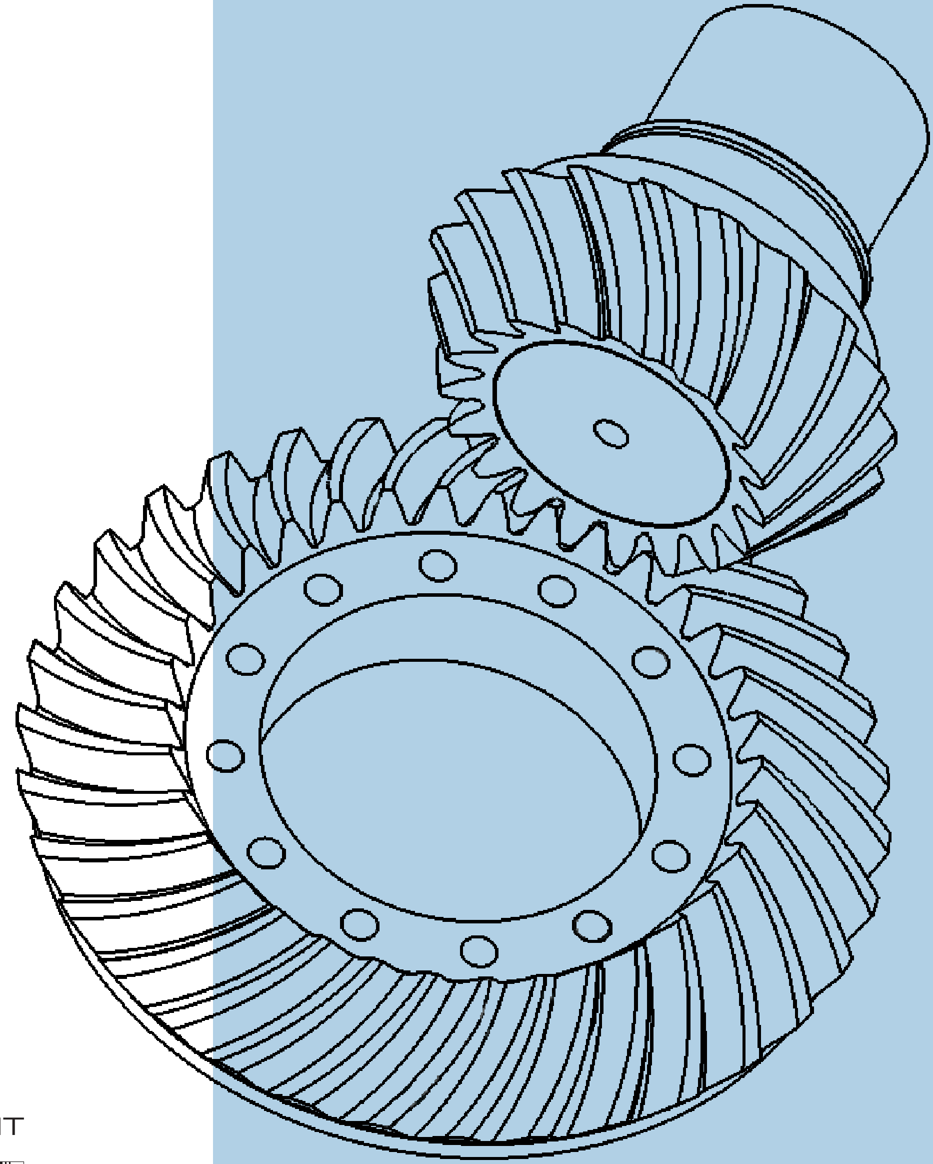
letnik/volume **52** - št./no. **9/06** - str./pp. **557-628**
Ljubljana, sept./Sept. 2006, zvezek/issue **497**

STROJNIŠKI VESTNIK
JOURNAL OF MECHANICAL ENGINEERING



cena 800 SIT

ISSN 0039-2480

Vsebina - Contents

Strojniški vestnik - Journal of Mechanical Engineering
letnik - volume 52, (2006), številka - number 9
Ljubljana, september - September 2006
ISSN 0039-2480

Izhaja mesečno - Published monthly

Strojniški vestnik - Journal of Mechanical Engineering 52(2006)9, 558-567
UDK - UDC 669.13:620.178.3
Izvirni znanstveni članek - Original scientific paper (1.01)

Trdnost litega železa in normaliziranega litega železa pri izmenični obremenitvi

The Strength of as Cast Iron and Normalized Cast Iron Subjected to Cyclic Loading

Mindaugas Leonavičius[1] – Algimantas Krenevičius[1] – Stanislav Stupak[1] – Gediminas Petraitis[1] – Marijonas Šukšta[1] – Žilvinas Bazaras[2]
([1]Vilnius Gediminas Technical University, Lithuania; [2]Kaunas Univ. of Technology, Lithuania)

V prispevku so predstavljeni rezultati eksperimentalnih in analitičnih raziskav pogosto se ponavljajoče utrujenosti posebnega litega in normaliziranega železa, ki ju kasneje v besedilu imenujemo GI (stopenjsko železo) in SGI (krogelno grafitno železo). Uveljavljeni vrsti železa smo spremenili, da bi dosegli boljše mehanske lastnosti in izboljšali odpornost proti nastajanju razpok, prav tako pa tudi njihovemu širjenju. Iz določenih mehanskih lastnosti vidimo, da normaliziranje spremeni mikrosestavo, poveča plastičnost in izenači meje prožnosti in trdnosti. V mikrosestavi opazovanega litega železa je vključen tudi grafit različnih velikosti, ki po toplotni obdelavi, pridobi krogelno obliko, poenoteno in manjšo velikost, tako da celotna mikrosestava postane bolj drobna. Po preizkušanju "kompaktne" izsredne napetosti CT (ASTM) na vzorcih smo za diagrame utrujenosti oblikovali območje faktorja razmerja rasti razpoke glede na jakost napetosti. In sicer za: GI lito železo ΔK_{th} = 6,5 do 8,6 MPa $\sqrt{m}$; za GI normalizirano lito železo ΔK_{th} = 8,2 do 10,3 MPa $\sqrt{m}$; zaSGI lito železoi ΔK_{th} = 8,0 do 9,6 MPa $\sqrt{m}$ in za SGI normalizirano lito železo ΔK_{th} = 8,7 do 9,8 MPa $\sqrt{m}$. Pri mejnih vrednostih faktorjev jakosti napetosti smo ugotovili opazne razlike ter jih povezali z nepravilnostmi v sestavi na različnih straneh vzorcev, ki so nastale med izdelavo in postopkom normalizacije. Opazovali smo tudi vpliv ΔK_{th} na velikost razpok vzorcev litega in normaliziranega litega železa. Nadaljnje raziskave in analiza razpok so pokazale vpliv premajhne enotnosti sestave. Predlagan analitični izraz za ΔK_{th} in odvisnost mehanskih lastnosti lahko uporabimo za izračun trdnosti izmenično obremenjenih velikih kosov.

(Ključne besede: lito železo, utrujanje materialov, lom materialov, razpoke)

This paper presents the results of an experimental and analytical investigation of the high-cycle fatigue of special as-cast and normalized irons, which later in the text are referred to as GI (grade iron) and SGI (spherical graphite iron). Well-known types of cast iron have been modified to achieve better mechanical properties and an improved resistance to crack formation and development as well as propagation. The defined values of the mechanical properties show that the normalizing changes the microstructure, enlarges the plasticity and makes uniform the limits of yield and strength. The microstructures of the investigated as-cast irons include graphite of different sizes, which, after the heat treatment, acquire a spherical shape, unify and reduce in size, and the whole microstructure becomes finer. After testing the compact eccentric tension CT (ASTM) specimens, the crack-growth rate versus the stress intensity factor range for the fatigue diagrams were constructed, and the threshold stress intensity ranges were determined: for GI as cast iron ΔK_{th} = 6.5 to 8.6 MPa $\sqrt{m}$; for GI normalized cast iron ΔK_{th} = 8.2 to 10.3 MPa $\sqrt{m}$; for SGI as cast iron ΔK_{th} = 8.0 to 9.6 MPa $\sqrt{m}$, and for SGI normalized cast iron ΔK_{th} = 8.7 to 9.8 MPa $\sqrt{m}$. The significant differences in the threshold stress intensity factors were determined and related to the structural imperfections at the different sites of specimens formed during the manufacturing and normalization process. For specimens of as-cast and normalized cast iron, the dependence of ΔK_{th} on the crack size was observed. An additional investigation and the fracture analysis show that it was influenced by the absence of structural uniformity. The suggested analytical expression of the ΔK_{th} and the dependence of the mechanical properties can be applied for calculating the strength of cyclically loaded large-sized parts.

(Keywords: cast iron, fatigue, fracture, threshold, cracks)

0 INTRODUCTION

The increase in the durability and reliability of machines, equipment and microstructures is connected with a rational application of mechanical properties, employing them to their limit values and with a large databank of values concerning deformation, strength and resistance to crack propagation. If the material of the element is uniform, it is sufficient to know the mechanical properties and values of the resistance to crack propagation and especially the threshold stress intensity range ΔK_{th}, which can be applied in design calculations ([1] to [14]).

Details of large-size mining-industry equipment, which exceeds 5 m in size, are produced for a particular purpose from cast iron. The longevity of such details exceeds 25 years, and the number of loading cycles enters the gigacyclic range ($N > 10^8$ cycles). The casting of hull details from GI (grade iron) and gears from SGI (spherical graphite iron) and the following heat treatment is connected with some problems. To achieve the required microstructure, it necessary to apply a heat-treatment normalization, which is to guarantee a microstructural change throughout the whole of the large volume. During the normalization process it is necessary to obtain microstructures with a pearlite matrix, but usually there remains some part of ferrite, which is mild and undesirable. A ferrite matrix around graphite nodules has a negative influence on the mechanical properties: it reduces the hardness and the strength. In addition, it is more difficult to control the cooling rate of large-size products. In this case the desirable microstructure is obtained by means of special additives, e.g., Mg, Ca, Ce, Y, Nd, Pr [10], which are introduced to the metal when casting it. In order to adjust the different kinds of cast iron to particular production conditions, different technological processes are applied. The available technological means do not ensure the structural change at every point of the body. Therefore, it is necessary to know the microstructure, the mechanical properties and the resistance to crack propagation after casting and heat treatment. Having defined the indices of the resistance to crack propagation, it is possible to choose such safety coefficients that can guarantee the application of a non-uniform material for the production of important details ([1] to [5]). The pearlite matrix, being harder and stronger than the ferrite matrix, raises the mechanical properties, e.g., the fatigue strength. Spherical, fine-sized graphite remises the stress concentrations and increases the threshold stress-intensity factor.

In [5] and [6] an attempt was made to find the relationship between the threshold ΔK_{th}, the yield limit $R_{p0.2}$, the strength limit R_m, *the* durability limit σ_R and others. The threshold ΔK_{th} also depends on the stress ratio, the temperature, the environmental impact, the overloading, the structural peculiarities of the environment and other factors. However, there is a lack of data concerning the ΔK_{th} dependence on the mechanical properties and microstructure that may be changed in the process of heat treatment.

1 EXPERIMENT

For the experiment four as cast iron and four normalized cast-iron plates of both kinds (GI and SGI) were prepared. The chemical compositions of the investigated irons are presented in Table 1.

The chemical compositions, the setting and the casting procedures were produced at the foundry, and differ from well known similar cast irons used in the USA, Germany and Australia [10]. During heat treatment the investigated plates were settled at the various sites of the furnace beside large sized details. The microstructure of the GI as cast iron is shown in Figure 1a. The graphite is present in the shape of flakes of different size; the structural matrix is represented by ferrite-pearlite. At some points the spherical graphite was formed. The microstructure of the normalized GI as cast iron is shown in Figure 1a. The microstructure is fine-grained, the graphite is spherical, and the base of the microstructure shows pearlite with a small amount of ferrite.

The microstructure of the SGI as cast iron is shown in Figure 2a. It consists of flakes of different size and spherical graphite. The matrix is pearlite with irregularly situated ferrite, although sometimes bainite occurs. The microstructure after normalizing

Table 1. *Chemical composition*

Cast iron	*C*	*Si*	*Mn*	*Ni*	*Mo*	*Cu*	*Cr*
	[%]						
GI	*3.64*	*1.75*	*0.87*	*0.497*	*0.52*	*0.518*	*0.062*
SGI	*4.96*	*1.17*	*0.083*	*0.68*	*0.19*	*1.01*	*–*

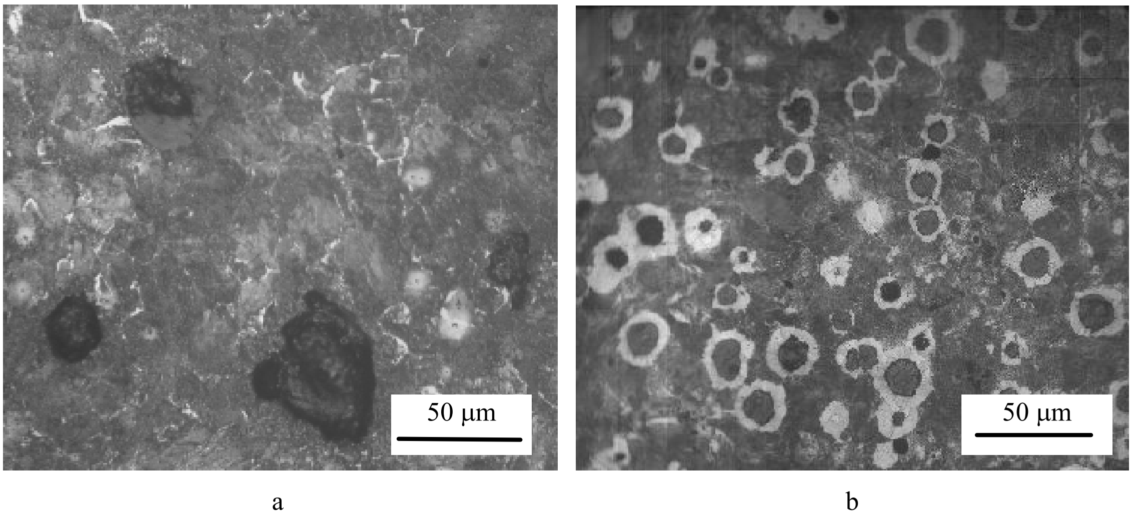


Fig. 1. *Microstructure of GI iron: a – as cast, b – normalized*

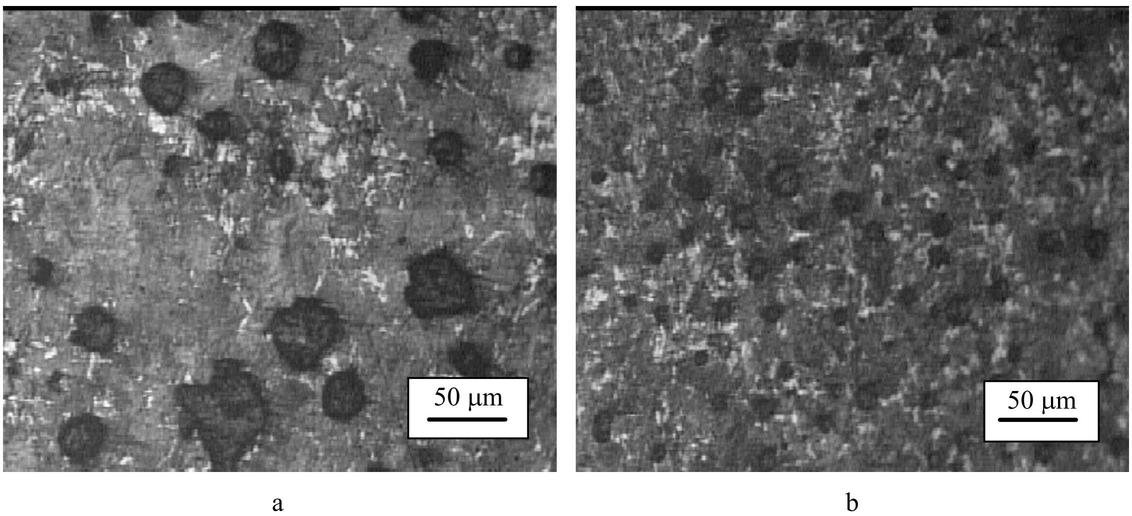


Fig. 2. *Microstructure of SGI iron: a – as cast, b – normalized*

is shown in Figure 2b. It consists of spherical graphite, small-grained pearlite, bainite and ferrite. As we can see, normalizing makes the microstructure uniform and finer. The obtained nodular graphite is of a similar size (GI and SGI).

From all the plates, compact-tension specimens (CT) were fabricated. The values of the mechanical properties were defined; they are presented in Table 2. The hardness of the GI as cast iron is 250 to 277 BHN, the normalized is 228 to 256 BHN, and the hardness of the SGI as cast iron is 289 to 311 BHN, and the normalized one is 290 to 311 BHN. As we can see, in the process of heat treatment, the hardness changes slightly. The heat treatment process consists of normalization and annealing, in accordance with the real construction technological process circumstances.

For determining the threshold stress intensity factor range ΔK_{th}, from GI and SGI cast irons, compact tension CT specimens were cut and shown in Figure 3.

After cyclic testing, additional cylindrical specimens (see Fig. 3) were cut from the CT specimens. The determined mechanical properties of each CT specimen were used to obtain the dependence between the threshold and the yield and the ultimate strength ratio ($R_m/R_{p0.2}$). In accordance with the ASTM E 647-00 methods [7], eight specimens of as cast iron, eight specimens of normalized GI cast iron and four as cast and four normalised SGI cast

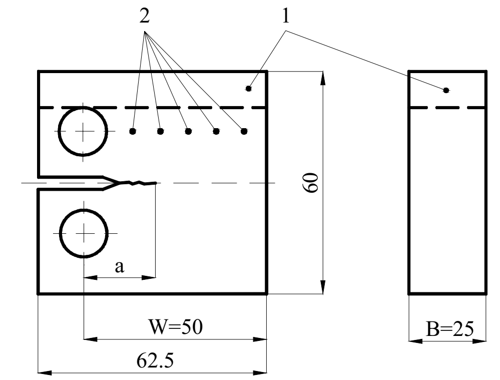


Fig. 3. *The CT specimen: 1 – tensile specimens preparation site; 2 – hardness measuring site*

Table 2. *Mechanical properties*

Cast iron		*Yield strength*	*Ultimate tensile strength*	*Elongation*
		$R_{p0.2}$ *[MPa]*	R_m *[MPa]*	*A [%]*
GI	*As cast*	*443 to 503*	*622 to 671*	*1.80 to 2.43*
	Normalized	*454 to 467*	*684 to 727*	*6.13 to 10.3*
SGI	*As cast*	*630 to 634*	*863 to 933*	*3.70 to 6.70*
	Normalized	*607 to 621*	*862 to 882*	*3.60 to 4.00*

iron specimens were tested (frequency 30 Hz, stress ratio $r \approx 0$). By applying the methods of calculation ([7] and [8]), the crack growth rate versus stress intensity factor range diagrams for fatigue were compiled and the stress intensity factor range ΔK (the variation of the stress intensity factor in a loading cycle) defined; this value was calculated using the formula:

$$\Delta K = \frac{\Delta F}{B \cdot W^{1/2}} f(\lambda) \quad (1),$$

where ΔF is the force range (the difference between the maximum and the minimum forces in a loading cycle), B is the thickness of the specimen (see Fig. 3.), W is the width of the specimen, $f(\lambda)$ is the geometric factor, calculated using the following :

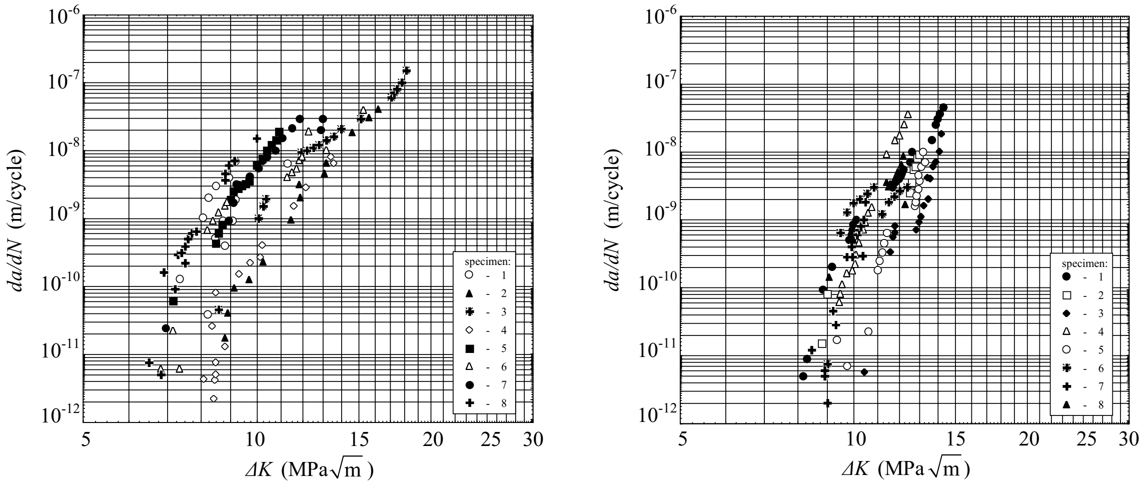
$$f(\lambda) = \frac{(2+\lambda)}{(1-\lambda)^{3/2}} \left(0.886 + 4.64\lambda - 13.32\lambda^2 + 14.72\lambda^3 - 5.6\lambda^4\right) \quad (2),$$

where $\lambda = a/W$, and a is the crack size.

The crack growth rate versus stress intensity factor range fatigue diagram of specimens of GI as cast iron is shown in Figure 4a. The crack growth rate versus stress-intensity factor range fatigue diagram of the normalized cast iron is presented in Figure 4b. The threshold ΔK_{th} = 6.5 to 8.6 MPa$\sqrt{\text{m}}$, and for the normalized cast iron ΔK_{th} = 8.2 to 10.3 MPa$\sqrt{\text{m}}$. The presented data show that normalisation increases the resistance to crack initiation and propagation, i.e., it increases the threshold stress-intensity range.

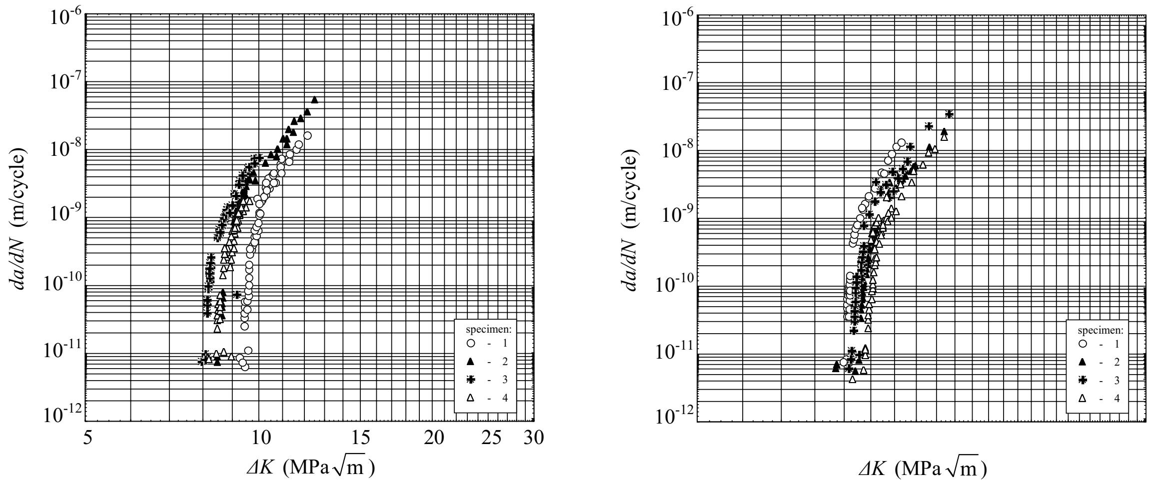
The crack growth rate versus stress intensity factor range fatigue diagram of specimens of SGI as cast iron is presented in Figure 5a and the normalized cast iron is presented in Figure 5b. The threshold for as cast iron ΔK_{th} = 8.0 to 9.6 MPa$\sqrt{\text{m}}$, and for normalized cast iron ΔK_{th} = 8.7 to 9.8 MPa$\sqrt{\text{m}}$.

In references [3], [5], [8] and [12] the dependence of K_c (fracture toughness) on crack size, crack arrest conditions and the relationship of these on other various factors is discussed. From our investigation it is possible to see that in some specimens, under a different crack size, different thresholds appear: when the depth of the fatigue crack increases, the threshold stress intensity range increases, too. In order to explain this phenomenon and to check whether some accidental factors have influenced the results, an additional SGI normalized cast iron compact specimen was tested. The produced crack growth rate versus stress intensity factor range diagram is shown in Figure 6. We can see in it that different ΔK_{th} values correspond to different crack sizes (16.2, 18.5, 21.1, 25.2 and 29.8 mm). Some difference can be explained by the crack front in the stress state in the crack tip; the crack front results from an inhomogeneous microstructure after the heat treat-



a b

Fig. 4. *Crack growth rate versus stress-intensity factor range of GI iron: a – as cast iron, b – normalized iron*



a b

Fig. 5. *Crack growth rate versus stress-intensity factor range of SGI iron: a – as cast, b – normalized*

ment and, consequently, the fracture mechanism changes.

