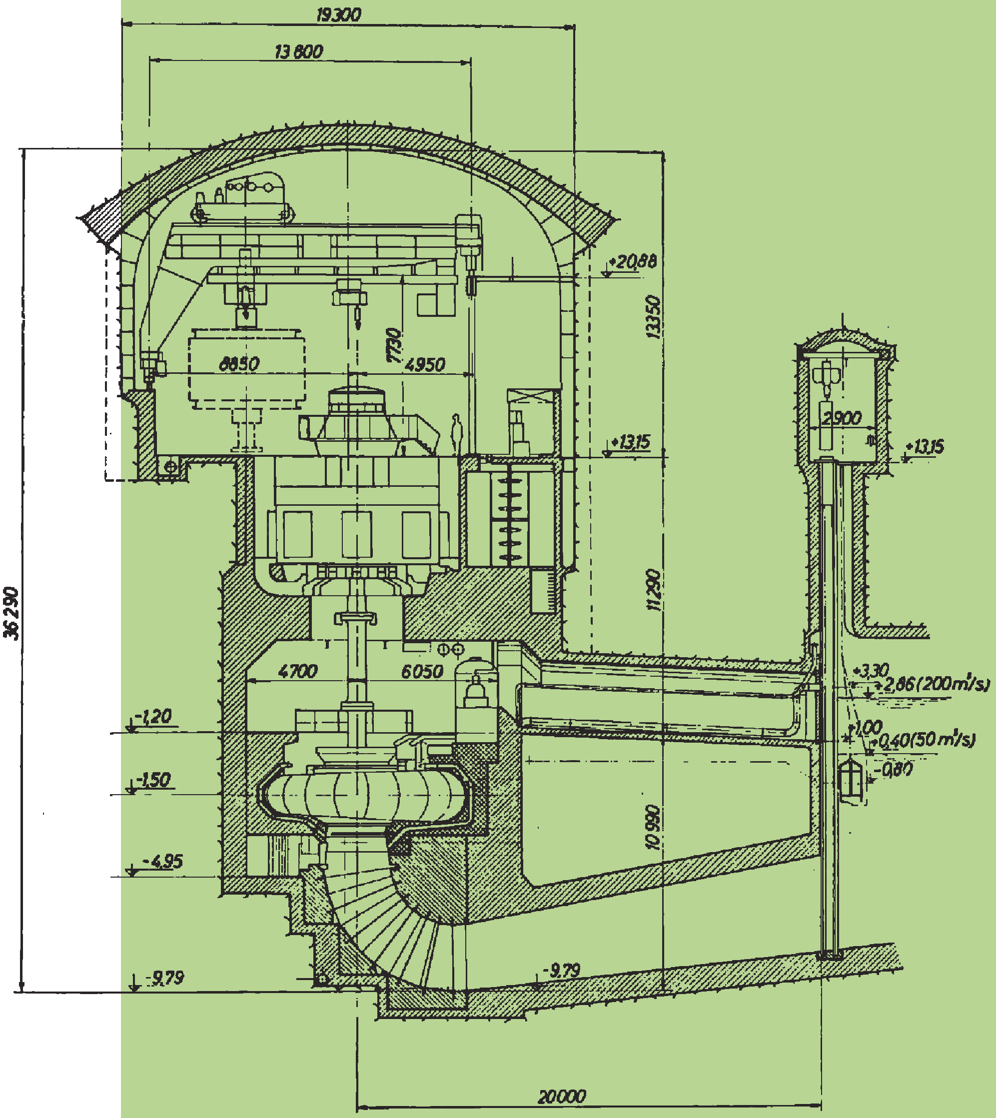

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Energijska in eksergijska analiza sotočnih in protitočnih prenosnikov toplote z uporabo merilnih podatkov

Energy and exergy analysis of a parallel and counter-flow heat exchangers using measured data

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Prispevek podaja energijsko in eksergijsko analizo sotočnih in protitočnih ločilnih prenosnikov toplote z uporabo marilnih podatkov. Sestavili smo merilno progo, na kateri smo merili vstopne in izstopne temperature in masni tok vode. Za določitev brezrazsežnega razmerja izgubljene eksergije in prenešenega toplotnega toka v odvisnosti od brezrazsežnih parametrov prenosnika toplote: razmerja absolutnih temperatur na vstopu π_T, *razmerja toplotnih moči* π_3 *in števila enot prenosnika toplote* π_2, *smo razvili analitični model. Za vse primere smo izračunali tudi učinkovitost prenosa toplote. Rezultate smo prikazali v ustreznih brezrazsežnih diagramih.*

(Ključne besede: prenosniki toplote, energijske analize, eksergijske analize, izmerjene vrednosti)

This paper presents an energy and exergy analysis of a parallel and counter-flow recuperative heat exchangers using experimental data. An experimental rig was constructed to measure the inlet and outlet temperatures and the mass flow rates of streams. The analytical model was developed to obtain a non-dimensional relationship between the destroyed exergy and exchanged heat-flow rate as a function of the non-dimensional parameters of a heat exchanger: the ratio of inlet absolute temperatures, π_T, *the ratio of the heat-capacity rates,* π_3, *and the number of heat-transfer units,* π_2. *The effectiveness of the heat exchange is also calculated for each case. The results are shown in appropriate non-dimensional diagrams.*

(Keywords: heat exchangers, energy analysis, exergy analysis, measured values)

0 INTRODUCTION

Energy-exergy analyses of heat exchangers have been the subject of much research over the past few decades, [1] to [7]. These analyses are based on the first and the second laws of thermodynamics. From such analyses the parameters for the improved operation of a heat exchanger can be obtained.

The destroyed exergy or the lost available work of a heat exchanger is due to two factors: the transfer of heat across the stream-to-stream temperature difference and the frictional pressure drop that accompanies the circulation of fluid through the apparatus. Taking into account these two parameters it is possible to optimize a heat exchanger on an entropy-generation minimization or on a minimum destruction of exergy ([8] and [9]). In this work the exergy destruction due to the pressure drop is neglected, because from experimental data it was clear that the pressure drop was very small.

1 DESCRIPTION OF THE MEASURING RIG

Figure 1. shows the experimental setup of the heat exchanger.

The studied heat exchanger was “double pipe” type with only one passage of every stream. The streams were a hot-water stream (as the stronger stream) and a cold-water stream (as the weaker one). The mass flow rate of the weaker stream was kept constant and equal to 0.002 kg/s. The values of the mass flow rate of the stronger stream were 0.004, 0.006, 0.008 or 0.01 kg/s. As can be seen from Figure

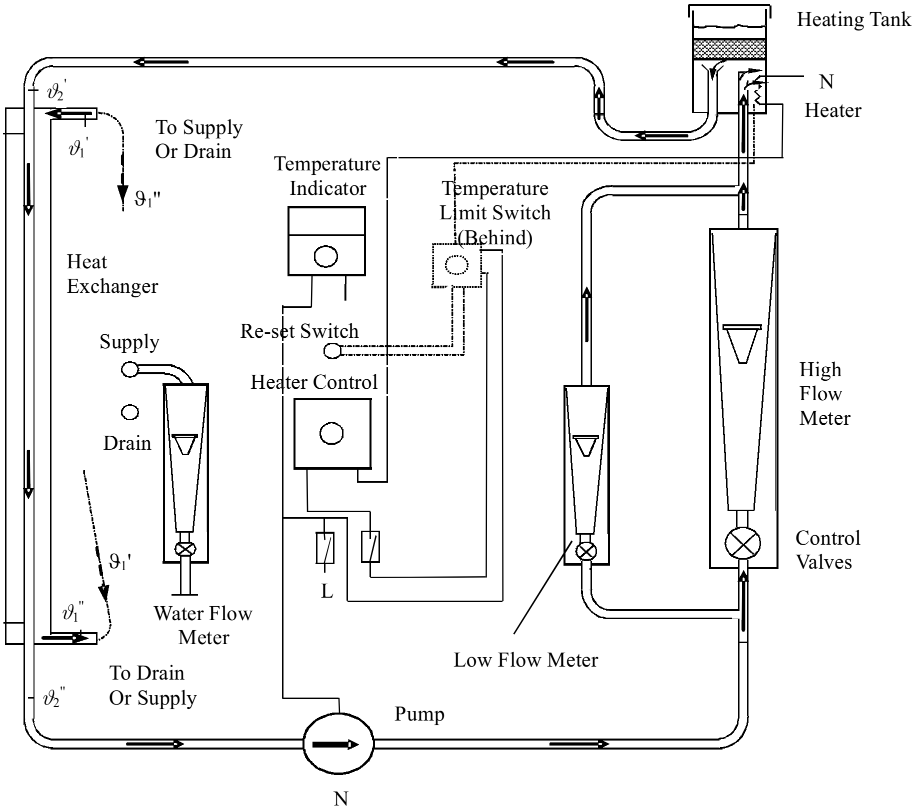

Fig. 1. *The experimental rig*

1, the inlet and outlet temperatures of the streams were measured. In each of four cases (for the each value of the mass flow rate), the inlet temperature of the stronger stream was kept constant and the inlet temperature of the weaker stream was varied four times. From the obtained four sets of the measured data, for each of the four cases, both for a parallel and a counter-flow heat exchanger, two non dimensional parameters (π_1 and π_3) were calculated. The parameters are presented in the appropriate diagrams, as shown in Figures 2 and 3.

The total heat exchanger area was 0.08 m^2.

For each point the exchanged-heat flow rate and the exergy destruction (entropy generation) are calculated by using the equations of the following mathematical model.

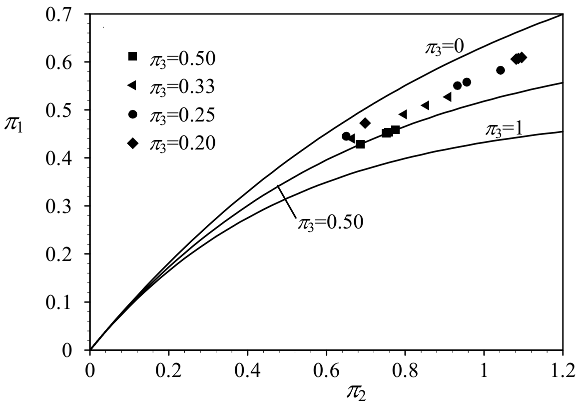

Fig. 2. *The positions of the measured operation points for a parallel-flow heat exchanger*

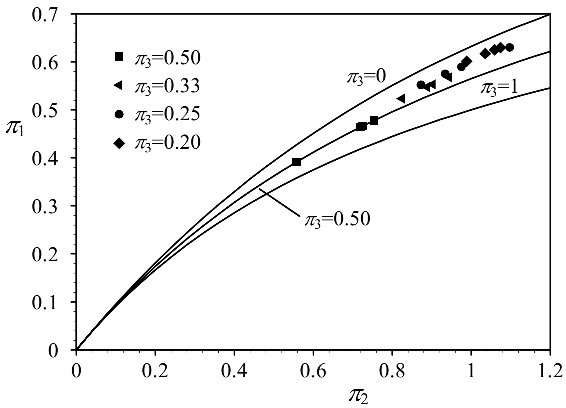

Fig. 3. *The positions of the measured operation points for a counter-flow heat exchanger*

2 MATHEMATICAL MODEL

The exchanged-heat flow rate between two streams can be calculated using the following equation ([10] and [11]):

$$\dot{Q} = C_1\left(\vartheta_1^{'} - \vartheta_1^{"}\right) = C_2\left(\vartheta_2^{"} - \vartheta_2^{'}\right) \quad (1).$$

The heat exchanger effectiveness ε is usually defined as:

$$\varepsilon = \pi_1 = \frac{\vartheta_1^{'} - \vartheta_1^{"}}{\vartheta_1^{'} - \vartheta_2^{'}} = \frac{\dot{Q}}{\dot{Q}_{\max}} \quad (2).$$

The exchanged-heat flow rate $\dot{Q}$ can be rewritten as:

$$\dot{Q} = \varepsilon \dot{Q}_{\max} = \varepsilon C_1\left(\vartheta_1^{'} - \vartheta_2^{'}\right) \quad (3).$$

Since the pressure drop of the two streams is neglected, the entropy generation can be calculated from the following equation [11]:

$$\dot{S}_{\text{gen}} = C_1 \ln\frac{T_1^{"}}{T_1^{'}} + C_2 \ln\frac{T_2^{"}}{T_2^{'}} \quad (4).$$

Using Equations (1) and (2), it is easy to transform Equation (4) into the form:

$$\dot{S}_{\text{gen}} = C_1 \ln\left(1\text{-}\varepsilon\left(1\text{-}\frac{T_2^{'}}{T_1^{'}}\right)\right) + C_2 \ln\left(1+\frac{C_1}{C_2}\varepsilon\left(\frac{T_1^{'}}{T_2^{'}}-1\right)\right) (5).$$

If the following terms for two non-dimensional parameters

$$\pi_{\text{T}} = \frac{T_2^{'}}{T_1^{'}}; \quad \pi_3 = \frac{C_1}{C_2} \quad (6)$$

are introduced into Equation (5), the equation for the entropy generation assumes the following form:

$$\dot{S}_{\text{gen}} = C_1 \ln\left(1\text{-}\varepsilon\left(1\text{-}\pi_{\text{T}}\right)\right) + C_2 \ln\left(1+\pi_3\varepsilon\left(\frac{1}{\pi_{\text{T}}}-1\right)\right) \quad (7).$$

After multiplying the above equation by the environmental temperature, T_0, the equation for the irreversibility or the exergy destruction is obtained as:

$$\dot{I} = Ex_{\text{destr}} = T_0 \dot{S}_{\text{gen}} = T_0\left(C_1 \ln\left(1\text{-}\varepsilon\left(1\text{-}\pi_{\text{T}}\right)\right) + C_2 \ln\left(1+\pi_3\varepsilon\left(\frac{1}{\pi_{\text{T}}}-1\right)\right)\right) \quad (8).$$

The above equation can be written in a non-dimensional form. For that purpose, it will be divided by the product of the heat capacity rate of the weaker stream, C_1, and the environmental temperature, T_0, as follows:

$$i_1 = \frac{\dot{I}}{T_0 C_1} = \ln\left(1\text{-}\varepsilon\left(1\text{-}\pi_{\text{T}}\right)\right) + \frac{1}{\pi_3}\ln\left(1+\pi_3\varepsilon\left(\frac{1}{\pi_{\text{T}}}-1\right)\right) \quad (9).$$

Because the scope of this work is to show the ratio of the irreversibility and the exchanged-heat flow rate, it is useful to write Equation (1) in a non-dimensional form, dividing it by the product $C_1 T_1^{'}$:

$$q_1 = \frac{\dot{Q}}{C_1 T_1^{'}} = \varepsilon\left(1-\pi_{\text{T}}\right) \quad (10).$$

Finally, Equation (9) is divided by Equation (10), and a relevant ratio is obtained:

$$\frac{i_1}{q_1} = \frac{\ln\left(1\text{-}\varepsilon\left(1\text{-}\pi_{\text{T}}\right)\right) + \frac{1}{\pi_3}\ln\left(1+\pi_3\varepsilon\left(\frac{1}{\pi_{\text{T}}}-1\right)\right)}{\varepsilon\left(1-\pi_{\text{T}}\right)} \quad (11).$$

For a parallel heat exchanger the effectiveness ε is obtained using the following formula [10]:

$$\varepsilon = \frac{1-\text{e}^{-(1+\pi_3)\pi_2}}{1+\pi_3} \quad (12).$$

and for a counter heat-transfer heat exchanger ε is estimated as [10]:

$$\varepsilon = \frac{1-\text{e}^{-(1-\pi_3)\pi_2}}{1-\pi_3\text{e}^{-(1-\pi_3)\pi_2}} \quad (13).$$

where:

$$\pi_2 = \frac{kA_0}{C_1} \quad (14).$$

As can be seen, this ratio is a function of the non-dimensional parameters π_3 and $\varepsilon = \pi_1$, which represent the operation points of the heat exchanger and which are obtained by the energy analysis of heat exchangers. The additional parameters for irreversibility or exergy destruction are the input temperature ratia, π_{T}, and the ambient temperature, T_0.

3 CALCULATION RESULTS AND DISCUSSION

The diagrams in Figures 4 and 5 present the values of i_1 and i_1/q_1 for a parallel-heat-flow heat exchanger, and the diagrams in Figures 6 and 7 for a counter-flow heat exchanger. These values are calculated using Equations (9) to (11) and Equations (12) and (13) for the parallel and the counter heat exchanger, respectively. The black points in the diagrams represent the values of the operating points, which are presented in Figures 2 and 3.

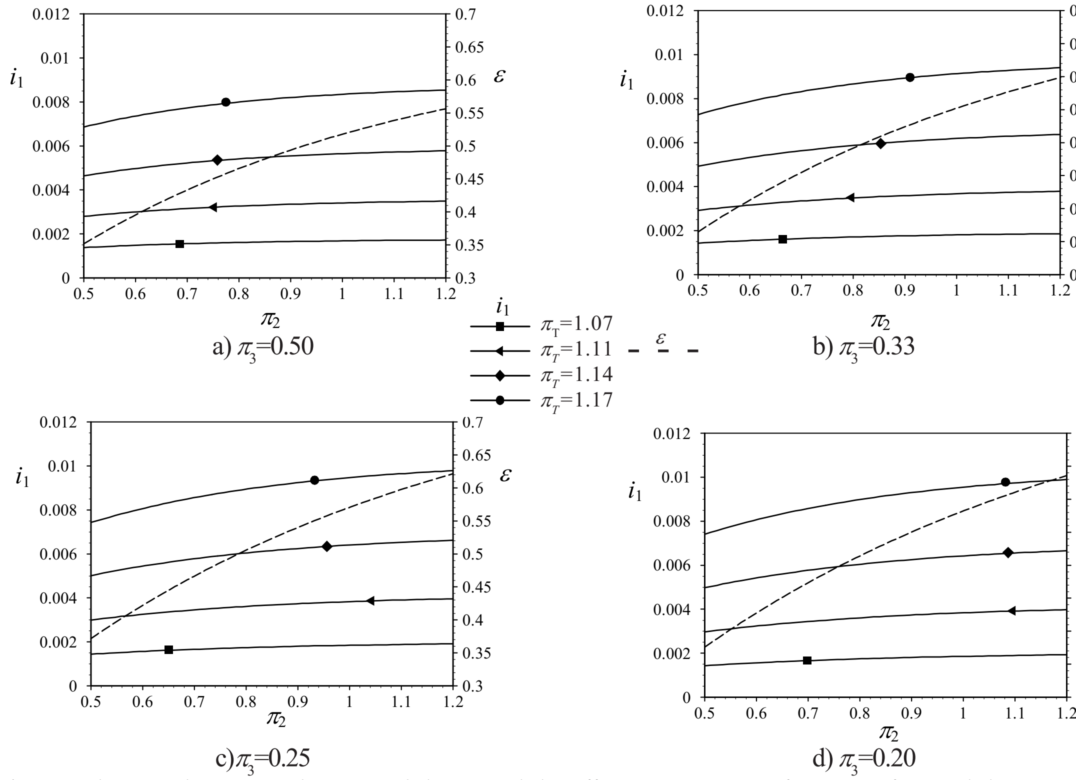

Fig. 4. *The non-dimensional irreversibility i_1 and the effectiveness ε as a function of π_2 and the parametric curves π_T for a) π_3=0.50, b) π_3=0.33, c)π_3=0.25 and d) π_3=0.20 for a parallel flow heat exchanger*

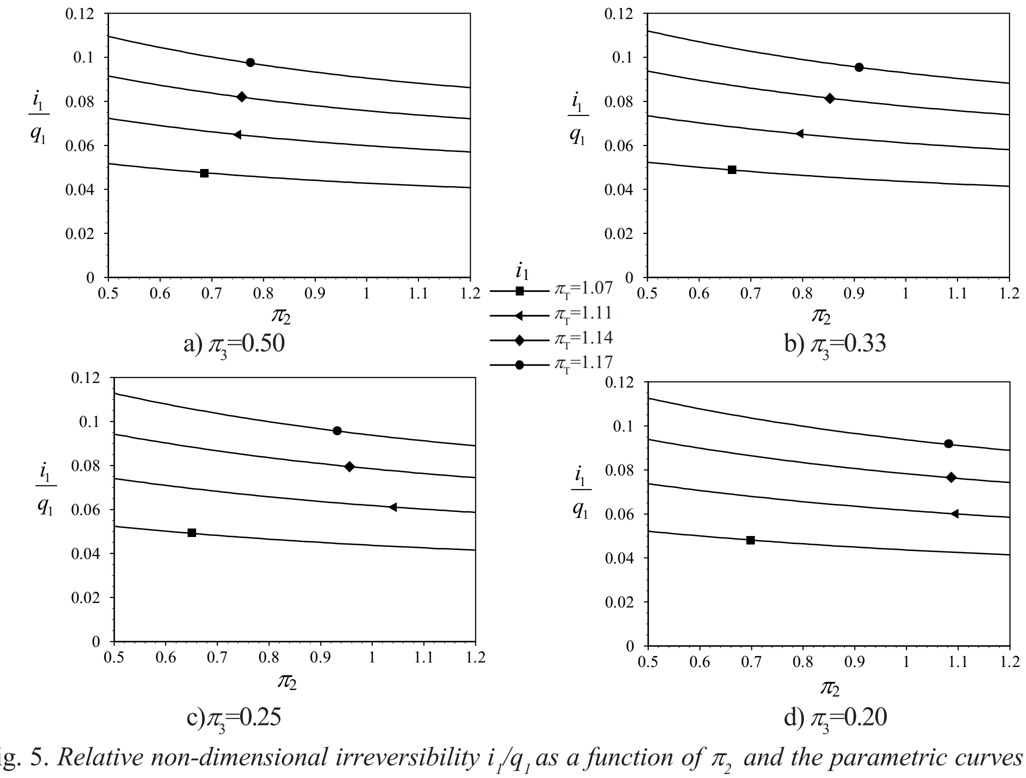

Fig. 5. *Relative non-dimensional irreversibility i_1/q_1 as a function of π_2 and the parametric curves π_T for a) π_3 = 0.50, b) π_3 = 0.33, a) π_3 = 0.25, a) π_3 = 0.20 for a parallel-heat-flow heat exchanger*

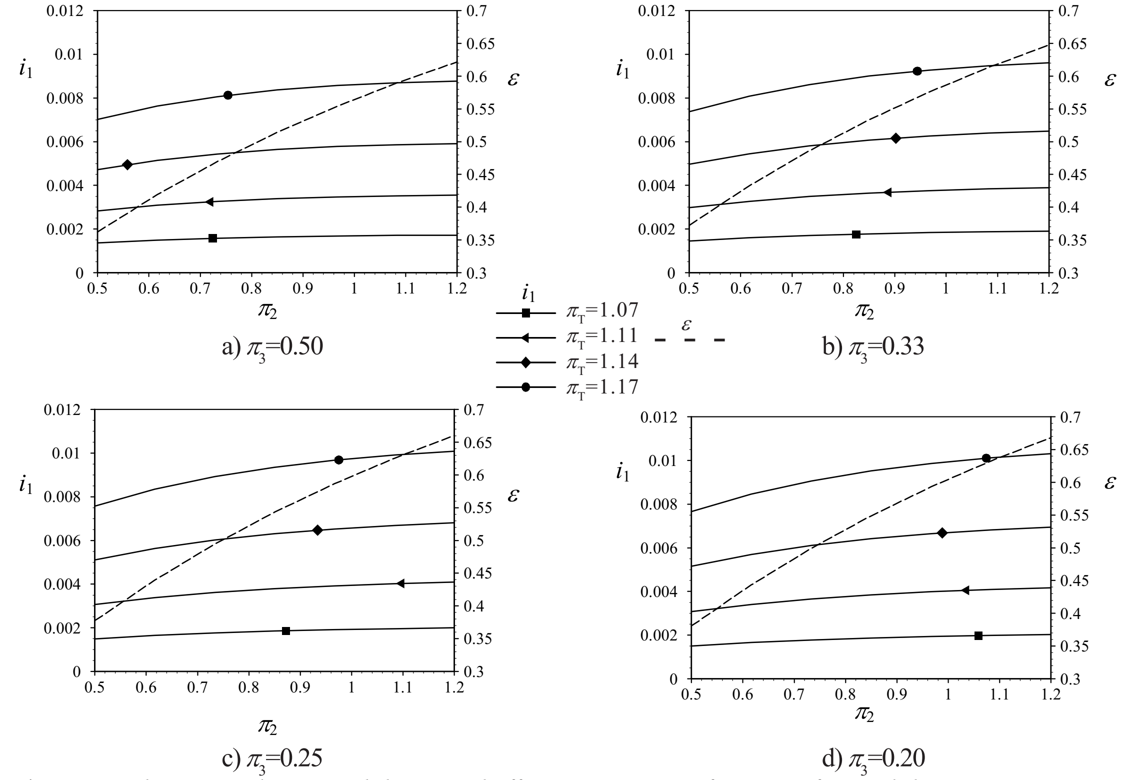

Fig.6. *Non-dimensional irreversibility i_1 and effectiveness ε as a function of π_2 and the parametric curves π_T for a) π_3=0.50, b) π_3=0.33, c)π_3=0.25 d) π_3=0.20 for a counter-flow heat exchanger*

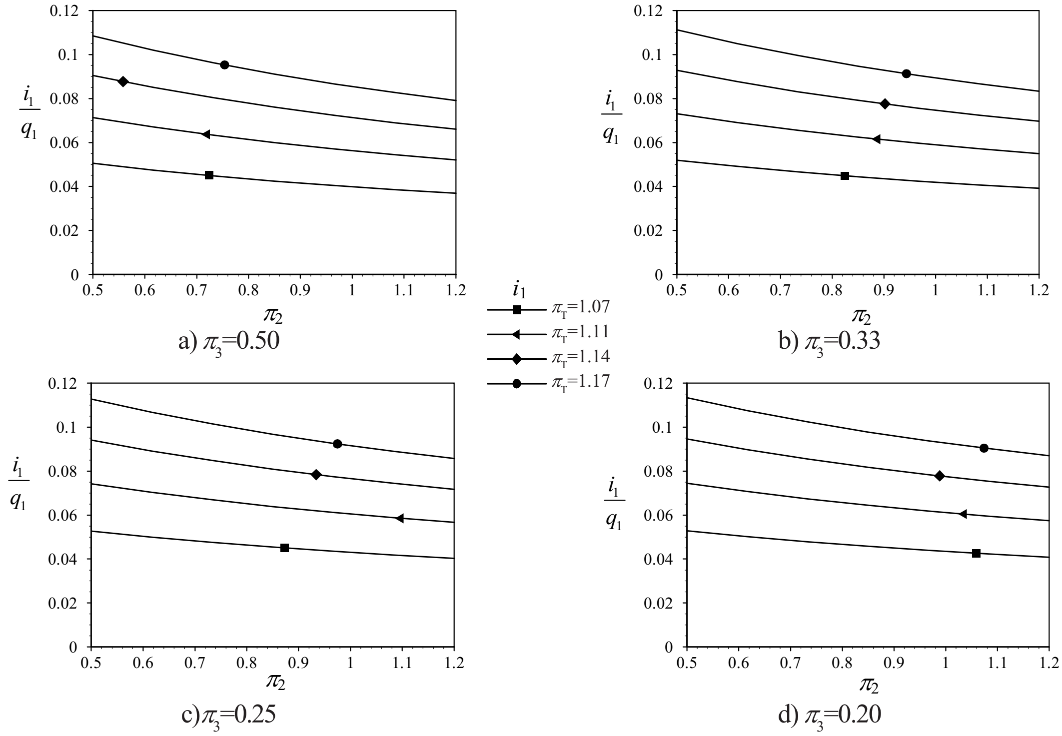

Fig. 7. *Relative non-dimensional irreversibility i_1/q_1 as a function of π_2 and the parametric curves π_T for a) π_3=0.50, b) π_3=0.33, c) π_3=0.25, d) π_3=0.20 for a counter-flow heat exchanger*

The above diagrams clearly show the relationship between the dimensionless values of i_1 and the dimensionless parameters π_2, π_3 and π_T. For each diagram it is possible to directly read the values of i_1 and ε for every case. It is obvious that the given values of π_2 and π_3 do not have a significant influence on i_1, but they have an influence on ε. The π_T ratio has the greatest influence on i_1, but it has no influence on ε. This can be quantitatively seen from Figures 4a and 4d, where the values $\pi_3 = 0.5$ and 0.2 and parametric values $\pi_T = 1.11$; 1.14 and 1.17 have the same value of $\pi_2 = 0.76$ and 1.09 respectively. For $\pi_3 = 0.5$, all operation points have the same value of ε, i.e., $\varepsilon = 0.455$, with the exergy destruction increasing from 0.0028 to 0.0078. On the other hand, for $\pi_3 = 0.2$ and the same parametric values of π_T and π_2 of 1.09, the value of ε is equal to 0.61. The associated exergy destructions are 0.0040, 0.0067 and 0.0076 respectively.