The fracture of an additional CT sample is shown in Fig 7. The observed crack stopping lines (defined 1 to 4) developed because of the change of load during the crack propagation rates decreasing procedures. At these lines the thresholds were determined: 1 - ΔK_{th} = 8.72 MPa $\sqrt{m}$ (2.816 · 10^6 cycles), 2 - ΔK_{th} = 8.75 MPa $\sqrt{m}$ (7.8495 · 10^6 cycles), 3 - ΔK_{th} = 9.41 MPa $\sqrt{m}$ (13.718 · 10^6 cycles), and 4 - ΔK_{th} = 9.81 MPa $\sqrt{m}$ (21.186 · 10^6 cycles). The surface of the crack development and the fatigue enlarging is shown in Fig 8a. The crack structure is reminiscent of a fragile disintegration, which usually takes place when the intergranular ties, for some reasons (a contaminated intergranular laminar, the presence of secondary phases, the segregation of alloying additives, etc.), are weaker than structural grains. At the top of the groove there are many crack focuses (up to 1 mm length), which at a different depth have united to form a main crack. Fig 8b shows the middle part of the fatigue-crack propagation area. Spaces that are close to crack stopping lines (defined 1 and 2) are of different roughness. The furrows and the different crack stopping lines show an irregular cracking front development and some inhomogeneity of the microstructure. The CT specimen's static fracture surface is depicted in Fig 8c. The fracture surface shows the

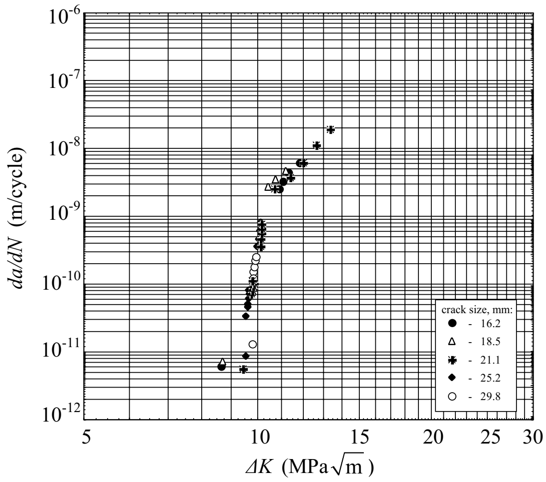


Fig. 6. *Crack growth rate versus stress intensity factor range of additional testings*

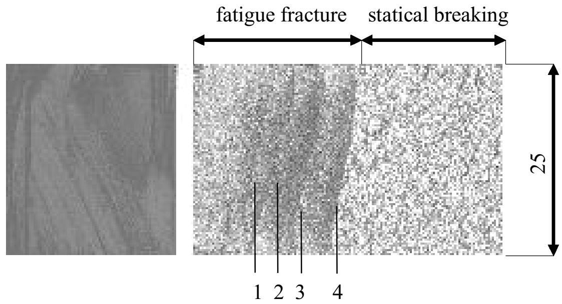


Fig. 7. *Fracture of CT specimen: 1 to 4 are crack-stopping tracks*

character of a fragile disintegration. In the fracture small pits can be seen; they have developed in the place of cavities, and around them crests have developed in the place of the connections. The cavities develop out of micro-pores, micro-cavities and micro-fissures in the material or arise under the influence of strains. At their base inhomogeneous formations can be found. It was observed that fragile streaks develop in the pearlite and in the plastic zones in the ferrite.

During fatigue precracking and the crack propagation rate decreasing procedure, the disintegration character changes. By decreasing the crack propagation rates to $da/dN=10^{-12}$ m/cycle the threshold stress intensity factor ΔK_{th} rises; however, the disintegration process becomes unclear in terms of its relation to the microstructure [5].

2 ANALYSIS OF THE MECHANICAL PROPERTIES AND THE THRESHOLD

In fracture mechanics, the general expression for the stress intensity factor is ([3], [5] and [8]):

$$K_I = Y \cdot \sigma \sqrt{a + a_0} \tag{3},$$

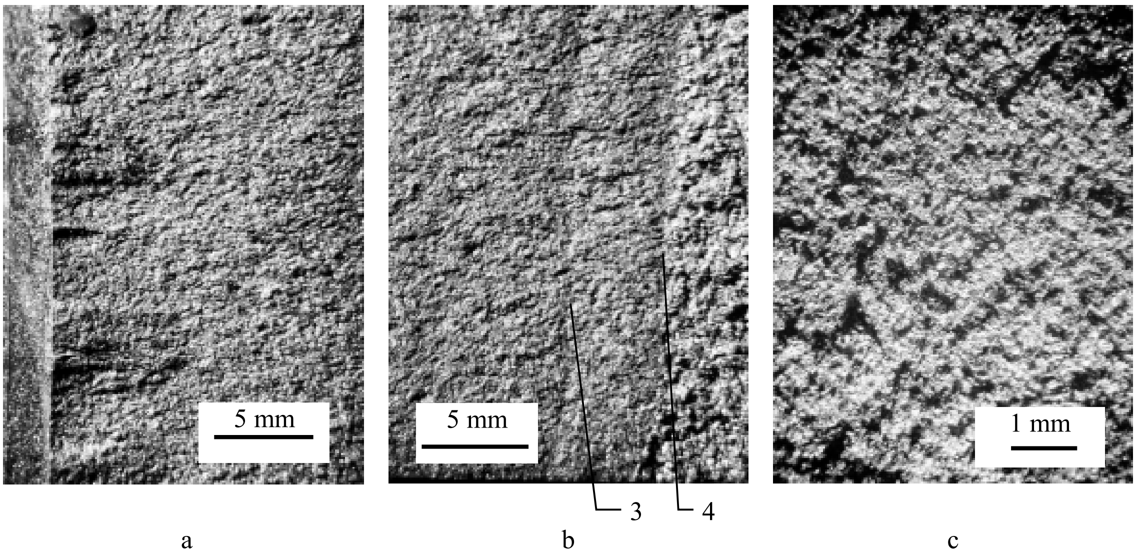


Fig. 8. *Fracture surface: a – fatigue crack initiation area, b – middle part of the fatigue crack propagation area (3 - ΔK_{th} = 9.41 MPa$\sqrt{m}$, N = 13.178 · 10^6 cycles, 4 - ΔK_{th} = 9.81 MPa$\sqrt{m}$, N = 21.186 · 10^6 cycles), c – static fracture surface*

where Y is geometric factor; σ is the stress, a is the crack size, a_0 is the structural defect size.

When $a = 0$, $\sigma = \sigma_R$ (durability limit), $K_I = \Delta K_{th}$, we have the threshold stress intensity range:

$$\Delta K_{th} = Y \cdot \sigma_R \sqrt{a_0} \quad (4).$$

The resistance to crack initiation and propagation depends on many factors and predetermines the longevity of the structural element: it depends directly on microstructure formations (inclusions, cavities, slide belts, defects of production and the exploitation). According to the experimental data obtained, the relations were set between the threshold ΔK_{th0} (when stress ratio $r \approx 0$) and the mechanical property values ratio $R_m/R_{p\,0.2}$, presented in Fig 9. A linear dependence is described by such a function:

$$\Delta K_{th0} = 5.087 \frac{R_m}{R_{p0.2}} + 1.306 \quad (5).$$

The obtained correlation coefficient equals 0.62. The results of a calculation using Formula (5) are compared with those obtained by experiments, and are presented in Table 3. The experimental values $\Delta K_{th,exp}$ were determined from the crack growth rate versus stress intensity factor range fatigue diagrams. In accordance with the ASTM the threshold stress-intensity factors are determined when the fatigue crack propagation rates are at 10^{-10} m/cycle. However, for the reassurance of longevity of mineral mining equipment the threshold stress-intensity factors must be taken from 10^{-10} to 10^{-12} m/cycle. The calculated values $\Delta K_{th,cal.}$ were determined from Equation (5). The additional points in Table 3 characterize the scatter of the threshold ΔK_{th} values. We can see that for the as-cast GI and SGI irons there are bigger deflections from the obtained dependence.

The limit stress intensity factor ΔK_{th} also depends on the asymmetry, the temperature, the environmental effect, the overloading, the inhomogeneity and other factors. The investigations [3], [5], [6] and [8] report an increase of the threshold ΔK_{th} and the fatigue crack growth rate with a change of stress ratio from 0 to 0.9. Under conditions of larger stress ratios ($r > 0.6$ to 0.7), the fracture process changes: its mechanism starts approaching that of the static fracture. Because the crack during the loading process remains open all the time, the threshold ΔK_{th} and the fatigue crack growth rate in a uniform stress intensity factor range becomes more independent of asymmetry. When the stress change is negligible ($r > 0.9$), the cyclic fracture becomes closer to a static fracture.

The shape of the fatigue diagram deforms and, having achieved higher tension values, abruptly breaks. Under conditions of a negative symmetry, its impact on the threshold stress intensity range ΔK_{th} considerably decreases; it is influenced by crack closing. Under conditions of a negative cycle asymmetry, the compressive stresses are often neglected, considering that $K_{min} = 0$ and $\Delta K = K_{max}$.

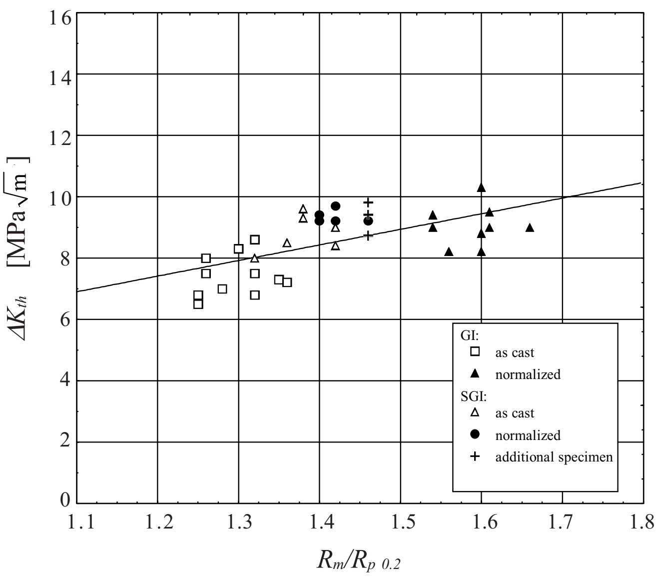


Fig. 9. *Dependence between ΔK_{th} and $R_m/R_{p\,0.2}$*

Table 3. *Comparison of experimental and calculated values*

Cast iron		Specimen	$R_m/R_{p\,0.2}$	$\Delta K_{th,\,exp}$	$\Delta K_{th,\,cal}$	Difference
				$[MPa\sqrt{m}]$	$[MPa\sqrt{m}]$	[%]
GI	As cast	1	1.30	8.3	7.9	4.6
		2	1.35	7.3	8.2	12.0
		3	1.32	8.6	8.0	6.7
		4	1.26	7.5	7.7	2.3
		5	1.36	7.2	8.2	14.2
		6	1.32	6.8	8.0	18.0
		7	1.28	7.0	7.8	11.7
		8	1.25	6.5	7.7	17.9
	Normalized	1	1.56	8.2	9.2	12.7
		2	1.60	8.8	9.4	7.3
		3	1.60	10.3	9.4	8.3
		4	1.54	9.4	9.1	2.8
		5	1.61	9.5	9.5	0
		6	1.66	9.0	9.8	8.3
		7	1.60	8.2	9.4	15.2
		8	1.54	9.0	9.1	1.6
SGI	As cast	1	1.38	9.3	8.3	10.5
		2	1.32	8.0	8.0	0.26
		3	1.36	8.5	8.2	3.2
		4	1.42	9.0	8.5	5.2
	Normalized	1	1.40	9.4	8.4	10.3
		2	1.46	9.2	8.7	5.1
		3	1.40	9.2	8.4	8.4
		4	1.42	9.7	8.5	12.1
SGI additional specimen	Normalized	1	1.46	8.7	8.7	0
				8.75		0.19
				9.4		7.2
				9.8		11.0
Additional point GI	As cast	4	1.26	8.0	7.7	3.6
		6	1.32	7.5	8.0	6.9
		8	1.25	6.8	7.7	12.7
	Normalized	5	1.61	9.0	9.5	5.5
Additional point SGI	As cast	1	1.38	9.6	8.3	13.3
		4	1.42	8.4	8.5	1.5
	Normalized	4	1.42	9.2	8.5	7.3

In practice, crack growth rate versus stress intensity factor range diagrams are most often applied with comparatively small stress range values (r = 0.05 to 0.1), because a larger cycle asymmetry may distort the kinetics of crack propagation. When calculating the negative stress ratio, it is difficult in laboratories to realise the negative part of the loading cycle. The stress ratio changes under service conditions in rather large ranges and influences the crack propagation. When calculating real structures, it is necessary to make corrections in the stress states, in the dimensions, the stress concentration and the surface conditions ([12] to [14]). For a practical calculations of ΔK_{th}, when assessing the stress ratio r [6]:

$$\Delta K_{th} = \Delta K_{th0}(1 - r)^{\gamma} \quad (6),$$

where ΔK_{th0} is the limit interval of the stress intensity factor, when $r = 0$; γ is a coefficient dependent on the material and fluctuates from 0.5 up to 1. Formula (6) shows a good agreement for steel when $0 < r < 0.6$.

Considering the experimental data and the performed analysis it is possible to get equations that are suitable for constructional elements and investigated cast irons. By using Formulae (5) and (6), it is possible to write:

$$\Delta K_{th} = \left(5.087\frac{R_m}{R_{p0.2}} + 1.306\right)(1-r)^{\gamma} \quad (7).$$

If there is a crack of length 2*l* on the surface of a detail, the crack development will be stopped when the limit stress interval correspondent ΔK_{th} does not exceed $\Delta\sigma_{th}$ calculated with Formula (4):

$$\Delta\sigma_{th} = \frac{\Delta K_{th}}{Y\sqrt{2l}} \quad (8).$$

By rearranging Formula (8) we obtain the stress range that is in accordance with the threshold stress intensity factor range ΔK_{th}:

$$\Delta\sigma_{th} = \frac{\left(5.087\frac{R_m}{R_{p0.2}} + 1.306\right)(1-r)^{\gamma}}{Y\sqrt{2l}} \quad (9).$$

The expression obtained can be used for calculating the strength of cyclically loaded large-size details, which remain inhomogeneous after the casting and heat treatment processes. To validate Equation (9) for details from the cast iron with another stress ratio an additional analysis based on experiments is necessary. However, it must be mentioned that the dependence between the threshold and the hardness of the specimens was not observed.

3 CONCLUSIONS

After performing an experimental analysis of the investigations and the results of as cast and normalized cast iron we found the following:

1. Normalizing of the details of large-size details makes the material structure uniform and improves the values of the mechanical properties and the resistance to fatigue-crack formation and propagation, although the variation in the identified properties is large. The identified threshold stress intensity range of the GI as-cast is ΔK_{th} = 6.5 to 8.6 MPa $\sqrt{\text{m}}$; and for normalized cast iron, ΔK_{th} = 8.2 to 10.3 MPa $\sqrt{\text{m}}$. The threshold for SGI as cast is ΔK_{th} = 8.0 to 9.6 MPa $\sqrt{\text{m}}$; and for normalized cast iron, ΔK_{th} = 8.7 to 9.8 MPa $\sqrt{\text{m}}$.
2. The crack growth rate versus stress intensity factor range diagrams created for as cast and normalized cast iron show when the crack growth $da/dN = 10^{-12}$ m/cycle threshold stress intensity range depends on the crack depth. The threshold ΔK_{th} increases when the crack depth increases.
3. The established expression between the threshold stress intensity range ΔK_{th} and the ultimate and the yield strength ratio $R_m/R_{p0.2}$ can be applied for a design strength calculation of the cyclically loaded structural elements with an inhomogeneous state complex. The identified function describes satisfactorily (the obtained correlation coefficient equals 0.62) the experimental data. For a wider application of the obtained dependence an additional analysis and calibration are required.

4 REFERENCES

[1] Marrow T.J., H. Cetinel, S. MacDonald, P.J. Withers, A. Venslovas, M. Leonavičius (2002) *Proceedings of the 14th Biennial Conference on Fracture – ECF14,* Vol. II / III, Sheffield, UK: EMAS, 2002, 443-450.

[2] Leonavičius, M., M. Šukšta, S. Stupak, G. Petraitis (2003) *Mechanika*, No 5(43), 13-18.

[3] Hertzberg R. W. (1996) Deformation and fracture mechanics of engineering materials. *John Willey & Sons Inc*., New York – Singapore.

[4] Dorazil E. (1991) High strength austempered ductile cast iron. *Ellis Horwood*, Prague.

[5] Панасюк В.В. (1990) Механика разрушения и прочность материалов. *Наукова gумка*, Киев.

[6] Kocanda S. (1985) Zmêczeniowe pêkanie metali. *Wydawnictwo naukowo-techniczne*, Warszawa.

[7] ASTM E 647-00. (2000) Standard Test Method for Measurement of Fatigue Crack Growth Rates.

[8] Anderson T.L. (1991) Fracture mechanics. Fundamentals and Application, *CRC Press*, Boston.

[9] Foth S.C., J.C. Newman, R.G Forman (2003) *International Journal of Fatigue*, No 25, 9-15.

[10] Žvinys J. (1999) Konstrukciniai lydiniai. Ketus. *Technologija*, Kaunas.

[11] Ботвина Л.Р. (2004) *Заводская лаборатория. Диагностика материалов,* No 4, 41-51.

[12] Broek D. (1989) The practical uses of fracture mechanics. *Kluwer Academic Publishers*, Dordrech/ Boston/London.

[13] Hudak Jr.S.J. (1981) *Journal of Engineering Materials and Technology*, No 1, 28-39.

[14] Трощенко В.Т. (2000) *Проблемы прочности,* No 5, 34-43.

Authors' Address:
Prof.Dr. Habil. Mindaugas Leonavičius
Prof.Dr. Algimantas Krenevičius
Prof.Dr. Stanislav Stupak
Mag. Gediminas Petraitis
Prof.Dr. Marijonas Šukšta
Vilnius Gediminas Technical Univ.
Dept. Strength of Materials
Sauletekio str. 11, LT-10223
Vilnius - 40, Lithuania
minleo@fm.vtu.lt
ma@fm.vtu.lt
stupakas@adm.vtu.lt
gedp@fm.vtu.lt
marijonas.suksta@fm.vtu.lt

Prof. Dr. Žilvinas Bazaras
Kaunas Univ. of Technology
Dept. of Transport Engineering
Kestucio str. 27, LT-44025
Kaunas, Lithuania
zilvinas.bazaras@ktu.lt

Prejeto: Received: 15.6.2005

Sprejeto: Accepted: 22.6.2006

Odprto za diskusijo: 1 leto
Open for discussion: 1 year

Strojniški vestnik - Journal of Mechanical Engineering 52(2006)9, 568-586
UDK - UDC 551.583:699.86:620.92(497.4)
Pregledni znanstveni članek - Preview scientific paper (1.02)

Povezava modela podnebnih sprememb z modelom toplotnega odziva stavb - primer Slovenije

The Connection Between the Climate Change Model and a Building's Thermal Response Model: A Case of Slovenia

Boris Vidrih[1] - Mojca Dolinar[2] - Sašo Medved[3]
([1]Termo, Škofja Loka; [2]Agencija RS za okolje, Ljubljana; [3]Fakulteta za strojništvo, Ljubljana)

Vodilni svetovni klimatologi menijo, da je celovito spreminjanje podnebja neizbežno. Temelj za tako razmišljanje je dejstvo, da se s podnebnimi spremembami že srečujemo, te spremembe pa naj bi bile v prihodnosti še bolj izrazite. Vplivi sprememb podnebja so in bodo opazni na vseh področjih človekovega delovanja, torej bodo vplivali tudi na oskrbo in rabo energije. Ker opazujemo dolgo časovno obdobje, ki je primerljivo z dobo trajanja stavb, raba energije v njih pa količinsko pomembna, je nujno, da gradnjo in obnovo stavb prilagodimo napovedanim podnebnim spremembam. Napoved toplotnega odziva stavb je osnova za celovito načrtovanje stavb in sistemov strojnih inštalacij, s katerimi v stavbah ustvarjamo primerno bivalno ugodje. Za napoved pričakovanega spreminjanja toplotnega odziva stavb v prihodnosti, je treba dandanes razpoložljive baze meteoroloških spremenljivk ustrezno popraviti. V prispevku prikazujemo različne scenarije podnebnih sprememb, ki jih pričakujemo na področju Slovenije in metode poprave izhodiščnih krajevnih meteoroloških baz. Za popravo uporabljamo poenostavljene prilagojene modele, s katerimi na podlagi metodologije oblikovanja testnih referenčnih let (TRL) izdelamo prilagojena testna referenčna leta (PTRL). Slednje nato uporabimo za napoved sprememb v rabi energije v stavbah in učinkovitosti izbranih naprav, ki uporabljajo naravne vire energije. Glede na napovedane podnebne scenarije za celinsko področje Slovenije se bo raba energije za ogrevanje stavb zmanjšala za 1,5 do 31,4 odstotkov. Bistveno bolj bodo napovedane podnebne spremembe vplivale na toplotno ugodje v stavbah poleti. Tudi v masivno grajenih stanovanjskih stavbah, ki so naravno prezračevane in v katerih je dandanes ustrezno toplotno ugodje, bodo primerne temperature poleti presežene v 20 do 33 odstotkih poletnega obdobja. Bistveno se bodo spremenile tudi učinkovitosti tehnik naravnega in aktivnega naravnega hlajenja. V hlajenih stavbah lahko pričakujemo med 2- do 40-krat večjo rabo koristne energije glede na sedanje stanje. Rezultati, predstavljeni v prispevku, potrjujejo, da je treba posledice globalnih podnebnih sprememb ocenjevati tudi z vidika rabe energije v stavbah in zasnovi stavb in sistemov strojnih inštalacij.

(Ključne besede: podnebne spremembe, modeliranje numerično, toplotni odzivi stavb, raba energije, Slovenija)

The world's leading climatologists believe that global climate changes are inevitable. The basis for this is the fact that we are already facing climate changes that will become even more significant in the future. The impact of climate changes is and will be noticeable in all fields of human activity; therefore, it will also influence the supply and demand of energy. Since we are observing a longer period of time, comparable to the lifespan of a building, and the amount of energy demanded is an important factor, it is necessary to adjust the building and the renovation of buildings to the predicted climate changes. The prediction of a building's thermal response is the basis for the integral planning of the building and building services installation with which we create suitable living conditions. In order to predict the expected changes in the building's thermal response in the future it is necessary to correct the available meteorological variable databases today. In this paper we present various climate-change scenaria expected for Slovenia and the methods for correcting the starting points of the local meteorological databases. For the correction we used simplified mathematical models with which we - by forming test reference years (TRYs) - elaborate corrected test reference years (CTRYs). The latter are used for declaring the changes in *energy demand in buildings and the effectiveness of a chosen building services installation that uses natural energy sources. As regards the predicted climate scenaria for the continental part of Slovenia, the energy use for heating buildings will be reduced by 1.5% to 31.4%. These climate changes will have a substantial influence on the thermal comfort in buildings during the summer. In the heavyweight and naturally ventilated residential buildings that are currently thermally comfortable, suitable summer temperatures will be exceeded during 20% to 33% of the summer. The effectiveness of natural and passive cooling techniques will radically change. In cooled buildings we can expect a 2-to-40-fold increase in the use of final (end-use) cooling energy when compared to today. The results presented in this paper confirm the fact that it is necessary to evaluate the consequences of global climate changes also from the point of view of energy use in buildings, their construction and building services installations.*

(Keywords: global climate change, numerical modelling, buildings thermal response, energy usage, Slovenia)

0 UVOD

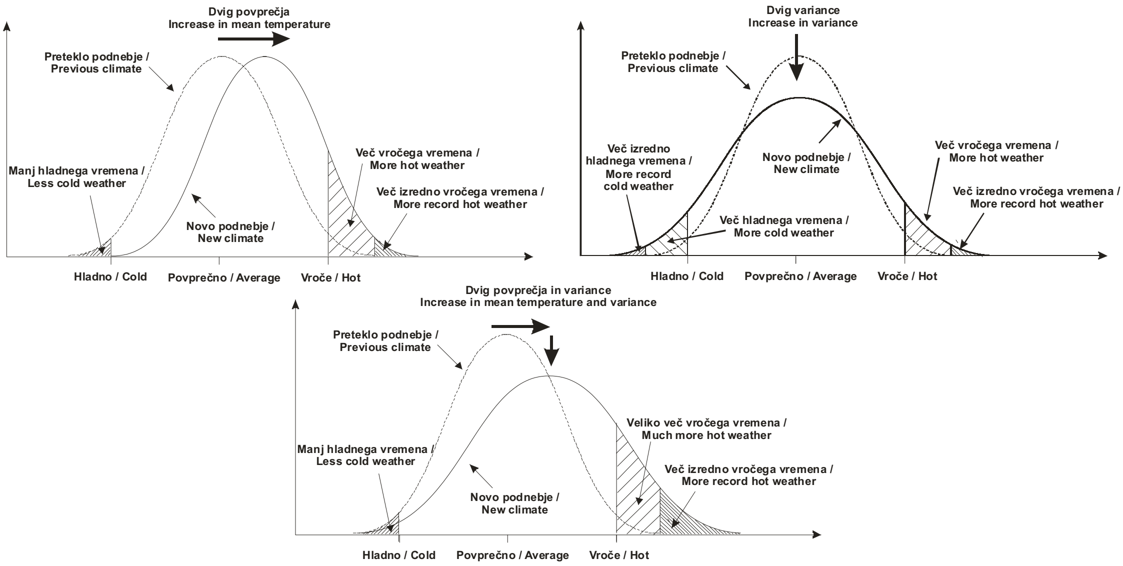
Zasnova sodobnih stavb, uporabljeni gradbeni materiali ter vgrajeni sistemi stavbnih strojnih inštalacij so v sodobnih stavbah medsebojno povezani in soodvisni. To pomeni, da lahko, oziroma moramo z povezanim načrtovanjem stavb in sistemov strojnih inštalacij izdelati stavbo za katero bodo značilni odlično bivalno ugodje, varčna raba energije in majhni pritiski na okolje. Takšen postopek je mogoč le s povezanimi računalniškimi orodji. Ta orodja omogočajo, da, glede na trenutne razmere v zunanjem okolju, geometrijski model stavbe, fizikalne zakonitosti prenosa toplote in snovi v stavbi in sisteme stavbnih instalacij, celovito in podrobno ovrednotimo stanje notranjega ugodja ter energijske in snovne tokove v navidezni stavbi ([1] in [2]). Za tako načrtovanje stavb se je uveljavil izraz celovito načrtovanje stavb.

Spreminjanje termodinamičnega stanja zunanjega okolja je zapleten pojav, na katerega vpliva vrsta naravnih in človeških dejavnikov. Opazovanje spreminjanja svetovne temperature našega planeta v 20. stoletju pokaže, da se je v zadnjem stoletju temperatura že povišala za 0,4 do 0,8 °C. Osnovo za raziskovanje pričakovanih sprememb podnebja v prihodnosti ponujajo modeli MSC. To so trirazsežni numerični modeli, v katere so zajeti fizikalni, kemijski in biološki pojavi v ozračju, oceanih, ledu in na zemeljskem površju ter povezava med temi sistemi. Mednarodni forum o podnebnih spremembah je na podlagi različnih socialno-ekonomskih scenarijev razvoja prebivalstva in gospodarstva izdelal štiri skupine scenarijev emisij toplogrednih plinov. Po teh scenarijih naj bi se

0 INTRODUCTION

In modern buildings their schemes, the building materials used and the built-in building services installations are linked and interdependent. This means that we can or rather have to - with the help of interactive planning - construct a building that will offer excellent living conditions, economical energy usage and not put too much pressure on the environment. Such a process is possible only with linked computer tools. These tools enable us to thoroughly and in detail evaluate the state of internal comfort, energy and material currents in a fictive building, while taking into account the present circumstances in the external environment, the geometrical model of the building, the physical elements of heat and material transfer in the building and its building service installations ([1] and [2]). The term integral building planning was coined for such planning.