It is obvious that parallel- and counter-heat-flow heat exchangers have very small values of the ratio i_1 and i_1/q_1 for the measured operation points. It is not possible to make a comparison with respect to exergy destruction and heat-transfer effectiveness of the researched cases, because they did not have the same non-dimensional π_2 variables.

4 CONCLUSION

The presented analytical relationship between the dimensionless exergy destruction and the heat-transfer effectiveness of a heat exchanger seems to be rather convenient, because it relates the dimensionless parameters (π_3; π_2 and π_T as additional parameter) relevant to the operation of a heat exchanger and the exergy destruction of a parallel and a counter-flow heat exchanger. It is possible to include the values of the measured operation points into the presented mathematical model and simultaneously calculate the heat-transfer effectiveness and the exergy destruction of the considered heat exchangers. It can be concluded that the exergy destruction for each case of both investigated heat exchangers is small. The main reason for such a conclusion is the fact that the operation values of π_T close to 1.

Furthermore, by introducing additional exergy destruction due to the pressure drop in the model, it is possible to develop an analytical model for the minimization of heat exchangers' exergy destruction.

5 NOMENCLATURE

A_0	overall heat-transfer area, m^2
C	heat-capacity rate of the stream, W/K
Ex	exergy, W
$\dot{I}$	exergy destruction, W
i_1	non-dimensional exergy destruction
k	overall heat-transfer coefficient, $W/(m^2K)$
$\dot{Q}$	heat-transfer rate, W
q_1	non-dimensional heat-flow rate
$\dot{S}$	entropy generation rate, W/K
T	thermodynamic (absolute) temperature, K
T_0	ambient temperature, K

Greek Letters

ε, π_1	heat-exchanger effectiveness
ϑ	Celsius temperature, °C
π_T	ratio of inlet absolute temperatures, K
π_2	number of heat-transfer units
π_3	ratio of heat-capacity rates

Subscripts

1	weaker stream
2	stronger stream
destr	destruction
gen	generated

Superscripts

‘	inlet
‘’	outlet

6 REFERENCES

[1] Bejan, A., (1977) Second law analysis in heat transfer, *Energy*, 5, (1977), pp. 721-732 .

[2] Rant, Z. (1956) Exergie, ein neues Wort für technische Arbeitsfähigkeit. *Forschung Ing. Wesens* 22(1956), pp. 36-37.

[3] Rant, Z. (1964) Thermodynamische Bewertung der Verluste bei technischen Energieumwandlungen, *BWK* 16(1964), pp. 453-457.

[4] Can, A., Buyruk, E., Eryener, D., (2002) Exergoeconomic analysis of condenser type heat exchangers, *Exergy- an International Journal* 2(2002) , pp.113-118.
[5] Galović, A., Virag Z., Mudrinić, S., (2003), Non-dimensional entropy analysis of condenser and/or evaporator type heat exchangers, *Transactions of Famena*, 27(2003), pp. 1-9.
[6] Gregorig, R. (1973) Wärmeaustausch und Wärmeaustauscher, *Verlag Sauerländer*, Frankfurt am Main.
[7] Galović, A., M. Živić, M. Andrassy, (2003) Entropijska analiza sotočnih prenosnikov toplote, *Strojniški vestnik* 49 (2), pp.100-110.
[8] Bejan, A., (1988) Advance engineering thermodynamics, *John Willey and Sons*, New York.
[9] Bejan, A. (1996) Entropy generation minimizaton, *CRC Press*, New York.
[10] Bošnjaković, F., K. F. Knoche, (1997) Technische Thermodynamik, Teil II, *Steinkopf Verlag*, Darmstadt.
[11] Çengel, Y.,Boles, M., A., (1994) Thermodynamics: an engineering approach, *McGraw-Hill Book Company*, New York.

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Numerični pristop toplotnih neporušnih preiskav skritih okvar

A Numerical Approach to Hidden Defects in Thermal Non-Destructive Testing

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(University of Zagreb, Croatia)

Uporaba infrardeče (IR) termografije kot neškodljiva preizkusna metoda za odkrivanje napak pod površino ter tudi za določevanje jakosti korozije veliko obeta. Razen omejitev, ki so posledica IR kamere same in toplotnih lastnosti preizkušanega materiala, nam da IR termografija v povezavi z ustrezno numerično metodo sprejemljive rezultate. Numerično simuliranje prenosa toplote nam omogoči ločeno analizo primernih parametrov, ki določijo razširjanje toplote v materialu, kot so: jakost in trajanje toplotnega vzbujanja, lastnosti materiala in začetni pogoji, prav tako pa tudi časovno porazdelitev nekaterih parametrov. Primerjava numerične simulacije in termografskih meritev, opisanih v [5], je dala zelo dobro ujemanje rezultatov. Iz numerične analize je jasno razvidna pomembnost določitve trenutka, ko kontrast doseže svojo največjo vrednost. Analiza nam prav tako pokaže, da lahko relativno izgubo materiala in premer napake določimo z največjo točnostjo v trenutku, ko kontrast doseže svojo največjo vrednost.

(Ključne besede: neporušno preizkušanje, termografija, metode nadzornih prostornin, numerično simuliranje)

The application of infrared (IR) thermography for detecting defects under the surface as well as for the estimation of the corrosion intensity seems to have good prospects as a non-destructive testing method. Besides the limitations which are the result of the IR camera itself and the thermal properties of the material detected, IR thermography produces acceptable results when combined with an appropriate numerical method. A numerical simulation of heat transport makes possible a separate analysis of the relevant parameters that characterize heat dissipation in the material, like the intensity and duration of the heat stimulation, the properties of the material and the starting conditions, as well as the time distribution of certain parameters. The comparison of a numerical simulation and thermographic measurements presented in [5] shows a very good agreement of the results. The importance of determining the moment when the contrast reaches its maximum can be clearly seen from the numerical analysis. The analysis also shows that a relative material loss and the diameter of the defect can be estimated with the best accuracy at the moment when the current contrast reaches its maximum.

(Keywords: non-destructive testing, thermography, control volume methods, numerical simulations)

0 INTRODUCTION

The development of thermal non-destructive testing (TNDT) started with the introduction of the first infrared sensors. Basically, the method consists of the thermal treatment of a sample and of the measuring of its thermal response in the spatial and temporal domain, $\vartheta=\vartheta(x,y,z,t)$. Experimentally, the method is based on recording the temperature distribution of a reference sample surface over time, using one of the known methods of infrared (IR) radiation recording. The theoretical part is reduced to solving the problem of heat conduction through the sample in the 1D, 2D or 3D domain over time.

The temperature field at the sample surface is the basis of all further analyses and conclusions on the possible presence of defects under the material surface and their parameters. The detection of a defect expressed by the discontinuity of the temperature field at the sample surface depends on the changes of thermodynamic and physical properties of the sample.

With regard to the temperature field, it is necessary to take into account all the additional influences important in forming the object temperature image (anisotropy of the basic sample material, variations in the surface state and the object's thermal stimulation, noise from measuring equipment, etc.), and to distinguish between a real defect and the artefact.

The paper presents the results of an examination of two models: one with defects underneath its surface made from a different material and the other with corrosion defects. The numerical simulation performed for both models is in fair accordance with measurement results.

1 THE BASICS OF THERMAL NON-DESTRUCTIVE TESTING

Although the beginning of thermal non-destructive testing is attributed to the time when the first IR detectors were discovered in 1914, and almost all TNDT methods used today were developed from the 1960s until the end of the 1970s, these methods did not yield the results expected in comparison with other non-destructive testing (NDT) methods. A major change occurred when a thermodynamic approach to the problem of heat conduction and transfer was introduced into the measurement result analysis. Basically, the method may be reduced to a number of steps: thermal stimulation of the object, surface temperature recording (temperature response), data processing and decision making.

The choice of the object thermal stimulation depends on the type of control to be performed (final testing, corrosion detection, improvement of visibility of impurities in the basic material, etc.). Rapid heating or cooling of the sample leads to the sudden appearance of hot or cold areas at the sample surface, and a high sensitivity of measurement may be achieved. Heating or cooling may be applied to the front or the rear side of the sample, depending on the purpose of the procedure. The front or the rear sample side refers to the surface to be inspected.

Nowadays TNDT methods are divided into two basic groups: methods for preventive maintenance and methods developed for special needs of defect detection in the material [1].

The choice of a TNDT method depends on the type of defect expected underneath the material surface, the object accessibility from both sides and geometrical characteristics of the sample.

The basic defect types in the object are as follows: surface or inside cracks, impurities in the material, surface roughness, variations of the coating thickness, poor clinging of the coating, surface delaminates and corrosion. The thermal properties of a solid may be regarded as functions of spatial coordinates $\lambda = \lambda(x,y,z)$ and $a = a(x,y,z)$. Every interruption or steep change of these functions represents a potential defect (impurity) in the basic material. The analysis of the functions $\lambda(x,y,z)$ and $a = a(x,y,z)$ represents the material analysis of the sample.

The problems TNDT deals with include temperature functions depending on numerous parameters, such as spatial coordinates, time, dimensions of the sample and its thermal properties, defect dimensions and thermal properties, and heat-exchange parameters. All these parameters have to be taken into account when evaluating measurement results and defining the defect parameters, e.g., position, shape, dimensions and thermal properties.

The basic parameter in TNDT analysis is a quantity defined as the contrast. There are several definitions of contrast [1]:

a) Temperature contrast, defined as the difference of the temperatures of spots at the object representing a sound material and a material with impurities:

$$\Delta T(t) = T_{nd}(x,y,t) - T_d(x,y,t) \quad (1).$$

b) Instantaneous (current) contrast, defined as the ratio of the temperature contrast and the sound material temperature:

$$C_r = \frac{T_{nd}(x,y,t) - T_d(x,y,t)}{T_{nd}(x,y,t)} = 1 - \frac{T_d(x,y,t)}{T_{nd}(x,y,t)} \quad (2).$$

c) Normalized contrast defined as a difference of ratia:

$$C_n = \frac{T_d(x,y,t)}{T_d{}^m(x,y,t)} - \frac{T_{nd}(x,y,t)}{T_{nd}{}^m(x,y,t)} \quad (3),$$

where the quantities in the denominators represent the peak temperatures at the chosen object surface spots with and without defects.

The selection of the contrast calculation mode during the analysis of the results also brings along possible dependences of the chosen contrast type on the process parameters, the heat flux density in the first place, sample heating time, uniformity of the thermal stimulation, as well as the uniformity of the optical properties of the object surface, the distance between the spots of the object surface, the temperatures that are taken for the contrast calculation and other parameters.

In order to achieve a simpler result analysis and to enable a comparison with other investigations, one should apply the contrast types that are less dependent on the process parameters and more dependent on the state of the material underneath the object surface as more appropriate.

2 NUMERICAL METHODS IN THERMAL NON-DESTRUCTIVE TESTING

A numerical simulation of heat transport through an object with defects makes it possible to evaluate the behaviour of various types of defects (position, geometry, defect material properties) with different initial and boundary conditions, without the noise that is normally present in experiments. A comparison of the results of the numerical analysis performed using the control volume method with the measurement results confirms the reliability of the numerical procedure.

The procedure of the numerical analysis of heat transport starts with the three-dimensional non-steady heat-transport equation in rectangular coordinates:

$$\rho\, c \frac{\partial \vartheta}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial \vartheta}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial \vartheta}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda \frac{\partial \vartheta}{\partial z}\right) + \phi_v \tag{4}$$

where: ρ – density, kg/m^3

c – specific heat capacity, J/(kgK)

λ – thermal conductivity, W/(mK)

ϑ – temperature, °C

x, y, z – spatial coordinates, m

ϕ – heat source or sink, W/m^3

Equation (5) is obtained by implicitly discretizing equation (4) [2]:

$$a_P\,\vartheta_P = a_E\,\vartheta_E + a_W\,\vartheta_W + a_N\,\vartheta_N + a_S\,\vartheta_S + a_T\,\vartheta_T + a_B\,\vartheta_B + b \tag{5}$$

with coefficients:

$$a_E = \lambda_e \frac{\Delta y \cdot \Delta z}{(\delta_x)_e} \quad a_W = \lambda_w \frac{\Delta y \cdot \Delta z}{(\delta_x)_w}$$

$$a_N = \lambda_n \frac{\Delta x \cdot \Delta z}{(\delta_y)_n} \quad a_S = \lambda_s \frac{\Delta x \cdot \Delta z}{(\delta_y)_s}$$

$$a_T = \lambda_t \frac{\Delta x \cdot \Delta y}{(\delta_z)_t} \quad a_B = \lambda_b \frac{\Delta x \cdot \Delta y}{(\delta_z)_b}$$

$$b = \phi_v \cdot \Delta x \cdot \Delta y \cdot \Delta z + a_P^o \cdot \vartheta_P^o \tag{7}$$

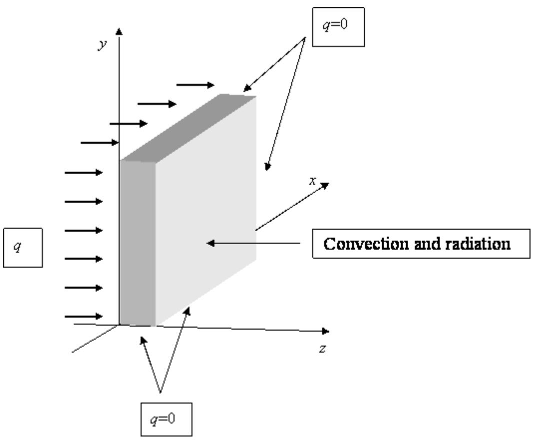
$$a_P^o = \frac{\rho \cdot c \cdot \Delta x \cdot \Delta y \cdot \Delta z}{\Delta t} \tag{8}$$

$$a_P = a_P^o + a_E + a_W + a_N + a_S + a_T + a_B \tag{9}$$

For each control volume the associated set of algebraic equations is to be solved. Boundary conditions are defined for all body surfaces according to the conditions in the experimental part.

3 DESCRIPTIONS OF MODELS AND MEASUREMENT PROCEDURE

Investigations were carried out for two models: the first one simulated the existence of air in the steel plate and the second defects due to corrosion.



$y = 0$, $y = h$	adiabatic boundary condition
$x = 0$, $x = b$	adiabatic boundary condition
$z = 0$	thermal simulation of the object in a defined time interval, free convection and heat radiation after heating
$z = \delta$	free convection and heat radiation, ambient temperature ϑ_o, temperature of the object in ambient ϑ_{ob}.

Fig. 1. *Boundary conditions*

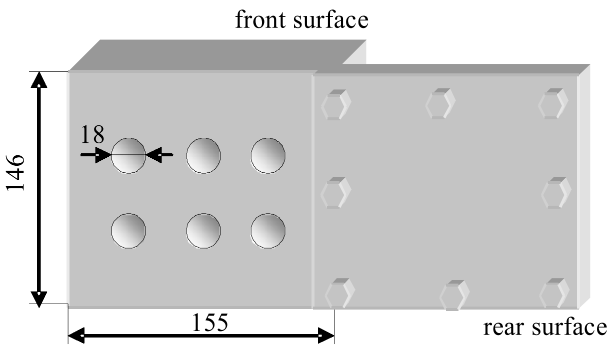


Fig. 2. *Model #1 geometry*

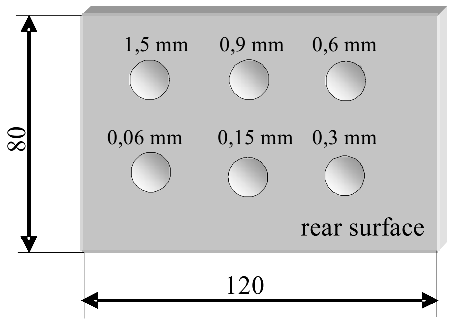


Fig. 3. *Model #2 geometry*

3.1 Model #1

Figure 2 represents the model geometry. The model consists of two 146 × 155 mm steel plates. In the base plate, which is 19 mm thick, cylindrical recesses 18 mm in diameter are milled, representing defects at various depths from the inspected surface. The 5 mm thick cover plate is tightly screwed to the base plate. The height of the cylinders milled into the base plate is in the range from 14 mm to 18 mm, so their distance from the inspection surface is between 5 mm and 1 mm [3].

The properties of the used steel are as follows: thermal conductivity $\lambda = 35$ W/(mK), thermal diffusivity $a = 9.96 \cdot 10^{-6}$ m^2/s. The model is mounted into a wooden frame that is filled with thermal insulation, so that at the lateral sides of the model an adiabatic boundary condition may be assumed. The thermal simulation of the model is performed using a 500 W spotlight. The heat radiation of the spotlight is directed through an aluminium sheet channel to the cover plate surface, and the temperature distribution is recorded on the opposite side of the model. For the numerical simulation a uniform thermal stimulation of the object is assumed. The temperature distribution at the object surface was measured using the IR AGA 680 STANDARD camera.

3.2. Model #2

The model for the simulation of the corrosion defects was a steel plate with dimensions 120 x 80 × 3 mm, as shown in Figure 3. The corroded areas are represented by six cylindrical recesses of 10 mm in diameter. The depth of each defect represents a particular loss of material caused by corrosion. For the numerical part of the investigation, corrosion is defined as a reduction of the material thickness, neglecting any changes in thermal properties of the material that may occur due to chemical reactions involved in the corrosion process.

The smooth front surface of the model was stimulated at the beginning of the simulation with a heat flux having a total energy of 78 J in a 5 ms time interval. The model was made of steel with known thermal properties, i.e., thermal conductivity $\lambda = 32$ W/(mK), thermal diffusivity $a = 1.65 \cdot 10^{-5}$ m^2/s. It is assumed that the thermal stimulation is uniform along the sample surface.

4 RESULTS OF THE NUMERICAL SIMULATION AND COMPARISON MEASUREMENTS

The problem was solved numerically by using the control-volume method. For solving the system of algebraic equations, the Gauss-Seidel procedure was used. The total number of control volumes was 15 960 for model #1, and 29 120 for model #2. The control-volume mesh was adapted to the observed problem. The mesh was condensed in the areas where steeper temperature gradients were expected.

The time step was also adapted to the stability and accuracy requirements of the discretized equation, so $\Delta t = 0.04$ s was adopted for model #1 and $\Delta t = 0.001$ s for model #2. The initial condition of the simulation assumed a model of uniform temperature.

4.1 Comparison of results

Model #1

The investigations carried out on model #1 were aimed to show the ability of the thermographic method to be used in the detection of defects under the surface in objects made of materials with a good

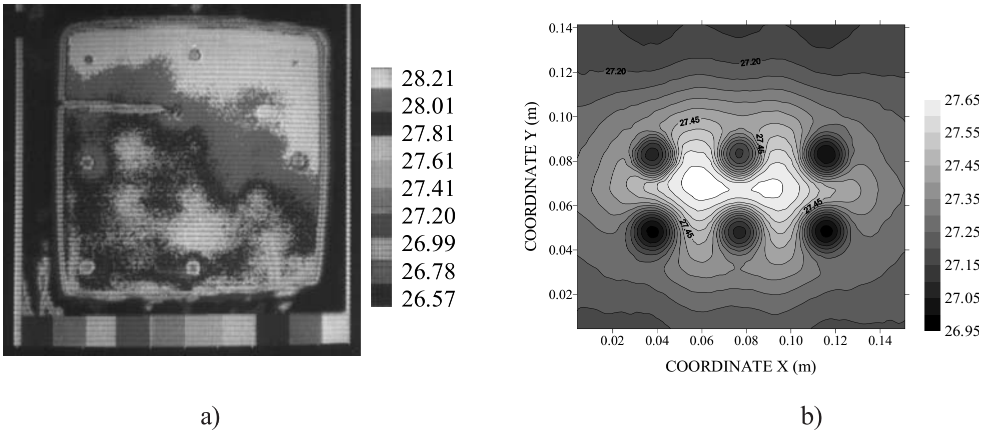


Fig. 4. *Temperature distribution at the smooth surface of model #1 after 120 s: a) experimentally recorded thermogram, b) result obtained by numerical simulation*

thermal conductivity, and to show the possibility of detecting the defect geometry, i.e., its dimensions and position (depth) in the object. It was shown that the detection of defect shape was better in short observation times, more shallow defects are easier to recognize, the maximum instantaneous contrast is directly connected with the distance of the defect from the observed surface, regardless of its dimensions.

Figure 4 shows a comparison of the experimental results and the numerical simulation. A relatively fair agreement between the results can be seen. In the thermogram on the left, in the upper right-hand corner there is an area of higher temperature, which can be explained by experimental noise rather than a measurement error. The contrast values are rather small, so in the recorded thermogram the deeper defects are barely noticeable.

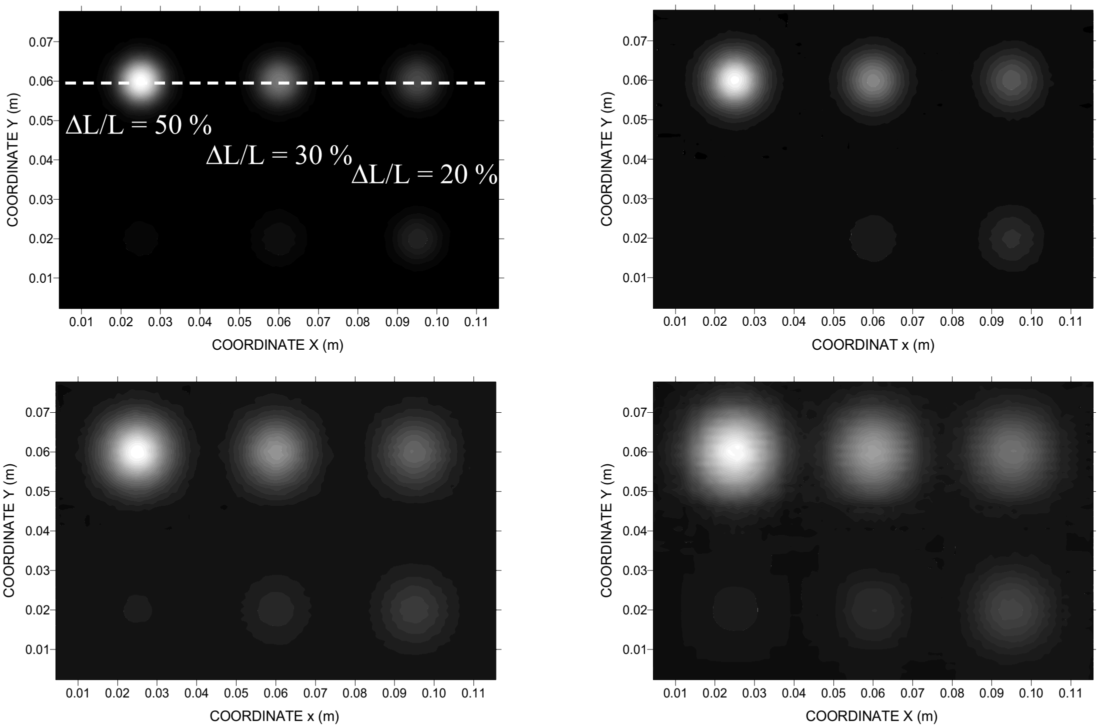


Fig. 5. *Numerically obtained temperature distributions on the front plate surface at 280 ms, 400 ms, 600 ms and 1000 ms time increments*

Model #2

The investigations carried out on model #2 were aimed to show the possibility of corrosion detection with thin metal plates. This paper presents the results of the numerical simulation carried out by the authors, and their comparison with the data obtained experimentally by Marinetti, Bison and Grinzato [4].

Temperature distributions at the plate surface for different time increments are shown in Figure 5.

A comparison of numerical and experimental results, as described in the literature [4], using the temperature distribution along the white dotted line in the thermogram for the time increment 280 ms in Figure 5, displays a very good agreement.

The corrosion degree estimation can be performed by using one of the inverse methods. The simplest algorithm relates the relative material loss and the instantaneous contrast in the following equation:

$$\frac{\Delta L}{L} = \frac{C(x,y,\tau_\infty)}{1 + C(x,y,\tau_\infty)} \tag{10}$$

The time interval during which the temperature response at the material surface is observed is most frequently expressed non-dimensionally, i.e., using the Fourier number:

$$Fo = \frac{a \cdot \tau}{L^2} \tag{11}$$

where a is the thermal diffusivity of the material, (m^2/s), τ is the time interval, (s), and L is the thickness of the plate, (m).

For large defects the heat transport can be reduced to a one-dimensional problem. The optimal inspection time is in the range Fo ≈ 0.6 to 2.0, and Equation (10) is recommended. The characterization of smaller defects of complex shape is recommended in the interval Fo ≈ 0.3 to 0.6 [5].