The changes of the thermodynamic state of the external environment are a complex phenomenon affected by a number of natural and anthropological factors. The observation of the changes of our planet's global temperature in the 20th century showed a temperature increase of between 0.4 and 0.8°C. The MSC (Mesoscale) models offer a basis for researching the expected climate changes in the future. These models are 3D models that include physical, chemical and biological processes in the atmosphere, oceans, ice and on the earth's surface as well as the interactions between these systems. On the basis of various socio-economic scenarios of population development and economy the international forum on climate changes (the Intergovernmental Panel on Climate Change - IPCC) worked out four groups of scenaria for the emissions of greenhouse gasses. According to these



Sl. 1. *Prikaz podnebnih sprememb; dvig povprečja, sprememba variance ter njun skupni vpliv [3]*
Fig. 1. *Climate change: increase in the mean temperature, increase in the variance of temperature and increase in the mean and variance of temperature [3]*

temperature na zemeljskem površju oz. troposferi povišale od 1,4 do 5,8 °C. Napovedujejo tudi da se bodo povišale tako najvišje kakor najnižje temperature, zato bo več vročih in manj mrzlih dni. Pogostejši bodo tudi vročinski valovi in zmanjšal se bo dnevni temperaturni razpon (sl. 1) [3].

Predvidene podnebne spremembe bodo vplivale tudi na rabo energije v stavbah. Dosedaj objavljene raziskave, ki navajajo povezavo med napovedanimi podnebni spremembami in rabo energije v stavbah ugotavljajo, da se bo raba energije za ogrevanje zmanjšala od 10% do 55%, ob povečani rabi energije za hlajenje od 50 % do 200% ([5] do [8] in [10]). Skupno vsem tem raziskavam je dvig temperature okolice glede na pričakovano celovito spremembo te meteorološke spremenljivke. Spremembe drugih spremenljivk ne upoštevajo. Tako dobimo neko sintetično leto, kar pa ne ustreza zahtevam metode oblikovanja testnih referenčnih let ([11] in [12]). Za področje Slovenije sicer obstajajo napovedi podnebnih sprememb ([13] do [15]), toda niso bile uporabljene na prilagojenih testnih referenčnih letih (PTRL). Zato v tem delu prikazujemo metodo prilagoditve krajevnega TRL, glede na več napovedanih scenarijev podnebnih sprememb v Sloveniji. Zaradi najbolj obsežnih arhivov meteoroloških podatkov smo za napovedovanje izbrali mesto Ljubljana. Tako

scenaria the temperatures in the boundary layer or troposphere would increase by 1.4 to 5.8°C. They also predict that the highest as well as the lowest temperatures will increase; therefore, we will have more hot and fewer cold days. Heat waves will be more frequent and the daily temperature span will be smaller (Fig. 1) [3].

The expected climate changes will also affect the energy usage in buildings. The published research dealing with the connection between the predicted climate changes and the energy usage in buildings ascertains that the energy use for heating will reduce by between 10% and 55%, while the use of energy for cooling will increase by 50% to 200% ([5] to [8] and [10]). Common to all of these researches is the temperature increase of the environment, taking into account the expected global change of this meteorological variable. They do not, however, consider the changes of other variables. In this way we get a sort of synthetic year; however, this does not suit the demands of the TRYs method ([11] and [12]). There are climate change predictions for the territory of Slovenia ([13] to [15]); however, they were not applied to the corrected test reference year (CTRY) method. This is why we showed the local TRY method for a number of predicted scenaria for Slovenia. Due to them being the most comprehensive archives of meteorological data we used Ljubljana for our prediction. Corrected TRY data (CTRY) in such a prilagojena TRL (PTRL) bomo združili z modelom toplotnega odziva stavb in napovedali spremembo rabe energije v izbrani stavbi in spremenjeno učinkovitost sistemov stavbnih inštalacij, ki uporabljajo naravne vire.

1 UGOTOVLJENE IN NAPOVEDANE SPREMEMBE PODNEBJA V SLOVENIJI

Meritve temperature zraka in drugih meteoroloških spremenljivk kažejo, da se podnebje spreminja tudi na območni ravni. Torej tudi v Sloveniji, kjer se je temperatura zraka v zadnjih 50 letih v povprečju zvišala v območju med 0,4 in 1,6 °C. Spremembe drugih veličin so manj izrazite, saj na primer v letnih količinah padavin v Sloveniji ni zaznati sprememb, izjemi sta Kočevje in Rateče, kjer se je v zadnjih 50 letih količina padavin zmanjšala med 16% in 21%. Pogostost skrajnih padavinskih dogodkov po Sloveniji se ni spremenila, statistično značilno pa se je spremenila jakost izrednih padavinskih dogodkov: v gorskem svetu so izredne padavine manj močne, v sredogorju bolj močne, ob obali in na ravninah v notranjosti pa sprememb jakosti izrednih padavin ni zaznati [15].

Klimatski scenariji za Slovenijo v naslednjem stoletju predvidevajo dvig temperature ozračja in povečanje sončnega obsevanja, medtem ko za padavine scenariji niso enotni [16]. Glede na rezultate simulacij s petimi MSC in upoštevanjem dveh scenarijev emisij, lahko sklepamo, da se bosta temperatura in sončno obsevanje v Sloveniji v 21. stoletju brez dvoma povečala. Pri tem ni izrazitih razlik med posameznimi območji Slovenije. Zanesljivost predvidevanj je veliko manjša za količino padavin, v splošnem pa prevladuje negativna usmeritev pri spremembah padavin. Če upoštevamo le najbolj verjetne spremembe za prvi dve tridesetletji 21. stoletja, potem velja za spremembe temperature obseg od + 1 °C do + 4 °C, za spremembe energije svetovnega obsevanja obseg od 0 % do +6 % in za spremembo padavin obseg od - 20 % do + 20 %. V preglednici 1 so prikazane napovedane spremembe izbrane vplivne spremenljivke in oznake najverjetnejših podnebnih scenarijev, ki jih bomo uporabili v naši raziskavi ([16] in [17]).

2 METODA OBLIKOVANJA PRILAGOJENIH TESTNIH REFERENČNIH LET

Prilagojena testna referenčna leta, ki vključujejo napovedane podnebne spremembe, smo

way will be merged with the model of the building's thermal response and thus we will predict the change in energy usage for a chosen building as well as the changed effectiveness of the building services installations that use natural sources.

1 DETECTED AND PREDICTED CLIMATE CHANGES IN SLOVENIA

Measurements of meteorological variables clearly indicate climate changes on a regional scale. The most significant changes in Slovenia were detected in temperature, which has risen between 0.4 and 1.6 °C on average over the past 50 years. The changes of other meteorological variables are less significant; in particular, there is no significant change in precipitation, with the exception of the measurement sites at Rateče and Kočevje, where the precipitation amount has fallen by 16% and 21%, respectively. The frequency of extreme precipitation events has not changed; however, there is a significant change in the intensity of precipitation events: precipitation is less intensive in the mountainous region, more intensive in the sub-Alpine region, and without change in the costal and lowland regions [15].

All climate-change scenaria show an increase in temperature and solar radiation energy in the next century for the entire area of Slovenia, while the predictions for precipitation are not homogenous [16]. According to the results of five different GCM and two different emission scenarios, we can state with high certainty that the temperature and the amount of solar radiation energy will increase in the 21st century in Slovenia. The reliability for precipitation scenarios is less certain, both an increase and decrease is expected, although the positive trend in precipitation is prevailing. If only the scenarios with highest likelihood are considered, than in the first 60 years of the 21st century the estimated change in Slovenia is between 1°C and 4°C for temperature, between -20% and +20% for precipitation and from +0% up to 6% in solar radiation in comparison to the mean 1961-1990 values. The possible combinations of the predicted changes for all three meteorological variables that were considered in our analysis are presented in Table 1 ([16] and [17]).

2 METHODOLOGY FOR CORRECTED TEST REFERENCE YEARS

CTRYs, which include expected changes of meteorological variables, are corrected on the basis

Preglednica 1. *Kombinacije sprememb vplivnih meteoroloških spremenljivk in oznake v različnih scenarijih podnebnih sprememb v Sloveniji*
Table 1. *The changes of influential meteorological variables for different climate-change scenaria for Slovenia*

	Povišanje temperature Temperature rise °C	Povečanje sončnega obsevanja Solar radiation energy rise %	Sprememba padavin Precipitation change %
sedanje TRL contemporary TRY	0	0	0
scenarij A scenario A	1	0	0
scenarij B scenario B	1	3	0
scenarij C scenario C	3	0	0
scenarij D scenario D	3	6	0
scenarij E scenario E	1	3	+20

oblikovali na podlagi dolgoletnih meritev samodejne meteorološke postaje v Ljubljani. Sicer redke manjkajoče vrednosti spremenljivk nadomestimo z interpolacijo. To smo naredili z metodo časovno-prostorske interpolacije z zlepki ([18] in [19]) interpolirali za čas manjkajočih podatkov, pri čemer so bili vozli zlepka zadnja meritev pred ustavitvijo in prva meritev po ustavitvi meritev ter vmesne meritve klasičnih zaznaval ob 7., 14. in 21. uri. Število vozlov je bilo odvisno od dolžine manjkajočega niza, v vsakem primeru pa smo imeli vsaj dva robna vozla. Edini pogoj za zlepek je bil, da je bila v vozlih zvezna, ne pa tudi zvezno odvedljiva (gladka), ker je običajno premalo podatkov, da bi lahko izračunali vse parametre polinoma druge stopnje. Funkcija $f_k(t)$ na odseku med zaporednima vozloma (x_i in x_{i+1}), kjer poznamo vrednosti, zapišemo:

of year-long measured meteorological variables from an automatic weather station (AWS) in Ljubljana. Otherwise rarely missing values of variables (the gap) are substituted with a spatial-temporal interpolation using spline functions ([18] and [19]). The knots of the interpolated function are the last measurement before the gap, the first measurement after the gap, and the measurements from classical stations in climatological terms at 7 a.m., 2 p.m. and 9 p.m. at the same location. The number of knots depends on the length of the gap; nevertheless, there are always at least two edge knots. The only condition for the function is that it is continuous in the knots, since there were usually not enough data to derive all the parameters for a continuously derivable function. The function $f_k(t)$ in the sequence segment between two successive knots (x_i and x_{i+1}) is:

$$f_k(t) = g(t) - \left[g(t_i) - x_i\right] + \frac{\left[g(t_i) - x_i\right] - \left[g(t_{i+1}) - x_{i+1}\right]}{t_{i+1} - t_i}\left[t - t_i\right]$$

kjer so:

t_i - čas v *i*-tem vozlu,
t_{i+1} - čas v *i*+1. vozlu,
x_i - robna vrednost funkcije $f_k(t)$ v *i*-tem vozlu,
x_{i+1} - robna vrednost funkcije $f_k(t)$ v *i*+1. vozlu,
$g(t)$ - potek meteorološke spremenljivke v času na sosednji postaji,
$g(t_i)$ - vrednost meteorološke spremenljivke v *i*-tem vozlu na sosednji postaji,
$g(t_i)$ - vrednost meteorološke spremenljivke v *i*+1. vozlu na sosednji postaji.

Najbolj razširjene metode oblikovanja PTRL, ki vključujejo napovedane spremembe podnebja so:

where:

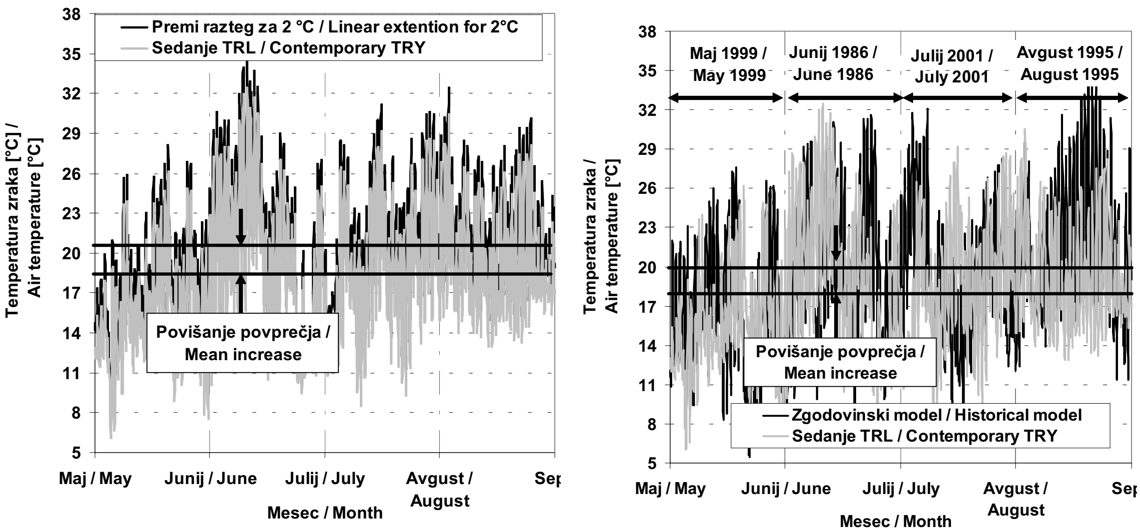
t_i - is the time in the i^{th} knot,
t_{i+1} - is the time in the $i+1^{th}$ knot,
x_i - is the value of the $f_k(t)$ in i^{th} knot,
x_{i+1} - is the value of the $f_k(t)$ in $i+1^{th}$ knot,
$g(t)$ - is the dependence of the meteorological variable on the time on the neighboring station,
$g(t_i)$ - is the value of the meteorological variable on the neighboring station in the i^{th} knot,
$g(t_i)$ - is the value of the meteorological variable on the neighboring station in the $i+1^{th}$ knot.

The most frequently used approaches to adopt CTRY on climate-change scenarios are: a linear premi razteg TRL ([13] do [15]), uporaba naključnostnih generatorjev vremena ([20] in [21]) ter uporaba zgodovinskega načina oblikovanja PTRL [22]. Na sliki 2 sta shematsko prikazana načina oblikovanja PTRL s premim raztegom in uporaba zgodovinskega načina oblikovanja PTRL.

Zadnji dve metodi sta računsko in časovno zahtevni, medtem ko je premi razteg izredno preprosta metoda. Pomanjkljivost vseh treh metod je, da ne upoštevamo spremembe porazdelitve in spremenljivosti meteoroloških spremenljivk zaradi podnebne spremembe, ampak upoštevamo le spremembo njene povprečne vrednosti. Pomanjkljivost nizov, oblikovanih z naključnostnim generatorjem vremena, je, da lahko pride do nesmiselnih zvez med posameznimi spremenljivkami, kar pa je izredno moteče pri kasnejši napovedi toplotnega odziva stavb. V tem primeru je še posebej pomembna smiselna zveza med temperaturo, vlažnostjo ozračja in sončnim obsevanjem. Kot najbolj primerno metodo zato izberemo metodo oblikovanja PTRL na zgodovinski način. Torej poiščemo iz obsežne baze krajevnih meteoroloških podatkov neko drugo delno obdobje (niz, običajno mesec dni), ki najbolj ustreza pričakovanemu, oziroma napovedanemu stanju. Tako ostajajo spremenljivke smiselno povezane, nekaj težav bi lahko predstavljala le nezveznost med posameznimi časovnimi obdobji (meseci), ki pa v primeru analize toplotnega odziva stavb ne pomeni velike pomanjkljivosti zaradi razmeroma velike toplotne vsebnosti gradbenih konstrukcij.

extension of the TRY ([13] to [15]), stochastic weather generators ([20] and [21]) and a historical approach [22]. In Figure 2 there are schematic representations of two methodologies to adopt the CTRY: a linear extension and a historical approach.

The last two methods have high computational and time requirements, while a linear extension is a very simple method. The weak point of all three described methods is that they do not consider the changes of the distribution and the variability of the meteorological variables, they only consider the changes of mean values. The weak points of the series constructed with the stochastic weather generator are the strange relations between the meteorological variables, which do not match reality, and could affect the predicted thermal responses of buildings. For thermal response modeling it is very important that there is a logical correlation between the temperature, the humidity and the solar radiation. The most suitable method, that fulfils that criterion, is the historical approach. From the database of hourly meteorological variables a month was selected, which is in all meteorological variables the closest to the average or predicted month. The correlations between the variables stay logical and natural; a minor problem is the discontinuity on the borders between months, which does not represent difficulties in the thermal response simulation, since buildings have a relatively large thermal capacity.



Sl. 2. *Shematični prikaz oblikovanja PTRL s premim raztegom TRL in na zgodovinski način iz baze krajevnih meteoroloških podatkov*

Fig. 2. *Schematic presentation of a linear extension methodology and a historical approach for the construction of the TRY*

Izbiro posameznih nizov smo naredili na podlagi dnevnih podatkov meteoroloških postaj, ki jih ARSO sistematično zbira v digitalni obliki v zadnjih dvanajstih letih. Sončno obsevanje smo izračunali iz trajanja sončnega obsevanja s preprostim parametričnim modelom. Za vsakega od scenarijev smo PTRL oblikovali kot skupek mesečnih nizov iz baze zgodovinskih krajevnih meteoroloških podatkov. Posamezni niz smo izbrali z uporabo Finkelstein-Schaferjeve statistike (FS) [22]:

The CTRY is constructed from representative months selected from the AWS hourly data, operated by the Environmental Agency of the Republic of Slovenia (EARS) in the past 12 years. The solar radiation energy was calculated from the sunshine duration. For every climate-change scenario from Table 1 the CTRY was also constructed from historical data on a monthly basis. The month was selected on the basis of Finkelstein-Schafer (SF) statistics [22]:

$$FS(p,m,y)=\sum_{i=1}^{N_m}\left|CDF(p_i,m,y)-CDF(p_i,m,N_y)\right|$$

kjer so:

FS(p,m,y) - Finkelstein-Schaferjeva statistika za meteorološko spremenljivko p, mesec m in leto y,

CDF(p_i,*m,y)* - zbirna porazdelitvena funkcija povprečnih dnevnih vrednosti meteorološke spremenljivke p za mesec m in leto y,

CDF(p_i,*m*,N_i) - zbirna porazdelitvena funkcija povprečnih dnevnih vrednosti meteorološke spremenljivke p za mesec m in več let (referenčno obdobje ali scenarij).

FS je sešteta po vseh obdobjih vrednosti zbirne porazdelitve (Nm). Za izbiro mesecev, ki sestavljajo posamezne referenčne nize, so nekatere meteorološke spremenljivke bolj pomembne od drugih. Teža posamezne spremenljivke pri izbiri je v največji meri odvisna od namena uporabe referenčnega niza. Na rabo energije za ogrevanje in hlajenje v največji meri vplivajo temperatura zraka, sončno obsevanje in vlaga. Kot ključne spremenljivke za izbiro mesecev za sestavo testnih nizov za referenčno leto (1961-1990) in za scenarije posameznih podnebnih sprememb smo zato izbrali povprečno dnevno temperaturo, mesečno vsoto celotnega obsevanja in padavin. Kljub vplivu vetra na rabo energije te spremenljivke nismo uvrstili kot ključne spremenljivke za izbiro ustreznega meseca, zaradi izjemno slabe kakovosti in neustreznosti meritev vetra pred letom 1990. Poleg tega je veter spremenljivka z zelo veliko spremenljivostjo in njene spremembe v prihodnosti so za zdaj nenapovedljive, torej jih v scenarijih spremembe podnebja nismo zajeli. Zbirno porazdelitveno funkcijo (CDF) smo izračunali za referenčno obdobje (1961-1990), za posamezne scenarije ter za vsak mesec v obdobju zadnjih 12 let (obdobje samodejnih meritev, za katerega imamo na voljo urne podatke). CDF za posamezne scenarije smo izračunali iz CDF za

where;:

FS(p,m,y) are the Finkelstein-Schafer statistics for the meteorological variable p, the month m and the year y

CDF(p_i,*m,y)* is a cumulative distribution function for mean daily values of the meteorological variable p for the month m and the year y

CDF(p_i,*m*,N_i) is a cumulative distribution function for the mean daily values of the meteorological variable p for the month m and Ni years (reference year or scenario)

FS is summed up along all intervals of the cumulative distribution function (Nm). For the CTRY correction some meteorological variables are more important than others. The weight of a single variable depends on the purpose for which the CTRY would be used. Energy use for heating and cooling mostly depends on the air temperature, the solar radiation energy and the humidity. Three climate variables are identified as being critical for CTRY construction, according to the climate-change scenarios: the temperature, the precipitation and the global radiation. Even if the wind influences energy use, it was not included among the critical variables for the selection of the separate months, because wind measurements were of very poor quality in the period before 1990. Furthermore, the variability of wind is very high and for the moment unpredictable, so it was not included in the climate-change scenarios. Cumulative distribution functions (CDFs) were calculated for the reference period 1961-2000, for all treated scenarios and for every separate month of the period of the past 12 years (the period of automated weather-station measurements, for which the hourly data were available). The CDF for a separate scenario was calculated from the CDF for the reference period (1961-2000) with a linear shift in the average values of all the variables, according to referenčno obdobje 1961-1990 s premim premikom posamezne spremenljivke glede na scenarij. Mera za izbiro meseca v referenčni niz je bila utežena vsota statistike FS:

the climate-change scenario. The measure for the selection of a separate month to be included in the CTRY, the weighted sum of FS(m,y) statistics for all three climate variables, is calculated using:

$$FS(m,y)=\sum_{p=1}^{3}W_p\cdot FS(p,m,y)$$

kjer so:

FS(m,y) - utežena vsota statistike FS za mesec in leto,

W_p - utež za posamezno spremenljivko (v našem primeru enaka za vse tri spremenljivke: 1/3),

FS(p,m,y) - statistika FS za posamezno spremenljivko (povprečno dnevno temperaturo, mesečno vsoto padavin in trajanje sončnega obsevanja), mesec in leto.

Kot referenčni niz je bil izbran mesec z najnižjo vrednostjo statistike FS. PTRL smo nato sestavili iz tistih dvanajstih referenčnih nizov, za katere vsota statistike FS za vse referenčne nize ni presegla 24. To mejo smo določili izkustveno [23], iz primerjave letne statistike FS in povprečnih letnih vrednosti posameznih spremenljivk niza. Slika 3 prikazuje sončno obsevanje in povprečne temperature iz različnih PTRL za obdobje ogrevanja in hlajenja stavb ob upoštevanju v preglednici 1 opisanih podnebnih scenarijev. Izdelana PTRL pomenijo najboljši približek scenarijev podnebnih sprememb zgodvinskim vrednostim.

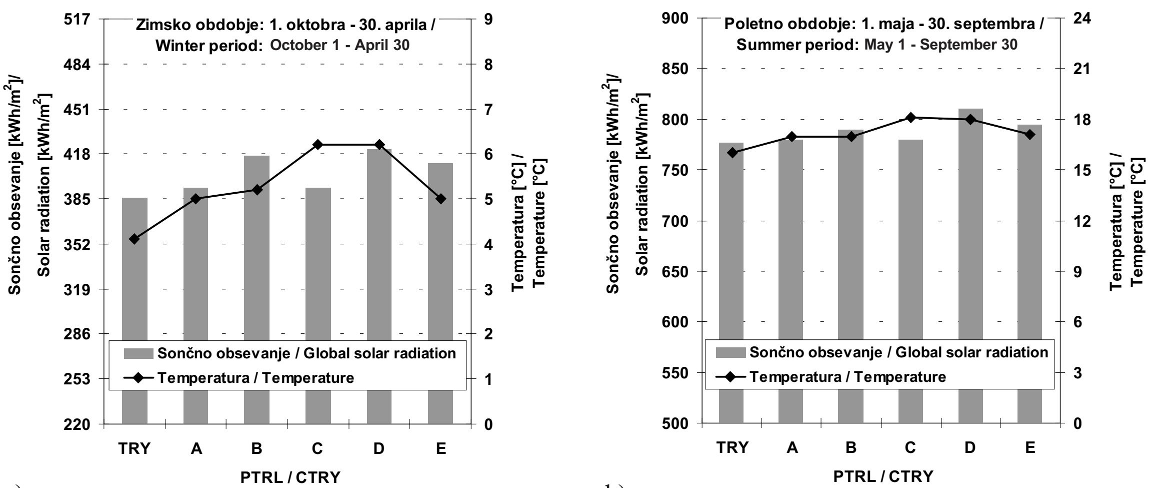
where:

FS(m,y) is the weighted sum of FS statistics for the month m and the year *y*,

W_p is the weight for a single meteorological variable (in the treated case all weights were equal to 1/3),

FS(p,m,y) is the FS statistic for a separate variable *p*, the month *m* and the year y

The month/year with the lowest value of FS statistics is selected for the construction of a reference year. The CTRYs are constructed only for those scenarios where the sum of FS statistics for all 12 months is lower than 24. The threshold of 24 is chosen empirically [23], according to the magnitude of the difference between the average and demanded values of the climate variables. Solar radiation energy and the mean temperature for different CTRYs are presented in Figure 3, separately for the heating and cooling periods. CTRYs are calculated and marked according to the scenarios from Table1. Corrected CTRYs are the best approximation for climate-change scenarios with historical measurements.



a) b)

Sl. 3. *Sončno obsevanje in povprečna temperatura okolice za a) zimsko in b) poletno obdobje iz različnih PTRL, ki vključujejo podnebne scenarije*

Fig. 3. *Solar radiation and mean yearly temperature for a) winter and b) summer period for the CTRY corresponding to different climate-change scenaria*

3 POVEZAVA MODELA PODNEBNIH SPREMEMB Z MODELOM TOPLOTNEGA ODZIVA STAVB

Zasnova sodobnih stavb, uporabljeni gradbeni materiali, učinkovitost sistemov stavbnih strojnih inštalacij in meteorološke spremenljivke odločilno prispevajo k energijski učinkovitosti stavb. Ob tem je pomembno, da je največji del porabljene energije v stavbah posledica zagotavljanja bivalnega ugodja. Pri tem imamo v mislih sisteme za ogrevanje, hlajenje in sisteme za prezračevanje.

V naši raziskavi smo za ovrednotenje napovedanih sprememb podnebja na toplotni odziv stavb uporabili numerični simulacijski program TRNSYS [25]. Na sliki 4 je prikazan primer toplotnega odziva izbrane stavbe. Navajamo ga lahko s temperaturami, ki se vzpostavijo v neogrevani in nehlajeni stavbi (nanadzorovani toplotni odziv) ali toplotni tokovi pri ogrevani in/ali hlajeni stavbi če temperaturo v stavbi omejimo (nadzorovani toplotni odziv stavbe). V tem primeru lahko določimo potrebno moč ogrevalnega in hladilnega sistem in tudi rabo energije za zagotavljanje načrtovanega toplotnega ugodja.

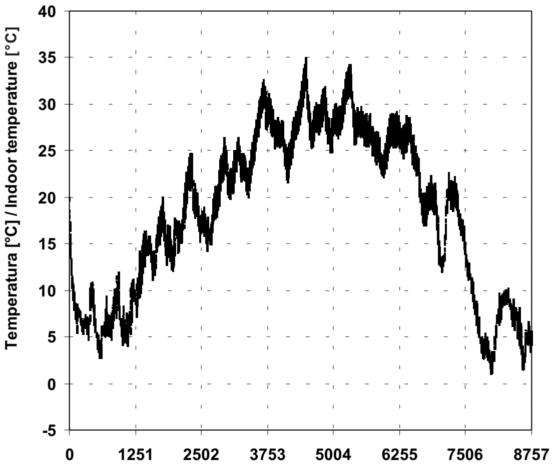
Majhna raba energije v sodobnih stavbah ne temelji zgolj na odlični toplotni izolaciji gradbenih

3 THE CONNECTION BETWEEN THE CLIMATE CHANGE MODEL AND THE BUILDINGS' THERMAL RESPONSE MODEL

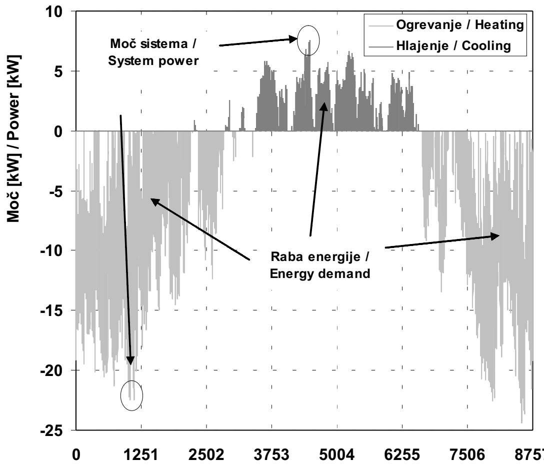
The basis of modern buildings, the used building materials, the effectiveness of the installations and the meteorological variables decisively contribute to a buildings' energy efficacy. Along with this it is important that the biggest share of the building's used energy is used to ensure a certain level of living comfort. For this we have in mind the systems for heating, cooling and air-conditioning.

In our research we have used a numerical simulation programme called TRNSYS in order to evaluate the effect the predicted climate changes will have on the building's thermal response [25]. Figure 4 shows a thermal response example for a chosen building. We can show the example with temperatures that are present in a non-heated or non-cooled building (uncontrolled building thermal response), or the heat flux at a heated and/or cooled building when we define the inner temperature (controlled building thermal response). In this case we can define the necessary heating or cooling power as well as the energy use needed to ensure the planned thermal comfort.

The low energy use in contemporary buildings is not based merely on the excellent heat insulation of



a)



b)

Sl. 4. *Toplotni odziv stavbe popisuje spreminjanje notranjega toplotnega okolja v odvisnosti od stanja v zunanjem okolju. Slika a) prikazuje primer nenadzorovanega toplotnega odziva stavbe in b) primer nadzorovanega toplotnega odziva, na podlagi katerega lahko določimo potrebno moč sistema ter rabo energije za zagotavljanje načrtovanega toplotnega ugodja*

Fig. 4. *Thermal response of house to determine the inner thermal comfort dependence from the environmental condition. Figure a) shows the uncontrolled building thermal response of a building and b) the controlled thermal response, where we can define the necessary heating and/or the cooling power and energy use to ensure the planned thermal comfort.*

elementov, temveč tudi na izrabi naravnih virov za ogrevanje (sprememba sončnega obsevanja) in hlajenje (nočno prezračevanje, hlapilno hlajenje, zemeljski prenosnik toplote). Ker poleg meteoroloških spremenljivk na toplotno ugodje v stavbi vpliva tudi njihova arhitektonska zasnova bomo v našem delu vpliv napovedanih podnebnih sprememb določili za izbrano stanovanjsko in poslovno stavbo, ki ju prikazuje slika 5. Povečanje debelin toplotne izolacije, ki je značilno za sodobne stanovanjske stavbe, zahteva svojski način gradnje stavb z lahkimi gradbenimi elementi v obliki prej izdelanih elementov. Posledica tega je majhna toplotna prehodnost, toda tudi majhna toplotna vsebnost gradbenih elementov in zato manjša učinkovitost naravnega ogrevanja s soncem in naravnega hlajenja. Zato v naši raziskavi, poleg obeh resničnih stavb, analiziramo tudi namišljeno "lahko" grajeno stanovanjsko stavbo z enakimi toplotnimi prehodnostmi gradbenih konstrukcij. Poslovna stavba ima 6 nadstropij. V sredini stavbe je atrij, ki je odprt prek vseh nadstropij in je na vrhu zasteklen. Senčenje in prezračevanje vseh stavb je izvedeno skladno z zahtevami učinkovite rabe energije v stavbah, torej mehansko z vračanjem toplote. Preostale pomembne toplotno tehnične lastnosti stavb navajamo v preglednici 2.

Numerični model toplotnega odziva stavb smo preverili v obeh zgrajenih stavbah z meritvami temperatur nenadzorovanega toplotnega odziva stavb v obeh znanih stavbah. Na sliki 6 je prikazano ujemanje izmerjene in numerično določene občutene temperature osrednjega prostora v stanovanjski stavbi v poletnem obdobju.

building elements, but also on the exploitation of a natural source of heating (transforming solar radiation) and cooling (night-time ventilation, evaporation cooling, ground heat exchanger). Since thermal comfort is not affected just by the meteorological variables but also by the architectural basis, we will deal with the impact of the predicted climate changes for a chosen residential and office building as shown in Figure 5. Increasing the thickness of heat isolation, which is typical for modern residential buildings, demands a specific method of building houses, with light, pre-factored building elements. This results in a low heat transfer as well as a low heat capacity of the building elements and therefore a lower efficiency of the natural heating and cooling. This is why we, alongside both real buildings, also analysed an imaginary 'lightweight' built residential building with equal heat transfer of the building constructions. The office building has six floors. In the centre of the building there is an atrium with a glass roof at the top. The shading and ventilation of all the buildings is performed in accordance with the demands of efficient energy use, i.e., mechanical with a heat exchanger. The other important technical and heat properties of the building are indicated in Table 2.

We verified the numerical model for the building's thermal response in both buildings by measuring the temperatures of the uncontrolled building thermal response in both existing buildings. In Figures 6 and 7 we show the accordance of the measured and the numerically defined operative temperature in the central room of the residential building and at the top of the atrium of the office building during the summer.

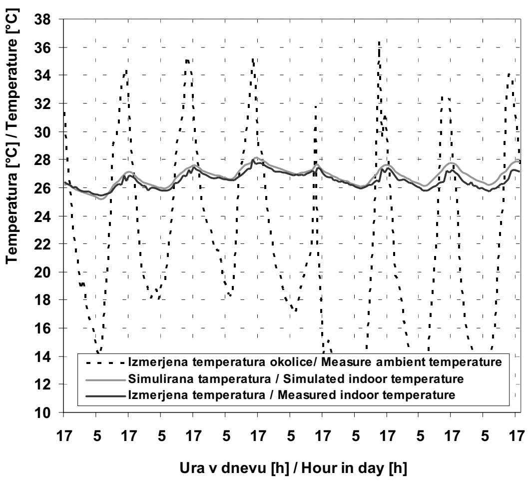
a)

b)

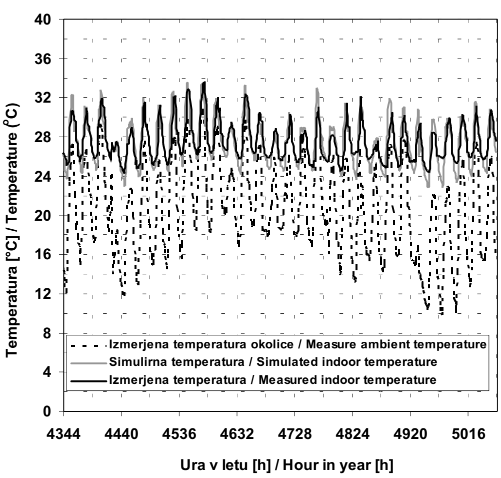
Sl. 5. *a) Stanovanjska in b) poslovna stavba v Ljubljani ([24] in [10])*
Fig 5. *a) Residential and b) office building in Ljubljana ([24] and [10])*

Preglednica 2. *Toplotno-tehnične lastnosti izbranih stavb*
Table 2. *Technical and thermal properties of the building*

	Stanovanjska stavba Residential building	Poslovna stavba Office building
Uporabna površina Living area	101 (191)	1986 (15063)
Temperatura (ogrevanje,hlajenje) Temperature (heating, cooling)	20°C, 26°C	20°C, 26°C
$U_{zunanji\ zid}$ [W/m^{2}K] $U_{exterior\ wall}$ [W/m^{2}K]	0,3	1,3
U_{streha} [W/m^{2}K] U_{roof} [W/m^{2}K]	0,1	0,4
U_{pod} [W/m^{2}K] U_{floor} [W/m^{2}K]	0,4	0,6
$U_{notranji\ zid}$ [W/m^{2}K] $U_{inner\ wall}$ [W/m^{2}K]	0,4	1,4
$U_{zasteklitev}$ [W/m^{2}K] $U_{glazing}$ [W/m^{2}K]	1,4	1,3
$g_{zasteklitev}$ [/] $g_{glazing}$ [/]	0,62	0,33
Količnik senčenja zasteklitve Sf Shading factor Sf	0,25	0,4
Zasedenost [h] Occupancy [h]	16^{00} - 7^{00}	7^{00} - 19^{00}
Notranji viri toplote [W/m^2] Gain [W/m^2]	3 W/m^2	5 W/m^2
Naravno prezračevanje [h^{-1}] Infiltration [h^{-1}]	0,2	0,2
Prisilno prezračevanje [h^{-1}] Ventilation [h^{-1}]	0,5	0,5



Sl. 6. *Eksperimentalna potrditev modela toplotnega odziva stanovanjske stavbe - primerjava izmerjenih in numerično določenih temperatur v osrednjem prostoru*
Fig. 6. *Experimental verification numerical model for the residential building - accordance of the measured and the numerically defined indoor temperature in the central room*



Sl. 7. *Eksperimentalna potrditev modela toplotnega odziva poslovne stavbe - primerjava izmerjenih in numerično določenih temperatur na vrhu atrija v poletnem obdobju*
Fig. 7. *Experimental verification numerical model for the office building - accordance of the measured and the numerically defined indoor temperature on the top of the atrium*

Za preverjanje numeričnega modela toplotnega odziva stavb smo v vseh primerih uporabili izmerjene vrednosti meteoroloških spremenljivk v istem obdobju. V obeh primerih menimo, da gre za uspešno preverjanje numeričnega modela. Razlike pri stanovanjski stavbi ne presežejo ± 0,4°C, pri poslovni stavbi pa so sicer nekoliko večje (do ±2,1°C), kar je razumljivo glede na dejstvo, da so notranji viri toplote, razsvetljava, gibanje ljudi in prezračevanje med conami težje sledljivi.

In order to verify the numerical model of the building's thermal response we used the measured values of meteorological variables over a certain period. We believe that we have a successful verification of the numerical model for both cases. The differences in the residential building do not exceed ±0.4°C and in the office building they do not exceed ±2.1°C, which is understandable considering the fact that the inner sources of heat, such as lighting, the movement of people and airing are difficult to follow.

4 VPLIV NAPOVEDANIH SPREMEMB PODNEBJA NA RABO ENERGIJE V STAVBAH

4 THE INFLUENCE OF THE PREDICTED CLIMATE CHANGES ON THE ENERGY DEMAND

Energijsko učinkovitost stavb zagotovimo z dvema skupinama ukrepov - kakovostno toplotno zaščito in vgradnjo sistemov, ki izrabljajo naravne vire toplote in hladu. Napovedane spremembe podnebja bodo vplivale tako na rabo energije za ogrevanje in hlajenje stavb kakor tudi na učinkovitost naprav, še posebej v poletnem času. Zato bomo poleg sprememb v rabi energije, potrebni za zagotavljanje toplotnega ugodja, analizirali tudi spremembe v učinkovitosti tehnik naravnega in dejavnega naravnega hlajenja. Med slednje uvrščamo povečano nočno naravno prezračevanje, ogrevanje in hlajenje zraka za prezračevanje pred vstopom v stavbo v zemeljskem prenosniku toplote in posredno hlapilno hlajenje.

V literaturi zasledimo, da je mogoče tudi v mestnih okoljih s primernim načrtovanjem prezračevalnih odprtin in prečnim prezračevanjem zagotoviti do 13-kratno urno izmenjavo zraka v stavbi [27]. V naši raziskavi smo upoštevali 5 h-1 nočno (med 20.00 in 7.00 zjutraj) naravno izmenjavo zraka v stavbah, ko je temperatura v stavbi višja od 23 °C. Ta vrednost pomeni najvišjo pričakovano vrednost v zavetrju. Temperatura zraka, ki vstopa v stavbo je enaka temperaturi okolice. Pri zemeljskem prenosniku toplote zrak vodimo z ventilatorjem skozi primerno dolgo cev, ki je zakopana vsaj 2,5 m pod površjem. Temperaturo zraka na vstopu v stavbo določimo z numeričnimi ali izkustvenimi modeli. V našem delu smo uporabili merilni izraz, ki ga je oblikoval Mihalakakou [28]. Izstopno temperaturo zraka iz zemeljskega prenosnika izračunamo z izrazom:

We ensure the building's energy efficiency with two types of measure - quality heat insulation and the inclusion of systems that use natural sources for heating and cooling. The predicted climate changes will affect the energy used for heating and cooling the buildings as well as the effectiveness of the devices, especially during the summer. For this reason we will - apart from the changes in energy demand in order to ensure thermal comfort - also analyse the differences in the efficiency of the natural and active cooling techniques. Among the latter we classify the increased night-time natural ventilation, heating and cooling the air before it enters the building through ground heat exchanger and indirect evaporation cooling.

We discovered in the literature that it is possible to ensure up to 13 per hourly air exchanges, even in urban surroundings, if we apply suitable ventilation holes' planning and cross-way ventilation [27]. In our research we paid special attention to 5 h-1 per night (between 8 pm and 7 am) of natural air exchanges in buildings when the temperature in the building exceeds 23°C. This value represents the highest expected value in wind-sheltered conditions. The air temperature entering the building is the same as the surrounding temperature. With the ground heat exchanger we lead the air (with the aid of a ventilator) through a suitable long tube buried at least 2.5 m underground. We define the air temperature at the building entrance with numerical and empirical models. In our work we used the empirical expression formed by Mihalakakou [28]. We can calculate the air temperature exiting from the ground heat exchanger with the following equation:

$$T_{izst} = T_{zemlje} + \left[\left(T_{okol} - T_{zemlje} \right) \cdot \varepsilon_{ref} \left(L \right) \cdot {}^{norm}_{Q,L}(z) \cdot {}^{norm}_{z,L}(Q) \right]$$

kjer so:

T_{zemlje} temperatura zemlje na globini cevi

where:

T_{zemlje} is the soil temperature at the depth of the prenosnika,

T_{okol} temperatura okoliškega zraka, ki vstopa v zemeljski prenosnik,

ε_{ref} referenčna učinkovitost zemeljskega prenosnika, odvisna od dolžine,

$^{norm}_{Q,L}(z)$ referenčna učinkovitost zemeljskega toplotnega prenosnika, odvisna od globine,

$^{norm}_{z,L}(Q)$ referenčna učinkovitost zemeljskega prenosnika odvisna od prostorninskega pretoka zraka.

Sodobni sistemi za mehansko prezračevanje morajo imeti vgrajen prenosnik za vračanje toplote svežemu zraku. Tak sistem lahko nadgradimo v sistem za posredno hlapilno hlajenje. Prenosno površino na strani odpadnega zraka omočimo in tako ustvarimo prenos toplote in snovi, s katerim se odpadni zrak hlapilno hladi. Posredno pa se hladi tudi svež zrak, ki prek prenosnika toplote teče v stavbo. Izstopno temperaturo zraka za prezračevanje stavbe določimo z izrazom [30]:

pipe heat exchanger

T_{okol} is the air temperature at the pipe's inlet

ε_{ref} is the reference effectiveness of heat exchanger, depending on the pipe's length

$^{norm}_{Q,L}(z)$ is the reference effectiveness of the heat exchanger, depending on the depth of the buried pipe below the earth's surface

$^{norm}_{z,L}(Q)$ is the reference effectiveness of the heat exchanger, depending on the flow rate of the air inside the pipe

Modern systems for mechanical ventilation have to include a heat exchanger that returns the heat to the fresh air. We can install this into the indirect vapour cooling system. We moisten the transferable surface on the waste-air side and thus create a surface for transferring heat and substances that cool the waste air. The fresh air that flows into the building through the heat transfer is also indirectly cooled. The exit air temperature for airing the building is determined by the following equation [30]:

$$T_{izst} = -1,2266 + 0,6011 \cdot T_{st} + (0,315 - 0,0028 \cdot T_{st}) \cdot T_{okol}$$

kjer sta:

T_{st} temperatura zraka v stavbi [°C],

T_{okol} temperatura okoliškega zraka, ki vstopa v prenosnik toplote [°C].

Izraz je oblikovan za tipični ploščni prenosnik toplote ob upoštevanju stalne 50% vlažnosti v stavbi [29].

Vrednotenje toplotnega odziva stavb ob upoštevanju različnih PTRL navajamo na dva načina:

- v primeru nenadzorovanega toplotnega odziva stavb, npr. število ur v letu, ko je občutena temperatura v stavbi višja od meje toplotnega ugodja (26 °C);
- kot spremembo v specifični rabi koristne energije za hlajenje, preračunane na m^2 bivalne površine;
- kot spremembo v specifični rabi koristne energije za ogrevanje, preračunane na m^2 bivalne površine.

Pri hlajenju stavb ne vrednotimo latentne toplote ovlaževanja ali razvlaževanja. Predstavljene tehnike naravnega hlajenja namreč ne vplivajo na absolutno vlažnost zraka, oziroma se pojavu kondenzacije celo namenoma izogibamo zaradi zdravstvenih načel. Poleg tega smo ugotovili, da PTRL, ki smo ga oblikovali glede na Scenarij E, ne omogoča smiselne prilagoditve TRL in smo ga v nadaljevanju zato opustili. Rezultate analiz navajamo najprej za stanovanjski stavbi. Na slikah 8, 9 in 10 so prikazani rezultati za masivno in lahko grajeno stanovanjsko stavbo.

where:

T_{st} is the indoor temperature of the building [°C]

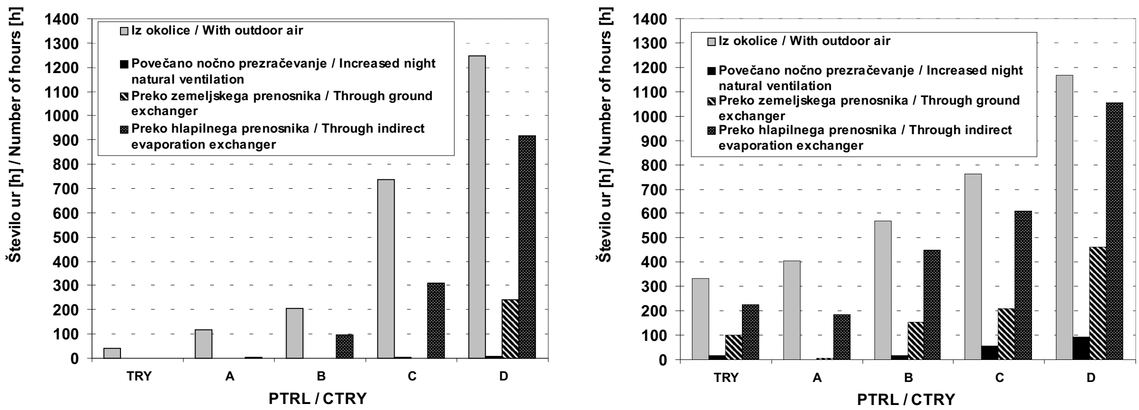
T_{okol} is the ambient temperature that flows into the heat exchanger [°C]

This formula was created for a typical heat-transfer surface that considers a constant 50% humidity in the building [29].

We can indicate the building's thermal response evaluation (with regard to various CTRYs) in two ways:

- in the case of an unsupervised building's thermal response as the number of hours in the year when the temperature in the building is higher than the limit of thermal comfort (26°C);
- as the change in the specific use of energy demand for cooling, calculated per m^2 of living area;
- as the change in the specific use of energy demand for heating, calculated per m^2 of living area.

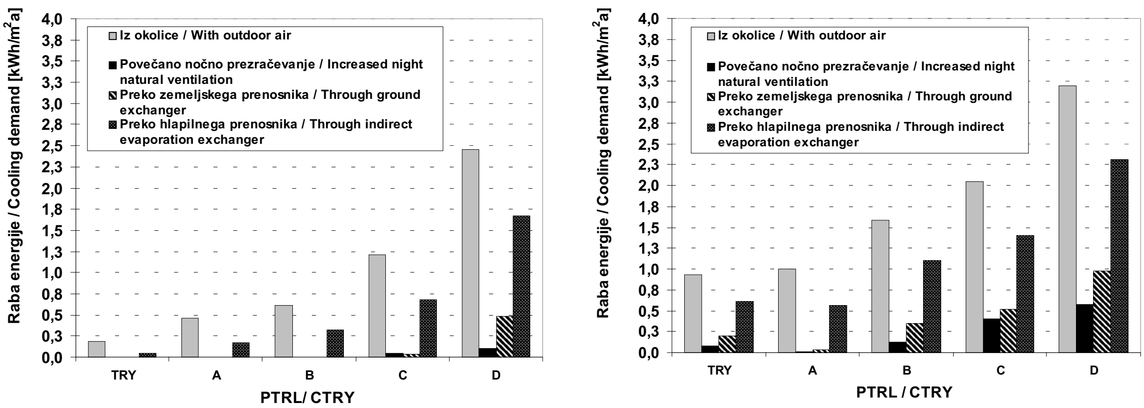
In the process of cooling buildings we do not take into account the latent heat of moistening or remoistening. Namely, the presented natural cooling techniques do not affect the absolute air humidity or deliberately avoid the condensation phenomena for health reasons. In addition, we discovered that the CTRY that we have formed for Scenario E does not enable reasonable corrections for the TRY and therefore we have omitted it. Firstly, we presented the analysis results for the two residential buildings. Figures 8, 9 and 10 show the results for heavyweight and lightweight built residential buildings.



a) b)

Sl. 8. *Število ur, ko je pri nenadzorovanem toplotnem odzivu stanovanjske stavbe občutena temperatura v stavbi nad 26 °C; a) za masivno in b) za lahko grajeno stavbo*

Fig. 8. *The number of hours when for an uncontrolled thermal response of the building the operating temperature is higher than 26°C a) for heavyweight and b) for lightweight built building*



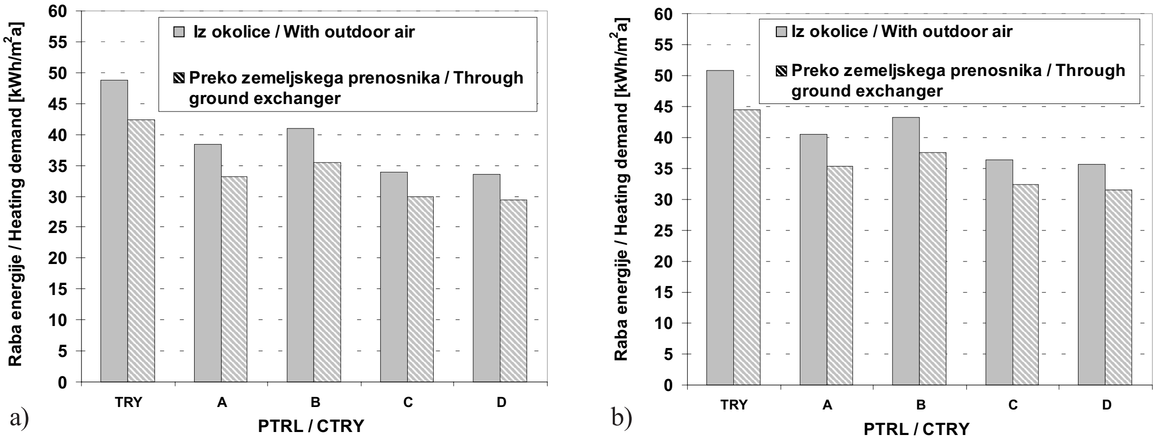
a) b)

Sl. 9. *Specifična raba koristne energije za hlajenje pri nadzorovanem toplotnem odzivu stanovanjske stavbe; a) za masivno in b) za lahko grajeno stavbo*

Fig. 9. *Specific use of energy demand for cooling, calculated per m^2 of living area for the controlled thermal response for a residential building a) for a heavyweight and b) for a lightweight built building*

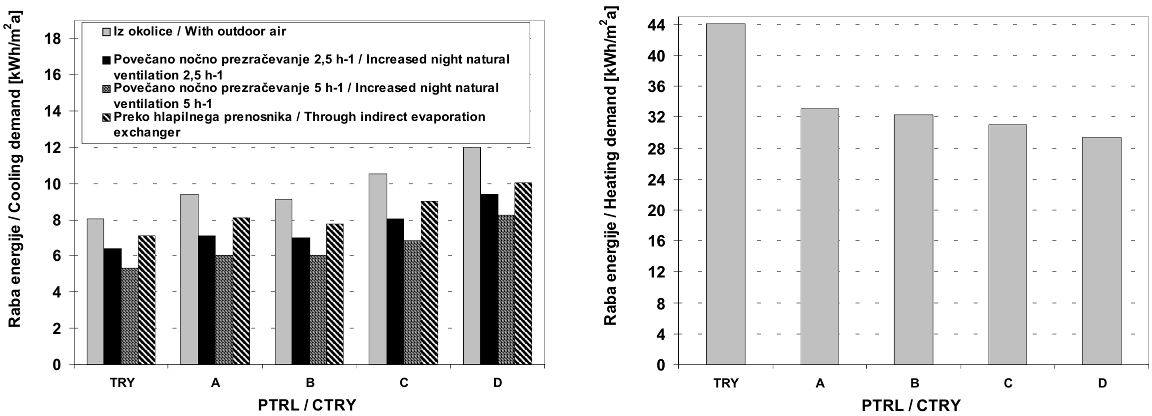
Poslovna stavba je prezračevana z mehanskim prezračevanjem in hlajena. Velike potrebne količine zraka za prezračevanje in pogosto omejena velikost zemljišča, kjer bi lahko namestili zemeljski prenosnik toplote, onemogočata uporabo te tehnike naravnega hlajenja. Zato jo v nadaljevanju ne obravnavamo. Ker povečanje nočnega prezračevanja vpliva na velikost celotnega prezračevalnega sistema, smo v raziskavah upoštevali poleg 5-kratne urne izmenjave zraka ponoči, tudi nižjo 2,5-kratno urno izmenjavo, ki jo lahko zagotovimo z manjšim prezračevalnim sistemom ob manjši porabi energije za delovanje sistema. Rezultate raziskav prikazuje slika 11.