Due to the three-dimensional heat diffusion the defect detection is more difficult, so it is recommended to use the temperature derivative by time according to the following equation:

$$M(x,y) = \frac{T(x,y,\tau_1) - T(x,y,\tau_2)}{\tau_1 - \tau_2} \tag{12}$$

In every case the shape of the corroded area is more precisely indicated in a shorter inspection time interval, but with a somewhat lower amplitude [5].

Figure 7 displays the temporal distribution of values according to Equation (10). In contrast to the data from [4], where the analysis was done for Fo = 0.68, the numerical simulation shows that the best results are obtained by inspection during the time of peak temperature contrast [3]. For all defects this was in the range Fo ≈ 0.21 to 0.32.

It is also important to select a reference point T_{nd} sufficiently far from the defect itself [6].

Table 1

Effective corrosion $\Delta L/L$	Estimation time Fo	Estimation of corrosion $\Delta L/L$	Error %
0.02	0.21	0.0199	-0.5
0.05	0.242	0.0466	-6.8
0.1	0.264	0.0902	-9.8
0.2	0.292	0.175	-12.5
0.3	0.31	0.264	-12.0
0.5	0.32	0.455	-9.0

The estimation of corrosion for particular defects is shown in Table 1.

The optimum time interval to estimate the defect contours (time interval during which the defect contours in the thermogram may be most accurately identified) is also the time interval for achieving the

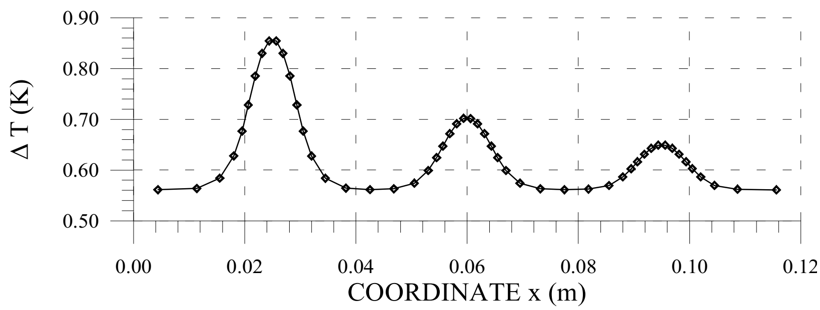


Fig. 6. *Temperature distribution on the dotted white line from Fig. 5 at time increment 0.28 s - numerical result*

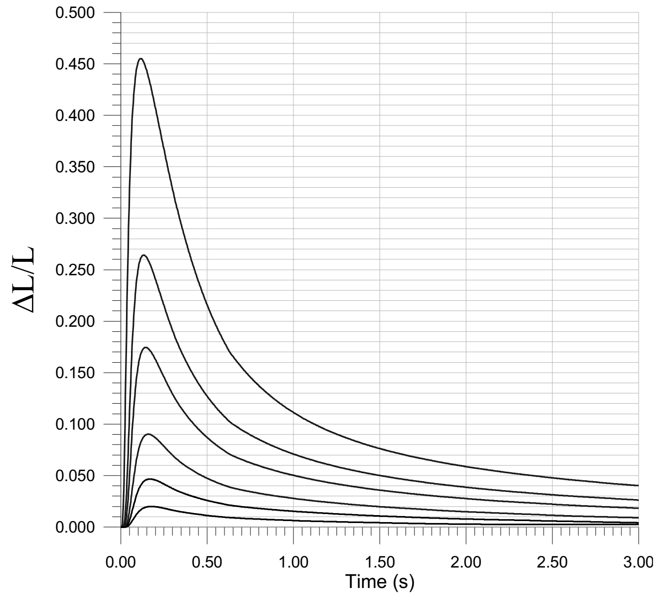


Fig. 7. *Time dependent distributions according to Equation (10)*

peak ΔT, where the reading of the diameter of each particular defect is done at half of the amplitude. Figure 8 displays the line temperature distributions along the defects in the time instant Fo = 0.28 (τ = 0.15 s).

The effective diameter of all the defects was 10 mm. The measured defect diameters are given in Table 2.

According to the literature data, material loss defects above some 20 % may be detected by thermography. The temperature time derivative according to equation (11) increases partially the defect visibility. In Figure 9, where the three-dimensional surface temperature distribution in the time instant

Table 2

Effective corrosion $\Delta L/L$	0.02	0.05	0.1	0.2	0.3	0.5
Measured defect diameter mm	10.16	10.16	9.83	9.83	9.83	9.5

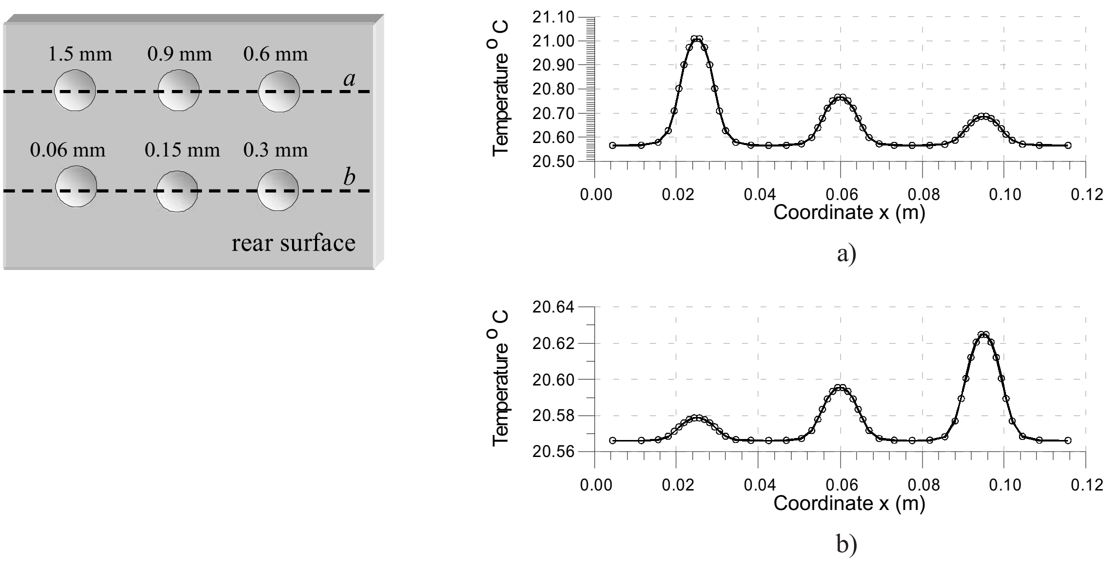


Fig. 8. *a) Line temperature distribution for cross-section a; b) Line temperature distribution for cross-section b*

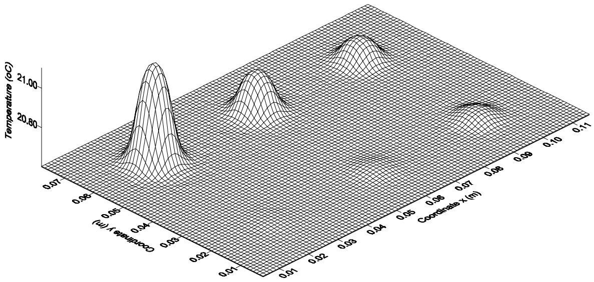


Fig. 9. *Temperature distribution for the time instant 0.1 s*

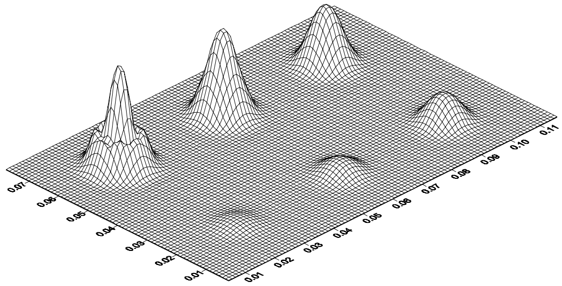


Fig. 10. *Temperature time derivative (0.05 to 0.1 s)*

0.1 s is shown, the smallest defect is not visible. On the other hand, the time derivative of temperature for $\tau_1 = 0.05$ s and τ_2 0.1 s in Figure 10 displays all the defects.

5 CONCLUSION

The performed investigation shows that both the thermographic and the numerical methods may be successfully employed in thermal non-destructive testing. The numerical approach enables the simulation of the influence of particular parameters, thus enabling a more universal overview of the influencing values. With the simulation of a process for a model with a defined number and distribution of defects it was established that the mutual influence of defects is very important, which may be directly concluded from the experimental part of the investigation. The numerical simulation also indicates situations when the three-dimensional diffusion cannot be neglected. It was also shown that the selection of an optimum inspection time interval is essential for a high-quality evaluation of the results. It can be concluded that a high-quality approach to thermal non-destructive testing necessarily requires a close link between experimental and numerical analyses in order to detect and determine all the relevant defect parameters.

6 REFERENCES

[1] D.P. Almond, P.M. Patel (1996) Photothermal science and technique, *Chapman & Hall*, London.

[2] S.V. Patankar (1980) Numerical heat transfer and fluid flow, *Hemisphere Publishing Corporation*, Mc Grow-Hill Book Co, Washington.

[3] I.Ilić-Boras, Š.Švaić (1997) Numerical simulation of the defect in specimen, *4th International Conference of the Slovenian Society for NDT*, Ljubljana.

[4] S.Marinetti, P.G.Bison, E.Grinzato (2002) 3D Heat flux effects in the experimental evaluation of corrosion by IR thermography, *QIRT'02, Quantitative InfraRed Thermography 6*, Dubrovnik, Croatia, 2002.

[5] E.Grinzato, V.Vavilov (1998) Corrosion evaluation by thermal image processing and 3D modelling, *Rev.Gen.Therm. Paris, France*, pp. 669-679.

[6] I. Boras, Š. Švaić (1998) Determination of the defect parameters in specimen by means of thermography and numerical methods, *Proceeding of The International Society for Optical Engineering*, San Antonio, Texas, USA, Vol. 3396, pp. 271-281.

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Metodologija načrtovanja zanesljivosti vozil med zasnovo

A Methodology for the Design of Reliable Vehicles in the Concept Stage

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Pri tako močni svetovni konkurenci je bistveno, da imajo motorna vozila veliko zanesljivost. Eden od načinov za doseganje tega cilja je metodologija načrtovanja zanesljivosti vozil. Stopnja načrtovanja je najbolj pomembna v dobi trajanja motornih vozil. Načrtovanje zanesljivosti v okviru faze načrtovanja je v neposredni povezavi z zanesljivostjo motornega vozila. Problem praktične metodologije za načrtovanje zanesljivosti motornih vozil je bil rešen z razvojem postopkov za ta namen. Osnova razvite metodologije predstavlja sodoben pristop k načrtovanju, ki zajema faze zasnove, predhodnega in glavnega načrtovanja z uporabo metode za načrtovanja zanesljivosti v teh fazah. Zaradi razpoložljivega prostora ta prispevek daje poudarek fazam zasnove načrtovanja zanesljivosti vozil.

(Ključne besede: motorna vozila, zanesljivost vozil, načrtovanje zanesljivosti, numerično simuliranje)

With world-wide competition so strong it is essential that motor vehicles have good reliability. One of the ways to reach this goal is the methodology for the design of reliable motor vehicles. The design stage is the most important in the life cycle of the motor vehicle. Reliability design, within the design stage, directly correlates with the reliability of the motor vehicle. The problem of the practical methodology for the reliability design of a motor vehicle was solved by developing a methodology for this purpose. The developed methodology represents a modern approach to design that comprises the phases of conceptual, preliminary and main design with the application of the method for reliability design within these phases. Due to the available space, this paper pays attention to the phase of the conceptual design of the vehicle's reliability.

(Keywords: vehicles, reliability, reliability design, numerical simulations)

0 INTRODUCTION

Reliability is a feature incorporated into a vehicle in the course of the design process, which is realised in the course of production by a high degree of technological discipline, and maintained in the exploitation by continual and stipulated maintenance and orderly usage. In designing reliability, it is necessary to predict or estimate the reliability of each motor-vehicle system element, as far as this is technically possible. The reliability is mainly determined on the basis of the ability of the given part or assembly or system to withstand the unforeseen overloading without catastrophic failure. The reliability of the vehicle elements (system, sub-system, assemblies, sub-assemblies, parts), especially of those critical in terms of reliability, is increasingly becoming the subject of special attention by vehicle designers and the automotive industry in general.

The activities within the design process for motor vehicles and their components are often the result of quite opposing requirements, for example, low vehicle mass combined with high payload, high reliability and safety combined with maximum material savings, and small outline combined with maximum passenger comfort. It is the vehicle designer who has the special responsibility to assess the effect of the technology he or she is converting, by way of his or her efforts and knowledge, into a complex product in accordance with numerous legal regulations. Covering the reliability requirements is inevitable, particularly when designing the motor vehicle's critical parts and assemblies. Providing the designed life with the requested reliability and safety, taking into consideration the appropriate legal regulations, is one of the requirements that have to be fulfilled with modern motor vehicles. Since reliability and long life are the primary goals in motor vehicles design, this means that developing and applying reliability design methods and techniques represents a significant activity in the vehicle-design process ([2], [3], [8], [9], [14], [15], [17] and [18]).

In the field of reliability, reliability-design methods and techniques have been developed to be applied in the phase of system design. However, these methods have been developed on different bases, so it is now difficult to determine which one is the most suitable for application in motor-vehicle design. Perceiving this problem, as well as the problem of comprehensive vehicle design, it has been concluded that it is possible to bind these methods into a single whole, with certain improvements, within the methodology of vehicle-reliability design. In this respect, vehicle-reliability design methodology has been developed ([20] and [21]), and the basis of the modern approach to technical system design, with its phases of concept, preliminary and detail design, are presented in Figure 1. Due to the available space, this paper pays attention to the phase of conceptual design of the vehicle's reliability.

1 RELIABILITY DESIGN

Incorporating reliability requirements and building them into the structure, by applying reliability-design methods and techniques, defines the vehicle's behaviour in terms of failure, and that is the vehicle designer's obligation and responsibility. The basic aim of vehicle-reliability design, i.e., of its elements, is reflected in decreasing the failure-event probability and possible human and material losses. Reliability design has a key role in motor-vehicle development, since reliability analyses and parameters are the entry data for analysing and realising the other design tasks, for the purpose of providing high vehicle effectiveness and efficiency. Maintaining the competing ability implies resolving numerous problems and issues of vehicle reliability and safety for the producer.

The aims of motor-vehicle design are often opposed to the specific dependability requirements, i.e., to the requirements related to reliability, availability and maintainability. This is the reason for investing great efforts and considerable means to meet these requirements. Integrating the overall design goals with the reliability requirements is conducted and mainly executed in the beginning of the initial design phases by establishing an appropriate reliability programme. The framework of the motor-vehicle reliability programme should be closely related to applying and mastering new technologies, as well as to possible difficulties in the design process. In other words, it ought to ensure the data and procedures for solving of these difficulties. In order to have an effective programme for providing vehicle reliability, it has to be planned and process-determined, i.e., with determined assignments, activities for completing them, and methods and techniques for the efficient execution of the activities. The basic tasks of a motor-vehicle reliability-enabling programme are as follows:

- determining the reliability requirements,
- realisation of the reliability-design process,
- supervision and control of the required reliability.

Vehicle users' sensitivity to failures is increasing. It is very often of decisive importance when deciding to purchase a particular vehicle. From the motor-vehicle user's point of view, the most important issue is the one related to the vehicle functioning without failure, i.e., it is related to the length of operating time, during which planned and indicated maintenance is provided. Failure data are the starting point for the quantitative analyses of the reliability, maintenance and safety of the vehicle elements. Bearing in mind the fact that the failure of a vehicle part or assembly is the basic concept for any reliability analysis, vehicle designers have to pay attention to the following:

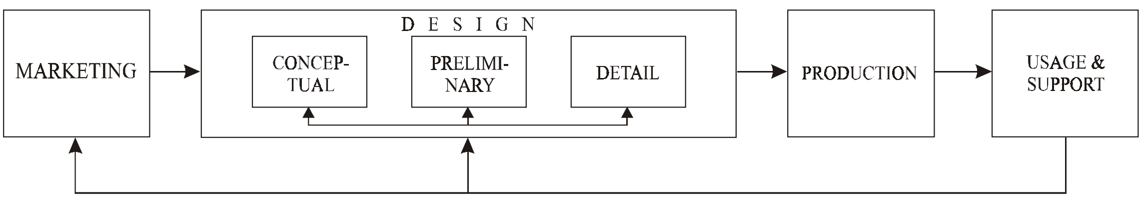


Fig. 1.

- decreasing and minimising the number of failures during operation,
- providing necessary and sufficient warning before a failure occurs,
- enabling the vehicle to continue operation at a lower level in the event of a failure,
- decreasing the costs and shortening the time required for the repair or replacement of the failed part.

The approach to motor-vehicle design that poses such and similar questions and finds the balance in a systematic manner between all the design requirements (functionality, reliability, maintenance, and logistic support) is the design approach and philosophy that ought to be accepted and applied, since it contributes to meeting the users' requirements, legal regulations and to raising the quality of vehicle usage, i.e., attaining market competitiveness. The basis of vehicle-reliability design are the methods of reliability design and the experimental databases ([1] to [3], [13] to [16] and [20] to [22]). Reliability design of vehicles and their elements ought to cover the following:

- the selection of parts and materials that have been standardised as much as possible;
- review and evaluation of all the parts and materials, prior to adopting the design documents, covering the operating characteristics, operating and critical stresses, manufacturing allowances and other features of the parts, for the determined and required function;
- applying only those constituent parts/assemblies that are capable of meeting the reliability goals, i.e., of meeting the requirements of the specification for reliability design.

The process of systems-reliability design includes a series of proceedings and working methods that in their essence have the character of predicting certain states that should be achieved within the system development. The design methods are developed and perfected with the objective of discovering the critical states stated in the process of system design, i.e., identifying possible errors, omissions and shortcomings. The decisions and selections based on the state analysis and on the results obtained from applied reliability-design methods, to a large extent contribute to a qualitative, efficient and effective achieving of the process of system design. The numerous difficulties in this kind of work and in the application of reliability-design methods, as well as the inevitable costs, can all be significantly decreased by a systematic approach, good planning, organised preparation and computer support. The initial bases and necessary preconditions for a complete inclusion of the reliability analysis and design into the vehicle-design process are the following:

- organised databases on failures, operating and critical loads and logistical parameters of motor vehicles and their elements;
- a systemised number of reliability-design methods supported by computer programmes;
- defined criteria for the selection of an optimum reliability-design method;
- the prior experience and knowledge of designers and the technological ability of motor-vehicle producers.

In accordance with the above, a reliability-design methodology has been developed covering the phases of conceptual, preliminary and detailed reliability design, so as to enable the designed system to contain certain, previously set reliability indicators. The framework and reliability design approaches are given for each of the phases, containing the sequence of applying the reliability design methods, the reasons and purpose of their application and the manner of evaluating the achieved results. Due to the wide scope of these results, this paper shows the phase of conceptual reliability design, as a portion of the developed vehicle-reliability design methods.

2 THE PHASE OF CONCEPTUAL RELIABILITY DESIGN

Realisation of the process of system reliability design begins with developing a logical model covering all the available levels of the system design. This implies an organised and systematic approach to using design methods and techniques related to reliability, so as to ensure that the system being designed contains certain reliability indicators that have been stipulated in advance. The final reliability-design objective is installing the stipulated reliability into the system structure ([13] to [16], [20] and [21]).

Identifying and defining the essence of the problem and the selection of the most acceptable solution, i.e., determining a set of quantitative and qualitative reliability requirements, represent the basic goals of reliability design within the phase of the conceptual designing. The correct outlining of the problem, i.e., of the questions, and the timely obtaining of the correct answers at the beginning of the reliability-design process is of special importance for the further realisation and for the success of reliability-design process. Therefore, it is necessary to answer the following questions:

- What is the requested, specified level of reliability?
- Why has that level of reliability been requested and specified?
- How do we realise the reliability requirements and their elements?
- What are the reasons for not being able to attain the requested reliability?
- Is the additional reliability improvement necessary?

Reliability design in the concept-design phase is primarily oriented towards defining the reliability specification and selecting the most acceptable solution from the point of view of a reliability-requirements meeting, which means that the reliability of vehicles and their elements is analysed. The process of vehicle designing is started by translating the users' requirements and needs into the specification for designing, i.e., into the design assignment within of the creation of the pre-design. The concept-design phase also defines the design goals from the point of view of meeting of the standards and regulations an of acceptable limit values, such as the following: the maximum torque burdening the transmission, the maximum operating speeds in individual transmission degrees (the tow diagram), the maximum speed and acceleration, the transmission ratio in the main transmission, and the maximum allowed level of noise. Determining the reliability requirements for each requested vehicle function was conducted on the basis of the identified stipulated functions and the desired reliability level for the covered mileage ([20] to [22]).

The biggest challenge for a reliability designer, and thus for the whole motor-vehicle designers' team, is the initial design activities, when it is possible to perform changes and modifications, practically without any significant material investments and loss of time. Therefore, the battle to successfully incorporate the reliability into the vehicle structure is either gained or lost on the issues of the accuracy, the comprehensiveness and the timeliness of the responses to the previously defined questions, as well as on the issue of forming of a precise and complete reliability specification. When aiming at providing a qualitative development of the concept design phase the literature was reviewed and research was conducted in the field of motor-vehicle reliability ([1], [5] to [8], [11] and [12]).

The basis of vehicle-reliability design methodology are the phases of concept, preliminary and detailed design and the following methods: quality function deployment (QFD), reliability specification , reliability block diagrams (RBDs), reliability functions (RFs), reliability prediction and modelling (RPM), reliability allocation methods (RAM), failure mode, effects and criticality analysis (FMECA), fault tree analysis (FTA), stress-strength interference (SSI), reliability qualification testing (RQT) and design review evaluation (DRE).

In defining the reliability requirements at the level of the vehicle-reliability concept solution and pre-design, the first seven methods were incorporated. In this respect, the reliability algorithm was defined in the conceptual phase, as shown in Figure 2.

2.1 The Algorithm of the Reliability Design Conceptual Phase

The designing of a motor vehicle is shown in the form of a flow diagram, describing in a graphic manner the activities and sequences of the characteristic activities and of the activities in the realisation of the design processes with feedbacks. The flow diagram, based on the following of the system procedure, which is also an algorithmic one, provides a complete understanding of the reliability design problem, so that no major portion is overlooked or omitted. The structure of the system-reliability design proceeding of the developed methodology, as stated earlier, is based on three basic phases: the concept, the preliminary and the detailed, while Figure 2 shows the conceptual phase. These phases often overlap and are executed alternately, with a returning to previous phases through a feedback mechanism. The mainstay of the developed reliability-design methodology is establishing the starting basis for the reliability design and to improve the designers' activities, rendering the improved proceedings of operation for a logical process of considering and deciding, using the methods and techniques of reliability design.

The concept reliability design covers the vehicle system level, where by applying the reliability design methods the systems are considered, i.e., options are evaluated and a decision is made regarding the most suitable solution, according to the established criteria devised on the basis of the vehicle reliability-design specification. In the phase of the vehicle-reliability concept design, the established sequence of applying reliability-design methods is based on their accuracy and complexity. Namely, the reliability methods that are relatively simple are applied first, while the attained results have a lower confidence level, i.e., they are of an orientational character. With the small step forward, a complex method (FMECA), with a higher confidence level, was introduced into the designing process, through which the initial results are corrected in an analytical manner, and substantially more accurate reliability parameters are defined ([11], [16] to [18] and [23]).

In the phase of concept reliability design, a reliability block diagram (RBD) is formed on the basis of knowing the vehicle system structure, the system functioning manner, i.e., the effect of system and subsystem failure on the vehicle's operation. Considering the structure of the vehicle and its systems, from the point of view of functioning, and that of the requested functions, defining is enabled of the satisfactory and unsatisfactory vehicle/ system operations, as well as the manner in which to achieve it. The system, which is divided into functional blocks (systems and subsystems), represents the appropriate connections in the reliability block diagram, which is defined on the basis of the goal function and on the functional block failure. These in turn bring about a vehicle/system failure. RBD represents the basis for defining the vehicle-reliability function. Upon defining the RBD and the reliability function, a further design proceeding is realised in accordance with steps 7 to 15.

2.2 The Method of Quality Function Allocation in the Reliability-Design Process

In accordance with the algorithm, and for the purpose of translating users' needs and requirements (step 1, Figure 2) into quantitative and qualitative indicators, the method of quality function deployment (QFD) is applied, i.e., the procedure for identifying all the factors affecting the design requirements with the aim of meeting users' requirements and the necessary methods and responsibilities for their control. Quality function deployment goes beyond the domain of reliability, since among the users' requirements there are also the users' wishes, but this is a useful and systematic way of pointing out the necessary activities of designing and control, aimed at enabling reliability. The quality deployment function is applied for the purpose of translating of users' requirements into product characteristics, and in that way quality deployment is translated into the user-oriented quality function. The final objective is including the user's "voice" into the process of product development and design, in this case vehicle development and design, regardless of whether it is a brand new or a modified product, with the aim of realising users' requirements with respect to quality.

2.3 Reliability Specification

The model that takes into account users' wishes, requests and needs for the purpose of attaining users' satisfaction, interpreted through the "quality houses", enables an equilibrium between the operating characteristics of the requested reliability levels and the maintenance needed, i.e., the degree of availability of a freight vehicle. In the course of the reliability-specification forming, compromises are quite possible and exchanges between reliability parameters and maintenance parameters for the purpose of accomplishing the requested availability degree, with minimising of the construction costs.

The reliability specification represents a starting point for reliability analyses and estimations, i.e., for the reliability design, and it is the constituent part of the documents related to the stipulated vehicle characteristics and performances. Defining the reliability specification of the vehicle, i.e., of its systems, is based on:

- the reliability data available from the manufacturer, distributor and user of the vehicle,
- requirements and needs of the user, as the main sources of information,
- many years of following up of the vehicle in operational conditions ([19] to [21]).

The specification (*steps 2 & 3, Figure 2*) implies defining the reliability level for the designed mileage and estimated number of failures. For instance, it can be adopted that there are no more than 10% of failures at 300,000 km of covered route. That implies that the number of vehicle systems failures will not be greater than 10%. In that respect, the reliability specification of the vehicle, as well as of its elements, where this level of reliability is expected, is as follows:

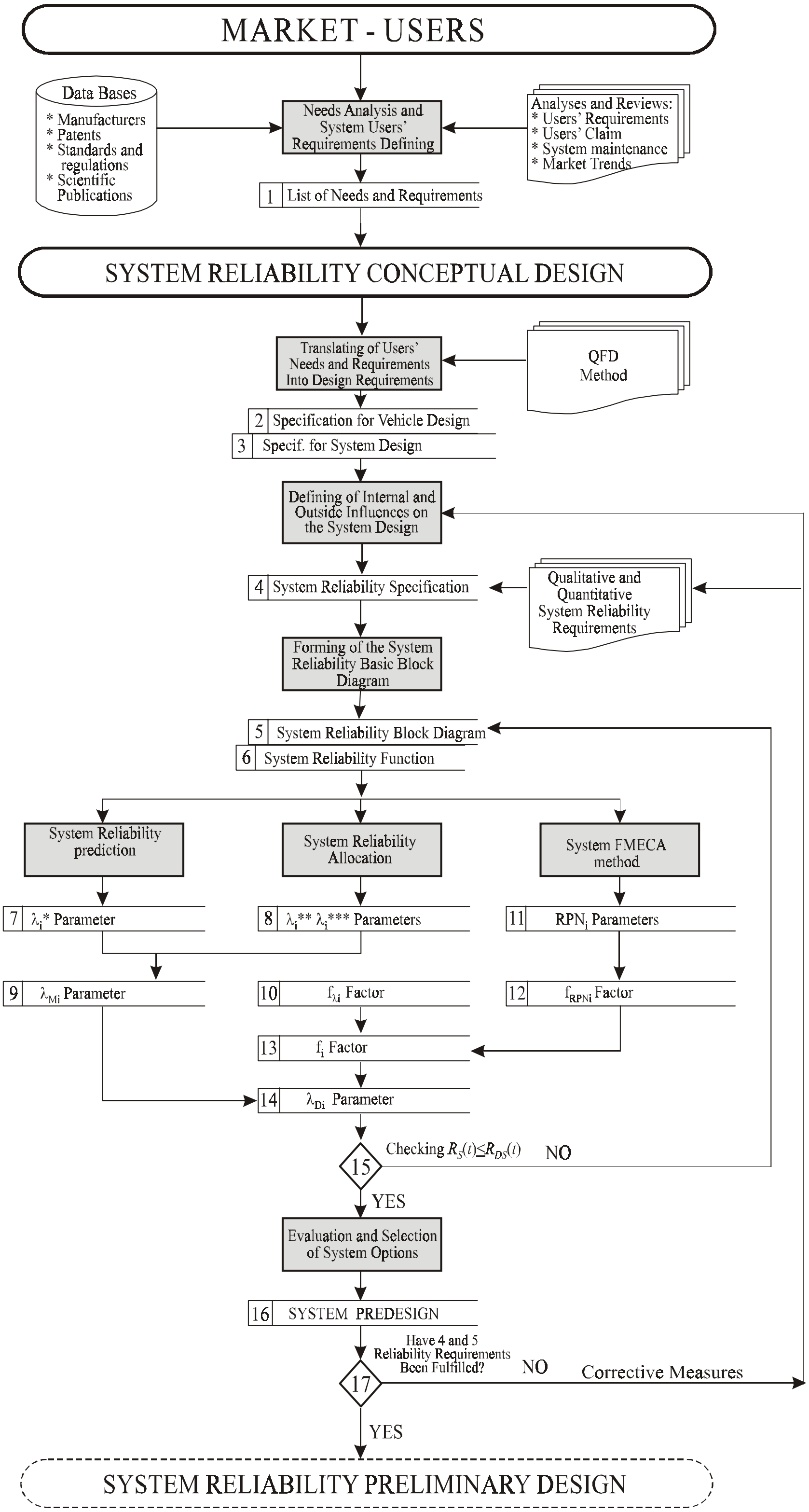

MARKET - USERS
Data Bases
* Manufacturers
* Patents
* Standards and regulations
* Scientific Publications
Needs Analysis and System Users' Requirements Defining
Analyses and Reviews:
* Users' Requirements
* Users' Claim
* System maintenance
* Market Trends
1 List of Needs and Requirements
SYSTEM RELIABILITY CONCEPTUAL DESIGN
Translating of Users' Needs and Requirements Into Design Requirements
QFD Method
2 Specification for Vehicle Design
3 Specif. for System Design
Defining of Internal and Outside Influences on the System Design
4 System Reliability Specification
Qualitative and Quantitative System Reliability Requirements
Forming of the System Reliability Basic Block Diagram
5 System Reliability Block Diagram
6 System Reliability Function
System Reliability prediction
System Reliability Allocation
System FMECA method
7 λ_i* Parameter
8 λ_i** λ_i*** Parameters
11 RPN_i Parameters
9 λ_{Mi} Parameter
10 $f_{\lambda i}$ Factor
12 f_{RPNi} Factor
13 f_i Factor
14 λ_{Di} Parameter
15
Checking $R_S(t) \leq R_{DS}(t)$
NO
YES
Evaluation and Selection of System Options
16 SYSTEM PREDESIGN
17
Have 4 and 5 Reliability Requirements Been Fulfilled?
NO
Corrective Measures
YES
SYSTEM RELIABILITY PRELIMINARY DESIGN

Fig. 2.

$$VT_{10\%}=300,000\ km \quad (1).$$

On the basis of this condition, the reliability specification (*step 4, Figure 2*) is:

$$R_S(300,000)=0.9 \quad (2).$$

2.4 Reliability Block Diagram

The reliability block diagram *(step 5, Figure 2)* was defined on the basis of the functional-technological connection of the vehicle elements and the analysis of element failures' effect on the vehicle. In other words, the effect of a vehicle system failure upon the vehicle is analysed in the phase of the concept design.

2.5 Reliability Function

On the basis of the defined reliability block diagram and the adopted exponential failure distribution, the reliability function of the vehicle, as well as of its systems, is defined (*step 6, Figure 2*), as follows:

$$\begin{aligned} R_V(t) = R_S(t) &= f_S\left[R_1(t),(R_2(t),.....,R_n(t)\right] = \\ &= f_S\left[e^{-\lambda_1 t}, e^{-\lambda_2 t},.....,e^{-\lambda_n t}\right] \end{aligned} \quad (3)$$

$$\begin{aligned} R_i(t) = f_i\left[R_{i.1}(t),R_{i.2}(t),.....,R_{i.n}(t)\right] &= \\ = f_i\left[e^{-\lambda_{i.1} t}, e^{-\lambda_{i.2} t},.....,e^{-\lambda_{i.m} t}\right] \end{aligned} \quad (4)$$

where:
- $R_v(t)=R_S(t)$ is the vehicle reliability,
- $R_i(t)$, λ_i reliability, i.e., system failure intensity of the vehicle, i=1- n,
- $R_{i.j}(t)$, $\lambda_{i.j}$ reliability, i.e., subsystem failure intensity of the system, j=1-m.

2.6 Predicting Reliability

On the basis of the available literature and reliability research on vehicles in operation, an estimate is performed, i.e., predicting possible values of failure intensity (*step 7, Figure 2*), i.e., the value is adopted between the following values:

$$\lambda^*_{\min} \langle \lambda^*_{\text{ado}} \langle \lambda^*_{\max} \quad (5)$$

where:
- $\lambda^*_{\min}, \lambda^*_{\text{ado}}, \lambda^*_{\max}$ are the minimum, the adopted, and the maximum value of failure intensity, respectively.

2.7 Reliability Allocation

In the concept reliability-design phase, the allocation methods are applied (step 8, Fig. 2) of equal distribution λ_i^{**} and λ_i^{***}, in the form:

$$\lambda_i^{**} = \frac{\lambda_S}{n} = \frac{-\ln R_S(t)}{n \cdot t} \quad (6)$$

$$\lambda_i^{***} = \frac{n_i\left[-\ln R_S(t)\right]}{n \cdot E_i \ \cdot t_i} \quad (7)$$

where:
- n, total number of system elements,
- t, the designed time of system operation
- n_i, total number of elements of the i-th subsystem,
- E_i, the subsystem significance degree,
- t_i, time of operation of the i-th subsystem.

The stated failure intensities are applied for determining the λ_{Mi} mean value (step[9, Fig. 2) and $f_{\lambda i}$ failure intensity factor (step 10, Fig. 2), in the form:

$$\lambda_{Mi} = \frac{\lambda_i^* + \lambda_i^{**} + \lambda_i^{***}}{3} \quad (8)$$

$$f_{\lambda i} = \frac{\lambda_{Mi}}{\sum_1^n \lambda_{Mi}} = \frac{\lambda_{Mi}}{\lambda_{DS}} \quad (9)$$

where:
- λ_{Mi}, the failure intensity mean value
- $\lambda_{DS} = \sum_{i=1}^{n} \lambda_{Mi}$, the designed vehicle-failure intensity value,
- $f_{\lambda i}$, the failure intensity factor.

2.8 Failure Mode, Effects and Criticality Analysis – FMECA

Conducting the analysis of the failure mode, the effects and the criticality (FMECA) makes it possible to identify all the potential and known modes of failure occurrences in the system assemblies/parts, their causes, the evaluation of the consequences and the assessment of the failure criticality. Individual system elements (subsystem, assembly, and part) can have several failure modes, since each stipulated function can have several failure modes. Failure modes are allocated, according to the required function, into three groups: complete function loss, partial function loss and wrong function, and this is important for conducting the FMECA method. For each failure mode, the possible effect is analysed at a higher level, i.e., at the whole system level.

By applying the FMECA method, the assessment of the vehicle elements' failure criticality is determined, RPN_i, *(step 11, Fig. 2)* in the form:

$$RPN_i = PF_i \cdot FDV_i \cdot PFR_i \tag{10}$$

where:
- RPN_i, failure criticality degree assessment,
- PF_i, probability of failure occurrence,
- FDV_i, the extent of failure consequence,
- PFR_i, probability of the failure detection.

The assessments of failure criticality RPN_i were applied to determine the failure criticality factor f_{RPNi} *(step 12, Fig. 2),* in the form:

$$f_{RPNi} = \frac{\frac{1}{RPN_i}}{\sum_1^n \frac{1}{RPN_i}} \tag{11}$$

where:
- f_{RPNi}, the failure criticality factor.

2.9 Designed Values of Failure Intensity and Reliability

On the basis of the above-determined values, the factor f_i is determined *(step 13, Fig. 2),* and the designed value of the failure intensity *(step 14, Fig. 2),* in the phase of concept reliability design, is in the form:

$$f_i = \frac{f_{\lambda i} + f_{RPNi}}{2} \tag{12}$$

$$\lambda_{Di} = f_i \lambda_{DS} \tag{13}$$

where in the above expressions:
- f_i, the factor of failure intensity mean value,
- λ_{Di}, the designed failure intensity value.

On the basis of the λ_{Di} design values, the reliability design value is determined in the phase of the concept reliability design, in the form:

$$R_{Di}(t) = e^{-\lambda_{Di} t} \tag{14}.$$

According to expressions (3) and (14), the designed vehicle reliability-function value is:

$$R_{DS}(t) = e^{-\lambda_{DS} t} = \prod_{i=1}^{n} R_{Di}(t) = e^{-t\sum_{i=1}^{n}\lambda_{Di}} \tag{15}.$$

Using a logarithm, the following is obtained:

$$\lambda_{DS} = \sum_{i=1}^{4} \lambda_{Di} \tag{16}$$

where:
- $R_{Di}(t)$, vehicle system reliability designed value,
- $R_{DS}(t)$, vehicle reliability designed value for the designed time t.

2.10 Checking

Checking *(step 15, Fig. 2)* of the set reliability value $R_S(t)$ and the designed one $R_{DS}(t)$, is done so as to satisfy the condition that:

$$R_S(t) \le R_{DS}(t) \tag{17}.$$

In the event of an exponential vehicle failure distribution, as adopted in this paper, the expression (14) is as follows:

$$R_S(t) = e^{-\lambda_S t} = e^{-t\sum_1^n \lambda_i} \le R_{DS}(t) = e^{-t\sum_1^n \lambda_{Di}} = e^{-\lambda_{DS} t} \tag{18}.$$

Using the logarithm of expression (18) we obtain:

$$\lambda_S = \sum_1^n \lambda_i \ge \lambda_{DS} = \sum_1^n \lambda_{Di} \tag{19}.$$

In the case that the condition given in Equation (18) is satisfied, further designing is continued in accordance with *steps 16 and 17, Fig. 2*, within the phase of preliminary reliability design. Otherwise, in accordance with *step 17, Fig. 2*, it is necessary to take corrective measures according to the given algorithm.

3 EXAMPLE

Due to the wide scope and the complexity of vehicle-reliability designing, this paper gives an example of motor-vehicle systems reliability design, i.e., of the mechanical power transmission system (hereinafter the PTS) of a freight vehicle within the phase of the concept reliability design. However, all that is presented for this particular system can be applied to other freight-vehicle systems as well, and to the vehicle as a whole. Structurally, this system comprises the following: clutch, gearbox, universal joint and rear axle.

The PTS's reliability depends on the reliability of its constituent parts, while the designing and the selection of parts have to be in accordance with the defined stipulated functions of those parts. The stipulated functions are those entered by designing into an item (system, subsystem, or part), jointly comprising its overall operational ability. The quality of the reliability analysis greatly depends on the ability of the designer to identify all the stipulated functions of an item, i.e., to classify the stipulated functions, achieving a definition of the priority. According to the number of constituent subsystems, assemblies and parts, their mutual relations, as well as the great number of stipulated functions, the PTS represents a complex system. Bearing in mind the fact that in the functional sense the PTS is a sequential link, it can be stated that the transmission system reliability design process is a very complex and demanding task that requires a timely establishment of a reliability programme. Taking into consideration the great limitations regarding reducing the number of constituent parts/

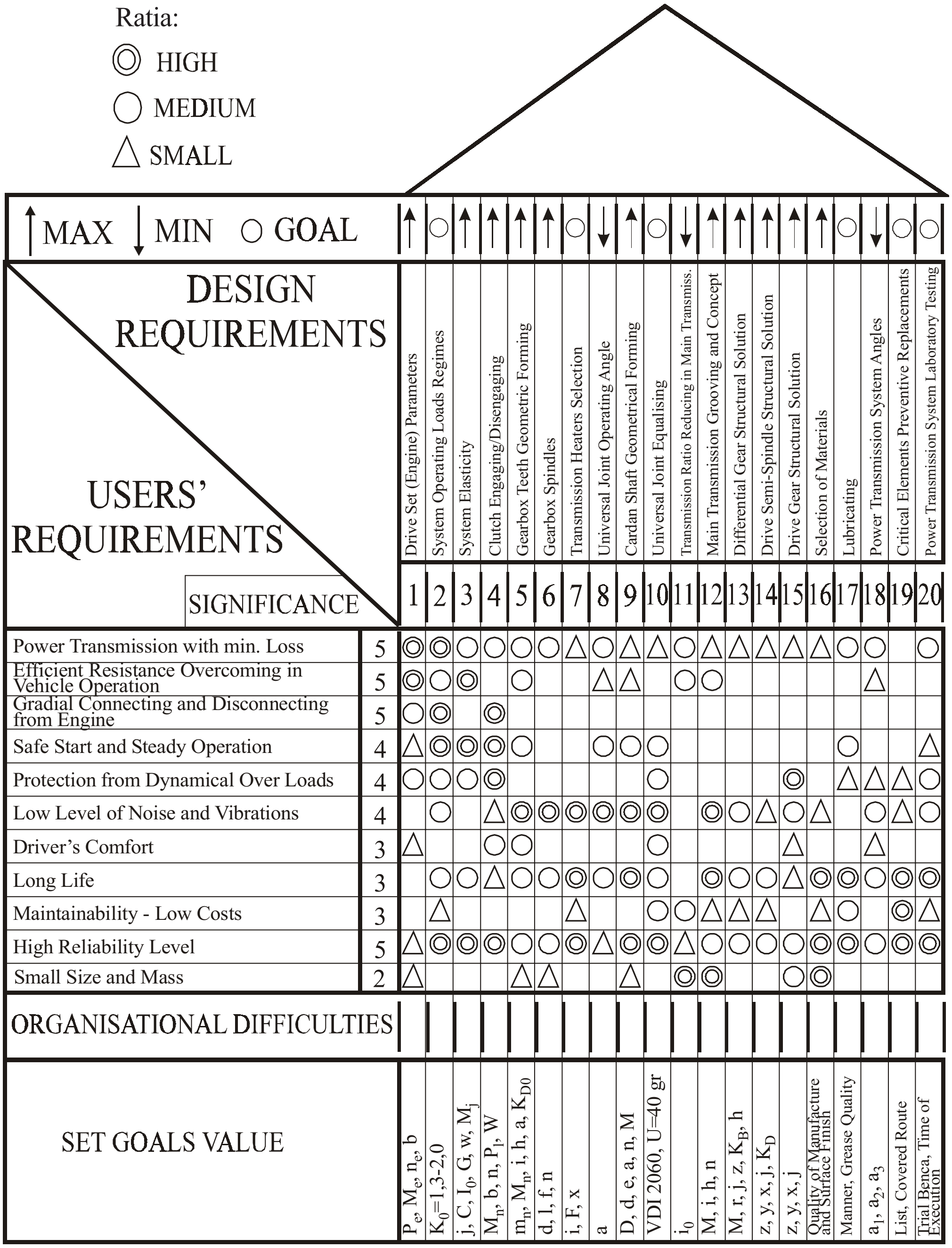


Fig. 3.

assemblies, accomplishing the stipulated system reliability can be obtained by applying reliability design methods and techniques. In accordance with the algorithm in Figure 2, the text below shows the proceeding of reliability design in the phase of concept reliability design for the PTS.

Step 1, Figure 2: Using the QFD method, the vehicle user's needs, requirements and leanings were identified in connection with the PTS, obtained on the basis of processing and analysing the filled-in questionnaires and interviews with a large number of freight-vehicle users. Numerous initial data expressed through the freight-vehicle users' requests and wants, were previously carefully "cleaned" to remove any impreciseness and fuzziness. After that, research of the relevant and measurable system characteristics, i.e., the design stipulations, was conducted, as well as the estimations of interdependence intensities, thus determining the design stipulations that have a major influence on the overall freight-vehicle users' requirements. The design parameters target values were also defined, as well as the guidelines according to which designers can influence the users' requirements. The "quality house" for the PTS, obtained by the QFD method, is shown in Figure 3.

In accordance with steps 2 & 3, Fig. 2, the specification for the PTS of $VT_{10\%}$=300,000 km was adopted, according to what is stated in defining expression (1). In accordance with this value, the stipulated level of PTS reliability was stipulated (*step 4, Fig. 2*), of:

$$R_{PTS} = R_S(300{,}000) = 0.9 \qquad (20)$$

for the designed time t, i.e., for the covered route of 300,000 km.

Step 5, Fig. 2: Based on the analysis of the functional-technological connection of the PTS elements, it was concluded that the PTS fails if there is a failure of the clutch or gearbox, or if there is a failure of the universal joint or drive gear. Therefore, it is a case of independent event failures. On the basis of this, the RBD represents a sequential link of 1-clutch, 2-gearbox, 3-universal joint and 4-drive gear, as shown in Figure 4.b. For example, Figure 4.a. shows the RBD for the vehicle. In defining the RBD for the vehicle, it was accepted that the failure of any system (from S_1, S_2 to S_{PTS} - power transmission system, up to S_n), causes vehicle failure as well.

In accordance with step 6, Fig. 2, and on the basis of the specified reliability, expression (20), the defined RBD, Figure 4.b. and the adopted exponential system-failure distribution, the "mechanical power transmission reliability function" was defined in the form:

$$R_S(t) = \prod_{i=1}^{4} R_i(t) = e^{-\left(\sum_{i=1}^{4}\lambda_i\right)t} = e^{-\lambda_S t} = 0.9 \qquad (21).$$

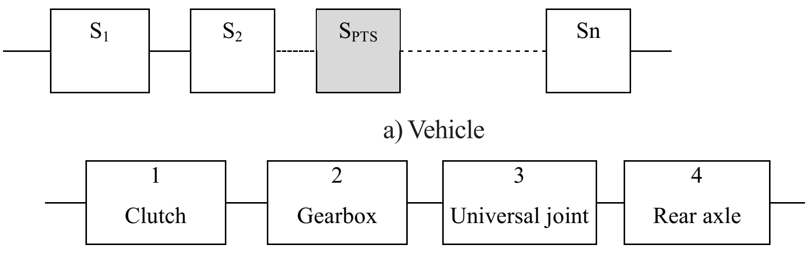
On the basis of this value, for the designed number of kilometres of t = 300,000 km, the failure intensity of the PTS is:

$$\lambda_s = -\frac{\ln R_S(t)}{t} = -\frac{\ln 0.9}{300000} = 0.3512 \cdot 10^{-6}\, km^{-1} \qquad (22)$$

where:

- $R_S(t)$, λ_S, the set value of failure reliability and intensity of PTS,
- $R_i(t)$, λ_i, $R_1(t)$, λ_1, $R_2(t)$, λ_2, $R_3(t)$, λ_3, $R_4(t)$, λ_4, of the failure reliability and the intensity of the subsystem (*i*), i.e., of the clutch, gearbox, universal joint and drive axle, respectively,
- *t=300,000* the freight vehicle designed number of covered kilometres.

After defining the reliability function, and on the basis of the available literature and reliability research performed on vehicles in operation, predicting and allocating failure intensity was performed. In that respect, the failure intensity values of λ_i^* according to Expression (5) *(step 7, Fig. 2)*



b) Power Transmission
Fig. 4.

were adopted and given in Table 1. This table also gives the failure-intensity values allocated by applying the method of equal distribution λ_i^{**} according to expression (6) and λ_i^{***} according to expression (7) (*step 8, Fig. 2*). On the basis of $\lambda_i^{*}, \lambda_i^{**}, \lambda_i^{***}$, the mean values λ_{Mi} were determined, in accordance with expression (8) (*step 9, Fig. 2*), and given in Table 1.

Using the FMECA method, a failure analysis was made and the values were set for the failure criticality degree assessment for the RPN_i according to expression (10) and given in Table 2, *(step 11 Fig. 2)*. On the basis of the RPN_i and expression (11), failure criticality factors were determined and given in Table 1, *(step 12, Fig. 2)*.

According to steps 10 & 13, Fig. 2, i.e., to Expressions (9) & (12), the values of factors $f_{\lambda i}$, i f_i were determined and given in Table 1. On the basis of λ_{Mi}· and these factors, according to Expression (13), the failure-intensity designed values were determined for $\lambda_{Di\,i}$ of the PTS subsystems and given in Table 1.

According to step 15, checking the set values for λ_S and $R_S(t)$, according to Expressions (20) & (22) with respect to the designed values, λ_{DS}, according to Expression (16), Table 1, and $R_{DS}(t)$ according to Expression (15), and consistent with Equations (18) & (19), is a positive one, i.e., we find that:

$$\lambda_S = 0.3512 \cdot 10^{-6} \geq \lambda_{DS} = \sum_{i=1}^{4} \lambda_{Di} = 0.3474 \cdot 10^{-6} \left[\mathrm{km}^{-1}\right] \tag{23}$$

Table 1

	Failure rate $\lambda \times 10^{-6}[\mathrm{km}^{-1}]$				Factor			Failure rate $\lambda \times 10^{-6}[\mathrm{km}^{-1}]$
	Predicting of reliability	Allocation reliability		**Mean value**				
Subsystem (i)	λ_i^{*}	Equal distribution λ_i^{**}	AGREE λ_i^{***}	λ_{Mi}	$f_{\lambda i}$	f_{RPNi}	f_i	λ_{Di}
1-Clutch	0.04	0.0878	0.017	0.0483	0.1390	0.0210	0.1745	0.06064
2-Gearbox	0.09	0.0878	0.13	0.1026	0.2952	0.2750	0.2851	0.09907
3-Universal joint	0.05	0.0878	0.034	0.0573	0.1617	0.2050	0.1834	0.06371
4-Rear axle	0.16	0.0878	0.17	0.1392	0.4001	0.3100	0.3550	0.12338
Checking				λ_{MS}= 0.3474	1.0000	1.0000	1.0000	λ_{DS}=0.3474

Table 2

FMECA FORM									
RELATED UNIT	COMPONENT	FAILURE				ACTUAL STATUS			
		KIND	EFFECT	CAUSE	CONTROL MEASURES	PF_i	FDV_i	PFR_i	RPN_i
Power transmission	Clutch	Power flow interruption	Loss of function	Main spring failure	Measuring of rigidity	3	10	8	240
		⋮							
	Gearbox	Power flow interruption	Loss of function	Spindle output failure (stuck, worn out)	Replacement	2	9	10	180
		⋮							
	Universal joint	Power flow interruption	Loss of function	Telescope failure (stuck, worn out)	Testing of operating loads	3	9	9	243
		⋮							
	Rear axle	Power flow interruption	Loss of function	Flat gear failure	Replacement	2	10	8	160
		⋮							

ESTIMATION OF CRITICAL DEGREE BASED ON						ESTIMATE OF CRITICAL DEGREE: Risk Priority Number – RPN RPN = PF x FDV x PFR		
Probability of Failure - PF		Failure Demerit Value - FDV		Probability of Failure Remedy - PFR				
NEGLIGIBLE	1	NEGLIGIBLE	1	CRITICAL	1	Estimated value of RPN		
LOW	2-3	LOW	2-3	HIGH	2-3	LOW	< 50	
MEAN	4-6	MEAN	4-6	MEAN	4-6	MEAN	50 -100	
HIGH	7-8	HIGH	7-8	LOW	7-8	HIGH	100 - 200	
CRITICAL	9-10	CRITICAL	9-10	NEGLIGIBLE	9-10	CRITICAL	>200	

$$R_S(t) = e^{-\lambda_S t} = 0.9 \le R_{DS}(t) = \prod_{i=1}^{4} R_{Di}(t) = e^{-t\sum_{i=1}^{4}\lambda_{D,i}} = \\ = e^{-\lambda_{DS} t} = e^{-0.3474\cdot 10^{-6}\cdot 300000} = 0.901 \quad (24)$$

As the condition given by Equation (18) *(step 15, Fig. 2)* was satisfied, further designing is continued in accordance with steps *16 & 17, Fig. 2*. As the conditions given by Equation (18) were fulfilled, thus simultaneously the conditions given in steps *16 & 17, Fig. 2,* were met. Further designing is continued within the phase of the preliminary reliability design. In this phase, the designing of assemblies, subassemblies and parts is performed, together with the checking of their concord with the values of failure intensities and reliability obtained in operation, by applying of FMECA and FTA methods. In the case that the reliability is to be improved for some of the elements, checking is performed by applying the FTA method, and, if needed, by the methods of stress-strength interference, reliability qualification testing (RQT) and design review evaluation.

4 CONCLUSION

In the modern process of designing vehicles and their elements (systems, subsystems, assemblies, subassemblies and parts), it is necessary to design vehicle reliability as well. For this purpose the methodology of vehicle-reliability design has been developed, with the phases of concept, preliminary and detailed design, based on the developed methods of reliability design.

Upon defining of the users' requirements by applying QFD methods, in the phase of concept design, the vehicle reliability specification is defined, as well as designing the vehicle systems' reliability, with checking of the set requirement for the vehicle-reliability level.