The office building is aired and cooled with a mechanical ventilation system. The large quantity of air needed for ventilation and the often limited size of the building site where the ground heat exchanger system could be placed make the use of this natural cooling technique impossible. For this reason we do not deal with it in the remainder of this paper. Since the increase of night-time ventilation affects the size of the entire ventilation system we have not only included the 5 exchanges per hour during the night, but also the 2.5 exchanges per hour that can be ensured with a smaller airing system with lower energy use. The results of the research are shown in Figure 11.



Sl. 10. *Specifična raba koristne energije za ogrevanje pri nadzorovanem toplotnem odzivu stanovanjske stavbe; a) za masivno in b) za lahko grajeno stavbo*

Fig. 10. *Specific energy demand for heating, calculated per m² of living area for the controlled thermal response for a residential building a) for a heavyweight and b) for a lightweight built building*



a) b)

Sl. 11. *Specifična koristna energija za hlajenje a) in ogrevanje b) poslovne stavbe*

Fig. 11. *Specific energy demand for a) cooling and b) heating, calculated per m² of living area for the controlled thermal response for a business building*

5 SKLEP

Iz pregleda dosedanjih objavljenih raziskav ([4] do [10]), ki povezujejo scenarije podnebnih sprememb in toplotni odziv stavb, lahko povzamemo, da avtorji napovedujejo zgolj spremembo v rabi energije, ne pa tudi vpliva podnebnih sprememb na toplotno ugodje. Tudi ne zasledimo raziskav o vplivih na učinkovitost tehnik naravnega hlajenja. Poleg tega podobne raziskave za podnebne značilnosti v Sloveniji še niso bile izdelane.

Pričakovano se bo raba koristne energije za ogrevanje stavb zmanjšala. Glede na napovedane podnebne scenarije za celinsko področje Slovenije za 1,5 % do 31,4% pri vseh stavbah, ki smo jih

5 CONCLUSION

From a review of the published studies ([4] to [10]) that link the climate-change scenarios we can conclude that the authors predict merely a change in energy use and not the influence that climate changes will have on thermal comfort. We also failed to find any research that looked at the influence on the effectiveness of natural cooling techniques. Moreover, similar researches on climate characteristics in Slovenia have so far not yet been elaborated.

As expected the use of final energy for heating buildings will reduce. According to the predicted climate scenarios for the Slovenian continental part it will be reduced by between 1.5%

analizirali, oziroma med 0,5 in 15,3 kWh/m^{2}a. Značilna večja raba energije za ogrevanje lahko grajenih stavb (v povprečju +6,1 % ali + 2,1 kWh/m^{2}a) bo ostala sorazmerna v primerjavi z masivno grajenimi stavbami. Verjetno pa je v tem primeru bolj kot navajanje specifične rabe energije za ogrevanje izbranih stavb, pomembno dejstvo, da pri oblikovanju zahtev o toplotni zaščiti stavb državnih ciljev ne smemo zastaviti tako nezahtevno, da bi jih namesto novih tehnologij "izpolnile" pričakovane podnebne spremembe. V poslovnih stavbah bo vpliv različnih napovedanih scenarijev podnebnih sprememb manj izrazit - specifična raba toplote za ogrevanje se bo zmanjšala za 10,9 do 14,8 kWh/m^{2}a, torej okvirno med eno četrtino in eno tretjino. To pripisujemo večjim notranjim virom toplote, večjim steklenim površinam in časovnemu vzorcu zasedenosti, ki so značilni za poslovne stavbe.

Bistveno bolj bodo napovedane podnebne spremembe vplivale na toplotno ugodje v stavbah poleti. Tudi v masivno grajenih stanovanjskih stavbah, ki so naravno prezračevane in v katerih je dandanes ustrezno toplotno ugodje, bodo primerne temperature poleti presežene za 20% do 33% časa, če se bodo uresničili najbolj neugodni scenariji (C in D). Lahko grajene stavbe so na videz manj občutljive za napovedane podnebne spremembe, kar pa je posledica večjih dnevnih sprememb temperatur. Pregrevanje v teh stavbah bo sicer časovno krajše, toda bolj izrazito. Učinkovitost zemeljskega prenosnika toplote, vgrajenega v prezračevalni sistem masivno in lahko grajenih stanovanjskih stavb se bo zmanjšala le pri skrajni spremembi podnebja, ki ga napoveduje scenarij D. V vseh obravnavanih primerih se hlapilno hlajenje kot tehnika dejavnega naravnega hlajenja izkaže kot zelo občutljivo za podnebne spremembe. Nasprotno pa velja, da je za vse obravnavane primere povečano nočno prezračevanje edina tehnika, s katero preprečimo pregrevanje stavb.

Za zagotavljanje primernega toplotnega ugodja bo potrebno stavbe hladiti s hladilnimi sistemi. Specifična raba na ravni koristne energije se bo v stanovanjskih stavbah povečala med 0,3 in 1,63 kWh/m^{2}a, oziroma 2 do 40 krat glede na sedanje stanje in različne upoštevane scenarije podnebnih sprememb. Relativne spremembe v rabi energije za hlajenje poslovnih stavb bodo manjše, toda absolutno večje, saj se bo raba energije za hlajenje v primeru izpolnitve najbolj neugodnega podnebnega scenarija povečala za 4 kWh/m^{2}a.

and 31.4% in all analysed buildings, which is between 0.5 and 15.3 kWh/m^{2}a. The characteristic larger amount of energy for heating lightweight constructed buildings (on average +6.1% or + 2.1 kWh/m^{2}a) will remain proportional in comparison to the heavyweight constructed buildings. Probably more important than stating the specific energy use for heating the chosen buildings is the fact that we must not set our national goals in forming the demands on the building's heat insulation so non-ambitiously, that the expected climate changes would realise them instead of the new technologies. The influence of the various predicted climate-change scenarios will be less distinctive in office buildings - the specific energy demand for heating will be reduced by between 10.9 and 14.8 kWh/m^{2}a, i.e., between 25% and 33%. This will take place due to the larger inner heat sources, larger glass surfaces and time of occupancy typical for office buildings.

The climate changes will have a greater influence on the thermal comfort in buildings during the summer. Even in heavyweight built residential buildings that are naturally aired and where today there is a suitable thermal comfort, the suitable temperatures during the summer will be exceeded for 20% to 33% of the time, if the most unfavourable scenarios come true (C and D). Lightweight built buildings are apparently less sensitive to the predicted climate changes, which is a consequence of the larger daytime temperature amplitudes. Overheating in these buildings will be shorter as regards time, but it will be more intensive. The effectiveness of a ground heat exchanger included in the ventilation system in heavyweight and lightweight built residential buildings will be reduced only in the extreme climate change predicted by scenario D. In all the discussed examples the evaporation cooling as an active natural cooling technique proves to be very sensitive to climate changes. In contrast, it is true that increased night ventilation is the only effective technique with which we can prevent overheating.

To ensure suitable thermal comfort it will be necessary to cool the buildings with cooling systems. The specific demand of fine energy will increase in residential buildings between 0.3 and 1.63 kWh/m^{2}a or 2-to-40 fold, according to the present conditions and the various climate-change scenarios. Relative changes in energy use for cooling office buildings will be smaller, but they will be bigger in absolute terms, since the energy use for cooling in the event of the most unfavourable climate scenario will increase by 4 kWh/m^{2}a. Amongst the natural cooling methods

Med tehnikami naravnega hlajenja, ki bi dopolnjevale hlajenje s hladilnimi sistemi, je najučinkovitejše povečano naravno nočno prezračevanje. Torej je treba pri zasnovi stavb, ki so mehansko hlajene, uporabiti tudi to tehniko. Potencial varčevanja energije z uporabo hlapilnega hlajenja, ovrednoten z zmanjšano specifično rabo energije, ki znaša v tem trenutku približno 14 %, se bo ohranil tudi pri vseh napovedanih scenarijih podnebnih sprememb.

Kakor smo že omenili, smo v naši raziskavi uporabili PTRL, izdelana z zgodovinskim modelom. Primerjava med pričakovanimi spremembami vplivnih meteoroloških spremenljivk, ki jih navaja preglednica 1 in značilnostmi PTRL, ki jih prikazuje slika 3, kažejo, da za vse načrtovane podnebne scenarije ni mogoče oblikovati povsem ustreznih PTRL. To dejstvo pripišemo dolgemu tesnemu nizu (mesec), ki smo ga uporabili v našem primeru. Tako bomo v prihodnje raziskali tudi desetdnevni in tedenski niz. Tako bi lahko raziskali tudi nekatere izjemne podnebne scenarije, kljub kratkemu časovnemu obdobju (12 let) popolnih baz meteoroloških podatkov, ki je na voljo na Agenciji R Slovenije za okolje. Ob tem bi bilo smiselno preučiti tudi primernost uteži W za posamezno meteorološko spremenljivko.

that would complement the cooling with cooling systems the most efficient is increased natural night-time ventilation. Therefore, it is necessary to use this technique in the future projecting of buildings that are mechanically cooled. The energy-saving potential with the use of evaporation cooling, evaluated with a reduced specific use of energy, which currently amounts to approximately 14%, will also be preserved in all the predicted climate-change scenarios.

As mentioned, we have used the CTRY in our research, elaborated with a historical model. The comparison between the expected changes of influential meteorological variables stated in Table 1 and the CTRY characteristics shown in Figure 3 indicate that it is not possible to form a totally suitable CTRY for all the predicted climate scenarios. We attribute this fact to the long series (one month) and the tight period of the meteorological hour database (only 12 years). In the future we will also research the decade and week series. Therefore, we could also research some extreme climate scenarios, despite the short time period (12 years) of the complete meteorological database available at the Agency for the Environment of the Republic of Slovenia. At the same time it would also be sensible to examine the adequacy of the weight W for individual meteorological variables.

6 LITERATURA
6 REFERENCES

[1] J.A.Clarke (2001) Domain integration in building simulation, *Energy and Buildings*, Volume 33, Issue 4, 303-309

[2] S. Citherlet (2001) Integration in building physics simulation, *Energy and Buildings*, Volumne 33, Issue 5, 417-518

[3] IPCC (2001) An assessment of the intergovernmental panel on climate change, *Synthesis Report*, Wembley, United Kingdom, 24-29 September, 2001

[4] T. Frank (2005) Climate change impacts on building heating and cooling energy demand in Switzerland, *Energy and Buildings*, Volumne 37, Issue 11, 1175-1185

[5] M.Christenson (2005) Climate warming impact on degree-days and building energy demand in Switzerland, *Energy Conversion and Management*, Volume 47, Issue 6, 671-686

[6] M.R. Gaterell (2005) The impact of energy externalities on the cost effectiveness of energy efficiency measures applied to dwellings, *Energy and Buildings*, Volume 37, Issue 10, 1017-1027

[7] C. Cartalis (2001) Modifications in energy demand in urban areas as a result of climate changes: an assessment for the southeast Mediterranean region, *Energy Conversion and Management*, Volume 42, Issue 14, 1647-1656

[8] K. Kaygusuz (2003) Energy policy and climate change in Turkey, *Energy Conversion and Management*, Volume 44, Issue 10, 1671-1688

[9] R. Matthias (2005) Regional energy demand and adaptations to climate change: Methodology and application to the state of Maryland, USA, *Energy Policy*, In Press, Corrected Proof, Available online 23 June 2005

[10] M. Camillieri (2001) Impacts of climate change on building performance in New Zealand, *Building & Information* 29, Volume 6, 440-450

[11] M. Santamouris, et al. (2006) Environmental design of urban buildings: An integrated approach, *James & James*, London
[12] B. Vidrih (2003) Računalniško modeliranje in eksperimentalna potrditev toplotnega odziva stavb, Diplomska naloga univerzitetnega študija, *Univerza v Ljubljani, Fakulteta za strojništvo*, Ljubljana
[13] B. Vidrih (2004) Vpliv klimatskih sprememb na toplotno ugodje v prostoru, Podiplomski seminar, *Univerza v Ljubljani, Fakulteta za strojništvo*, Ljubljana
[14] B. Černe (2003) Vpliv klimatskih sprememb na rabo energije v naseljih, Podiplomski seminar, *Univerza v Ljubljani, Fakulteta za strojništvo*, Ljubljana
[15] A. Sušnik - urednica (2003) Ranljivost slovenskega kmetijstva in gozdarstva na podnebno spremenljivost in ocena predvidenega vpliva, Poročilo za vlado RS, *Agencija RS za okolje*, Ljubljana
[16] K. Bergant (2003) Projekcije simulacij globalne klime na lokalni nivo in njihova uporaba v agrometeorologijo, Doktorska disertacija, *Univerza v Ljubljani, Biotehniška fakulteta*, Ljubljana
[17] L. Kajfež-Bogataj (2005) Podnebne spremembe in ranljivost kmetijstva, *Acta agriculturae Slovenica*, 85, 25-40
[18] C. DE Boor (2002) A practical guide to plines, Second edition, *Springer*, New York.
[19] L. Schumaker (1981) Spline functions, Basic theory, *John Wiley and Sons*, New York.
[20] L. Adelard (1999) Elaboration of a new tool for weather data sequences generation, *Proceedings of IBPSA Conference*, Kyoto, Japan
[21] A. Aguiar (1999) Assesing the value of typical meteorological years built from observed and from synthetic data for building thermal simulation, *Proceedings of IBPSA Conference*, Kyoto, Japan
[22] G. Levermore (2003) Climate change test reference years for buildings and urban environment. *Proceedings of ICUC Conference*, Lodz, Poland.
[23] M.Dolinar (2005) Predicted changes in energy demands for heating and cooling due to climate change
[24] C. Schittich (2003) Solar architecture (Strategies, Visions, Concepts), *Birkhausen - Publishing for Architecture*, Basel, 2003
[25] TRNSYS 15 (2000) A transient system simulation program, Reference manual, Solar energy laboratory, *Univesity of Wisconsion*, Madison.
[26] M. Umberger, (2004) Prve pasivne stavbe v Sloveniji, *Zgradbe, energija in okolje 2004*, Terme Čatež, Slovenija, 9-14
[27] V. Geros (2005) On the cooling potential of night ventilation techniques in the urban environment, *Energy and Buildings*, Volume 37, Issue 3, 243-257
[28] G. Mihalakakou (1995) Parametric prediction of the buried pipes cooling potential for passive cooling applications, *Solar Energy*, Volume 55, Issue 3, 163-173
[29] J. Fechner (2002) Altbaumodernisierung, Der praktische Leitfaden, *Springer-Verlag*, Dunaj.
[30] C. Arkar, B. Cerkvenik, S. Medved, M. Dimnik, S. Grum, A. Poredoš, L. Tavčar (2005) Raziskava učinkovitosti lamelnih rekuperatorjev toplote VING. *Fakulteta za strojništvo, Laboratorij za ogrevalno, sanitarno in solarno tehniko*, Ljubljana.

Naslovi avtorjev: Boris Vidrih
Termo d.d.
Trata 32
4220 Škofja Loka
boris.vidrih@fs.uni-lj.si

Mojca Dolinar
Agencija RS za okolje
Vojkova 1b
1000 Ljubljana

prof.dr. Sašo Medved
Univerza v Ljubljani
Fakulteta za strojništvo
Aškerčeva 6
1000 Ljubljana
saso.medved@fs.uni-lj.si

Authors' Addresses: Boris Vidrih
Termo Ltd.
Trata 32
4220 Škofja Loka, Slovenia
boris.vidrih@fs.uni-lj.si

Mojca Dolinar
The Environmental Agency of RS
Vojkova 1b
1000 Ljubljana, Slovenia

Prof.Dr. Sašo Medved
University of Ljubljana
Faculty of Mechanical Engineering
Aškerčeva 6
1000 Ljubljana, Slovenia
saso.medved@fs.uni-lj.si

Prejeto:
Received: 23.1.2006

Sprejeto:
Accepted: 22.6.2006

Odprto za diskusijo: 1 leto
Open for discussion: 1 year

Strojniški vestnik - Journal of Mechanical Engineering 52(2006)9, 587-591
UDK - UDC 621.89:517.988
Kratki znanstveni prispevek - Short scientific paper (1.03)

Variacijski način določitve enačbe mazanja ne-newtonske tanke plasti

A Variational Approach to the Establishment of a Lubrication Equation for a Non-Newtonian Thin Film

Ji-Huan He - Li-Na Zhang
(Shanghai Donghua University, People's Republic of China)

V prispevku je predstavljen nov postopek izpeljave enačbe mazanja za ne-newtonsko tanko plast. Enačba Reynoldseve vrste je izpeljana neposredno iz varacijskega načela kot pogoj stacionarnosti. V postopku izpeljave smo uporabili tudi metodo istoležne motnje.

(Ključne besede: enačbe Reynolds, tok nenewtonski, mazanje, metode perturbacij)

This paper provides a new approach to deriving a lubrication equation for a non-Newtonian thin film. The Reynolds-type equation is directly deduced from a variational principle as a stationary condition. The homotopy perturbation method is also applied in the derivation procedure.

(Keywords: Reynolds-type equation, non-Newtonian flow, lubrication, perturbation methods)

0 INTRODUCTION

In the analysis of many lubrication problems, the most important thing is to establish a lubrication equation. Often, the number of governing equations can be reduced by a direct elimination of the pertinent variables. In this process of elimination some of the equations are in effect satisfied identically, and the error (in an approximate analysis) remains in the reduced set of governing equations. The standard approach to the establishment of the Reynolds equation is to integrate the governing equations over the film; the integration constants are determined from the boundary conditions. The procedure is easy for Newtonian lubrication, but it is very difficult for non-Newtonian conditions ([1] to [6]). Clearly, by a judicious identification of the integration constants we can arrive at different forms of Reynolds-type equations and therefore cast the error of the approximate analysis in the obtained lubrication equations.

Variational theory is a powerful tool in finite-element methods and when dealing with the cavitations in lubrications. Our aim in this paper is to deduce the required lubrication equation by minimizing the energy functional, and the obtained Reynolds-type equation, therefore, best serves to describe the lubrication problem. The technique developed provides a powerful mathematical tool for engineers in tribology.

1 OUTLINE OF THE DERIVATION

For a better illustration of the basic procedure, making the underlying idea clear and not clouded by unnecessarily complicated forms of mathematical expressions, we consider a one-dimensional lubrication problem as an illustrating example.

The geometrical configuration of a one-dimensional slider bearing, considering the squeeze-action effect, is shown in Figure 1. It is assumed that the flow is isothermal, incompressible and laminar, and that the lubricant inertia effect is small. According to the thin-film theory of hydrodynamic lubrication, the equations of continuity and motion in Cartesian coordinates reduce to:

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

$$\frac{\partial p}{\partial x} = \frac{\partial \tau_{xz}}{\partial z} \quad (2)$$

$$\frac{\partial p}{\partial z} = 0 \quad (3).$$

And the nonlinear constitutive relation is written in the following general form:

$$\tau_{xz} = \mu_0 \frac{\partial u}{\partial z} + \sum_{n=1}^{m} a_n (\frac{\partial u}{\partial z})^{2n+1} \quad (4),$$

where μ_0 is the zero shear-rate viscosity, which is equivalent to the viscosity of Newtonian fluids, and a_n $(n \geq 1)$ denotes a nonlinear factor accounting for non-Newtonian effects.

In view of Eq.(4), Eq.(2) can be rewritten in the form:

$$\frac{\partial p}{\partial x} = \frac{\partial}{\partial z}\left[\mu_0 \frac{\partial u}{\partial z} + \sum_{n=1}^{m} a_n (\frac{\partial u}{\partial z})^{2n+1}\right] \quad (5).$$

The boundary conditions are illustrated in Fig.1.

The variational approach to lubrication has now become a popular tool for establishing various Reynolds-type equations for various non-Newtonian lubrication problems ([7] and [8]). This paper aims to establish a variational principle for the above problem; the Euler equations of the searched variational functional are Eqs. (1), (3) and (5). To this end, we apply the semi-inverse method [9], and establish a trial-functional in the following form

$$J(u, w, p) = \int_0^L \int_0^h L(u, w, p) dxdz \quad (6),$$

where u, w and p are independent variables, L is a trial-Lagrangean. There exists many approaches to the construction of a trial-Lagrangean, and illustrating examples can be found in Refs.[10] to [13]. In this paper we write the trial-Lagrangean in the form:

$$L(u, w, p,) = -p(\frac{\partial u}{\partial x} + \alpha \frac{\partial w}{\partial z}) + (1-\alpha) w \frac{\partial p}{\partial z} + F(u) \quad (7),$$

where F is an unknown function of u and its derivatives, α is an arbitrary constant. The advantage of the above trial-Lagrangean lies in the fact that the stationary condition with respect to p is Eq.(1).

Calculating the variation with respect to u, we have the following Euler equation:

$$\frac{\partial p}{\partial x} + \frac{\delta F}{\delta u} = 0 \quad (8),$$

where $\delta F/\delta u$ is called the variational derivative with respect to u, defined as:

$$\frac{\delta F}{\delta u} = \frac{\partial F}{\partial u} - \frac{\partial}{\partial x}\frac{\partial F}{\partial u_{,x}} - \frac{\partial}{\partial z}\frac{\partial F}{\partial u_{,z}} \quad (9).$$

The Euler equation (8) should satisfy one of the field equations, e.g., Eq.(5), so we set:

$$\frac{\delta F}{\delta u} = -\frac{\partial p}{\partial x} = -\frac{\partial}{\partial z}\left[\mu_0 \frac{\partial u}{\partial z} + \sum_{n=1}^{m} a_n (\frac{\partial u}{\partial z})^{2n+1}\right] \quad (10),$$

from which F can be identified as:

$$F = \frac{1}{2}\mu_0 (\frac{\partial u}{\partial z})^2 + \sum_{n=1}^{m} \frac{1}{2n+2} a_n (\frac{\partial u}{\partial z})^{2n+2} \quad (11).$$

By incorporating the boundary conditions, we finally obtain the following generalized variational principle:

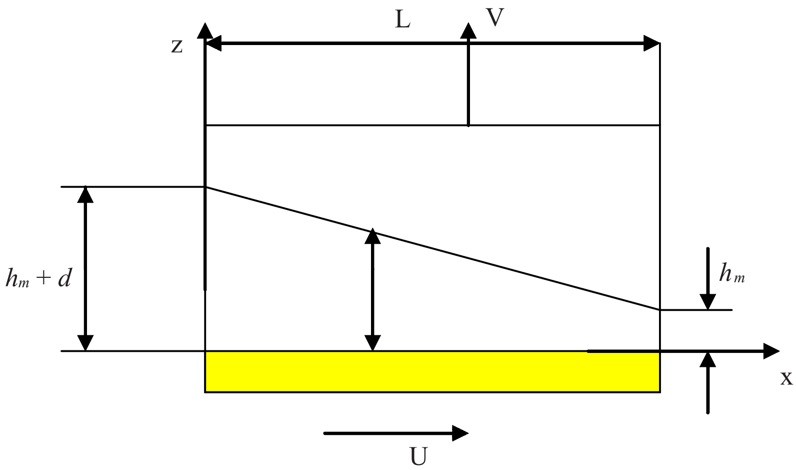


Fig.1 *Geometrical configuration of a wide slider bearing*

$$J(u,w,p)=\int_0^L\int_0^h\left\{\begin{array}{l}-p(\frac{\partial u}{\partial x}+\alpha\frac{\partial w}{\partial z})+(1-\alpha)w\frac{\partial p}{\partial z}+\\+\frac{1}{2}\mu_0(\frac{\partial u}{\partial z})^2+\sum_{n=1}^{m}\frac{1}{2n+2}a_n(\frac{\partial u}{\partial z})^{2n+2}\end{array}\right\}dxdz$$
$$-\int_0^L(1-\alpha)\left[w(h)-w(0)\right]pdx+\int_0^L U\,\tau_{xz}\big|_{z=0}\,dx \quad (12).$$

Note: at the boundary, Eq.(4) is considered as a constraint.

It is easy to prove that all Euler equations satisfy the governing equations (1), (3) and (5), and the boundary conditions. Calculating the first variation with respect to *u,w,* and *p*, we have:

$$\delta J(u,w,p)=\int_0^L\int_0^h\left\{\begin{array}{l}\frac{\partial p}{\partial x}\delta u-\frac{\partial u}{\partial x}\delta p+\frac{\partial p}{\partial z}\delta w-\frac{\partial w}{\partial z}\delta p-\\-\frac{\partial}{\partial z}\left[\mu_0(\frac{\partial u}{\partial z})^2+\sum_{n=1}^{m}a_n(\frac{\partial u}{\partial z})^{2n+1}\right]\delta u\end{array}\right\}dxdz$$
$$+\int_0^L(1-\alpha)\,w\big|_0^h\,\delta p dx-\int_0^L u\delta\left[\mu_0(\frac{\partial u}{\partial z})^2+\sum_{n=1}^{m}a_n(\frac{\partial u}{\partial z})^{2n+1}\right]\Bigg|_{z=0}dx$$
$$-\int_0^L(1-\alpha)\left[w(h)-w(0)\right]\delta p dx+\int_0^L U\,\delta\tau_{xz}\big|_{z=0}\,dx=0. \quad (13).$$

Considering the independence of δ*u*, δ*v*, and δ*p*, and noting the constraint , Eq.(4), we obtain, as steady conditions, Eqs.(1), (3), (5), and boundary conditions *w*=*w*(*h*) at *z*=*h,* *w*=*w*(0) at *z*=0, and *u*=*U* at *z*=0.