For the purpose of applying the developed methodology, vehicle element failures databases were established, as well as those of the vehicle elements' critical loads. The application of the concept-phase reliability-design methodology has been demonstrated on the example of a mechanical power transmission system. In essence, all that has been presented for this particular system can also be applied to other vehicle systems and elements, and even to the vehicle as a whole.

On the basis of this study it can be concluded that the developed and applied conceptual phase of the methodology enables vehicle-reliability designing at the level of vehicle systems, with the objective of obtaining of a reliable vehicle, which in any case is one of the main prerequisites for competitiveness in the motor-vehicle market.

5 LITERATURE

[1] Blanchard B.S., Fabrycky W.J. (1998) Systems engineering and analysis, Third edition, *Prentice Hall*, New Jersey.

[2] O' Connor, P. (1990) Practical reliability engineering, *John Wiley and Sons*, Chichester, UK.

[3] Todorović, J., Zelenović, D. (1990) System effectiveness in mechanical engineering, *Naučna knjiga*, Beograd.

[4] Ivanović, G., Stanivuković, D. (1988) Analysis and designing of reliability, *Vojna štamparija*, Beograd.

[5] Maguire M., Hagen M. (1999) Explosion of new products creates challenges, *Quality Progress*.

[6] Ettlie J. E. (2000) Managing technological innovation, *John Wiley&Sons, Inc.*

[7] Foster S.T. (2001) Managing quality: an integrative approach, *Prentice Hall*, New Jersey.

[8] Torbin, V., Ohotnikov, G., Egorov, E. (1988) Effektivnost tehničeskih sistem, tom 3, *Mašinostroenie*, Moskva.

[9] Ivanović, G., Popović, P., Stojović, M. (1992) The fault tree analysis application in motor vehicle design, *ATA, Proceedings*, pp 1105-1114, Florence, Italy.

[10] Ivanović, G., Popović, P., Stojović, M., Đokić, M. (1994) Fault tree analysis applied to vehicle design, *International Journal of Vehicles Design*, Vol. 15, N 3/4/5, pp. 416-424, UK.

[11] Knežević, J., Papić,. Lj., Aronov, J. (1996) Advanced approaches to reliability and safety assurance of complex systems on the basis of FMECA method, *6th MIRCE Symposium*, Exeter, UK.

[12] Verma, D., Knežević, J. (1995) Development of fuzzy requirements matrix to support conceptual system design, *5th MIRCE Symposium*, pp. 339-345, Exeter, UK.

[13] Grubišić,V. (1985) Criteria and methodology for lightweight design of vehicle components subjected to random loads, *SAE 850367*.
[14] Vickman, S. (1986) The Volvo experience in reliability technology, *FISITA 865099*, Beograd.
[15] Vikman, S. (1988) Research for automotive reliability analysis methods", *Proceedings "Automobile Reliability"*, Prague.
[16] Brunner, F. (1988) Considerations about reliability prediction for safety related vehicles components, *Proceedings "Automobile Reliability"*, Prague.
[17] Todorović, J. (1988) Technical system failures analysis, *Kvalitet i pouzdanost*, br. 59, Beograd.
[18] Frey, E. (1992) FMEA Strategy, *ATA: Innovation and reliability in automotive design and testing, Proceedings*, pp 1077-1088, Florence, Italy.
[19] Demić, M., Popović, P. (1999) Determination of actual loads of dump truck systems and aggregates, *MVM- Mobility& Vehicles Mechanics*, V 25, No 2&3, pp. 3-29, Kragujevac.
[20] Popović P., Ivanović G. (2001) The methodology for reliability design of mechanical systems, *11th International MIRCE Symposium, Proceedings*, Exeter, UK, December.
[21] Popović P., Ivanović G. (2002) The methodology for reliability design of power transmission, Proceedings, *2002 International Body Engineering Conference and 2002 Automotive and Transportation Technology Congress*, 2002-01-2201, Paris, France, July.
[22] Popović P. (1988-1992) Research work in the field of motor vehicle reliability (the reports for the needs of FAP), *INN VINCA, The Engines and Vehicles Institute*, Beograd.
[23] IEC, Technical Committee No. 56 (1984) Reliability and maintainability, Fault Tree Analysis.
[24] MIL-STD-2070 (1977) Procedures for performing a failure mode, effects and criticality analysis for aeronautical equipment.

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Iskanje okvar ležajev z uporabo Meyerjevih algoritmov

Bearing-Fault Detection Using the Meyer-Wavelet-Packets Algorithm

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Pri mnogih uporabah je bila uspešno upoštevana omejitvena lastnost valčni paket (VP) pri časovno-frekvenčni analizi. V tem prispevku raziskujemo novo metodo iskanja okvar ležajev na osnovi VP z uporabo Meyerjevega filtra, tako dobimo Meyerjev algoritem (MVP). Predlagani MVP algoritem smo ocenili za simulirane signale in signale v dejanskem času. Z upoštevanjem tega smo uporabili učinkovito metodo za skrajšanje preračunov algoritma. Tako je algoritem primernejši za sprotno odkrivanje okvar ležajev in zato učinkovit način za obdelavo signalov nihanj in drugih mehanskih sistemov.

(Ključne besede: napake na ležajih, odkrivanje napak, algoritmi, vibracijski signali)

The localization property of wavelet packets in a time-frequency analysis has been successfully considered in many applications. In this paper, a new method of bearing-fault detection is investigated using a WP basis with the Meyer filter leading to the Meyer wavelet packets (MWPs) algorithm. The proposed MWP algorithm is evaluated for simulated and real-time signals. In this respect, an efficient method is used to greatly reduce the algorithm's computations. This makes the algorithm more suitable for the online detection of failures in bearings, and also an effective candidate for the processing of vibration signals in other mechanical systems.

(Keywords: bearing fault detection, MWP, algorithms, vibration signals)

0 INTRODUCTION

A ball bearing consists of an inner race, an outer race and a number of rolling balls, as shown in Fig. 1 [1]. Normally, the metal fatigue produced between the above elements yields some mechanical vibrations, which in time lead to bearing damage and increases in the machine’s noise level. The contamination, corrosion, improper installation, and lubrication of bearings can effectively speed up the damage rate [2].

Bearing failures may be detected by analyzing vibration signals, which contain the machine’s dynamic information [3]. This is performed by inspecting the characteristic frequencies of the defect computed from the bearing dimensions and shaft’s rotating speed as [2]:

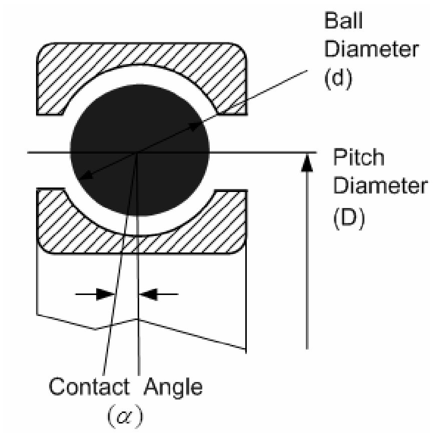


Fig. 1. *A typical bearing structure*

$$f_i = \frac{N}{2}\left[1 + \frac{d}{D}\cos(\alpha)\right] f_r \quad (1)$$

$$f_o = \frac{N}{2}\left[1 - \frac{d}{D}\cos(\alpha)\right] f_r \quad (2)$$

$$f_b = \frac{D}{d}\left\{1 - \left[\frac{d}{D}\cos(\alpha)\right]^2\right\} f_r \quad (3),$$

where N shows the number of balls, f_r is the shaft's rotating speed, α denotes the contact angle of the balls and races, f_b, f_i, f_o, and express, respectively, the frequencies of the defective ball, the inner race, and the outer race, and d and D are the balls and pitch diameters, as illustrated in Fig. 1.

Vibration signals measured on the machine's surface are normally embedded in background noise, and therefore, high-precision techniques should be established for detecting and/or diagnosing machine failures. Consistent with other findings in the literature, to resolve the frequency content of a signal using the short-time Fourier transform, a sufficient data record is required. It is well known, however, that when the latter technique is applied to a large number of samples, the time localization is lost. This becomes more significant for non-steady signals when the detection of transients and movements (containing drift, trends, abrupt changes, etc.) is required. The ineffectiveness of this algorithm in such cases may lead to poor results and wrong conclusions.

The use of wavelet packets has recently been considered for analyzing bearing defects, using coif4 wavelets [4]. The capability of this technique in concentrating on a desired portion of the frequency content of a signal in the time-frequency domain has received increasing attention in different applications. In this paper, a Meyer-packet-wavelets algorithm is proposed for bearing-fault detection. Accordingly, an effective technique is designed based on the relevant WP tree to reduce the number of computations. The outline of the paper is as follows. In Section 2, a brief review of wavelet packets and the Meyer filter is presented. In Section 3, the proposed wavelet-packet algorithm is described for bearing fault detection and is evaluated using the simulated and real-time data. In Section 4, a method is considered for reducing the required computations, and the conclusions are presented in Section 5.

1 WAVELET PACKETS

Assume that the quadrature mirror *lowpass* and *highpass* filters of an orthogonal wavelet are, respectively, given by $h(n)$ and $g(n)$. The wavelet-packet coefficients are then defined by subsampling the convolutions of $d_j^p(n)$ with $h(-2n)$ and $g(-2n)$ as [5]:

$$d_{j+1}^{2p}(n) = d_j^p(n) * h(-2n)$$
$$d_{j+1}^{2p+1}(n) = d_j^p(n) * g(-2n) \quad (4),$$

where $0<p<2^j-1$. The corresponding structure of the above wavelet-packet filter-band is depicted in Fig. 2 for two levels of decomposition. As it can be seen, the output of each branch passes separately through the quadrature mirror lowpass and highpass filters. Appropriate selection of the branches results in the desired sub-band frequency in the time-frequency domain.

To analyze precisely the frequency content of a signal, wavelets with high-frequency localization are desirable. Orthogonal Shannon wavelets have the highest frequency resolution among the various

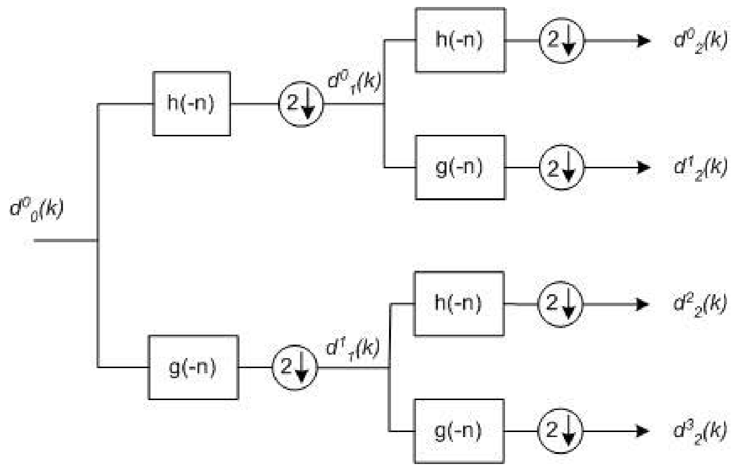


Fig. 2. *Wavele- packet filter-bank decomposition with successive filtering and subsampling*

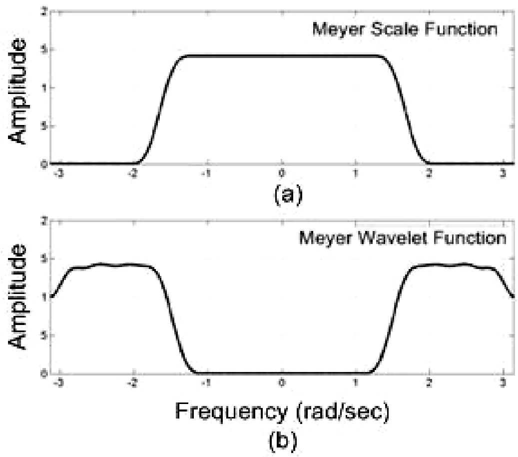


Fig. 3. *Meyer filters, a) lowpass, b) highpass*

wavelets. The lowpass and highpass filters corresponding to these wavelets divide the frequency domain in rectangular forms within $[-\pi/2, \pi/2]$ and $[-\pi, -\pi/2] \cup [\pi/2, \pi]$ [5]. The sharp edges of these filters, however, lead to non-causal wavelets in the time domain. In practice, an approximation filter may be used. Such an approximation in the time domain is the Meyer wavelet, whose frequency band is shown in Fig. 3. The smoothed edges of this filter correspond to much faster decaying wavelets than the Shannon wavelets in the time domain. Due to the unlimited length of the Meyer wavelet, its approximation, the discrete Meyer wavelet, is considered.

3 THE PROPOSED MAYER-WAVELET-PACKET BEARING-FAULT-DETECTION ALGORITHM

Consider a hole inside the inner race or outer race of a bearing. According to Section 1, a rotating shaft with a constant speed generates an impulsive vibration on the spot where the balls pass over the defect. This, in turn, excites the characteristic frequencies of a bearing component that can be estimated from the vibration signal measured on the machine surface.

To detect a bearing fault, the signal energy can be measured within a sub-band around the characteristic frequency of the bearing component. When this energy increases compared to that of the healthy one, we can decide if the inner race (or the outer race) is defective. This procedure is illustrated in Fig. 4.

The energy of the wavelet-packet coefficients is computed at each node, *(j,p),* of the tree as [4].

$$E = \left(\sum_{k=1}^{M} \left(d_j^p(k) \right)^2 \Big/ M \right)^{1/2} \qquad (5),$$

where $d_j^p(k)$ are the wavelet-packet coefficients and M shows the number of coefficients. Note that the amount of computed energy shows the severity of a defect [2]. These energies are next compared to the same values measured from the associated healthy bearing. This procedure has already been applied to *coif4* wavelets [4]. In this paper, the proposed algorithm, which we call the *Meyer wavelet packets* (*MWPs*) bearing-fault detection algorithm is designed using the *discrete Meyer (dmey)* wavelet. This wavelet has a narrower bandwidth in the frequency domain with respect to that of the *coif4,* leading to a higher frequency resolution in the time-frequency

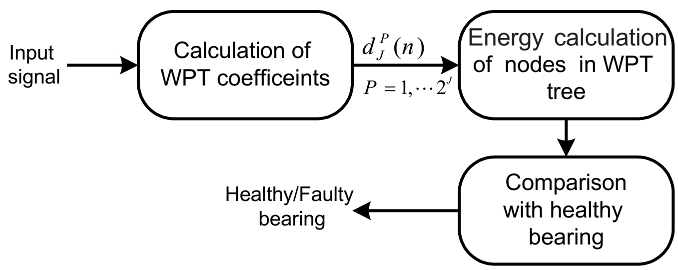


Fig. 4. *Bearing-fault detection algorithm using wavelet packets*

domain. To present this, Fig. 5 shows the amplitudes of the corresponding wavelet-packet coefficients for an input signal composed of two sinusoids at *10* and *30 Hz* as.

$$x(t) = \sin(2\pi 10t)+\sin(2\pi 30t) \tag{6}$$

This signal is sampled at 64 Hz and decomposed to the level of *J=5* by utilizing the *dmey* and *coif4* wavelets. Observe that the frequency bands of the sinusoids, shown by darker lines, are clearly resolved by the *dmey* wavelet compared to those of the *coif4,* indicating its higher frequency resolution.

3.1. Performance of MWP for Simulated Signals

The capability of the *MWP* algorithm is evaluated for simulated bearing signals assuming that the outer race is damaged. The bearing specifications are assumed to be *pd* = 65 mm, *bd* = 15 mm, *n* = 8 and $\beta = 0$, for which the characteristic frequencies are obtained based on (1 to 3) as f_r = 33.3, f_{ih} = 20.5 and f_{bh} = 68.31 Hz. The healthy bearing-vibration signal is assumed to be the sum of three low-amplitude sinusoids given by:

$$x_h(t) = 0.5\cos(2\pi\cdot f_r t) + 0.1\cos(2\pi\cdot f_{ih} t) + +0.1\cos(2\pi\cdot f_{bh} t) \tag{7}$$

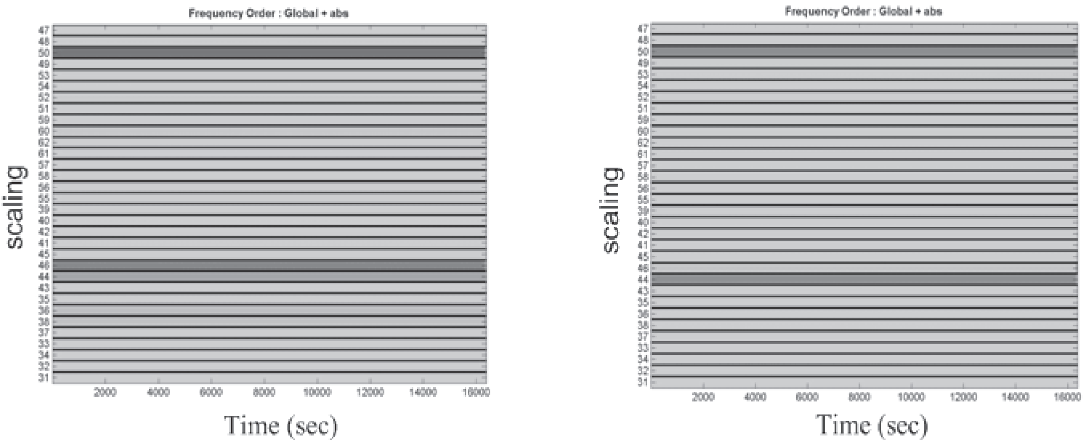
where the subscript h denotes the healthy state. To define the outer-race defect, another sinusoidal signal is also added to (7) in three individual experiments representing different levels of severity as

$$\begin{aligned} x_{d_1}(t) &= x_h(t) + 0.5\cos(2\pi.f_o t) \\ x_{d_2}(t) &= x_h(t) + \cos(2\pi.f_o t) \\ x_{d_3}(t) &= x_h(t) + 2\cos(2\pi.f_o t) \end{aligned} \tag{8}$$

where the subscript *d* indicates the signal of the defective bearing. A white Gaussian noise with zero-mean and a variance of 0.01 is also added to the signal as the background noise. The signals are sampled at 1024 Hz, leading to 16384 samples. The *demy* wavelet-packet coefficients are computed for 8 levels (j=8). In this way, the frequency region between 0 and 512 Hz is divided into 256 two-Hz bandwidths. Fig. 6 shows the energies of the 70 nodes of the wavelet-packet tree for bearing signals defined in (8). From the figure it is clear that the measured energies between nodes 43 to 47 have significantly increased as a result of the defect.

3.2. Performance of MWP for Real Data

In this experiment the performance of the MWP algorithm is inspected for real-time bearing signals. Accordingly, Figs. 7-*b* and *c* show the recorded signals of a bearing with a hole in the inner or outer race. The real data are provided for a shaft speed of 2000 *rpm* with a 40 *kHz* sampling rate filtered out from a low-pass filter with a cut-off frequency of 15 *kHz* [3]. The number of input samples is 4096. The test specifications are similar to those used in Section 3.1. From (1) and (2), the theoretical frequencies of the defective inner and outer race bearings are, respectively, obtained as f_i = 164and f_O = 102.5 Hz.



(a) (b)

Fig. 5. *Time-frequency representation of wavelet-packet coefficients for a sinusoidal signal composed of two harmonics at 10 and 30 Hz for a) coif4 wavelets, b) dmey wavelets*

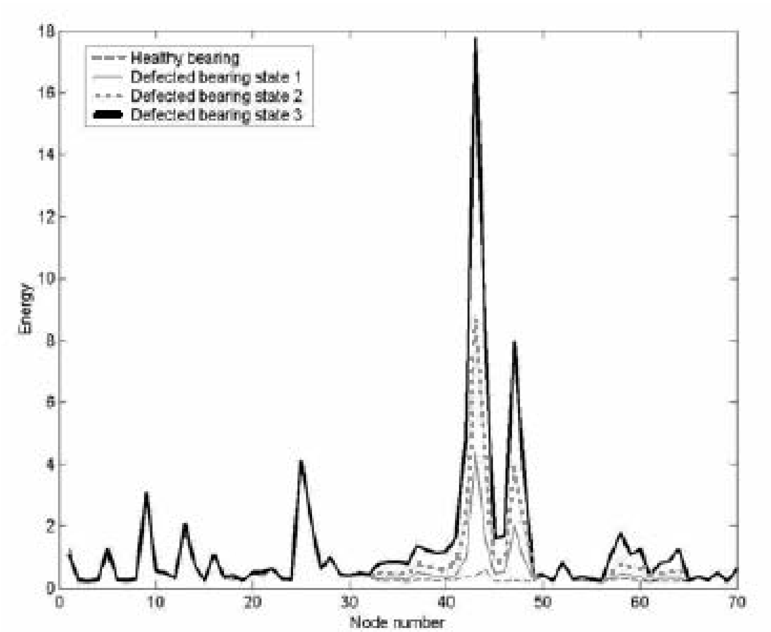


Fig. 6. *Energies of wavelet-packet nodes for the three simulated signals of a presumably defective bearing based on (8)*

The wavelet-packet coefficients of these signals are computed using the *dmey* wavelet to the level of j=12. As a result, the frequency band between 0 and 20 *kHz* is divided into 4096 sub-bands of 4.88 *Hz*. The corresponding defect frequencies are then given by the nodes between 12 and 50 or 12 and 31 for the inner or outer races, respectively. Table 1 presents the measured energies of the healthy and defective signals for the mentioned sub-bands. The respective increase of the energy in each case clearly shows the presence of a fault.

4 COMPUTATIONAL COMPLEXITY OF MWP

To find a defect, our inspection may only be concentrated around the defect characteristic frequency that is known, *a priori*. This starts with the determination of the corresponding path and nodes of the wavelet-packet tree towards the defect frequency. The schematic diagram of such a procedure is depicted in Fig. 8, wherein the thick line represents a typical path of the wavelet-packet tree towards an assumed defect frequency with 3 levels of decomposition (j=3). In this way there is no need to compute all the wavelet packet coefficients, but only the coefficients of the specified path. Next, the total energy is computed based on these coefficients, which accordingly leads to an extensive reduction in the algorithm computations.

In general, for a signal of length *N*, the number of real additions, A_{add}, and multiplications, A_{mul}, of a wavelet-packet tree for the decomposition level of J with the quadrature-mirror filter of order M is given by [7]:

$$A_{add} = A_{mul} = M \times J \times N \tag{9}$$

Using the specified path of the wavelet-packet tree mentioned above, the number of computations reduces to [7]:

$$A_{add} = A_{mul} = \frac{1}{2} M \times N \times \left(1 - \frac{1}{2^J}\right) \tag{10}$$

which is *1/2J* of that given by (9).

Table 1. *Energies of the dmey wavelet-packet coefficients for the bearing signals*

Bearing Condition \ Nodes	12 to 50	12 to 31
Healthy	0.0439	0.0987
Inner-race defected	0.0779	0.0380
Outer-race defected	0.0261	0.1056

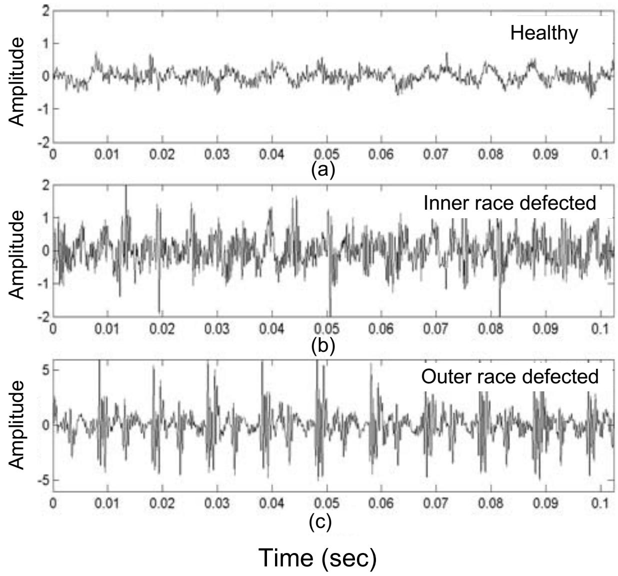


Fig. 7. *Real-data bearing signals for a) healthy, b) defective inner race, and c) defective outer race*

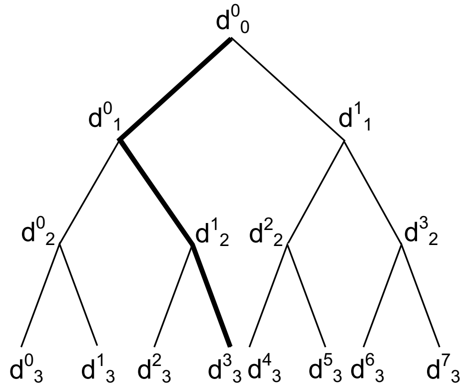


Fig. 8. *A wavelet-packet tree with a typical specified path (thick line) towards the defect frequency*

5 CONCLUSIONS

In this paper a new bearing-fault detection algorithm, which we called the MWP algorithm, was proposed, based on the *dmey* wavelet-packet coefficients. This algorithm gives a higher resolution when detecting bearing defects compared to that of the *coif4* wavelet; however, it requires more computations. To resolve the latter problem, an efficient technique was designed by considering a specific path of the wavelet-packet tree towards the defect frequency. The number of computations was then reduced by a factor of twice the number of decomposition levels. This, as a consequence, made the proposed MWP algorithm more appropriate for the online processing of bearing-fault detection.

6 REFERENCES

[1] Eren L., Devany J. (2001) Motor bearing damage detection via wavelet analysis of the starting current transient. *IEEE Instrumentation and Measurement Technology Conference*, Budapest, 21-23 May 2001.

[2] R. R. Schoen, T. G. Habetler, F. Kamran, R. G. Bartheld (1995) Motor bearing damage detection using stator current monitoring, *IEEE Trans. on Industry Applications,* 31(1995), pp. 1274-9.

[3] J. Lin, L. Qu (2000) Feature extraction based on Morlet wavelet and its application for mechanical failure diagnosis, *Journal of Sound and Vibration*, 234(1)(2000), pp. 135-148.

[4] Eren, L., Devany, J. (2002) Bearing damage detection via Wavelet Packet. *IEEE Instrumentation and Measurement Technology Conference, Anchorange, USA*, 21-23 May 2002.
[5] Mallat, S. (1998) A wavelet tour of signal processing, *Academic press*.
[6] Barber, A. (2002) Handbook of noise and vibration control, *Elsevier,* Advanced Technology.
[7] Guo, H. (1995) Theory and application of the shift-invariant, time-varying and undecimated Wavelet Transform*, Master's Thesis*, Rice University, Houston, USA.