It is easy and straightforward to obtain the various constrained functionals from the above generalized functional by enforcing some of the field equations into the functional (13). We will not write all of them, only the most important one:

$$J(p)=\int_0^L\int_0^h\left\{\frac{1}{2}\mu_0(\frac{\partial u}{\partial z})^2+\sum_{n=1}^{m}\frac{1}{2n+2}a_n(\frac{\partial u}{\partial z})^{2n+2}\right\}dxdz+$$
$$+\int_0^L\left[w(h)-w(0)\right]pdx+\int_0^L U\,\tau_{xz}\big|_{z=0}\,dx \quad (14).$$

It is easy to prove $\delta^2 J>0$, so the functional, Eq.(14), is a minimum energy principle.

From Eq.(5) we have:

$$\mu_0\frac{\partial u}{\partial z}+\sum_{n=1}^{m}a_n(\frac{\partial u}{\partial z})^{2n+1}=z\frac{\partial p}{\partial x}+C \quad (15),$$

where *C* is an integration constant, it can be approximately identified by the assumption t_{xz}=0 at *z=h*/2. Under such a condition we have:

$$\mu_0\frac{\partial u}{\partial z}+\sum_{n=1}^{m}a_n(\frac{\partial u}{\partial z})^{2n+1}=(z-\frac{h}{2})\frac{\partial p}{\partial x} \quad (16).$$

We should obtain an explicit expression for ∂*u*/∂*z*. To this end, we illustrate a new homotopy perturbation method ([14] to [19]) to solve the expression approximately. The basic idea of the homotopy perturbation method is to construct a homotopy in the form:

$$(\mu_0+\beta)\frac{\partial u}{\partial z}-(z-\frac{h}{2})\frac{\partial p}{\partial x}=-\varepsilon\left[\beta\frac{\partial u}{\partial z}+\sum_{n=1}^{m}a_n(\frac{\partial u}{\partial z})^{2n+1}\right] \quad (17),$$

where ε is a homotopy parameter, and β is a linearized factor defined as:

$$\sum_{n=1}^{m}a_n(\frac{\partial u}{\partial z})^{2n+1}=\beta\frac{\partial u}{\partial z} \quad (18),$$

and can be identified by the method of weighted residuals, which requires:

$$\int_0^A x(\sum_{n=1}^{m}a_n x^{2n+1}-\beta x)dx=0 \quad (19),$$

where *A* is a fixed value for a definite problem.

It is obvious that when ε=0, Eq.(17) becomes a linearized equation, and when ε=1, we recover the nonlinear equation. The homotopy perturbation method applies the homotopy parameter to expand the solution in the form:

$$\frac{\partial u}{\partial z}=(\frac{\partial u}{\partial z})_0+\varepsilon(\frac{\partial u}{\partial z})_1+\varepsilon^2(\frac{\partial u}{\partial z})_2+\cdots \quad (20).$$

By setting ε=1, we obtain an approximate expression for ∂*u*/∂*z*.

To illustrate the procedure, we are concerned here with finding the real root of the polynomial equation:

$$x^5+x-1=0 \quad (21).$$

Construct a homotopy:

$$(1+\beta)x-1=\varepsilon(\beta x-x^5) \quad (22),$$

where the linearized factor β can be determined from the relation:

$$\int_0^1 x(\beta x-x^5)dx=0 \quad (23),$$

leading to the result β=3/7. By perturbation technique, we obtain an approximate solution to order 2: *x*=0.75999.

Now turn back to our main procedure, after we get the explicit expression of ∂*u*/∂*z*, we submit the obtained result into the minimum variational principle, Eq.(14). To illustrate the procedure, we consider the special case of Eq.(4):

$$\tau_{xz}=\mu_0\frac{\partial u}{\partial z}+\mu_0\gamma(\frac{\partial u}{\partial z})^3 \quad (24).$$

The cubic constitutive model can be applied to dilatant fluids for $\gamma>0$, and pseudoplastic fluids for $\gamma<0$. In the case when γ is a small parameter, we have:

$$\frac{\partial u}{\partial z} = \frac{1}{\mu_0}(z-\frac{h}{2})\frac{\partial p}{\partial x} - \frac{\gamma}{\mu_0^3}(z-\frac{h}{2})^3(\frac{\partial p}{\partial x})^3 + O(\gamma^2) \quad (25).$$

Now substituting Eq.(25) into the functional (14):

$$J(p) = \int_0^L\int_0^h \left\{ \frac{1}{2}\mu_0 \left[\frac{1}{\mu_0}(z-\frac{h}{2})\frac{\partial p}{\partial x} - \frac{\gamma}{\mu_0^3}(z-\frac{h}{2})^3(\frac{\partial p}{\partial x})^3 \right]^2 \right\} dxdz +$$

$$+\int_0^L\int_0^h \left\{ \frac{1}{4}\mu_0\gamma \left[\frac{1}{\mu_0}(z-\frac{h}{2})\frac{\partial p}{\partial x} - \frac{\gamma}{\mu_0^3}(z-\frac{h}{2})^3(\frac{\partial p}{\partial x})^3 \right]^4 \right\} dxdz$$

$$+\int_0^L \left[w(h) - w(0) \right] p dx - \int_0^L \frac{h}{2} U \frac{\partial p}{\partial x} dx, \quad (26)$$

integrating from z=0 to z=h, and neglecting higher-order terms of γ, we have the following functional:

$$J(p) = \int_0^L \frac{1}{2}\frac{1}{\mu_0}\left[\frac{1}{12}h^3(\frac{\partial p}{\partial x})^2 - \frac{3\gamma}{320\mu_0^3}h^5(\frac{\partial p}{\partial x})^4 \right] dx +$$

$$+\int_0^L \left[w(h) - w(0) \right] p dx - \int_0^L \frac{h}{2} U \frac{\partial p}{\partial x} dx \quad (27).$$

Calculating the variation with respect to p, we have the following Reynolds-type equation:

$$-\frac{\partial}{\partial x}\left[\frac{h^3}{12\mu_0}(\frac{\partial p}{\partial x}) - \frac{3\gamma h^5}{80\mu_0^3}(\frac{\partial p}{\partial x})^3 \right] + \left[w(h) - w(0) \right] + \frac{1}{2}\frac{\partial}{\partial x}(Uh) = 0 \quad (28).$$

Note that :

$$w(h) - w(0) = \frac{\partial h}{\partial t} \quad (29).$$

We, therefore, have the following final form:

$$\frac{\partial}{\partial x}\left[\frac{h^3}{\mu_0}(\frac{\partial p}{\partial x}) - \frac{9\gamma h^5}{20\mu_0^3}(\frac{\partial p}{\partial x})^3 \right] = 12\frac{\partial h}{\partial t} + 6\frac{\partial}{\partial x}(Uh) \quad (30).$$

The obtained Reynolds-type equation, Eq.(30), has a very similar structure to the Reynolds equation for Newtonian lubrication.

2 CONCLUSION

Non-Newtonian lubricants are commonly found in engineering. Here we illustrate the utility of a derivation of a Reynolds-type equation from a variational functional. The technique developed can be readily applied to any other lubrication problems, and the present paper can be used as a paradigm for the establishment of a Reynolds-type equation for various lubrication problems.

Acknowledgement

This work is supported by the Program for New Century Excellent Talents in University.

3 REFERENCES

[1] Liu,J.-R.(2001) Now-Newtonian effects on the dynamic characteristics of one-dimensional slider bearings: Rabinowitsch fluid model, *Trib. Lett.,* 10(4) 237-243

[2] Gao, C.Y., Cai, L., Bi, Q.S.(2004) Micro-elastohydrodynamics lubrication of point contacts with coexistence of longitudinal and transverse roughness , *International Journal of Nonlinear Sciences and Numerical Simulation,* 5(2) 113-120

[3] Zhang, C.H., Wen, S.Z., Luo, J.B.(2002) Lubrication theory for thin film lubrication accounting for the ordered film model , *International Journal of Nonlinear Sciences and Numerical Simulation,* 3 (3-4) 481-485

[4] Wang, W., Lan, Z.W., Ji, H., et al.(2002) Nanometer scale interfacial lubrication of PFPE lubricants ZDOL and AWA at hard disk interface , *International Journal of Nonlinear Sciences and Numerical Simulation,* 3 (3-4) 511-514

[5] Raju, V.C.C., Vasudeva, R.Y., Yegnanarayana, G.(2002) Generalized one-dimensional Reynolds' equation for micropolar fluid film lubrication, *International Journal of Nonlinear Sciences and Numerical Simulation,* 3 (2) 161-166

[6] Wang, C.C., Jang, M.J. Yeh, Y.L. (2006) Bifurcation and nonlinear dynamic analysis of a flexible rotor supported by relative short gas journal bearings , *Chaos, Solitons & Fractals,* In Press, Corrected Proof, Available online 6 January 2006

[7] He, J.H.(2003) , *International Journal of Nonlinear Sciences and Numerical Simulation,* 4 (3) 313-314

[8] He, J.H.(2004) Variational principle for non-Newtonian lubrication: Rabinowitsch fluid model , *Applied Mathematics and Computation,* 157(1)(2004) 281-286

[9] He, J.H. (2004) Variational principles for some nonlinear partial differential equations with variable coefficients , *Chaos, Solitons & Fractals*, 19(4)(2004) 847-851
[10] Liu,H.M. (2004) Variational approach to nonlinear electrochemical system , *International Journal of Nonlinear Sciences and Numerical Simulation* ,5 (1): 95-96
[11] Liu,H.M. (2005) Generalized variational principles for ion acoustic plasma waves by He's semi-inverse method, *Chaos, Solitons & Fractals, 23(2) 573-576*
[12] Zhang,J. J.-Y Yu, N.Pan (2005) Variational principles for nonlinear fiber optics, *Chaos, Solitons & Fractals,* 24(1)309-311
[13] Momani,S., S. Abuasad (2006) Application of He's variational iteration method to Helmholtz equation *,Chaos, Solitons & Fractals,* 27(5)(2006) 1119-1123
[14] He, J.H. (2005) Application of homotopy perturbation method to nonlinear wave equations*, Chaos, Solitons & Fractals,* 26 (3) 695-700
[15] He, J.H. (2005) Homotopy perturbation method for bifurcation of nonlinear problems, *International Journal of Nonal Simulation,* 6 (2)207-208
[16] He, J.H. (2000) A coupling method of a homotopy technique and a perturbation technique for non-linear problems, *International Journal of Nonlinear Mechanics ,* 35 (1) 37-43
[17] El-Shahed, M. (2005) Application of He's Homotopy Perturbation Method to Volterra's integro-differential equation , *International Journal of Nonlinear Sciences and Numerical Simulation,* 6 (2) 163-168
[18] He J.H. (2006) Some asymptotic methods for strongly nonlinear equations, *International Journal of Modern Physics B*, 20(10) (2006) 1141-1199
[19] He J.H. (2006) New Interpretation of homotopy perturbation method , *International Journal of Modern Physics B* , Vol. 20, No. 18 (2006) 2561-2568

Authors' Address: Dr. Ji-Huan He
Li-Na Zhang
College of Science
Shanghai Donghua University
1882 Yan'an Xilu Road
Shanghai 20051
People's Republic of China
jhhe@dhu.edu.cn

Prejeto: Received: 6.10.2005
Sprejeto: Accepted: 22.6.2006
Odprto za diskusijo: 1 leto
Open for discussion: 1 year

Strojniški vestnik - Journal of Mechanical Engineering 52(2006)9, 592-598
UDK - UDC 531.391:534.01
Kratki znanstveni prispevek - Short scientific paper (1.03)

Splošna siva prenosno matrična metoda in uporaba v izračunu naravnih frekvenc sistemov

The Universal Grey Transfer Matrix Method and Its Application in Calculating the Natural Frequencies of Systems

You-Xin Luo[1] - Hong-Zhong Huang[2] - Xianfeng Fan[2]
([1]Hunan University of Arts and Sciences, China; [2]University of Electronic Science and Technology of China, China)

Za analizo ter vodenje načrtovanja dinamičnih sistemov potrebujemo učinkovite metode izračuna naravnih frekvenc sistemov. V prispevku predlagamo splošno sivo prenosno matrično metodo. Pri tej metodi sta za izračun naravnih frekvenc dinamičnega sistema uporabljeni splošna siva teorija ter metoda z združevanjem splošne sive matematike in prenosne matrike. Na osnovi predlagane metode smo znotraj programa Matlab razvili posebno orodje. Opisani so tudi trije primeri, ki potrjujejo izbiro predlagane metode.

(Ključne besede: sistemi dinamični, frekvence naravne, matrične metode prenosne, matrične metode sive)

In order to analyze dynamic systems and to guide dynamic systems' design, effective methods for the calculation of the natural frequencies of systems are needed. The universal grey transfer matrix method is proposed in this paper. In this method, the universal grey theory and method are used to calculate the natural frequencies of dynamic systems by combining universal grey mathematics with a transfer matrix. A specific Matlab toolbox based on the proposed method is developed. Three examples are given to verify the proposed method.

(Keywords: dynamic systems, natural frequencies, transfer matrix methods, universal grey mathematics)

0 INTRODUCTION

Natural frequency is considered in many engineering fields, such as structural dynamic systems design, when we either want to avoid resonance or to utilize resonance. Interval analysis (or so-called interval mathematics) was originally put forward to estimate the natural frequency calculating errors. Since the first literature on interval mathematics was published in 1966 [1], interval mathematics has developed very quickly. But when interval data are calculated, different operation sequences for calculating independent variables result in different extending intervals. Though this issue has been studied by some scholars, the optimum calculating sequence is still required ([2], [3], [11] and [12]). Zhang et al studied the extending problems of trigonometric function monotony and interval analysis methods on mechanism error analysis. However, the errors decided by means of the interval analysis method can sometimes be larger than the errors obtained with the extremum method. Chen obtained some useful results using the perturbation approach for the upper and lower parameters in the structural interval and the perturbation approach for an interval matrix based on the perturbation approach [5]. However, the interval operation criterion used by Chen is unable to analyze uncertainty issues. The grey systematic theory and its application have been rapidly developed in the control field, since it was introduced in 1982 ([6], [7] and [9]). The growth of this theory is determined by its mathematical depiction. The grey set was creatively put forward by Wang et al., and based on which, the mathematical operating laws were introduced in [6]. But like interval mathematics, some of the algebraic nature cannot be extended when the grey data are analyzed. This limits its application. Therefore, Wang et al put forward the concept of the universal grey set, the foundation of the universal grey algebra, and the foundation of the universal grey mathematics analysis [7]. These universal theories are more powerful than the fuzzy set theory and the ordinary grey theory when dealing with uncertainty issues. At the same time, the application based on the above universal theories can be extended to overcome the disadvantages of interval analysis or the ordinary grey operation. Therefore, these extended means (methods) to deal with engineering problems using the universal grey theory have several practical applications. Based on the basic concepts in the universal grey data [7], in this paper the transferring between the universal grey data and interval grey data, and the interval estimating using the universal grey data are studied. The Matlab scripts that combine universal theories and a matrix-transfer approach are developed. The natural frequencies of a dynamic system are calculated by the developed Matlab scripts. Examples are given to verify the proposed methods. The conclusions are drawn in the final section.

1 FUNDAMENTALS OF THE UNIVERSAL GREY MATHEMATICS

1.1 Concept of universal grey data [7]

Definition 1: Assume an universe of discourse *U*=*R* (the set of real numbers), then the universal grey set in R is called the universal grey data set, denoted as *g*(*R*). The elements in *g*(*R*) are called universal grey data, denoted as:

$$g=(x,[\underline{\mu},\overline{\mu}]), x\in R, \underline{\mu},\overline{\mu}\in R \qquad (1),$$

where x is an observed value, $[\underline{\mu},\overline{\mu}]$ is the grey information part of x. $g(0)=(0,[0,0])$ and $g(1)=(1,[1,1])$ are the zero element and the unit element in *g*(*R*), respectively. $g'(0)$, referred to as the sub-zero element, denotes the universal grey data with a zero observing part and a non-zero grey information part.

Definition 2: $\forall g_1=(x_1,[\underline{\mu}_1,\overline{\mu}_1]), g_2=(x_2,[\underline{\mu}_2,\overline{\mu}_2])$, define g_1=g_2 if and only if $x_1=x_2, \underline{\mu}_1=\underline{\mu}_2, \overline{\mu}_1=\overline{\mu}_2$.

Definition 3: For any $g=(x,[\underline{\mu},\overline{\mu}])\in g(R)$, define the negative element of g in $g(R)$ to be $-g=(-x,[\underline{\mu},\overline{\mu}])$. If $\mu\neq 0$, define the inverse element of g in $g(R)$ to be $g^{-1}=(x^{-1},[\underline{\mu}^{-1},\overline{\mu}^{-1}])$.

Based on the above definitions, addition and multiplication can be defined in *g*(*R*). More details can be found in [7] and [9]. Using the negative element and addition, the subtraction operation can also be defined. Similarly, the division operation can be defined using inverse elements and multiplication.

It can also be determined that the universal grey addition is a closed loop satisfying the associative law and the commutative law in mathematics. The universal grey multiplication is a closed loop that copes with the associative law and the commutative law. The universal grey multiplication operation satisfies the distribution law to the universal grey addition operation [7]. It should be noted that when there is universal grey data like are (0,[-0.3/0,-0.2/0]) in the universal grey data operation, the 0 in the denominator should be eliminated. When programmed in the Matlab environment, the 0 in the denominator should be replaced with a minimum data such as 10 to 18. The calculated results are not then influenced too much.

1.2 Transformation between universal grey data and interval data

In an application, $\underline{\mu}$ and $\overline{\mu}$ in the universal grey data $(x,[\underline{\mu},\overline{\mu}])$ can be considered as the lowest or uppermost degrees of the belief to x. For example, if $\underline{\mu}=0.6, \overline{\mu}=0.8$, then the degree of the belief to x is in the range of [0.6*x*,0.8*x*]. Therefore, a universal grey data can be remarked using an interval data as $(x,[\underline{\mu},\overline{\mu}])=[x\underline{\mu},x\overline{\mu}]$, $\underline{\mu}$ and $\overline{\mu}\in[-1,1]$. An interval grey data $[a, b]$ can also be remarked using a universal grey data $(x,[\underline{\mu},\overline{\mu}])$ [6]. We speak concretely:

(1) when $a>0$, there is [*a*, *b*]=(*b*,[*a*/*b*,1]).
Let the interval grey number be [1,2]=(2,[0.5,1]).

(2) when $ab<0$ and $\max\{|a|,|b|\}=b$, there is [*a*, *b*]=(*b*,[*a*/*b*,1]).
Let the interval grey number be [-1,2]. Here, *a*=-1,*b*=2, *ab*=-2, $\max\{|-1|,|2|\}=2$. So, [-1,2]= (2,[-0.5,1]).

(3) when $ab<0$ and $\max\{|a|,|b|\}=|a|$, there is [*a*, *b*]=(*a*,[*b*/*a*,1]).
Let the interval grey number be [-2,1]. Here, *a*=-2,*b*=1, *ab*=-2, $\max\{|-2|,|1|\}=2$. So, [-2,1]= (-2,[-0.5,1]).

(4) when b<0, there is [a, b]=(a,[b/a,1]).
Let the interval grey number be [-2,-1]. Here, *a*=-2,*b*=-1<0. So, [-2,-1]=(-2,[0.5,1])

universal grey number $(x,[\underline{\mu},\overline{\mu}]) \rightarrow$ interval number $[x\underline{\mu},x\overline{\mu}]$

(a) The flow chart of the *ug*0.*m* function

interval data $[a,b] \rightarrow$

$$\begin{cases} \text{if } a>0 \text{ then universal grey number } g=(x,[\underline{\mu},\overline{\mu}])=(b,[a/b,1]) \\ \text{if } ab<0 \text{ and } \max\{|a|,|b|=b\} \text{ then universal number } g=(x,[\underline{\mu},\overline{\mu}])=(b,[a/b,1]) \\ \text{if } ab<0 \text{ and } \max\{|a|,|b|=|a|\} \text{ then universal number } g=(x,[\underline{\mu},\overline{\mu}])=(a,[b/a,1]) \\ \text{if } b<0 \text{ then universal grey number } g=(x,[\underline{\mu},\overline{\mu}])=(a,[b/a,1]) \end{cases}$$

$\rightarrow$ output universal gray number $g=(x,[\underline{\mu},\overline{\mu}])$

(b) The flow chart of the *ug*1.*m* function

Fig. 1. *The flow charts of the function programs*

Based on the above procedure, we developed two Matlab functions named *ug*0.*m* and *ug*1.*m*. The flowcharts of both functions are shown in Figs. 1 (a) and (b). The universal grey data can be obtained using both of the functions.

For example, a=[3,8] and b=*ug*1(a), then the result b=(8,[0.3750,1.0000]) will be obtained. Then a1=*ug*0(b)=[3.0000,8.0000] will be the final result.

1.3 Section analysis function of universal grey functions ([6], [7] and [9])

Universal grey data can extend the real data, and universal grey functions can extend ordinary real-data functions. Assume, $x=f(x)$ is an ordinary real-data function, and x and y are real data. x can be extended by universal grey, denoted as $g(x)$. $g(x)=(x,[\underline{\mu},\overline{\mu}])$. Then the universal grey extension of $f(x)$, $f(gx)$, can be calculated using:

$$f(g_x)=(f(x),[f(\underline{\mu}x)/f(x),f(\overline{\mu}x)/f(x)]) \quad (2).$$

After extending, the real foundational elementary functions are called universal grey foundational elementary functions, which keep the properties of foundational elementary functions. However, interval mathematics loses these properties. Universal grey data can also realize an interval analysis.

Example: testify $f(x)=xf(x\text{-}7)\text{-}6\text{-}1/(x(x\text{-}4)\text{-}30)$ has no roots in the interval of [8, 10], and estimate its maximum and minimum values in [7], [8] and [10].

The solution (with the extending interval method) is:

$$F[8,10]=([8,10])(([8,10])-7)-6-$$
$$-\frac{1}{([8,10])([8,10]-4)-30}=[1.5,23.9667],0\notin F[8,10]$$

This testifies that $f(x)$ has no real roots in [8, 10] and its maximum value is no more than 23.9667, its minimum value is no less than 1.5.

But a rational function is different because of its operating sequence, it could have a different interval extend function. For example, make the related formula write into the formula $f(x)=x^2\text{-}7x\text{-}6\text{-}\text{-}1/(x(x\text{-}4)\text{-}30)$ in this case. F[8, 10] is again calculated according to the changed formula. Its solution is different: if its form is changed, its resolution is different, and it is even unable to be calculated.

The universal grey number could eliminate this shortcoming. For the above example, as [8, 10] = (10, [0.8, 1]), there is F[8, 10] = [1.5, 23.9667]. If $f(x)$ is re-written as $f(x)=(x^2\text{-}11x^3\text{-}8x^2\text{+}234x\text{+}179)/(x^2\text{-}4x\text{-}30)$, then there still is F[8, 10] = [1.5, 23.9667]. Therefore, the results will not be affected by the changes of formula forms using the universal grey number.

1.4 A non-linear equation homology universal grey algorithm based on homology perturbation

The Newtonian iteration formula $x_{n+1}=x_n - f(x_n)/f'(x_n)$ is a famous method for solving the non-linear equation $f(x)=0$. Based on homology perturbation, reference [8] constructs homology functions and shows that the famous Newtonian iteration formula $x_{n+1}=x_n\text{-}f(x_n)/f'(x_n)$ can only research an approximate solution of the homology perturbation. A new iteration formula that has faster convergence was proposed by Zen et al [8]:

$$x_{n+1}=x_n-\frac{f(x_n)}{f'(x_n)}-\frac{f''(x_n)}{2f'(x_n)}\left(\frac{f(x_n)}{f'(x_n)}\right)^2 \quad (3).$$

Eq. (3) is the universal grey extension employed in this paper. A given precision is used as a condition to stop the iteration through $\|d(x_{n+1},x_n)\|<\varepsilon$ (see [7]). d is the universal grey distance.

2 THE APPLICATION OF THE UNIVERSAL GREY MATRIX TRANSFERRING METHOD IN CALCULATING THE NATURAL FREQUENCIES OF SYSTEMS

2.1 The universal grey matrix transferring method

When any element of a matrix is a universal grey number, the matrix is called a universal grey matrix. When the matrix transferring method is actualized, its elements are either real or complex numbers. If any element is a universal grey number, the matrix transferring method is called the universal grey matrix transferring method.

The procedure for calculating natural frequencies using the universal grey matrix transferring theory can be given as below.

(1) Construct the sub-transfer matrix C_i, find the symbol formula of C (C is a transferring matrix) using the means of a symbol by deducing [10].

(2) Obtain Z_n (the subsequent state vector) and Z_0 (the original state vector) according to the boundary conditions.

(3) Achieve the high-order equation $f(k_i, J_i, m_i, \omega)=0$ using the Maple symbol reasoning method, and by substituting the mean values of the interval values k_i, J_i, and m_i into the equations $f(k_i, J_i, m_i, \omega)=0$. Then, find the initial natural frequency ω_i^0 of ω [2].

(4) Extend the universal grey data. Assume the universal grey data of k_i, J_i, m_i as $\tilde{k}_i, \tilde{J}_i, \tilde{m}_i$ and extend $f(k_i, J_i, m_i, \omega)=0$ to $\tilde{f}(\tilde{k}_i, \tilde{J}_i, \tilde{m}_i, \tilde{\omega})=0$. Here, $\tilde{f}(\cdot)$ denotes the continuation function of $\tilde{f}(\cdot)$. The set $\tilde{\omega}_i^0$, as the original value, came from the universal grey extension based on ω_i^0. Evaluate the solution $\tilde{\omega}_i$ using the homology universal grey non-linear equation algorithm based on the homology perturbation in Section 1.4.