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Mrežne organizacije - novi vzorec 21. stoletja

Network organizations - a new paradigm of the 21st century

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Globalizacija in hiter tehnološki razvoj terjajo, da organizacije razvijajo konkurenčnost na svetovni ravni. To je velik problem, predvsem za majhna in srednje velika podjetja, ki imajo omejeno razpoložljivost virov; to so ljudje, denar, razvojno-proizvodne zmogljivosti ali znanje. Zaradi tega je nujno, da se osredotočijo (specializirajo) na izbrana področja poslovnih dejavnosti, kjer imajo možnost razvijanja in doseganja svetovne konkurenčne zmožnosti. Preostale izdelke ali storitve, ki so potrebni za opravljanje sedanje ali načrtovane poslovne dejavnosti, pa poiščejo zunaj lastne organizacije, na svetovnem trgu. Splošno lahko rečemo, da tehnološko napredna podjetja iz razvitih držav iščejo v večini primerov proizvodne partnerje s ceneno delovno silo za opravljanje dejavnosti z nižjo stopnjo dodane vrednosti. Organizacije iz tehnološko manj razvitih regij pa velikokrat iščejo poslovne partnerje za razvoj in prenos novih tehnologij v prakso lastnih podjetij. Seveda je v primeru organizacij iz razvitih in manj razvitih držav ter regij mogočih več motivov za iskanje poslovnih partnerjev zunaj lastne organizacije. Predvsem gre za tiste organizacije, ki se želijo razvijati s stalnim prenavljanjem na vseh področjih poslovanja. Pri tem se organizacije soočajo s potrebo, da na novo opredelijo organizacijo in organiziranost svojega poslovanja. Zamisli, ki jih teorija ponuja, izhajajo iz teorije mrežne organizacije, projektnega vodenja in poslovnih grozdov.

(Ključne besede: mrežne organizacije, projektno vodenje, poslovni grozdi, vrednostne verige)

Globalization and rapid technological advances require organizations to develop competitively at the world level. This poses great problems, particularly for small and medium-sized companies, which have limited resources in terms of personnel, money, development, production capacities and knowledge. Therefore, it is very necessary for them to focus on selected areas of business activities where they are likely to develop competitiveness on the world market. Other products or services required to perform their current or anticipated business activities can be procured outside their own organization in the open market. Generally speaking, the technologically developed companies from developed countries in most cases try to find production partners with cheap manpower to perform their activities with lower added value. The organizations from technologically less-developed regions try to find the business partners for the development and transfer of new technologies into practice in their own companies. Of course, for the organizations from developed and less-developed countries and regions there can be several reasons why they try to find business partners outside their own organization. Here, we are concerned with the organizations wanting to develop by constantly innovating in all areas of their business activities. Organizations also face the need to redefine the way they set up their business activities. The concepts, offered by theory, issue from the theory of network organization, project management and industrial clusters.

(Keywords: network organization, project management, industrial clusters, value chains)

1 ZNAČILNOSTI EKONOMIJE ENAINDVAJSETEGA STOLETJA

1.1 Značilnosti novega ekonomskega reda

Hiperglobalisti trdijo, da živimo danes v svetu brez meja [31]. S to trditvijo se lahko strinjamo ali pa

1 CHARACTERISTICS OF THE 21ST CENTURY ECONOMY

1.1 Characteristics of the new economic order

Today, the hyperglobalists claim, people are living in a world without borders [31]. We can agree tudi ne, vendar, neizpodbitna resnica je, da se v sodobnem svetu vedno bolj soočamo s svetovno konkurenco pred lastnimi vrati. Bodisi da gre za ponudbo različnih izdelkov ali za konkurenco pri zaposlovanju delovne sile. Iz tega lahko sklepamo, da bodo državne meje vedno manjša ovira v mednarodnem poslovanju podjetij. Pri tem ne gre samo za spremembo ekonomskega reda, temveč tudi za velike svetovne kulturne spremembe. Značilnosti sprememb, ki se skrivajo pod dežnikom novega ekonomskega reda, so (sl. 1):

– globalizacija izdelkov in storitev,
– hiter tehnološki razvoj,
– nova svetovna delitev dela,
– spremembe na področju lociranja gospodarskih dejavnosti,
– spremenjene perspektive zaposlovanja,
– novi svetovni finančni sistem in
– na znanju temelječa ekonomija.

Hiter tehnološki razvoj ni povzročil samo hitrega razvoja novih izdelkov in storitev, temveč tudi to, da se je s pomočjo novih tehnologij, predvsem na področju informatike, telekomunikacij in transporta, svet zmanjšal. Seveda se svet ni fizično zmanjšal, dramatično pa so se povečale in pocenile in se še nadalje večajo in cenijo možnosti komuniciranja, fizične dostopnosti ter informacijskega obvladovanja sveta. Ena izmed najpomembnejših, generičnih tehnologij je medmrežna (spletna) tehnologija, ki je omogočila začetek nastajanja novega ekonomskega reda, prav tako kakor je tehnologija parnega stroja omogočila razvoj industrijske dobe.

with this point or not; however, it is an incontestable fact that in the modern world we increasingly face world competition on our own doorstep. Here, on the one hand, we are concerned with the offer of different products and, on the other hand, the competition in employing the manpower. It can be concluded that national borders will be a smaller and smaller obstacle to companies' international business operations. Here, it is not only the change of the economic order, but also great global changes in culture that are in question. The changes hidden under the umbrella of the new economic order are characterized by (Fig. 1):

– the globalization of products and services,
– rapid technological developments,
– a new global division of work,
– changes in the location of economic activities,
– changed prospects of employment,
– a new global financial system,
– an economy based on knowledge.

The fast technological development has brought about not only an expansive and rapid development of new products and services, but it has meant that due to new technologies, particularly in the areas of information science, telecommunications and transport, the world has become smaller. Of course, the world has not become physically smaller, but the possibilities of communicating, physical accessibility and control of the world by information have been dramatically increased and reduced in price – and are still being increased and reduced in price. One of the most important, generic technologies is internet technology, ensuring the outset of the new economic order like steam-engine technology ensured the development of the industrial age.

Sl. 1. *Značilnosti sprememb, ki se skrivajo pod dežnikom novega ekonomskega reda*
Fig. 1. *Characteristics of the changes hidden under the umbrella of the new economic order*

Na področju svetovne delitve dela se že nekaj zadnjih desetletij spoprijemamo s spremembami vzorca klasične delitve dela, ki je temeljila na predpostavki, da gospodarsko napredne države razvijajo in ustvarjajo industrijske izdelke, medtem ko države iz manj razvitih delov sveta zagotavljajo surovine in pomenijo trg za prej omenjene izdelke. Ta potek spreminjanja se je začel počasi razvijati že takoj po drugi svetovni vojni. V današnjem razvitem svetovnem gospodarstvu imamo opravka že s zahtevnimi in prepletenimi položaji, pri katerih se soočamo z razčlenitvijo gospodarskih postopkov in prestavljanje posameznih delov širom po svetu. Pojavljajo se nove gospodarsko hitro se razvijajoča področja, ki skupaj s starimi središči razvitih držav tvorijo novo zahtevno prepleteno celoto svetovnega gospodarstva. Med posameznimi področji se krepijo poslovne povezave, podprte s sodobno informacijsko-komunikacijsko in transportno tehnologijo. Vzpostavlja se nova delitev dela, ta temelji na gospodarstvu, ki ga usmerja znanje. Države in področja, ki bodo imele dovolj znanja, da bodo razvijale svetovno konkurenčno ponudbo, se bodo gospodarsko uspešno razvijale, medtem ko se bodo tiste, ki jim to ne bo uspevalo, morale zadovoljiti z gospodarsko podrejenostjo.

V zvezi s tem se dogajajo tudi spremembe na področju postavljanja gospodarskih dejavnosti. Sodobna podjetja postavljajo posamezne dele svojih gospodarskih dejavnosti v tistih delih sveta, kjer je razpoložljivost potrebnih virov in stroškovna sestava poslovanja najugodnejša. Dosežki na področju razvoja informatike in telekomunikacij ter razmeroma cenen transport omogočajo sodobnemu podjetju, da lahko razvija mrežo svoje gospodarske dejavnosti po vsem svetu.

Novi svetovni finančni sistem temelji na finančnih tokovih usmerjanih iz svetovnih finančnih središč, ki so medsebojno povezani, saj sprememba na enem koncu povzroči tudi spremembe pri drugih. Zaradi novih tehnologij finančne izmenjave ne poznajo meja in se lahko v trenutku izvedejo iz enega na drug konec sveta.

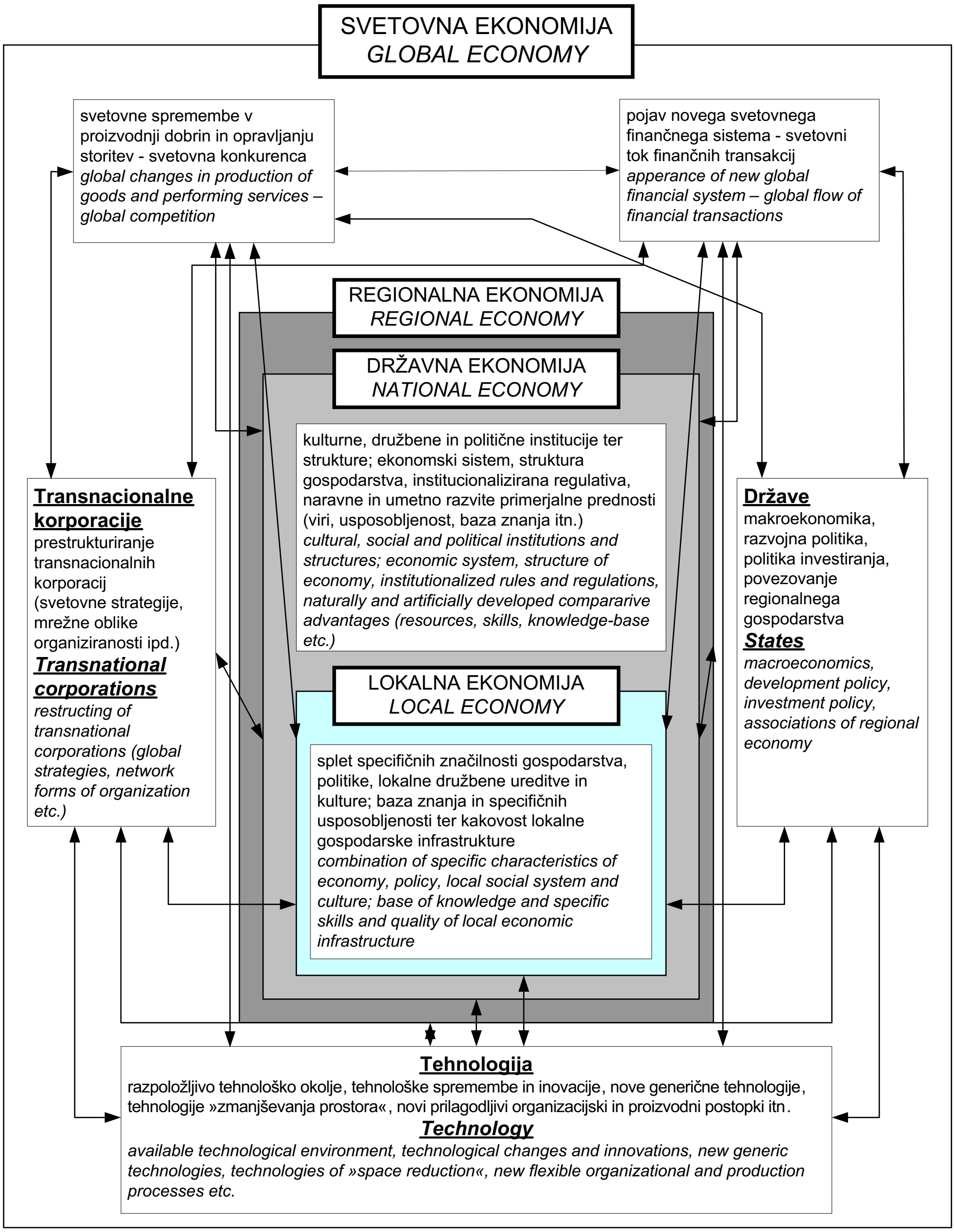
Gospodarska kriza enega dela sveta lahko hitro povzroči destabilizacijo drugega dela sveta. Če hočemo ali ne, svet postaja vedno bolj povezan. Slika 2 prikazuje globalizacijske pojave kot sistem medsebojno povezanih logičnih celot, ki pomenijo dejavnike in gibala ekonomije enaindvajsetega stoletja.

During recent decades, in the area of the global division of work, we have been facing changes to the pattern of the conventional division of work based on the assumption that the economically developed countries develop and produce industrial products, whereas the countries from less-developed parts of the world supply the raw materials and are the market for the above-mentioned products. This process of changes started to develop slowly immediately after the second world war. In today's developed world economy we have to do deal with complex and intertwined situations, where the segmentation of the economic processes and relocating the individual segments all over the world are faced. New, economically rapidly developing regions appear, forming a new, complex and intertwined whole of the global economy together with the old centres of the developed countries. Business associations, supported by the modern information, communications and transport technology, intensify between the individual regions. A new division of work, based on the knowledge-oriented economy, is being established. Countries and regions that have enough knowledge to develop competitive products will rapidly develop economically, while those not managing to do that will have to be satisfied with economic subordination.

In this respect, changes concerning the location of economic activities occur. Modern companies locate the individual segments of their economic activities in those parts of the world where the availability of the required resources and the cost structure of the business operations are the most favourable. The achievements in the area of the development of information science and telecommunications and the relatively cheap transport enable a modern company to develop the network of its economic activity worldwide.

The new global financial system is based on financial flows controlled by the world's financial centres, which are interconnected, since a change at one end causes changes at the others. Due to new technologies these financial operations know no borders and can be carried out from one end of the world to the other in the matter of a moment.

An economic crisis in one part of the world can cause the destabilization of another part of the world. The world is becoming more and more interdependent. Figure 2 shows the globalization processes as a system of interconnected logical units representing the factors and prime movers of the 21st century economy.



Sl. 2. *Ponazoritev globalizacijskih pojavov kot sistema medsebojno povezanih logičnih celot [31]*
Fig. 2. *The globalization processes as a system of interconnected logical units representing the factors and prime movers of the 21st century economy [31]*

1.2 Novi načini organiziranja poslovnih dejavnosti

Sodobne tehnologije omogočajo, da lahko postavimo del proizvodnje ali izvajanje določene poslovne funkcije kjerkoli po svetu. Sodobna podjetja nenehno analizirajo svoje poslovne dejavnosti, analizirajo svetovni trg in iščejo

1.2 New ways of organizing business activities

Modern technologies enable us to locate a part of the production or the execution of a certain business function anywhere in the world. Modern companies permanently analyze their business activities, analyze the global market and search for business opportunities poslovne priložnosti za izboljšanje poslovanja lastnega podjetja. Pojavljajo se nove oblike mrežnega organiziranja poslovanja podjetij, ki organizirajo posamezne poslovne dejavnosti v tistih delih sveta, kjer je s poslovnega vidika najugodnejše. Bodisi da gre za ceno delovne sile, specialna znanja, surovine ali kaj drugega. Oblikujejo se meddržavne proizvodne mreže (MPM), na katere oblikovanje in razvoj vplivajo razvitost poslovnega okolja vključenih držav, področij, državni ter regionalni vladni predpisi, družbeno-kulturne razmere in podobno. Svet postaja vedno bolj prepletena mreža, ki jo sestavlja niz različnih MPM in vanj vključenih specializiranih gospodarskih osebkov, ki delujejo na različnih delih sveta. Analize geoekonomskega zemljevida kažejo, da so lahko poslovne dejavnosti porazdeljene ali zbrane, vendar z veliko željo organizirati takšne dejavnosti v okviru geografsko lokaliziranih grozdov [31]. Grozdi imajo lahko eno izmed naslednjih dveh splošnih lastnosti, in sicer so:

– splošni ali
– specializirani poslovni grozdi.

Nastanek in razvoj splošnih poslovnih grozdov temelji na predpostavki, da ima človeško delovanje težnje po združevanju in oblikovanju urbanih okolij. Koristi se kažejo v urbanem gospodarstvu, katerega koristi so delitev stroškov cele vrste storitev. Večja koncentracija in obseg povpraševanja tvorita hitrejši razvoj ustrezne poslovno-razvojne infrastrukture ter druge izobraževalne in kulturne ponudbe, ki se v primeru razpršitve subjektov povpraševanja po tovrstnih storitvah ne bi razvila ali pa bi se počasneje razvijala. Tovrstni grozdi lahko nastanejo kot rezultat naravnega razvoja neke države – področja ali kot rezultat uresničevanja razvojne politike določene države ali področja.

V nasprotju s splošnimi poslovnimi grozdi pa nastajajo specializirani poslovni grozdi (SPG) v tesni povezavi z določeno gospodarsko panogo ali odsekom. Podjetja in organizacije, ki delujejo znotraj takšnega grozda se nagibajo k tesnejšemu poslovnemu sodelovanju in povezovanju. Znotraj takšnih SPG najdemo vse od podjetij, bank, izobraževalnih in raziskovalnih ustanov ipd. Tovrstno povezovanje ima običajno ugoden vpliv na povečevanje inovacijske zmožnosti vključenega gospodarstva ter večanje njegove poslovne uspešnosti. Cilj SPG je povečati svetovno konkurenčno zmožnost vključenega dela

to improve the business operations of their own company. New forms of network organization of the companies' business activities appear, organizing the individual business activities in the parts of the world where this is most favourable from the business point of view, whether the price of the manpower, special skills, raw materials or something else is in question. Transnational production networks (TPNs) are formed, whose formation and development are influenced by the stage of development of the business environment of the included countries, regions, national and regional government rules and regulations, socio-cultural conditions and the like. The world becomes an increasingly intertwined network consisting of a series of different TPNs and specialized economic entities included in them and working in different parts of the world. Analyses of the geo-economic map show that the business activities can be distributed or concentrated, but the tendency is to organize such activities in the frame of geographically localized clusters [31]. The clusters may have one of the following two general properties, i.e., they can be:

– General industrial clusters
– Specialized industrial clusters.

The formation and development of the general industrial clusters is based on the assumption that human activities tend towards agglomerating and forming urban environments. The advantages are reflected in the urban economy, whose benefits are the division of the costs of a series of services. Greater concentration and the extent of the demand bring about faster development of the relevant business-development infrastructure and educational and cultural offers that would not develop or would develop more slowly in the case of the dispersion of the subjects of the demand for such services. Such clusters can be the result of the spontaneous development of a country/region or the result of the implementation of the development policy of a country/region.

In contrast to the general industrial clusters the specialized industrial clusters (SICs) are the result of close association with an economic branch or sector. The companies and organizations working within such a cluster tend towards closer business cooperation and association. SICs may include companies, banks, educational and research institutions, etc. Such associating usually has a favourable effect on the growth of the innovation capability of the economy included and on the increase of its business success. The objective of the SIC is to increase the global competitiveness of the included part of the economy in the selected area of its activigospodarstva na izbranem področju njegovega delovanja ter celotnega, s tem povezanega, geografskega področja.

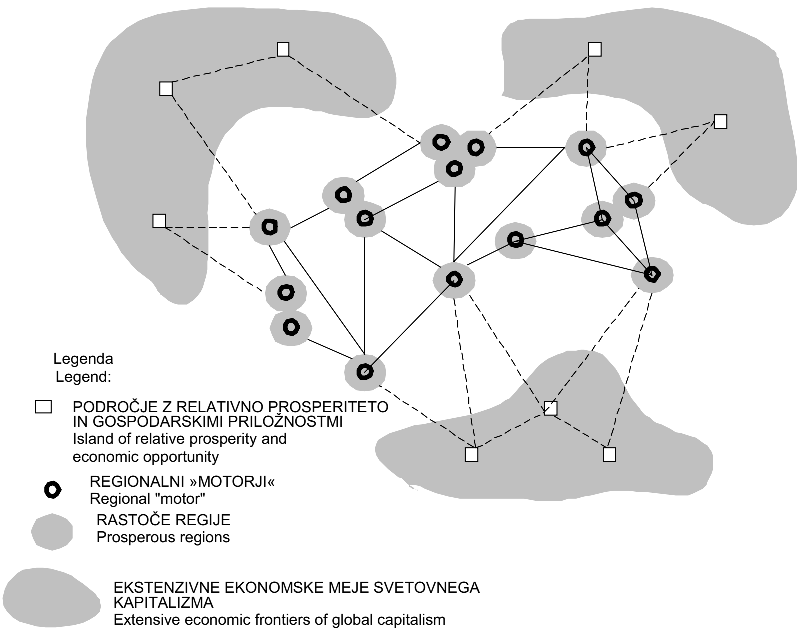
Poslovni interes je eno izmed temeljnih gonil za nastanek in razvoj SPG. Pobudnik nastanka in razvoja posameznih delov SPG je lahko eno ali več podjetij, ki želijo tako zagotoviti boljše razmere za razvijanje lastne konkurenčne zmožnosti. Prilastkov, ki vplivajo na nastanek, večanje in razvijanje določenega SPG je več, in sicer:

– naravne danosti ali kritičen obseg ključnih dejavnikov, potrebnih za razvoj SPG (znana specifična znanja in usposobljenosti, izdelki, storitve, obvladovanje tehnologij itn.)
– posnemanje uspešnih podjetij,
– povečan obseg povpraševanj,
– pojav novih potreb in povpraševanj,
– raven znanja in usposobljenosti človeških virov, vključenih v to panogo ali dejavnost,
– razvitost regionalnega inovacijskega okolja, povezanega s to panogo ali dejavnostjo,
– stopnja razvitosti kulture podjetništva in poslovnega sodelovanja,
– stopnja razvitosti regionalne podjetniške infrastrukture,
– stopnja medčloveškega in medorganizacijskega zaupanja,
– stopnja razvitosti organizacijske kulture poslovnega okolja SPG,

ties and the entire geographical area concerned.

Business interest is one of the basic prime movers for the formation and development of a SIC. The incentive for the formation and development of the individual segments of the SIC can be given by one or several companies wanting, in this way, to ensure better conditions for developing their own competitiveness. There are several attributes that have an effect on the formation, growth and development of a certain SIC, for example:

– Natural conditions or a critical extent of the key factors required for the development of the SIC (existing specific knowledge and skills, products, services, mastering of technology, etc.).
– Imitation of the successful companies.
– Increased extent of the existing enquiries.
– Appearance of new needs and enquiries.
– Level of knowledge and qualifications of human resources active in that branch or activity
– Degree of development of the regional innovation environment relevant to that branch or activity.
– Degree of development of the culture of entrepreneurship and business cooperation.
– Degree of development of the regional entrepreneurial infrastructure.
– Degree of trust in relations between people and organizations.
– Degree of development of the organizational culture of the SIC business environment.



Sl. 3. *Shematski prikaz geografije svetovne ekonomije [31]*
Fig. 3. *Diagrammatic representation of the geography of the global economy [31]*

– stopnja podpore lokalnih in državnih organov ter
– stopnja usklajenosti in sodelovanja državnih vlad pri podpori razvoja medržavnih regionalnih SPG.

Svetovno ekonomijo sestavljajo torej organizacijske in geografske mreže. Organizacijske mreže obsegajo prepletenost omenjenih MPM, medtem ko geografsko mrežo sestavljajo splošni in specializirani poslovni grozdi, locirani v posameznih regijah sveta. Slika 3 je značilen prikaz geografije svetovne ekonomije.

1.3 Potreba po spremembi poslovanja podjetij

Vse te spremembe, ki jih prinaša sodobno poslovno okolje, moramo znati izkoristiti v svoj prid, sicer nam lahko povzročijo veliko težav. Dinamika sprememb se ne zmanjšuje, temveč povečuje. Slika 4 prikazuje nekatere od osnovnih značilnosti sodobnega poslovnega okolja ter s tem povezane ključne dejavnike uspeha. Slednji se nanašajo na značilnosti poslovanja, ki jih najdemo v podjetjih in organizacijah, ki uspešno poslujejo v novih razmerah poslovanja.

Stalne spremembe in negotovost sta temeljni značilnosti novega ekonomskega reda. V zadnjih letih se vsepovsod veliko govori in piše o spremembah. Kljub temu pa se spremembe v praksi, v večini primerov, ne izvajajo tako hitro kakor bi želeli. Zakaj? Predvsem zaradi tega, ker je izvajati spremembe v lastnem okolju velikokrat težavna naloga. Najlaže je biti oportunist in se prepustiti tokovom. Vendar ti tokovi običajno ne vodijo k ciljem, ki jih tako radi

– Degree of support for the local and state authorities.
– Degree of coordination and cooperation of the state governments in supporting the development of interstate regional SICs.

Thus, the global economy comprises both organizational and geographical networks. The organizational networks cover the intertwining of the TPNs, whereas the geographical network is represented by the general and specialized industrial clusters located in the individual regions of the world. Figure 3 illustrates the geography of the global economy.

1.3 The need to change the business activities of companies

All these changes, brought about by the modern business environment, must be used profitably, otherwise they can cause many difficulties. The dynamics of the changes does not decrease, rather it increases. Figure 4 shows some of the basic characteristics of the modern business environment and the relevant key success factors. The latter relate to the characteristics of the business activities met in the companies and organizations successfully operating in the new business conditions.

Constant changes and insecurity are the basic characteristics of the new economic order. During recent years the changes have been discussed and described everywhere. In spite of that, in most cases the changes are not implemented in practice as fast as desired. Why is this? Particularly, due to the fact that implementing the changes in one's own environment is often a difficult task. It is easiest to be opportunist and to let things go. However, this attitude does not

Značilnosti / Characteristics
- ✓ Svetovna konkurenca / Global competition,
- ✓ Hiter tehnološki razvoj / Fast technological development,
- ✓ Stroškovno učinkovita delitev proizvodnih kapacitet / Cost effective allocation of production resources,
- ✓ Poslovno sodelovanje in prevzemi / Business cooperation and takeovers,
- ✓ Okoljski problemi / Ecological problems,
- ✓ Socialna trenja / Social tensions,
- ✓ Hitre spremembe / Quick changes,
- ✓ Nestabilnost/ Instability

Ključni dejavniki uspeha / Key Success Factors
- ✓ Identifikacija ključnih pristojnosti / Identification of key competences,
- ✓ Specializacija/ Specialization,
- ✓ Tehnološka odličnost/ Technological excellence,
- ✓ Vrhunska kakovost / Top quality,
- ✓ "Zunanje izvajanje" in "mreženje"/ "Outsourcing" and "networking"
- ✓ Nadziranje postopkov podjetja /Companyprocesses control,
- ✓ Nadzor nad stroški /Cost control
- ✓ Prilagodljiva organizacija podjetja / Flexible enterprise organization

Sl. 4. *Svetovno poslovno okolje – značilnosti in ključni dejavniki uspeha*
Fig. 4. *Global business environment – characteristics and key success factors*

optimistično zapišemo v različne razvojne dokumente in se običajno nanašajo na mednarodno uveljavljanje in povečanje konkurenčne zmožnosti lastnih podjetij, gospodarskih odsekov, industrij, regij, držav itn. Vzrokov za opisane probleme je več. Naštejmo nekaj od njih:

– pomanjkanje informacij,
– pomanjkanje potrebnega znanja in usposobljenosti,
– neinovativno okolje,
– napačna prepričanja in navade,
– odsotnosti prave motivacije,
– odsotnost podjetniškega duha itn.