2.2 Software development for universal calculating

Based on the universal grey mathematical theory and the above procedures, a universal grey operating toolbox was developed in the Matlab environment. The universal grey operating toolbox is based on a universal grey class, referred to as the UgClass. Besides the functions *ug*0.*m* and *ug*1.*m* mentioned before, the functions *ugMatrixPlus.m*, *ugMatrixSubtract.m*, *ugMatrixTimes.m*, and *ugMatrixDivision.m* are developed. The flow chart of the main program is shown in Fig. 2. In this figure, we indicate each Matlab function.

$$\text{user directory} \backslash @UgClass \backslash \left\{ \begin{array}{l} UgClass.m \\ ug0.m \\ ug1.m \\ ugMatrixPlus.m \\ ugMatrixSubtract.m \\ ugMatrixTimes.m \\ ugMatrixDivsion.m \\ ugFunction.m \\ ugPower.m \end{array} \right.$$

Fig. 2. *The flow chart of the main program*

2.3 Examples

Example 1 [9]: Fig. 3 is a dynamic model of an equal-diameter discs system. The left end is fixed and the right end is free. The rotating inertia of each disc is J. The sprain stiffness of the axis is k. Find the natural frequencies of the freely sprain vibration.

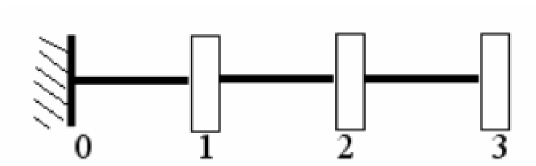


Fig. 3. *The equal-diameter disc system*

The boundary conditions are:

$$\theta_0 = 0, M_3^R = 0$$

where, θ_0 is the torsion angle of the left-hand end 0, and M_3^R is the torque of the right-hand end 3.

The transferring matrix is:

$$C_i = \begin{bmatrix} 1 & 1/k \\ -\omega_n^2 J & 1-\omega_n^2 \frac{J}{k} \end{bmatrix}$$

where ω_n is the angular frequency of the discs system [9].

After deducing in the Maple environment we get:

$$M_3^R = (1 - \frac{\omega_n^6 J^3}{k^3} + \frac{5\omega_n^4 J^2}{k^2} - \frac{6\omega_n^2 J}{k}) M_0 = 0$$

Because of $M_0 \neq 0$ the following is true:

$$f(k, J, \omega_n) = 1 - \frac{\omega_n^6 J^3}{k^3} + \frac{5\omega_n^4 J^2}{k^2} - \frac{6\omega_n^2 J}{k} = 0$$

With the symbolic solution methods, we get:

$$\omega_{n1}=0.445\sqrt{\frac{k}{J}},\omega_{n2}=1.247\sqrt{\frac{k}{J}},\omega_{n3}=1.802\sqrt{\frac{k}{J}} \quad \text{(rad/s)}$$

Extending them with the universal grey method their values amount to $\tilde{J}=(1,[1,1])$, $\tilde{k}=(1,[1,1])$, then $\tilde{\omega}_{n1}=(0.445,[1,1])$, $\tilde{\omega}_{n2}=(1.247,[1,1])$, and $\tilde{\omega}_{n3}=(1.802,[1,1])$. Clearly, the solutions obtained with the symbolic solution methods are the same solutions as obtained with the universal grey method.

Example 2 [4]: As with the frame construction in Fig. 4, the parameters of the construction are shown below.

(1) The upper limit and lower limit of the stiffness parameters (N/m) are $k_1^I=[2000,2020]$, $k_2^I=[1800,1850]$, $k_3^I=[1600,1630]$, $k_4^I=[1400,1420]$, $k_5^I=[1200,1210]$, and $k_6^I=[1000,1008]$, respectively.

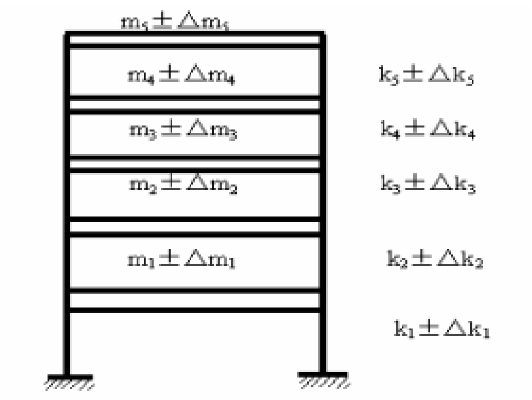


Fig. 4. *The frame structure*

(2) The upper limit and lower limit of the mass parameters (unit: kg) are $m_1^I=[29,31]$, $m_2^I=[26,28]$, $m_3^I=[26,28]$, $m_4^I=[24,26]$, and $m_5^I=[17,19]$, respectively.

The sub-transfer matrix and the transfer matrix can be obtained using the transfer matrix method. Considering the boundary conditions, we determine that the power of ω in $f(k_i,J_i,m_i,\omega)=0$ is 10 using the symbol reasoning method. The coefficient of the high-order equation of ω is a function of known parameters.

We replace the corresponding parameters using the mean values in the equation of $f(k_i,J_i,m_i,\omega)=0$, i=1,2,3, and 4. For example, let $k_1^I=2010$, and $m_1^I=30$. We can find the original values to be transferred to the universal grey number. Set ε=0.01, and we solve the above equation. The value of it can, however, be smaller in order to improve the precision. Then, we transfer the universal grey data to the grey data. The results are shown in Table 1. For a comparison study, the interval perturbation solutions based on the Deif method and the perfect solutions are given in Table 1 at the same time. It is clear that the proposed method can get the same or even more precise results than the Deif analysis method is able to provide.

Example 3 [4]: A mass-spring system is shown in Fig.5. The interval expressions of mass and spring stiffness are:

$$[K]=\begin{bmatrix} [3800,3830] & [-1820,-1800] & 0 & 0 & 0 \\ [-1820,-1800] & [3400,3430] & [-1610,-1600] & 0 & 0 \\ 0 & [-1610,-1600] & [3000,3010] & [-1416,-1400] & 0 \\ 0 & 0 & [-1416,-1400] & [2600,2620] & [-1210,-1200] \\ 0 & 0 & 0 & [-1210,-1200] & [1200,1210] \end{bmatrix}$$

$$[M]=\begin{bmatrix} [29,30] & 0 & 0 & 0 & 0 \\ 0 & [26,28] & 0 & 0 & 0 \\ 0 & 0 & [26,28] & 0 & 0 \\ 0 & 0 & 0 & [26,28] & 0 \\ 0 & 0 & 0 & 0 & [17,19] \end{bmatrix}$$

Table 1. *Comparison of natural frequencies*

		ω_1	ω_2	ω_3	ω_4	ω_5
Perfect solutions[4]	Upper limit	7.8303	47.820	109.40	174.00	230.08
	Lower limit	4.6166	40.643	98.180	157.84	209.51
Interval perturbation solutions based on Deif [4]	Upper limit	7.7702	47.661	109.17	173.66	229.69
	Lower limit	4.5623	40.643	97.966	157.53	209.15
Proposed method		[4.6166, 7.8303]	[40.6431, 47.821]	[98.181, 109.40]	[157.84, 173.99]	[209.51,230.08]

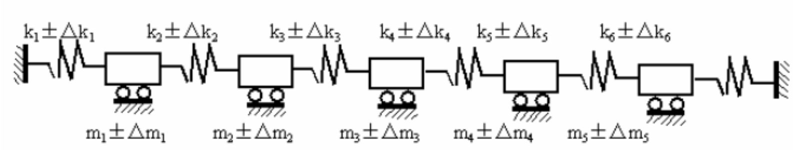


Fig. 5. *The spring-mass system*

Table 2. *Comparison of natural frequencies*

		ω_1	ω_2	ω_3	ω_4	ω_5
Perfect solutions [4]	Lower limit	5.05895	42.42973	100.30453	159.81766	211.36365
	Upper limit	7.03611	45.73130	107.32792	172.14525	226.78797
Interval matrix perturbating solution based on Deif [4]	Lower limit	4.82429	41.72490	99.47379	158.93609	210.11230
	Upper limit	7.18635	46.30420	107.93573	172.51133	227.43530
Proposed method		[5.05884, 7.03655]	[42.42854, 45.73256]	[100.30154, 107.33104]	[159.81563, 172.14531]	[211.36258, 226.78912]

In this case ε=0.01. The analyzed results are obtained with the proposed universal grey transfer matrix method. Then, the universal grey data is transferred to the grey data. The solutions are shown in Table 2. The solutions show that the results obtained with the proposed method are the same as that obtained by the perfect method; namely, the lower limit and the upper limit obtained with the perfect one method are almost the same, with the end points of the interval grey data obtained with the proposed methods. The interval perturbation based on the Deif method in [4] completes the work with some errors. Compared with other methods, it is clear that the proposed method is more effective.

3 CONCLUSION

In this paper, universal mathematics is introduced. The high-order equation can be found with the transfer matrix method combined with symbol reasoning. The solution can be obtained with the universal grey method. A specific Matlab toolbox for the universal grey operation is developed. The calculating process and the examples of the natural frequencies' analysis of the structure are studied using the universal grey transfer matrix method. The paper shows that the proposed method is an effective and reliable method that is easy to program. For this reason it will have a wide range of applications in dynamic system design and vibration analysis. However, if the dynamic system is too complicated, the reasoning will be more complicated and will exceed the memory of the computer. In this case, the universal grey matrix perturbation will be used [6].

Acknowledgements

This research was partially supported by the Key Scientific Research Fund of Hunan Provincial Education Department (04A036) and the Scientific Research Fund of the Ministry of Education of China (02108).

4 REFERENCES

[1] R. E. Moore (1979) Methods and applications of interval analysis. Philadelphia.

[2] M. S. G. Tsuzuki and M. Shimada, M. (2003) Geometric classification tests using interval arithmetic in b-rep solid modeling. *J. Braz. Soc. Mech. Sci. & Eng.*, Oct./Dec. 2003, 25(4): 396-4022.

[3] J. Y. Zhang and S. F. Shen (1992) Interval analytic approach in mechanical error analysis. *Journal of Technical College of East China*, 1992, (2): 13-19 (in Chinese).

[4] J. Y. Zhang and S. F. Shen (1996) Calculating mechanism. Beijing: *Publishing House of National Defense Industry*, 1996 (in Chinese).
[5] S. H. Chen (1999) Matrix perturbation theory in structural dynamic design. Beijing: *China Science Press*.
[6] Q. Y. Wang , K. D. Liu, J. P. Chen, et al. (1990) Mathematics method and application of the grey systematic theory. Chengdu: *Southwest Jiaotong University Publishing House* (in Chinese).
[7] Q. Y. Wang (1996) Grey mathematics foundation. Wuhan: *Huazhong University of Science & Technology Press* (in Chinese).
[8] J. L. Zen , Y. X. Luo , Z. M. He, et al. (2002) A homology continuation algorithm based on homology perturbation and its application to mechanism synthesis. *Journal of Mechanical Transmission*, 2002, 26(4): 12-14 (in Chinese).
[9] Y. X. Luo (2003) Universal grey mathematics and its application to interval analysis of uncertain structural systems. *Advances in Systems Science and Applications*, 2003, 3(4): 522-530.
[10] W. C. Qian (2002) The application of Mathematica in transfer matrix methods. *Mechanics and Practice*, 2002, 24(1): 38-41 (in Chinese).
[11] A. Asaithambi, and S. K. Agrawal (1998) Inverse kinematic solution of robot manipulators using interval analysis. *ASME J. Mech. Design*, 1998, 120:147-150.
[12] S. S. Rao and L. Berke (1997) Analysis of uncertain structural system s using interval analysis. *AIAA Journal*, 1997, 35(4): 727-735.

Authors' Addresses:
You-Xin Luo
Hunan University of Arts and Sciences
Department of Mechanical Engineering
Changde, 415000, China

Hong-Zhong Huang
Xianfeng Fan
Univ. of Electronic Science and Technology
School of Mechatronics Engineering
Chengdu, Sichuan, 610054, China
hzhuang@uestc.edu.cn

Prejeto:
Received: 14.9.2005

Sprejeto:
Accepted: 22.6.2006

Odprto za diskusijo: 1 leto
Open for discussion: 1 year

Strojniški vestnik - Journal of Mechanical Engineering 52(2006)9, 599-612
UDK - UDC 658.56:004.41
Strokovni članek - Speciality paper (1.04)

Razvoj generične strukture in programskih modulov elementarnega delovnega sistema porazdeljenega tiskanja

Development of the Generic Structure and Programming Modules of an Elementary Work System for Distributed Printing

Franc Rotar[1] - Alojz Sluga[2]
([1]iWare, Ljubljana; [2]Fakulteta za strojništvo, Ljubljana)

Uveljavljena organizacija proizvodnih sistemov ni več skladna s potrebami današnjega tržnega okolja. Odgovor današnjim proizvodnim potrebam, kot posledice globalizacije in razvoja sodobnih informacijsko komunikacijskih tehnologij, so porajajoči novi vzorci proizvodnih sistemov. Med njimi so najbolj prepoznavni Holonski, Bionični[1], fraktalna tovarna ter zahtevni prilagodljivi proizvodni sistemi (ZPPS).

Pričujoči prispevek predstavlja zasnovo in tehnično rešitev porazdeljenega proizvodnega problema skladno z opredelitvami proizvodnih danosti in razmerij med njimi, kakor jih definira vzorec ZPPS. V rešitvi so uporabljene moderne informacijsko komunikacijske tehnologije (IKT) za uvajanje porazdeljenih informacijskih rešitev. Razvit je sistem porazdeljenega označevanja izdelkov za podjetje, razprostranjeno po več državah. Zamisel sistema, definirana v vzorcu ZPPS in izveden v tem delu, omogoča geografsko razširitev do poljubnih meja. Uporaba sodobnih informacijsko-komunikacijskih tehnologij omogoča funkcionalno razširitev do meja, omejenih samo s potrebami označevanja izdelkov.

(Ključne besede: sistemi proizvodni, kooperacija, sistemi delovni, strukture dejavne)

The traditional manufacturing system paradigm has deficiencies in the modern, global world related to market demands, which are changing so quickly that only the most agile manufacturers can follow them. In response, new manufacturing paradigms have evolved in recent decades. Of these, the holonic, bionic, fractal factory and complex adaptive manufacturing systems (CAMS) paradigms are the most popular.

CAMS principles are being used and CAMS objects (virtual work systems) are built in order to deliver a distributed solution for product labeling at various levels in a company that has production plants around Europe. Modern information and communication technologies (ICTs) are being utilized to build a system that produces labels at n locations based on the demands from m places. It is the company's policy, not the concept or the implementation issues, that limits the size and the functionality of the presented labeling system in a distributed environment.

(Keywords: manufacturing systems, cooperation, work systems, agent structure)

0 UVOD

Za današnjo produktivnost in kakovost proizvodnih postopkov je ključnih nekaj mejnikov. Proizvodnja devetnajstega stoletja je še obrtniškega značaja. V začetku dvajsetega stoletja Adam Smith utemelji proizvodni vzorec industrijske proizvodnje. V zadnjem delu dvajsetega stoletja nastajajo novi proizvodni vzorci kot odgovor na

0 INTRODUCTION

Several milestones have marked the way towards the current performance of manufacturing systems. In the 19th century, only craftsman-type manufacturing existed. At the beginning of the 20th century, Adam Smith laid the foundations for the industrial manufacturing paradigm, and at the end of the 20th century, new manufacturing paradigms evolved

[1] Izraz holonski je pridevniška oblika izraza "holon", ki ga je Arthur Koestler predlagal l.1989 v knjigi The Ghost in the Machine. Izraz holon je sestavljenka grških besed holos=celota in proton=del. Izraz bionični se nanaša na bioniko, t.j. na nauk med biologijo in tehniko, ki tehnična vprašanja rešuje po zgledih iz narave.

splošen napredek (in s tem povezane spremembe) in kot odgovor na nove možnosti za dejansko organizacijo in za izvedbo proizvodnih postopkov. Proizvodni postopki so tudi vedno bolj informacijsko podprti.

Petdeseta leta prejšnjega stoletja zaznamujejo prvi objektno grajeni programski prevajalniki, predhodniki današnjih objektnih programskih jezikov. Sodelava strojne in programske opreme je v zadnjih desetih letih omogočila izdelavo obsežnih informacijsko-komunikacijskih sistemov, znanilnikov prehoda iz industrijske v informacijsko oziroma poindustrijsko družbo.

Strojniški napredek (hiter in razmeroma cenen prevoz - letala, velike ladje, hitri vlaki) in komunikacijski napredek (splet, zanesljivo telefonsko omrežje) sta omogočila globalizacijo. Organizacijske in ekonomske vede postavljajo nove vzorce organizacij in ekonomije v novem okolju. Novo okolje se od starega razlikuje po raznolikosti sodelujočih kultur in po geografski razprostranjenosti enega samega gospodarsko - ekonomsko - ekološko - sociološkega sistema, ki je naenkrat nastal iz več manjših slabo povezanih sistemov z majhnim medsebojnim vplivom. V novem okolju je mogoča (in ekonomsko upravičena) izdelava in prodaja večjih serij izdelkov, delno lokaliziranih za posamezna tržišča. Proizvodnja se seli na področja z optimalno kombinacijo cene dela, še zadovoljive kulture dela in majhne oddaljenosti izdelkov od tržišč. Prodajni, razvojni in proizvodni sistemi postajajo porazdeljeni. Hitra dinamika globalnega mesta narekuje prilagodljivost sedanjih in prihodnjih proizvodnih sistemov.

V tem prispevku z uporabo sodobnih informacijsko komunikacijskih tehnologij rešujemo problem označevanja izdelkov, torej sledljivosti izdelkov v porazdeljeni proizvodnji globalno delujočega podjetja. Porazdeljeno proizvodnjo strukturiramo po vzorcu ZPPS [1].

1 TEORIJA

1.1 Zapleteni prilagodljivi proizvodni sistem (ZPPS)

Proizvodni sistemi novih generacij se odzivajo na zahteve trga. Načrtna proizvodnja je stvar preteklosti, hiter odziv na spremembo tržnih razmer je nujno potreben. Raznolikost izdelkov (tržne zahteve), inovacije oz. izboljšave (za zmanjšanje

in a response to general progress (and changes related to it), and as a response to new possibilities for the effective organization and for the implementation of manufacturing systems, mainly driven by contemporary information and communication technologies (ICTs).

In the 1950s the first object-built program compilers emerged - they were the predecessors of the current object-oriented programming languages. The synergy of hardware and software in the past ten years allowed the development of large information and communication systems - the precursors of the transition from the industrial society to the information society (i.e., post-industrial society).

Technical progress (for example, in logistics, i.e., fast and cost-effective transport by airplanes, large ships, fast trains and a network of motorways) and progress in communications (for example, the internet and a reliable phone network) made globalization possible. Organizational and economic sciences set new paradigms for organizations and the economy in the new environment. The new environment differs from the old one in the diversity of the participating cultures and in the geographic diffusion of a single business-economy-social system, which evolved from several smaller loosely linked systems with weak interactions. The new environment allows for economically justified manufacturing and the sale of products in larger series, partially localized for individual markets. Manufacturing is being transferred into regions with an optimal combination of labor cost, acceptable labor culture and a short distance between the products and the markets. Sales, development and manufacturing systems are becoming distributed. The fast dynamics of globalization calls for the adaptability of current and future manufacturing systems.

In this paper a solution for the labeling of products (by using contemporary ICT) is described, which also allows the traceability of products in the distributed manufacturing of a globally operating company. The CAMS paradigm, as defined by Peklenik [1], has been used to set up the distributed manufacturing structure.

1 BACKGROUND

1.1 Complex Adaptive Manufacturing System (CAMS)

New-generation manufacturing systems respond quickly to market demands. Planned production is a matter of the past; a quick response to market changes is essential. Product diversity (due to market demands), improvements and innovations stroškov ali za dodatno funkcionalnost) vodijo v zmanjševanje serij in v vse večjo zapletenost in zahtevnost proizvodnje. Hiter odziv na zahteve trga zagotavlja konkurenčno prednost in s tem tudi tržno prevlado.

Pomembne lastnosti sistema, ki izpolnjuje zahteve proizvodnih sistemov nove generacije, so [1]:
- prilagodljiva organizacijska struktura,
- podprtost postopka odločanja s kakovostnim in dobro vpeljanim informacijskim sistemom,
- ključne odločitve sprejema usposobljen osebek, oz. fizična oseba oz. načrtovalec postopkov, operater ali vodja skupine.

Za konkurenčnost na trgu je bistvena hitrost oziroma kratek reakcijski čas za tržne spremembe in spremembe v okolju. Gornje lastnosti proizvodnemu sistemu omogočajo hitro odzivanje.

Glavno vlogo pri doseganju razgibanosti proizvodnih dejavnosti zahtevnih prilagodljivih proizvodnih sistemov ima osebek s svojim znanjem in izkušnjami (pristojnost) pri opravljanju predpisanih del.

Generični model tovarne, kot proizvodni sistem novih generacij, je definiral Peklenik ([1] in [2]). Tovarna je strukturirana kot trinivojski zahtevni prilagodljivi proizvodni sistem, ki je sestavljen iz podsistemov s svojskimi funkcijami in lastnostmi. Le ti so uvajani v obliki med seboj povezanih osnovnih delovnih sistemov (ODS) različnih tipov. Vsak izmed ODS uvaja en delovni postopek (npr. načrtovanje, struženje, nadzor). ODS so povezani materialno (obdelovanci prehajajo med ODS) in informacijsko preko svojih informacijskih zastopnikov oz. dejavnikov oz. virtualnih delovnih sistemov (VDS) [3].

1.2 Moderne informacijsko komunikacijske tehnologije

Sodobni programski jeziki so C++, objektni Pascal in Java. Sodobni Operacijski Sistemi (OS) so Unix, Linux in Win32 sistemi oziroma MS Okna. Za zadnjih deset let je značilen izbruh komunikacijskih tehnologij. Nekatere se odlično dopolnjujejo, druge se popolnoma izključujejo [4]. Tretje so narejene zato, da omogočajo komunikacijo med sicer nezdružljivimi programskimi komponentami. V preglednem naboru tehnologij se omejujemo na tiste, ki so potrebne za usposobljeno uvajanje

(for the reduction of costs or for additional functionality) lead to smaller series and to the ever-increasing complexity of manufacturing. A faster response to market requirements ensures competitive advantage and thus market dominance.

A system that fulfils the requirements of a new generation of manufacturing systems should have the following important features [1]:
- an adaptive organizational structure
- a decision-support process should be implemented by using a high-quality and properly organized information system
- key decisions are made by a competent person, i.e., a procedure planner, operator or team leader.

A fast response to time-to-market changes and to changes in the environment is essential in order to retain a competitive advantage. The features mentioned above facilitate the fast response of a manufacturing system.

The person, using his/her knowledge and experience (competence) during his/her prescribed work, has the main role in achieving the dynamics of manufacturing activities for complex adaptive manufacturing systems.

A generic model of a factory as a new generation of manufacturing system was defined by Peklenik ([1] and [2]). It is structured as a three-level complex adaptive manufacturing system and consists of subsystems with specific functions and features. These are implemented in the form of mutually interlinked elementary work systems (EWS) of various types. Each EWS implements one work process (e.g., planning, product development, design, cutting). EWSs are linked material-wise (workpieces pass between EWSs) and information-wise (by their information agents, i.e., virtual work systems (VWS) [3]).

1.2 Modern Information and Communication Technologies

The modern programming languages are C++, object Pascal and Java. The modern operating systems (OSs) are Unix, Linux and Win32 systems (i.e., MS Windows). The past ten years have been characterized by a boom in new communication technologies. Some of them supplement each other perfectly, while others are mutually exclusive [4]. The third type of technology has been built in order to allow communications between otherwise incompatible programming components. Our overview of technologies is limited to those that are needed for a proper implementation of porazdeljenega proizvodnega sistema po načelih vzorca ZPPS.

Za razvoj porazdeljenih uporab obstoji več modelov (in istoimenskih tehnologij uvajanja), od katerih prednjačijo trije:

COM/DCOM/.NET (objektni model komponent/objektni model porazdeljenih komponent/mreža). To je model največjega proizvajalca programske opreme, Microsofta.

CORBA (arhitektura posrednikov zahtev skupnih objektov). To je model, katerega specifikacijo in podporno tehnologijo je skupaj pripravljalo in podprlo več ko 800 proizvajalcev z vsega sveta.

SOAP (standard za spletne storitve). To je standardizacija dostopa ter uporabe metod objektov specifičnih izvedb modelov COM in CORBA).

Vodilna pri postavljanju integracijskih standardov sta Sun z Javo in Web Services ter Microsoft s C# ter okoljem .NET.

Oba postopka, CORBA in .NET, imata svoje prednosti in pomanjkljivosti, predvsem glede na hitrost delovanja ter na prenosljivost programa. Vsi proizvajalci programske opreme sprejemajo tudi standarde XML in SOAP, katere postavlja skupnost W3C. Uporabnikom in načrtovalcem sistemov niti ni pomembno, kateri od obeh postopkov bo prevladal, saj bosta lahko predvsem zaradi standardizacije protokolov klicev oddaljenih funkcij ter uporabe tako imenovanih servisov oba postopka kljub različnemu ozadju lahko sodelovala v enovitih velikih porazdeljenih sistemih.

2 NAČRTOVANJE PORAZDELJENEGA SISTEMA TISKANJA

Postopek porazdeljenega tiskanja z m mest zahtevanja in z n mest tiskanja strukturiramo po vzorcu ZPPS v ODS zahtevanja in v izvedbi tiskanja ODS. ODS se sporazumevajo preko VDS, svojih zastopnikov v informacijskem okolju. VDS je strukturiran kot programski dejavnik (sl. 1).

Prenos podatkov med ODS in VDS pa poteka preko ustreznih vmesnikov. Zahtevanja ODS tiskanja so strukturirana kot posredniki. Njihove lastnosti so:

- zmožnost ustanovitve virtualne delovne skupine (grozdenje) in
- znotraj nje koordinacija celotnega opravila.

VDS vseh ODS, tako zahtevanja kakor izvedbe tiskanja, so sestavljeni iz štirih osnovnih

a distributed manufacturing system in accordance with the CAMS paradigm principles.

Several models (and implementation technologies) are used for the development of distributed applications; three of them prevail:

COM/DCOM/.NET (Component Object Model / Distributed Component Object Model / Net). This is the Microsoft's model.

CORBA (Common Object Request Broker Architecture). The specification and supporting technology of this model have been jointly prepared and supported by more than 800 companies from all over the world.