Če analiziramo, kaj je skupnega vsem tem problemom ugotovimo, da so to problemi, ki jih mora znati reševati sodobno vodenje. Pri tem imamo v mislih pojmovanje vodenja, kot dejavnosti in stroke ter vodenja kot ljudi, ki izvajajo te naloge.

2 MREŽNA ORGANIZACIJA IN POSLOVNI GROZDI

2.1 Mrežne organizacije

Organizacijsko sestavo opredeljujemo kot vsoto načinov, kako neka organizacija členi svojo dejavnost na posamezne poslovne dejavnosti ter kako jih usklajuje. Organizacijska struktura je sredstvo, s katerim vodenje, z organizacijskega vidika, uresničuje svoje poslovne cilje. Postopek oblikovanja organizacije temelji na analizi strateških ciljev ter poslovnega okolja organizacije. Na podlagi tako pridobljenih spoznanj se postavi ustrezna organizacijska sestava, katere ustreznost je treba stalno preverjati. V današnjem času hitrih sprememb se kmalu lahko zgodi, da sedanja organizacija ne ustreza več dejanskim potrebam organizacije.

Klasična organizacija poslovanja je temeljila na visoki stopnji sestavljenosti in podprtosti s podrobno opredeljenimi pravili za delo. Sodobna organizacija, ki mora zadostiti potrebam nestabilnega in hitro se spreminjajočega okolja, temelji na bolj ohlapnih elementih vodenja, kakor so poslovni cilji, strategije in vrednote. Slika 5 prikazuje ustreznost obeh modelov vodenja in organiziranja glede na stopnjo nestabilnosti in negotovosti v poslovnem okolju organizacije. Seveda je slika 5 samo poenostavljen prikaz različnosti obeh modelov. Vedeti je treba, da ostaja v določenih primerih določitev opravil še naprej pomemben prilastek potrebne organiziranosti poslovanja sodobnega podjetja.

usually lead to the goals optimistically written down in various development documents and is usually related to the international establishment and growth of the competitiveness of one's own companies, economic sectors, industries, regions, states, etc. These problems arise for several reasons, some of them being:

– lack of information,
– lack of required knowledge and qualifications,
– a non-innovative environment,
– wrong beliefs and habits,
– absence of the correct motivation,
– absence of an entrepreneurial spirit.

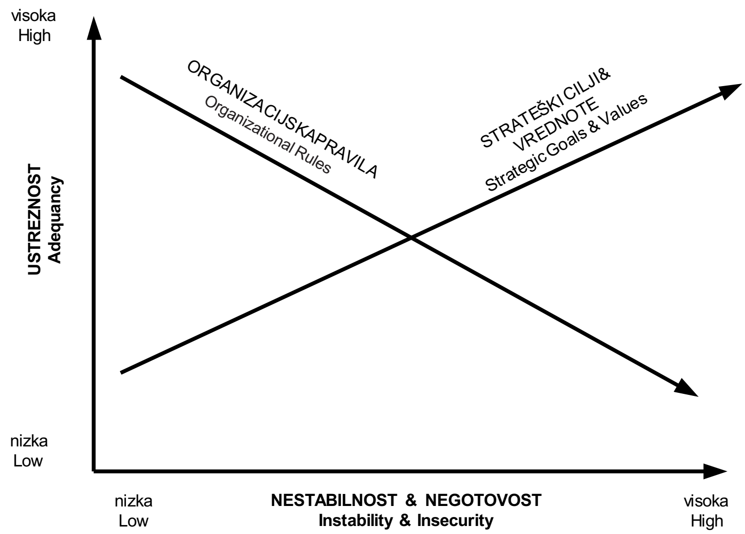
When analyzing what these problems have in common it can be seen that these are the problems that modern management must know how to solve. Here we mean management as an activity and science and management as personally performing the tasks.

2 NETWORK ORGANIZATION AND INDUSTRIAL CLUSTERS

2.1 Network organizations

The organizational structure is defined as the sum of the ways that an organization breaks down its activity into individual business operations and how it coordinates them. The organizational structure is a means by which the management realizes its business targets from the organizational point of view. The process of the formation of the organization is based on the analysis of the strategic targets and the business environment of the organization. The findings help to outline a suitable organizational structure whose adequacy must be verified continuously. At the present time of rapid changes it is likely that the existing organization will no longer comply with the actual needs of the organization.

The conventional organization of business activities was based on a high degree of structuring and was supported by detailed rules and regulations for work. The modern organization, having to meet the needs of the unstable and rapidly changing environment, is based on undefined elements of management, such as business targets, strategies and values. Figure 2 shows the adequacy of both models of management and organization with respect to the degree of instability and insecurity in the business environment of the organization. Of course, Figure 2 is only a simplified representation of the differences between the two models. It must be borne in mind that in some cases the determination of the tasks still remains an important attribute of the required organization of the business operations of the modern company.



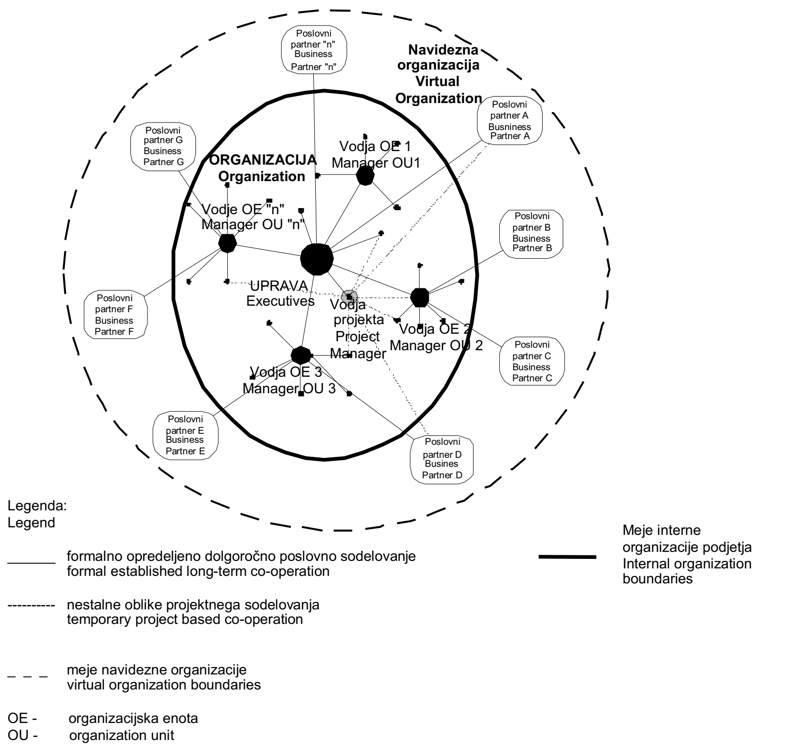
Sl. 5. *Primernost modelov vodenja in organiziranja, glede na stopnjo stabilnosti poslovnega okolja*
Fig. 5. *Adequacy of the models of management and organization with respect to the degree of stability of the business environment*

Osnove teorije organizacije podjetij industrijske dobe, ki so jo postavili Max Weber, Frederick W.Taylor, Henry Fayol in njihovi sodobniki, temeljijo na birokratskem modelu organizacije in organiziranja poslovanja. Glavne značilnosti takšne organizacije so razvrstitev, relativna zaprtost in togost. Takšna organizacija je bila ustrezna za podjetja industrijske dobe, saj je bilo poslovno okolje razmeroma stabilno. Danes, ko se spoprijemamo s potrebami hitrega razvoja in zmožnosti stalnega prilagajanja, pa je takšna organizacija neustrezna. Kot odgovor na to težavo se v zadnjem času pojavljajo različne oblike mrežne organizacije.

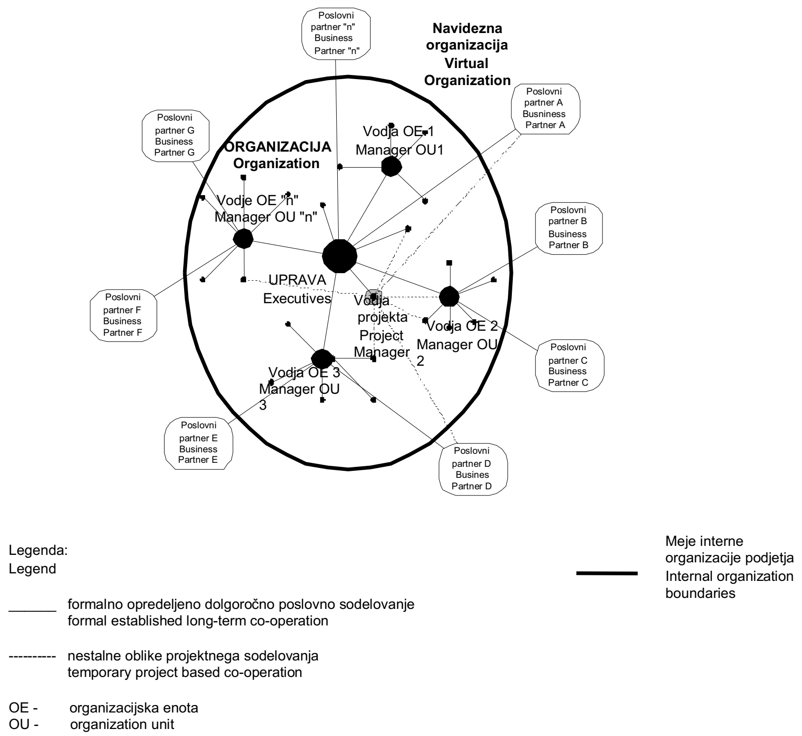
Mrežne organizacije lahko označimo kot zapletene prilagodljive sisteme brez osrednjega razvrstilnega nadzora z več vzporedno delujočih enot [17]. Mrežne organizacije imajo zmožnost hitrega prilagajanja brez potrebe po vzpostavitvi toge razvrstilne oblike upravljanja. Mrežno organizacijo lahko uporabimo za organiziranje dejavnosti lastne organizacije ali skupine poslovno povezanih organizacij. V primeru lastne organizacije gre za vzpostavitev različnih uporab navidezne organizacije, medtem ko gre pri skupini poslovno povezanih organizacij za skupen interes sodelovanja na določenem poslovnem področju. Glede na stopnjo formalne povezanosti ločimo naslednje oblike mrežnih organizacij, in sicer:
- trdne mrežne organizacije in
- mehke mrežne organizacije.

The basis of the theory of organization of industrial-age companies, as set forth by Max Weber, Frederick W. Taylor, Henry Fayol and their contemporaries, is the bureaucratic model of the organization and the organizing of business activities. The main characteristics of such an organization are hierarchy, relative locking up and rigidity. Such an organization was appropriate for the companies of the industrial age, since the business environment was relatively stable. Today, when the needs for rapid development and the capability of permanent adaptation are faced, such an organization is inappropriate. In answer to this problem various forms of network organization have recently appeared.

Network organizations can be defined as adaptable systems without the central hierarchical control and with several units working in parallel [17]. Network organizations are capable of adapting themselves quickly without the need to establish a rigid hierarchical form of management. The network organization can be used for organizing the activities of one's own organization or a group of organizations with business connections. In the case of our own organization the establishing of different applications of virtual organization is in question, whereas in the case of the group of organizations with business connections the joint interest in cooperation in a certain business area is concerned. With respect to the degree of formal connection the following forms of network organizations are distinguished:
- well-structured network organizations,
- open network organizations.



Sl. 6. *Ponazoritev primera trdne mrežne organizacije*
Fig. 6. *Illustration of the example of a well-structured network organization*



Sl. 7. *Ponazoritev primera mehke mrežne organizacije*
Fig. 7. *Illustration of the example of an open network organization*

Pri trdnih mrežnih organizacijah (sl. 6) gre za notranjo mrežno organiziranost in trajnejše oblike formalnih povezav med več neodvisnimi sodelujočimi organizacijami.

Pri mehkih oblikah mrežne organizacije (sl. 7) gre za nestalne oblike poslovnega sodelovanja med organizacijami, vključenimi v mrežno organizacijo. Interesi za sodelovanje so lahko zelo različni. Od poslovnega obveščanja do uresničitve skupnih tržnih ali razvojnih projektov.

2.2 Organizacija poslovnih grozdov

Videli smo, da so poslovni grozdi nastali kot odgovor na globalizacijo in hiter tehnološki razvoj ter s tem potrebo po pospešenem razvijanju globalne konkurenčne zmožnosti gospodarskih dejavnosti v okviru posameznih držav ali področij. Poslovni grozdi predstavljajo geografsko opredeljene povezave med predstavniki (sl. 8) gospodarskih dejavnosti, razvojno-raziskovalnih ter izobraževalnih ustanov, vlade, finančnih ustanov ter ustanov za podporo in razvoj poslovnega sodelovanja (PRps). Ta opredelitev velja tako za splošne kakor za specializirane poslovne grozde, ki smo jih omenili v poglavju 1.2.

Sodobne države iščejo in dejavno sodelujejo pri razvijanju perspektivnih gospodarskih dejavnosti. Običajno gledanje makroekonomistov na podjetje kot "črno škatlo", ki se razumno odziva na spremembe v tržnem okolju ter s tem v zvezi osredotočanje na makroekonomske probleme, je zamenjalo osredotočanje vlad na mikroekonomsko raven. Skrb sodobnih vlad niso posamezna podjetja, temveč dolgoročno usmerjanje na večanje konkurenčne zmožnosti poslovnih grozdov, ki jih sestavljajo tako podjetja kakor razvojno raziskovalne

Well-structured network organizations (Fig. 6) feature internal network organizing of the organizations and lasting forms of formal connections between independent participating organizations.

Open forms of network organization (Fig. 7) are unstable forms of business cooperation between the organizations included in the network organization. The interests in cooperation may be very different, ranging from passing business information to the realization of joint commercial or development projects.

2.2. Organization of industrial clusters

As mentioned above, industrial clusters have been introduced in answer to globalization, rapid technological development and, consequently, the need for the accelerated developing of the global competitiveness of economic activities in the frame of individual countries or regions. Industrial clusters represent geographically defined connections between the representatives (Figure 8) of economic activities, research-and-development and educational institutions, government, financial institutions and institutions that support the development of business cooperation (SD bc). This definition relates to the general as well as the specialized industrial clusters mentioned in section 1.2.

Modern countries seek and actively take part in developing prospective economic activities. The traditional macroeconomists' view of the company as a "black box", rationally responding to changes in the market environment, and consequently focusing on macroeconomic problems has been replaced by the focusing of governments on the microeconomic level. Modern governments do not pay much attention to the individual companies, but to long-term orientation towards the growth of competitiveness of industrial clusters consisting of companies as well as research-

Sl. 8. *Partnerji v poslovnih grozdih*
Fig. 8. *Partners in industrial clusters*

ustanove ter organizacije, ki zagotavljajo finančna sredstva za financiranje razvoja podjetij v grozdu. Grozdi so običajno vezani na določeno področje, ki je lahko znotraj ene države, lahko pa pokriva ozemlje tudi več držav. Poglavitni cilj tovrstnih vladnih podpor je vzpodbujati specializacijo, poslovno povezovanje in sodelovanje ter konkurenčno delovanje znotraj grozdov. Pomemben namen je podpirati sodelovanje majhnih in srednjevelikih podjetij z velikimi podjetji. Poslovni grozdi nastajajo in se razvijajo s pomočjo ustanov za podporo in razvoj poslovnega sodelovanja (PRps), ki jih lahko ustanovijo državne ali regionalne vlade ali pa tudi kar sama podjetja.

V teoriji obstaja več definicij pojma "poslovni grozd". Skupni imenovalec vseh definicij pa je:
– povezanost,
– mreženje in
– specializacija.

Predvsem pa predstavljajo poslovni grozdi priložnost za majhna in srednjevelika podjetja, ki morajo prav tako kakor velika podjetja razvijati svetovno konkurenčno ponudbo. Pri tem se spopadajo s problemom kritičnega obsega zmogljivosti lastnega podjetja, lastnih razvojnih zmožnosti, trženjskih možnosti, znanja in še bi lahko naštevali. Odgovor na rešitev opisanega problema je specializacija, iskanje ustreznih poslovnih partnerjev, povezovanje in ustvarjanje navideznega podjetja znotraj poslovnega grozda. Z navideznim podjetjem rešimo problem proizvodnih stroškov, obsega poslovanja in razvoja, medtem ko je mednarodna prepoznavnost in uveljavljenost poslovnega grozda v veliko pomoč in podporo pri trženju podjetja in njegovi vidnosti na svetovnem trgu. V poslovni grozd vključena podjetja oblikujejo vrednostne verige stalnih ali projektnih poslovnih povezav med posameznimi v grozdu sodelujočimi podjetji in organizacijami. Grozd je običajno odprt sistem, tako da so te poslovne povezave tudi s podjetji in organizacijami zunaj njega. Poslovne povezave nastanejo na osnovi:
– navpičnih,
– vodoravnih in
– sosrednih strategij poslovnega povezovanja.

Strategija navpičnega poslovnega povezovanja temelji na specializaciji in povezovanju podjetij, in sicer od proizvajalca materiala ali surovine pa do izdelovalca končnega izdelka. Strategija vodoravnega povezovanja temelji na specializaciji in povezovanju podjetij, ki delujejo v okviru iste

and-development institutions and organizations providing the financial means for financing the development of companies in a cluster. Usually, the clusters can be restricted to a certain region, which may be located within one state or it may cover the territory of several states. The basic target of government support is to stimulate specialization, business associating and cooperating and competitive behaviour within clusters. An important target is to support the cooperation of small and medium-sized companies with big companies. Industrial clusters are formed and develop with the assistance of institutions for the support and development of business cooperation (SD bc), which may be established by national or regional governments or simply by the companies themselves.

In theory, there are several definitions of the term "industrial cluster". The common denominators of all these definitions are:
– connecting,
– networking,
– specialization.

Industrial clusters are an opportunity, particularly for small and medium-sized companies, to develop their competitiveness like big companies. Moreover, they face the problem of a critical extent of the capacities of their own company, development capabilities, marketing possibilities, knowledge and the like. The solution to the described problem is specialization, searching for appropriate business partners, connecting and creating a virtual company within the industrial cluster. A virtual company solves the problem of production costs, the range of business activities and development, whereas the international renown and the establishment of the business cluster promote the company's marketing activities and how it is perceived on the world market. Companies as a part of the industrial cluster form the value chains of the permanent and the project business connections between the individual companies and organizations taking part in the cluster. Usually, the cluster is an open system so that there are business connections also with companies and organizations outside it. Business connections are formed on the basis of:
– vertical strategies of business connections,
– horizontal strategies of business connections,
– concentric strategies of business connections.

The strategy of vertical business connections is based on the specialization and connection of companies from the maker of the material or raw material to the producer of the final product. The strategy of horizontal connecting is based on the specialization and connectpanoge ali področja gospodarskega delovanja. Strategija sosrednega povezovanja pa temelji na povezovanju s specializiranimi podjetji in organizacijami, ki zagotavljajo podporne storitve in izdelke, za učinkovitejše in uspešnejše izvajanje določenih poslovnih dejavnosti operative in razvoja podjetij, vključenih v grozd.

Pri razvijanju lastne mreže poslovnih povezav vzpostavljajo podjetja prej omenjene trde in mehke oblike mrežne organizacije, ki deluje znotraj poslovnega grozda. Slika 9 je poskus značilnega prikaza primera organizacije takšnih mrež znotraj poslovnega grozda. Koordinacijo takšnega poslovnega grozda izvaja izbrana ali za to posebej oblikovana ustanova za podporo in razvoj poslovnega sodelovanja (PRps).

V poslovnih grozdih se hitreje razvija tudi namensko inovacijsko okolje, ki ponuja boljše razmere za hitrejši razvoj dejavnosti podjetij ter poslovnega grozda kot celote.

3 SPECIALIZACIJA IN RAZVIJANJE LASTNE RAZVOJNO-PROIZVODNE MREŽE

3.1 Matrika vrednostne verige podjetja

Člene vrednostne verige podjetja predstavljajo posamezna področja poslovanja, ki jih podjetje potrebuje, da lahko opravlja svojo dejavnost.

ing of companies active within the frame of the same branch or area of economic activities. The strategy of concentric connecting is connecting with specialized companies and organizations providing support services and products for more efficient and more successful execution of certain operational and development business activities of companies included in the cluster.

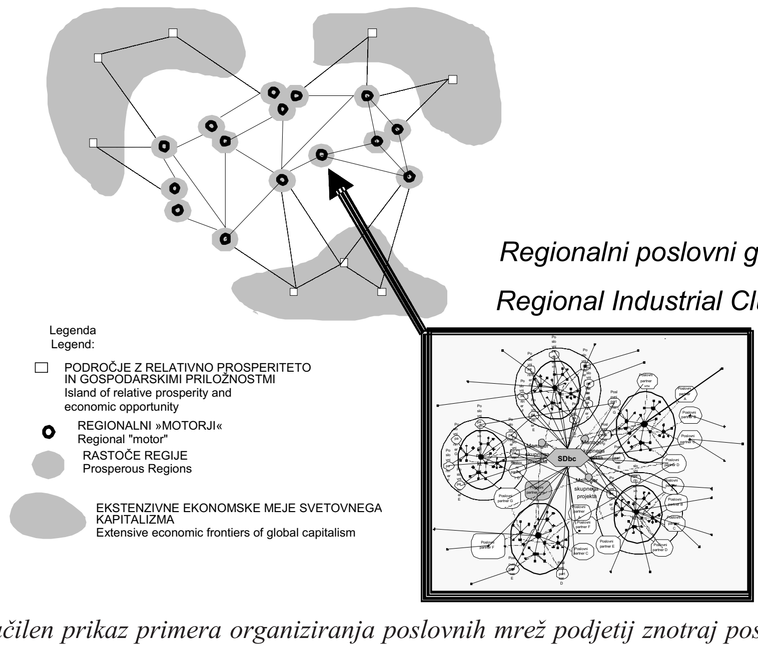
When developing one's own network of business connections the companies establish the mentioned well-structured and open form of network organization operating within the industrial cluster. Figure 9 is an attempt to show illustratively an example of organizing such networks inside the business cluster. The coordination of such an industrial cluster is performed by a selected or purposely formed institution for the support and development of business cooperation (SD bc).

Industrial clusters facilitate a faster development of the specific-purpose innovation environment offering better conditions for the faster development of the companies' activities and the industrial cluster as a whole.

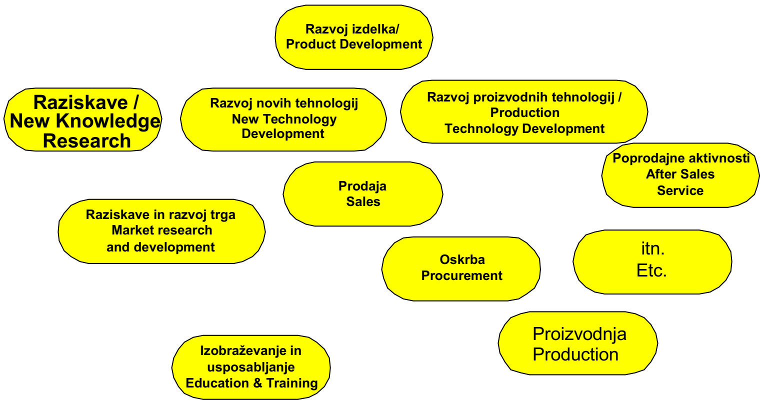
3 SPECIALIZATION AND DEVELOPING ONE'S OWN DEVELOPMENT-PRODUCTION NETWORK

3.1 Matrix of the company's value chain

The value-chain links of the company are represented by the individual business areas that the



Sl. 9. *Značilen prikaz primera organiziranja poslovnih mrež podjetij znotraj poslovnega grozda*
Fig. 9. *Illustrative representation of an example of organizing business networks of companies inside the industrial cluster*



Sl. 10. *Področja poslovanja kot členi vrednostne verige podjetja*
Fig. 10. *Business areas as the elements of companies' value chain*

Posamezno področje poslovanja opredeljuje logično celoto strokovnih nalog, ki jih mora podjetje izvajati. Področja poslovanja se nanašajo na razvoj, trženje, oskrbo, proizvodnjo, finance, in podobno. Naloga vodenja podjetja je, da razpozna in opredeli vsa področja poslovanja, ki jih podjetje potrebuje ter zagotovi njihovo ustrezno izvajanje (sl. 10).

Vsebina, organizacija in organiziranost delovanja posameznega področja morajo biti prav tako kot izdelek in proizvodna tehnologija predmet stalnega prenavljanja. Ni problem samo postaviti pravo vsebino, organizacijo in organiziranost delovanja posameznega področja poslovanja, temveč tudi medsebojno povezanost med posameznimi področji (npr.: povezava med razvojem, proizvodnjo, financami ipd.). Ločimo osnovna in podporna področja poslovanja. Osnovna področja poslovanja so elementi temeljnega poslovnega postopka. Ta pa obsega vse od razvoja izdelka pa do njegove prodaje na trgu. Medtem ko podporna področja poslovanja omogočajo, da se to v resnici tudi zgodi. Področja poslovanja, ki to omogočajo so poslovno načrtovanje, organiziranje, financiranje, vodenje in nadziranje.

V vsakem podjetju se odvijata dva sočasna postopka, ki sta medsebojno tesno povezana (sl. 11):
– tehnični postopek in
– podjetniški postopek.

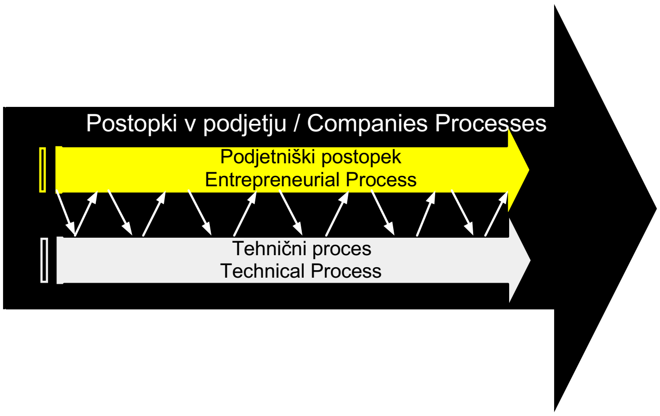
Tehnični postopek obsega zaporedje vseh nalog, ki jih je treba opraviti, da izdelek naredimo. Rezultat tehničnega postopka je "dokončan izdelek". Poslovni postopek omogoča prvi postopek, njegov rezultat je prodan izdelek in "realiziran dobiček". Prvi postopek pomeni tehnični del, drugi postopek pa poslovni del

company needs to perform its activity. The individual business area defines the logical frame of professional tasks that the company has to perform. The business areas relate to development, marketing, supply, production, finances, etc. The company's management is responsible for identifying and defining all business areas that the company needs, and to ensure they perform correctly (Fig. 10).

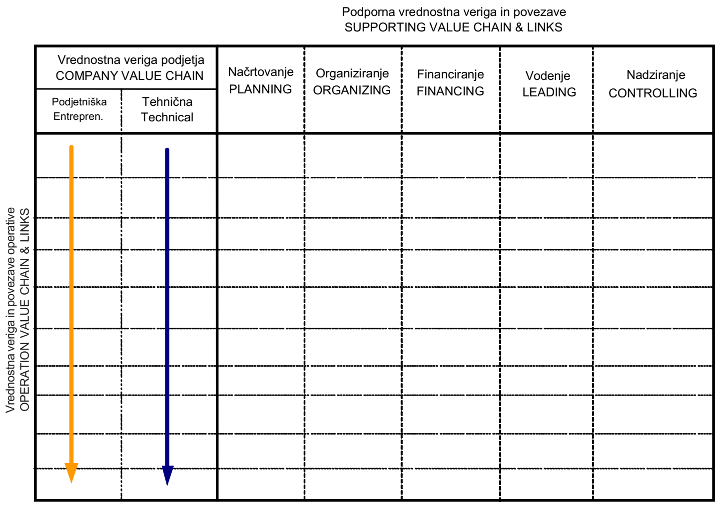
The contents, organizing and organization of the functioning of the individual area must be subject to constant innovation, just like the product and the production technology. It is not the only problem to set forth correct contents, organization and organizing the functioning of the individual business area, but also to set forth the interconnecting of the individual area (e.g., the connections between development, production, finances etc.). Primary and supporting business areas are distinguished. The primary business areas represent the elements of the basic business process ranging from development of the product to its sale on the market. On the other hand, the supporting business areas make that actually happen. The supporting business activities include business planning, organizing, financing, managing and supervising.

In any company two simultaneous, closely connected processes are going on (Fig. 11):
– technical process,
– entrepreneurial process.

The technical process comprises the sequence of all tasks that have to be performed in order to make the product. The result of the technical process is the "finished product". The entrepreneurial process makes the first process possible, its result is the sold product and the "realized profit". The first process represents the technical part, whereas the second process represents



Sl. 11. *V vsakem podjetju potekata dva sočasna postopka, tehnični in podjetniški proces*
Fig. 11. *In any company two simultaneous, closely connected processes are going on*



Sl. 12. *Matrika vrednosti podjetja*
Fig. 12. *The company's value-chain matrix*

vrednostne verige podjetja, ki v povezavi s členi podporne vrednostne verige predstavlja matriko vrednosti podjetja (sl. 12).

Prikaz praktičnega primera tehnične in poslovne vrednostne verige s področja orodjarske industrije:

Elementi tehnične vrednostne verige orodjarskega podjetja so:
– raziskave in razvoj novih tehničnih znanj,
– razvoj novih proizvodnih tehnologij,
– konstruiranje orodja,
– tehnologija izdelave orodja,
– izdelava orodja,
– testiranje orodja,
– zagon orodja,
– vzdrževanje orodja,
– recikliranje orodja (po koncu dobe trajanja orodja).

the business part of the company's value chain and forms the value matrix of the company in conjunction with the links of the supporting value chain (Fig. 12).

Representation of a practical example of the technical and business value chain in the tool-making industry:

Elements of the technical value chain of a tool-making company:
– research and development of new technical knowledge,
– development of new production technologies,
– design of tools,
– tool manufacturing technology,
– tool manufacture,
– tool tests,
– start-up of tools,
– tool maintenance,
– tool recycling (after the expiration of the tool's service life).

Elementi podjetniške vrednostne verige orodjarskega podjetja:
– raziskave in razvoj poslovnih znanj,
– razvoj novih tehnologij poslovanja,
– trženje in prodaja,
– oskrba proizvodnje,
– proizvodnja,
– predaja orodja naročniku,
– poprodajne dejavnosti.

Tehnična in poslovna vrednostna veriga morata biti usklajeni ter predmet stalnega iskanja novosti in uvajanja inovativnih rešitev, ki so osnova za dvigovanje konkurenčne zmožnosti podjetja.

3.2 Matrika vrednostne verige poslovnega grozda

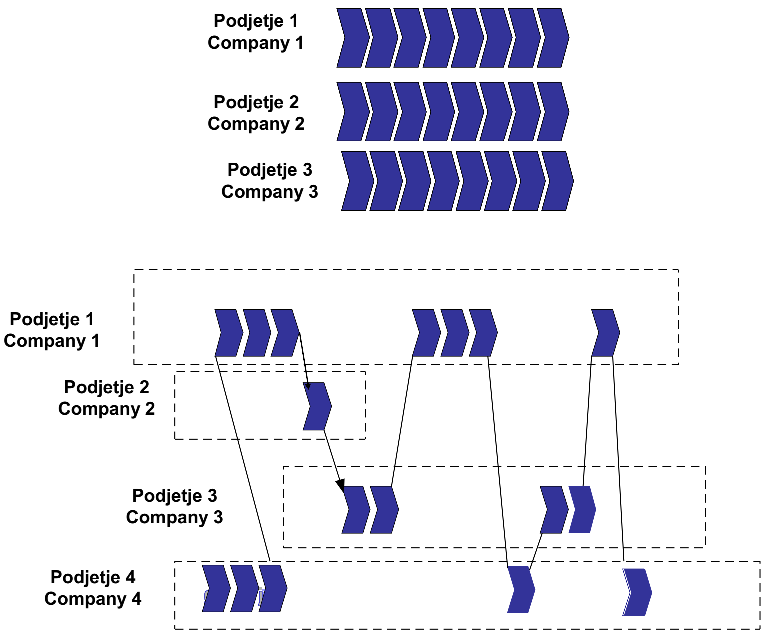
Vrednostna veriga poslovnega grozda se nanaša na opredelitev medsebojno povezanih specializiranih dejavnosti, s katerimi podjetja in organizacije vstopajo v poslovne povezave z drugimi osebki poslovnega grozda, s katerimi sodelujejo pri izvedbi lastnega izdelka. Slika 13 je prikaz primera poslovno nepovezanega podjetja, ki opravlja vse poslovne dejavnosti znotraj lastnega podjetja ter visoko specializiranega podjetja, ki izvaja v lastnem podjetju samo določene poslovne dejavnosti, preostale pa zagotavlja prek poslovnih povezav z ustreznimi poslovnimi partnerji. Na sliki pa imamo prikaz tipologije poslovnih povezav, ki nastajajo med podjetji

The elements of the entrepreneurial value chain of a tool-making company:
– research and development of new business knowledge,
– development of new business technologies,
– marketing and sale,
– supplies for production,
– production,
– client's taking-over of tool,
– after-sales activities.

The technical and business value chain must be coordinated and subject to constantly introducing novelties and innovative solutions, which are a prerequisite for increasing the company's competitiveness.

3.2 Matrix of the value chain of an industrial cluster

The value chain of the industrial cluster refers to defining the interconnected specialized activities with which the companies and organizations enter into business connections with other business-cluster entities taking part in the completion of the product. Figure 13 illustrates the example of a company without external business connections, performing all the business activities inside its own company, and a highly specialized company performing only certain business activities within the company, while the others are performed through business connections with relevant business partners. It can be seen that very different situations are in



Sl. 13. *Vrednostna veriga nepovezanih in povezanih podjetij in organizacij*
Fig. 13. *Value chain of unconnected and connected companies and organizations*

in organizacijami poslovnega grozda. Vidimo, da imamo lahko opravka z zelo različnimi situacijami, od mehkih do trdih oblik poslovnega povezovanja, predmet povezovanja je lahko vsak člen poslovnega postopka, ki pomeni člen vrednostne verige podjetja. Glede na vsebino poslovnega sodelovanja se oblikujejo stalne poslovne povezave, ki so temelj za izvajanje integriranega in neprekinjenega poslovnega postopka, pri katerem sodeluje več podjetij ali pa nestalne – projektne poslovne povezave.

Pri poslovnih grozdih prav tako ločimo:
– osnovne in
– podporne povezave

Prikaz praktičnega primera členov verige osnovnih povezav s področja orodjarske industrije:
– razvoj novih tehnologij in materialov,
– trženje in prodaja,
– snovanje in konstruiranje,
– nabava,
– računalniške analize in simulacije,
– specialne proizvodne storitve,
– preproste proizvodne storitve,
– proizvodnja materiala in polizdelkov,
– izdelava standardnih delov,
– montaža in testiranje,
– izdelava polizdelkov za končnega kupca,
– vzdrževanje orodij pri kupcu,
– razdeljevanje ter
– storitve.

Posamezni člen osnovne vrednostne verige pomeni potencialno specializacijo in samostojno dejavnost podjetja.

Vrednostne verige osnovnih povezav med podjetji in organizacijami poslovnega grozda nastanejo skladno z razvojno strategijo poslovnega grozda. Ta običajno temelji na tvorjenju v poglavju 2.2 omenjenih navpičnih, vodoravnih in sosrednih poslovnih povezav.

Podporo in usmerjanje razvoja vrednostnih verig poslovnega grozda zagotavljajo členi podporne vrednostne verige, ki zagotavljajo pogoje uspešnejšemu poslovnemu povezovanju podjetij in organizacij, in sicer tako da usmerjajo osnovne člene vrednostne verige, ki jih tvorijo podjetja in organizacije poslovnega grozda. Člene podporne vrednostne verige sestavljajo naslednje poslovne dejavnosti:
– trženje poslovnega grozda,
– podpora postopkom specializacije organizacij in poslovnega povezovanja,

question, from open to well-structured forms of business connections; any part of the business process as a part of the company's value chain can be the subject of outsourcing. According to the contents of the business cooperation permanent business connections as a basis for the execution of the integrated and continuous business process in which several companies take part or temporary-project business connections are formed.

In industrial clusters the following connections are also significant:
– primary connections,
– supporting connections.

The following is a practical example of the links in a chain of primary connections in the toolmaking industry:
– the development of new technologies and materials,
– marketing and sales,
– conceiving and designing,
– purchasing,
– computer analyses and simulations,
– special production services,
– simple production services,
– production of materials and semi-finished products,
– manufacture of standard parts,
– installation and testing,
– manufacture of semi-finished products for the end user,
– maintenance of tools on the buyer's premises,
– distribution,
– services.

The individual link of the primary-value chain represents potential specialization and the company's independent activity.

The value chains of primary connections between the companies and organizations of the industrial cluster are formed in accordance with the industrial cluster development strategy. The latter is usually based on forming vertical, horizontal and concentric business connections, as mentioned in Section 2.2.

The support and orientation of the development of industrial cluster value chains are ensured by the supporting value-chain links that create conditions for successful business connections of companies and organizations by orienting the value-chain primary links formed by companies and organizations of the business cluster. The supporting value-chain links consist of the following business activities:
– the marketing activities of the industrial cluster,
– supporting the processes of the specialization of organizations and business connecting processes,

– podpora izvajanju skupnih razvojnih projektov,
– izobraževanje in usposabljanje,
– štipendijski skladi,
– razvoj sodelovanja z regionalno oblastjo in nosilci gospodarskega razvoja,
– informacijski sistem.

Podjetja - organizatorji poslovnih mrež znotraj grozda, skupaj s sodelujočimi podjetji in drugimi ustanovami organizirajo poslovne verige, s katerimi zagotavljajo kupcem optimalno vrednost ponujanih izdelkov in storitev.

Ustanove za podporo in razvoj poslovnega sodelovanja (PRps), ki so vodenje poslovnega grozda morajo skrbeti za usmerjanje, motiviranje in podporo poslovnega sodelovanja in povezovanja. Skladno s tem morajo zagotavljati in razvijati ustrezno podporno vrednostno verigo za to potrebnih specializiranih storitev.

Glavno izhodišče vsakega dela v vsakem sodelujočem podjetju ali organizaciji poslovnega grozda mora biti ***"vrednost za končnega kupca"***. Da bi bil grozd poslovno uspešen, mora vsako podjetje ali organizacija v verigi prispevati največji delež svoje vrednosti.

– supporting the execution of joint development projects,
– education and training,
– scholarship funds,
– developing cooperation with regional authorities responsible for the development of the region,
– information system.

In conjunction with the participating companies and other organizations, the leading companies, the organizers of business networks within the cluster, organize the business chains, thereby ensuring the optimum value of the products and services offered to the buyers.

The institutions for the support and development of business cooperation (SD bc), representing the industrial cluster management, must take care of orienting, stimulating and supporting the business cooperation as well as connecting. Accordingly, they must provide and develop a suitable supporting value chain of specialized services, required to that end.

The basic driving force of each work in any participating company or organizations of the industrial cluster must be ***"the value for the end user"***. For the cluster to be successful each company or organization in the chain must contribute the maximum share of its value.

4 LITERATURA
4 REFERENCES

[1] W.S.Birnbaum William. (1990) If your strategy is so terrific, how come it doesn't work, *Amacom*, New York.
[2] T.Grundy, L. Brown (2002) Strategic project management, *Thomson Learnig*, London.
[3] D.Hahn (1991) Strategic management-tasks and challenges in the 1990s, *Long Rang Planning*, Vol. 24, No.1, Pergamon Press, London.
[4] A. Hax, N. Majluf (1996) The strategy concept and process, *Prentice Hall*, New Jersey.
[5] C.W.L. Hill Charles, G.R. Jones Gareth (1995) Strategic management theory, *Houghton Mifflin*, Boston.
[6] D.J. Hunger, T.L.Wheelen (1995) Strategic management, *Addison-Wesley*, New York.
[7] A.S.Judson (1990) Making strategy happen, *Basil Blackwell*, Oxford.
[8] D. Lock (2000) Project management, *Gower*, Hampshire.
[9] H.Macmillan, M.Tampoe (2000) Strategic management, *Oxford University Press*, Oxford.
[10] J.J. Phillips, T.W. Bothell, G.L. Snead Lynne (2002) The project management scorecard, *Butterworth-Heinemann*, London.
[11] Jaklič M. et al. (2004) Zaključno poročilo: Evalvacija ukrepov za spodbujanje razvoja grozdov v Sloveniji v obdobju 2001-2003, *Inštitut za konkurenco in sodelovanje, Ekonomska fakulteta, Univerza v Ljubljani*, Ljubljana.
[12] P. Raimond, E. Colin Eden (1990) Making strategy work, *Long Rang Planning*, Vol. 23 No. 5, Pergamon Press, London.
[13] H.C. Riekhof (1993) Hearusforderung fuer die strategische Planung, *ZfFO*, Vol.63, No.5, Giessen.
[14] G. Saloner, A. Shepard, J. Podolny (2001) Strategic management, *John Wiley & Sons*, New York.
[15] J.L. Thompson (2001) Understanding corporate strategy, *Thompson Learning*, London.
[16] Archer N.P. (2004) Project management in network organizations, *PM Research Conference, PMI*, London.
[17] Broyderick C.S. (1996) The 7 universal laws of customer value, *Times Mirror*.

[18] Beukerma L., Coenen H. (1999) Global logistic chains, *Globalization and Labour Relation*, Cheltenham.
[19] Drucker P. (2002) Managing in the next society, *St.Martin's Press*, New York.
[20] Fuld L. (1995) The new competitor intelligence, *John Wiley & Sons*, New York.
[21] Godin S. (2002) Survival is not enough, *The Free Press*, New York.
[22] Gould D. (2006) Virtual organization, daveg@seanet.com, on web published paper.
[23] Hisrich R. et al. (2005) Entrepreneurship, Sixth Edition, *McGraw Hill Irwin*, Boston.
[24] Harvard Business Essentials: Entrepreneur's Toolkit (2005) *Harvard Business School Press*, Boston.
[25] A. Marsh & McLennan Company: Future automotive industry structure 2015 (2004) *MERCER Consulting*.
[26] Oesterle H. et al. (2001) Business networking, *Springer*, Berlin.
[27] Jordan J., Michel F. (2000) Next generation manufacturing, *John Wiley & Sons*, New York.
[28] G. Peyton Richard (2004) Toolmakers cluster of Slovenia, TCS-LENS feasibility study, *World Tech Inc., McLean*, VA.
[29] Economics, making sense of the modern economy (1999) *The Economist*, London.
[30] Tapscott D. (1998) Blueprint to the digital economy, *Mc Graw- Hill*, New York.
[31] Dicken P. (2003) Global shift, *The Guilford Press*, New York.

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DIPLOMIRALI SO

Na Fakulteti za strojništvo Univerze v Ljubljani so pridobili naziv univerzitetni diplomirani inženir strojništva:

dne *23. februarja 2007*: Boris IVIĆ, Marko NOVAK, Uroš POGAČNIK.

Na Fakulteti za strojništvo Univerze v Mariboru je pridobil naziv univerzitetni diplomirani inženir strojništva:

dne *22. februarja 2007*: Boštjan JAN.

*

Na Fakulteti za strojništvo Univerze v Ljubljani so pridobili naziv diplomirani inženir strojništva:

dne *12. februarja 2007*: Aleš JENKO, Primož JUVAN, Boštjan KOPAČ, Mitja MAREN, Franci NOSE;

dne *13. februarja 2007*: Anton LEKŠE, Darko MALNARIČ, Boštjan ŠKRABEC, Marko ŠOŠTARKO, Marko ŽNIDARŠIČ.

Na Fakulteti za strojništvo Univerze v Mariboru so pridobili naziv diplomirani inženir strojništva:

dne *22. februarja 2007*: Andrej ARNUGA, Robert BROZ, Marjan DOVAR, Izidor GOMILŠEK, Boris HEBAR, Branko KOROŠEC, Kristijan PIPAN.

Navodila avtorjem - Instructions for Authors

Članki morajo vsebovati:
- naslov, povzetek, besedilo članka in podnaslove slik v slovenskem in angleškem jeziku,
- dvojezične preglednice in slike (diagrami, risbe ali fotografije),
- seznam literature in
- podatke o avtorjih.

Strojniški vestnik izhaja od leta 1992 v dveh jezikih, tj. v slovenščini in angleščini, zato je obvezen prevod v angleščino. Obe besedili morata biti strokovno in jezikovno med seboj usklajeni. Članki naj bodo kratki in naj obsegajo približno 8 strani. Izjemoma so strokovni članki, na željo avtorja, lahko tudi samo v slovenščini, vsebovati pa morajo angleški povzetek.

Za članke iz tujine (v primeru, da so vsi avtorji tujci) morajo prevod v slovenščino priskrbeti avtorji. Prevajanje lahko proti plačilu organizira uredništvo. Če je članek ocenjen kot znanstveni, je lahko objavljen tudi samo v angleščini s slovenskim povzetkom, ki ga pripravi uredništvo.

VSEBINA ČLANKA

Članek naj bo napisan v naslednji obliki:
- Naslov, ki primerno opisuje vsebino članka.
- Povzetek, ki naj bo skrajšana oblika članka in naj ne presega 250 besed. Povzetek mora vsebovati osnove, jedro in cilje raziskave, uporabljeno metodologijo dela,povzetek rezulatov in osnovne sklepe.
- Uvod, v katerem naj bo pregled novejšega stanja in zadostne informacije za razumevanje ter pregled rezultatov dela, predstavljenih v članku.
- Teorija.
- Eksperimentalni del, ki naj vsebuje podatke o postavitvi preskusa in metode, uporabljene pri pridobitvi rezultatov.
- Rezultati, ki naj bodo jasno prikazani, po potrebi v obliki slik in preglednic.
- Razprava, v kateri naj bodo prikazane povezave in posplošitve, uporabljene za pridobitev rezultatov. Prikazana naj bo tudi pomembnost rezultatov in primerjava s poprej objavljenimi deli. (Zaradi narave posameznih raziskav so lahko rezultati in razprava, za jasnost in preprostejše bralčevo razumevanje, združeni v eno poglavje.)
- Sklepi, v katerih naj bo prikazan en ali več sklepov, ki izhajajo iz rezultatov in razprave.
- Literatura, ki mora biti v besedilu oštevilčena zaporedno in označena z oglatimi oklepaji [1] ter na koncu članka zbrana v seznamu literature. Vse opombe naj bodo označene z uporabo dvignjene številke[1].

OBLIKA ČLANKA

Besedilo članka naj bo pripravljeno v urejevalnilku Microsoft Word. Članek nam dostavite v elektronski obliki.

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

Papers submitted for publication should comprise:
- Title, Abstract, Main Body of Text and Figure Captions in Slovene and English,
- Bilingual Tables and Figures (graphs, drawings or photographs),
- List of references and
- Information about the authors.

Since 1992, the Journal of Mechanical Engineering has been published bilingually, in Slovenian and English. The two texts must be compatible both in terms of technical content and language. Papers should be as short as possible and should on average comprise 8 pages. In exceptional cases, at the request of the authors, speciality papers may be written only in Slovene, but must include an English abstract.

For papers from abroad (in case that none of authors is Slovene) authors should provide Slovenian translation. Translation could be organised by editorial, but the authors have to pay for it. If the paper is reviewed as scientific, it can be published only in English language with Slovenian abstract, that is prepared by the editorial board.

THE FORMAT OF THE PAPER

The paper should be written in the following format:
- A Title, which adequately describes the content of the paper.
- An Abstract, which should be viewed as a mini version of the paper and should not exceed 250 words. The Abstract should state the principal objectives and the scope of the investigation, the methodology employed, summarize the results and state the principal conclusions.
- An Introduction, which should provide a review of recent literature and sufficient background information to allow the results of the paper to be understood and evaluated.
- A Theory
- An Experimental section, which should provide details of the experimental set-up and the methods used for obtaining the results.
- A Results section, which should clearly and concisely present the data using figures and tables where appropriate.
- A Discussion section, which should describe the relationships and generalisations shown by the results and discuss the significance of the results making comparisons with previously published work. (Because of the nature of some studies it may be appropriate to combine the Results and Discussion sections into a single section to improve the clarity and make it easier for the reader.)
- Conclusions, which should present one or more conclusions that have been drawn from the results and subsequent discussion.
- References, which must be numbered consecutively in the text using square brackets [1] and collected together in a reference list at the end of the paper. Any footnotes should be indicated by the use of a superscript[1].

THE LAYOUT OF THE TEXT

Texts should be written in Microsoft Word format. Paper must be submitted in electronic version.

Do not use a LaTeX text editor, since this is not compatible with the publishing procedure of the Journal of Mechanical Engineering.

Equations should be on a separate line in the main body of the text and marked on the right-hand side of the page with numbers in round brackets.

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 v slovenskem jeziku, npr. časovno spremenljiva geometrija (ČSG).

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.

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

Vse označbe na slikah morajo biti dvojezične.

Preglednice

Preglednice morajo biti zaporedno oštevilčene in označene, v besedilu in podnaslovu, kot preglednica 1, preglednica 2 itn. V preglednicah ne uporabljajte izpisanih imen veličin, ampak samo ustrezne simbole, da se izognemo dvojezični podvojitvi imen. K fizikalnim veličinam, npr. *t* (pisano poševno), pripišite enote (pisano pokončno) v novo vrsto brez oklepajev.

Vsi podnaslovi preglednic morajo biti dvojezični.

Seznam literature

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

[1] A. Wagner, I. Bajsić, M. Fajdiga (2004) Measurement of the surface-temperature field in a fog lamp using resistance-based temperature detectors, *Stroj. vestn.* 2(2004), pp. 72-79.

[2] Vesenjak, M., Ren Z. (2003) Dinamična simulacija deformiranja cestne varnostne ograje pri naletu vozila. *Kuhljevi dnevi '03*, Zreče, 25.-26. september 2003.

[3] Muhs, D. et al. (2003) Roloff/Matek Maschinenelemente – Tabellen, 16. Auflage. *Vieweg Verlag*, Wiesbaden.

SPREJEM ČLANKOV IN AVTORSKE PRAVICE

Uredništvo Strojniškega vestnika si pridržuje pravico do odločanja o sprejemu članka za objavo, strokovno oceno recenzentov in morebitnem predlogu za krajšanje ali izpopolnitev ter terminološke in jezikovne korekture.

Avtor mora predložiti pisno izjavo, da je besedilo njegovo izvirno delo in ni bilo v dani obliki še nikjer objavljeno. Z objavo preidejo avtorske pravice na Strojniški vestnik. Pri morebitnih kasnejših objavah mora biti SV naveden kot vir.

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Avtorji vseh prispevkov morajo za objavo plačati prispevek v višini 20,00 EUR na stiskano stran prispevka. Prispevek se zaračuna po sprejemu članka za objavo na seji Uredniškega odbora.

Units and abbreviations

Only standard SI symbols and abbreviations should be used in the text, tables and figures. Symbols for physical quantities in the text should be written in italics (e.g. *v, T, n,* etc.). Symbols for units that consist of letters should be in plain text (e.g. ms^{-1}, K, min, mm, etc.).

All abbreviations should be spelt out in full on first appearance, e.g., variable time geometry (VTG).

Figures

Figures must be cited in consecutive numerical order in the text and referred to in both the text and the caption as Fig. 1, Fig. 2, etc. Pictures may be saved in resolution good enough for printing in any common format, e.g. BMP, GIF, JPG. However, graphs and line drawings sholud be prepared as vector images, e.g. CDR, AI.

When labelling axes, physical quantities, e.g. *t, v, m,* etc. should be used whenever possible to minimise the need to label the axes in two languages. Multi-curve graphs should have individual curves marked with a symbol, the meaning of the symbol should be explained in the figure caption.

All figure captions must be bilingual.

Tables

Tables must be cited in consecutive numerical order in the text and referred to in both the text and the caption as Table 1, Table 2, etc. The use of names for quantities in tables should be avoided if possible: corresponding symbols are preferred to minimise the need to use both Slovenian and English names. In addition to the physical quantity, e.g. *t* (in italics), units (normal text), should be added in new line without brackets.

All table captions must be bilingual.

The list of references

References should be collected at the end of the paper in the following styles for journals, proceedings and books, respectively:

[1] A. Wagner, I. Bajsić, M. Fajdiga (2004) Measurement of the surface-temperature field in a fog lamp using resistance-based temperature detectors, *Stroj. vestn.* 2(2004), pp. 72-79.

[2] Vesenjak, M., Ren Z. (2003) Dinamična simulacija deformiranja cestne varnostne ograje pri naletu vozila. *Kuhljevi dnevi '03*, Zreče, 25.-26. september 2003.

[3] Muhs, D. et al. (2003) Roloff/Matek Maschinenelemente – Tabellen, 16. Auflage. *Vieweg Verlag*, Wiesbaden.

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