SOAP (Simple Object Access Protocol) model. This is standardization of access and use of object methods of various implementations of COM and CORBA models.

The leading companies that set the integration standards are Sun (Java and Web Services) and Microsoft (C# and .NET environment).

Both CORBA and .NET have their advantages and drawbacks, especially with respect to the speed of execution and the portability of the code. All software developers also accept the XML and SOAP standards set by the W3C consortium. For the users and system planners it is not really important which of these methods will prevail, because, due to the standardization of remote-function call protocols and due to the use of services, both methods will be able to cooperate in large uniform distributed systems despite their different backgrounds.

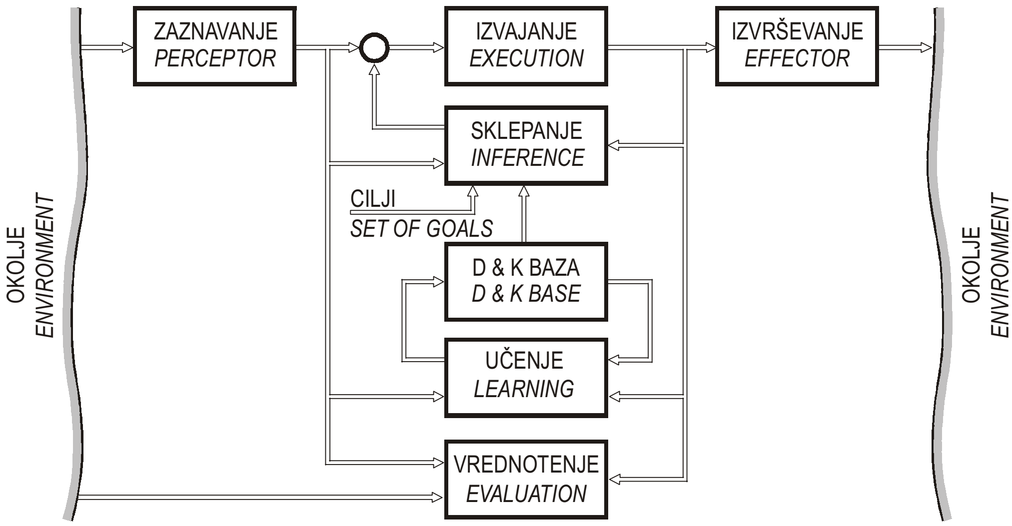
2 DISTRIBUTED PRINTING SYSTEM DESIGN

The process of distributed printing, based on the demands from m places and n printing locations, should be structured in accordance with the CAMS paradigm to the EWSs of demands and to the EWSs of printing locations. EWSs communicate via VWSs - these being their agents in the IT environment. A VWS has a structure of a software agent (Fig. 1).

Data between the EWS and the VWS are transferred via interfaces. The EWSs of printing demands are structured as mediators. Their features are:

- the capability of establishing a virtual workgroup (clustering),
- the coordination of the complete task within the workgroup.

The VWSs of all the EWSs (both those on demand and the execution of printing) consist of



Sl. 1. *Generična struktura dejavnika VDS [5]*
Fig. 1. *Generic VWS agent structure [5]*

elementov [5]:
- dojemanja,
- izvršilnega elementa,
- posledice in
- mehanizma sklepanja.

Vloga dojemanja (sl. 1) je v opazovanju dogajanja v informacijski mreži z razpoznavanjem zanj bistvenih informacij, ki jih posreduje izvršilnemu elementu.

Element izvajanja opravi zadano nalogo in preda rezultate posledični stopnji, ki jih sporoča nazaj v informacijsko mrežo. Mehanizem sklepanja nadzira postopke elementa izvajanja. Sklepanje temelji na podlagi znanih podatkov, učenja ter ciljev.

Posredniki, dejavniki porazdelitvenih zahtev tiskanja, v informacijski mreži iščejo tiste porazdeljene dejavnike ODS tiskanja, katerih ODS so tehnološko zmožni izvesti zahtevano tiskanje v zahtevani količini in v zahtevanem časovnem roku. Postopek iskanja rešitve naloge je sestavljen iz treh faz:

Ponujanje: V tej, prvi fazi posrednik oblikuje zahtevo po izpolnitvi naloge. Vsi dejavniki, ki imajo funkcionalne zmožnosti, odgovorijo s ponudbo. Nastane dinamična skupina medsebojno konkurenčnih dejavnikov ponudbe tiskanja.

Pogajanje: Posrednik začne pogajanje z VDS tiskanja. V sklopu pogajalske funkcije išče posrednik skupni optimum za izvajanje opravila, medtem ko posamezni dejavniki optimirajo lokalno opravilo. Pogajanje se krožno ponavlja, dokler posrednik ne ugotovi, da rešitev ustreza zahtevam opravila (s sprejemljivimi odstopanji).

four basic elements [5]:
- preceptor,
- executing element,
- effector,
- inference mechanism.

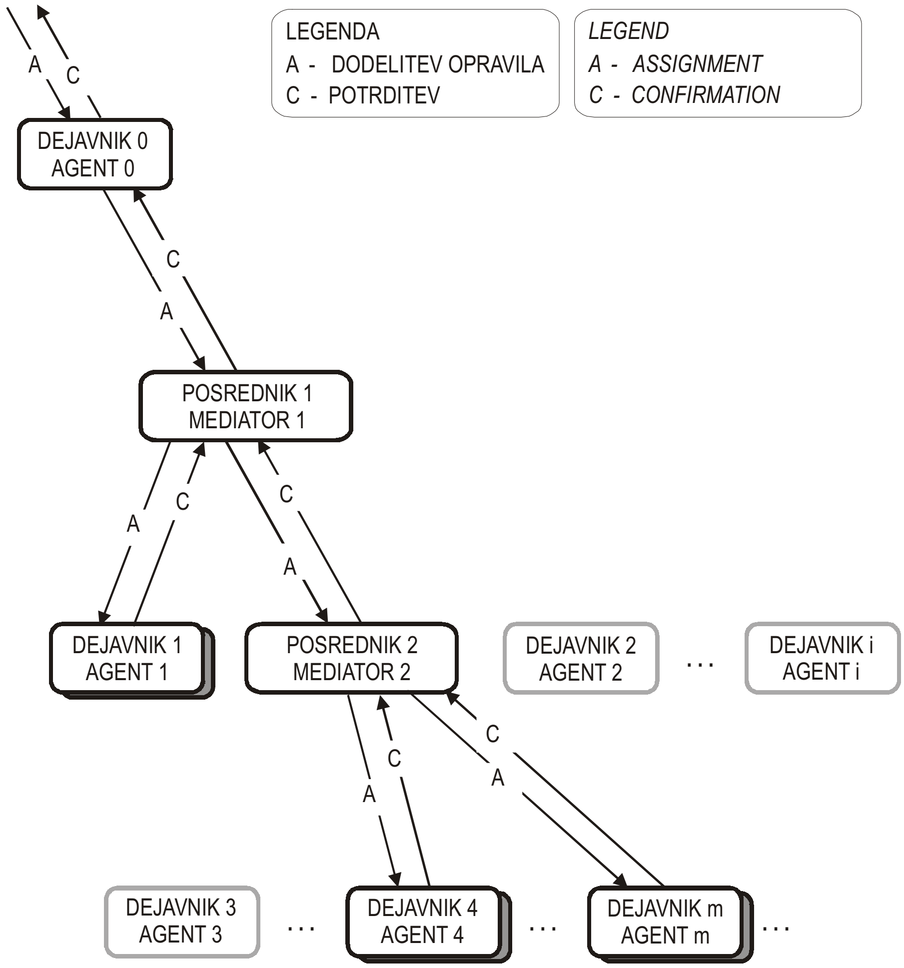
The role of a perceptor (Fig. 1) is to monitor the information network and to recognize the relevant data, which should be sent to the executing element.

The executing element performs the task given and forwards the results to the effector, which sends them back to the information network. The inference mechanism controls the executing element processes. Inference is based on the known data, learning and goals.

Mediators - agents of distributed printing demands - search those distributed agents of the printing EWSs in the information network, whose EWSs have technical capacities to perform the requested printing job in the requested volume and within the required time frame. The solution-finding process consists of three phases:

Offer: In this first phase the mediator forms a request for fulfilling the task. All agents that possess the required functional capabilities respond by sending an offer. Thus, a dynamic group of mutually competitive agents for the print offer is created.

Negotiating: The mediator starts negotiations with printing VWSs. Within the negotiating function the mediator tries to find the overall optimum for performing the task, while individual agents optimize the local tasks. Negotiations are cyclically repeated until the mediator finds a solution that fulfills the task requests (within acceptable tolerances).



Sl. 2. *Dinamična skupina dejavnikov v postopku dogovarjanja [5]*
Fig. 2. *Dynamic group of agents in the mediation process [5]*

Sklepanje dogovora: Posrednik dodeli opravila izbranim dejavnikom tiskanja, ki potrdijo veljavnost dodelitve in potem opravilo tudi opravijo.

Postopek usklajevanja med VDS zahtevkov in tiskanja se začne takoj, ko se v okolju pojavi novo, še ne opravljeno opravilo in kadar se pojavi motnja v izvajanju že dodeljenih opravil.

Uvajanje porazdeljenega sistema tiskanja z modernimi IKT v vzorcu ZPPS poteka na ravni uvajanja VDS, zastopnikov ODS in integracije VDS z informacijskim okoljem in z ustreznimi EDSi.

2.1 Uvajanje mreže zahtevkov VDS in tiskanja VDS

Vzorec ZPPS za reševanje porazdeljenih proizvodnih problemov ponuja a) obliko dejanskega

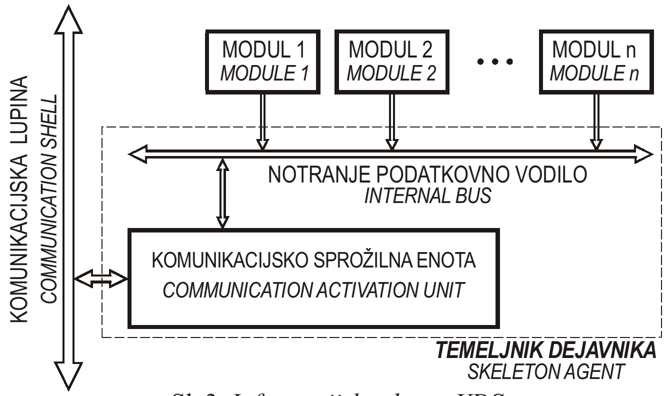
Agreement-making: The mediator assigns the tasks to the selected printing agents, who confirm the validity of the assignment and then they perform the task.

The process of coordination between the VWSs of demands and the VWSs of printing starts as soon as a new task appears, or in case of a disturbance, during the execution of previously assigned tasks.

Implementation of a distributed printing system using a modern ICT with the CAMS paradigm occurs on the level of the implementation of the VWSs, the EWS representatives and the integration of the VWSs with the information environment and with appropriate EWSs.

2.1 Implementation of a network of demand VWSs and printing VWSs

Using the CAMS paradigm for solving distributed manufacturing problems, one obtains a)



Sl. 3. *Informacijska shema VDS*
Fig. 3. *VWS information scheme*

strukturiranja problema, b) vsebino posameznih gradnikov (ODS, VDS), in c) vsebino informacijskih tokov med njimi. Moderne IKT pa predstavljajo potrebno komunikacijsko infrastrukturo in ponujajo potrebna orodja za reševanje praktičnih porazdeljenih proizvodnih problemov.

VDS zahtevkov in tiskanja so sestavljeni iz osnovnega gradnika - imenujemo ga temeljnik dejavnika - in iz nanj pripetih različnih delovnih modulov (sl. 3).

Temeljnik dejavnika s svojim naborom metod:
- se sporazumeva s temeljniki drugih VDS v informacijski mreži in
- omogoča vključitev različnih delavnosti v VDS za zastopanje različnih ODS tiskanja z uporabo različnih modulov.

Temeljnik VDS sestoji iz (sl. 3):
- komunikacijsko sprožilne enote in iz
- notranjega podatkovnega vodila.

Komunikacijsko sprožilna enota omogoča delavnost temeljnika VDS. Interno podatkovno vodilo omogoča notranji prenos sporočil med moduli in temeljnik dejavnika.

Pomemben del strukture VDS je namenjen tudi povezovanju z ustreznim ODS.

2.2 Delavni moduli VDS

Delavni moduli so sklenjene programske enote, v katerih izpeljemo različne delavnosti VDS:
- načrtovanje,
- uporabniški vmesnik,
- in vmesnik med ODS in dejavnikom.

Delovni moduli so strukturirani v drevesne strukture (sl. 4).

a form of effective problem structure, b) the contents of individual components (EWS, VWS), and c) the contents of information flows between them. Modern ICT represents the required communication infrastructure, and it provides for the required tools to solve the practical problems of distributed manufacturing.

Demand and printing VWSs consist of the basic component - the skeleton agent - and of various functional modules that are fixed to it (Fig. 3).

The purpose of the skeleton agent and its methods is:
- to communicate with the skeletons of other VWSs in the information network,
- to allow the activation of various VWS functionalities for the representation of various printing EWSs by means of various modules.

The VWS skeleton consists of (Fig. 3):
- a communication activation unit,
- an internal data bus.

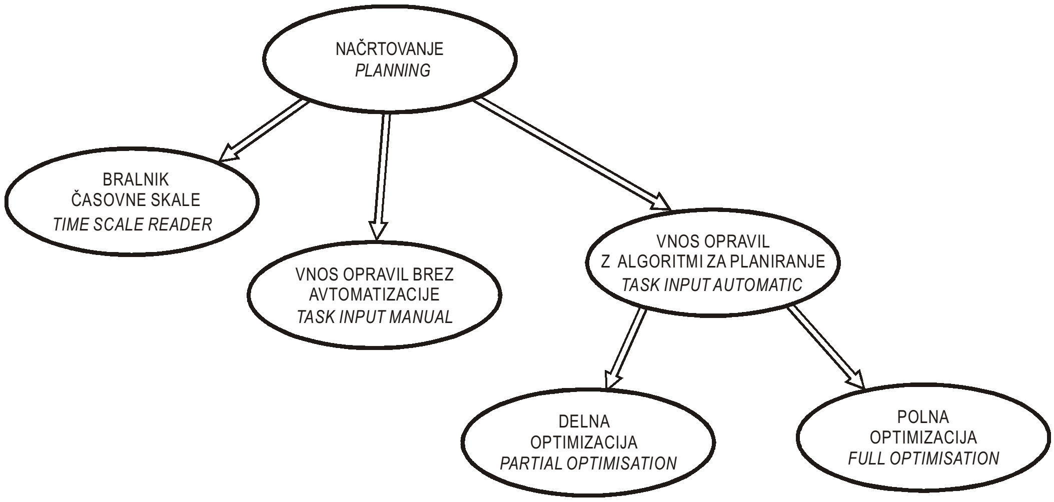
The communication activation unit enables the VWS skeleton functionalities. The internal bus enables the internal flow of data between the agent skeleton and the modules.

An important part of the VWS structure is allocated to connections with the appropriate EWS.

2.2 VWS functional modules

Functional modules are self-contained program entities that contain various VWS functionalities:
- planning
- the user interface,
- the EWS-agent interface.

Functional modules have the form of tree structures (Fig. 4).



Sl. 4. *Drevesna struktura modula načrtovanja*
Fig. 4. *Tree structure of a modular planning*

3 REZULTATI

3.1 Podjetje z porazdeljenim označevanjem izdelkov

Podjetje ETI d.d. je eden izmed pomembnih proizvajalcev električne zaščitne opreme na svetovnem trgu. Večino svojih izdelkov prodaja na tujih tržiščih. Izdelke izdeluje z lastno blagovno znamko in z blagovno znamko velikih kupcev (Siemens, Kopp, ECG in drugi).

Organizacijsko zrelost je podjetje dokazalo s pridobitvijo certifikata ISO 9000 že v daljnem letu 1993, danes pa ima pridobljen že tudi certifikat ISO 14000.

Potreba po stalnem večanju produktivnosti oz. potreba po nižanju stroškov je začela zahtevati tudi reorganizacijo podjetja. Strategija reorganizacije je običajna: - funkcije, ki pomenijo ožjo specialnost podjetja (core competences), naj ostanejo in naj se razvijajo znotraj matičnega podjetja. Preostale funkcije (izvajanje manjših oz. strateško manj pomembnih funkcij) pa naj izvajajo dobavitelji. Ekonomske analize pokažejo, da so za izvajanje manjših del kooperanti cenejši od dela v podjetju.

3.2 Dvojec ODS, VDS tiskarne nalepk

Tiskarna nalepk predstavlja dvojec ODS, VDS, ki ima bistvene lastnosti sklenjenega delovnega sistema:
- avtonomno delovanje oz. načrtovanje in obdelava podatkov naročil,

3 CASE STUDY: DISTRIBUTED LABEL PRINTING

3.1 Company with distributed labeling of products

The ETI d.d. company from Slovenia is one of the important producers of electrical protection equipment on the global market. The company sells most of its products on foreign markets. Some products of the company bear their own trademark and others are labeled by the trademarks of large customers: Siemens, Kopp, ECG and others.

The company proved its organizational competence by obtaining the ISO 9000 certificate in 1993, and today it has the ISO 14000 certificate.

Due to the need for a continuous increase in quality and productivity, the reduction of costs and due-date reliability the company has to be reorganized. The reorganization strategy is typical: functions that represent the core competences of the company should remain within the company (as well as development of these functions). The remaining functions (the execution of smaller or strategically less important functions) should be performed by suppliers. Economic analyses have proven that for smaller jobs the outsourcing companies are cheaper than manufacturing within the company.

3.2 Label printing EWS-VWS system

The label printing EWS-VWS system has the essential properties of a closed work system:
- autonomous operation, i.e., the planning and processing of orders,

- zmožnost komunikacije s sistemi v okolici ter preglednost delovanja,
- sprejemanje in potrditev naročil (iz poslovnega sistema in zunanjih naročil),
- načrtovanje lastnih virov in
- uresničitev opravil.

3.2.1 Struktura ODS

Na napravi za izvajanje postopka (NIP) poteka tiskanje (sl. 5). Postopek tiskanja obsega nastavitev tiskalnika (izbira tiskalnega traku, nalepk, tiskalnika) ter fizično izvedbo tiskanja. Povratna vezava postopka tiskanja in tiskalnika je kibernetska ponazoritev naravne povratne zveze fizikalnih pojavov (prihodnost je odvisna od preteklosti). (Primer: papir se zatrga - nadaljevanje tiskanja je drugačno kakor v primeru normalnega tiskanja).

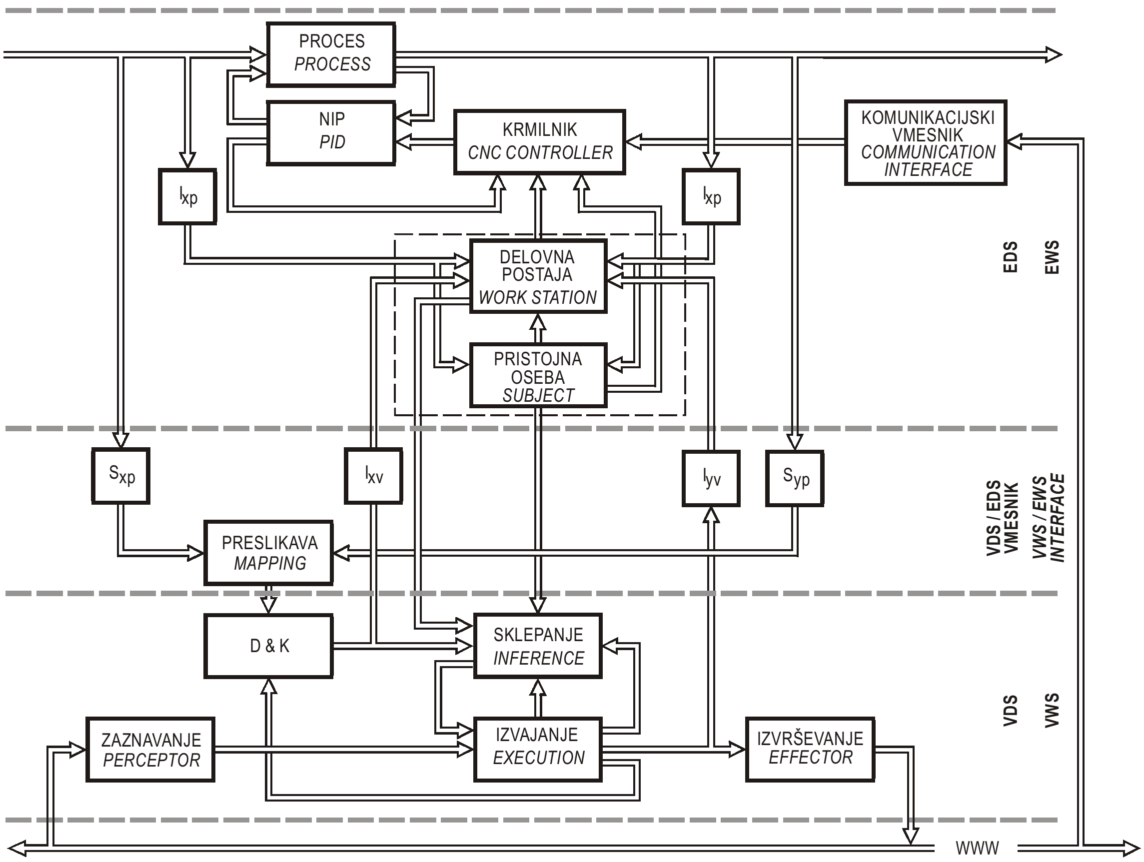
Vhodi v ODS tiskanja so:
- nalepke različnih oblik, velikosti, barve, predtiska,
- trakovi za tiskalnik različnih tipov, širine in barve

- capability of communication with environmental systems and transparency of operation,
- acceptance and confirmation of orders (from the business system of external orders),
- planning its own resources,
- accomplishment of tasks.

3.2.1 EWS structure

The Process Implementation Device (PID) performs the printing process (see Figure 5). The printing process consists of setting up the printer (selection of the printing ribbon, labels, and printer) and the printing process itself. The feedback between the printing process and the printer is a cybernetic representation of the natural feedback in physical phenomena (the future depends on the past). (For example, if a paper jam occurs, the printing continues in a different way than in normal printing).

The EWS printing inputs consist of:
- labels of various shapes, sizes, color and pre-print,



Sl. 5. *Tiskarna etiket ODS in VDS*
Fig. 5. *Label printing EWS-VWS system*

ter
- vsebinske ter nadzorne informacije.

Izhodi iz ODS so natisnjene nalepke v zahtevani obliki v skladu s predpisi označevanja predmetov.

Osebek, kot informacijsko podprta pristojna oseba preko vmesnikov Ixp, Iyp (sl. 5), nadzoruje postopek tiskanja. V primeru razlike med želenim in dobljenim izhodom z uporabo vmesnika na delovni postaji ali krmilnika tiskalnika vpliva na tiskalnik in s tem na postopek tiskanja.

Krmilnik (sl. 5) pretvarja podatke o strukturi nalepk ter podatke o potrebni količini natisnjenih nalepk v tiskalniku razumljivo kodo (rasterska grafika, specifični programski jeziki tiskalnikov). Povratna zveza od tiskalnika do krmilnika obvešča krmilnik o fizičnem tiskanju oziroma o nepravilnostih delovanja tiskalnika.

Nadzorne informacije (naročilo vrste in števila nalepk, prioriteta tiskanja, stanje tiskalnika) prehajajo z spletne mreže preko zaznavanja, vmesnika Ixv, delovne postaje in krmilnika v napravo za izvajanje postopka tiskanja. Izvajanje naročil pa poteka z informacijske mreže prek zaznavanja, modulov izvajanja in sklepanja, vmesnika Iyv, delovne postaje in krmilnika.

Podatki o označevalnih nalepkah prehajajo z internetne mreže preko perceptorja, vmesnika Ixv, delovne postaje in krmilnika v napravo za izvajanje postopka.

3.2.2. Struktura VDS

Tiskarne nalepk VDS zastopa Tiskarne nalepk ODS v informacijskem svetu oz. v informacijski mreži. Definicije dejavnikov [6] ne predvidevajo razmeroma obsežnega uporabniškega vmesnika med ODS in pripadajočim VDS. Zato je vmesnik definiran v ravni med ODS in VDS (sl. 5). Vsebinsko so vmesniki v tem, vmesni ravni dveh tipov:
- zaznavala (Sxp, Syp) ki omogočajo spremljanje postopka tiskanja ter preko elementa preslikave (sl. 5) polnijo bazo podatkov D&K;
- vmesnike (Ixv in Iyv) po katerih dobiva osebek bistvene podatke o delovanju dejavnika ter informacije o opravilih, ki jih mora ODS obdelati.

Vse informacije v elektronski obliki (naročila, dejavnosti pridobivanja posla, podatki o nalepki - recepti in drugo) prejema dejavnik VDS po zaznavanju. Zaznavanje je torej enota, ki iz mreže pobira za ODS, katerega predstavlja na mreži, bistvene podatke.

- printer ribbons of various types, width and color,
- content and control data.

The EWS output consists of printed labels of the required design, in accordance with the regulations on the labeling of goods.

The subject, being an information-supported competent person, controls the printing process using the Ixp and Iyp interfaces (Figure 5). In the case of a discrepancy between the reference value and the actual output, the subject influences the printer (and thus the printing process) using the workstation interface.

The CNC controller (see Figure 5) converts the data on the label structure and the data on the required quantity of printed labels to the code, intelligible to the printer (the raster graphics, the specific printer programming language). The printer- controller feedback informs the controller about the actual printing and about possible problems in the printer operation.

The control data (an order of a particular type and the number of labels, the printing priority, the printer status) pass from the internet via the perceptor, the Ixv interface, the workstation and the CNC controller to the printing-process implementation device. The processing of orders is done from the information network via the perceptor, execution and inference modules, the Iyv interface, the workstation and the controller.

Data on the marking labels pass from the internet via the perceptor, the Ixv interface, the workstation and the CNC controller to the process-implementation device.

3.2.2 VWS structure

The label printing VWS represents the label printing EWS in the IT world (in the information network). Agent definitions [6] do not anticipate an extensive user interface between the EWS and its corresponding VWS, so the interface is defined on the level between the EWS and VWS (Figure 5). From the content point of view, there are two types of interfaces on this intermediate level:
- sensors (Sxp, Syp) allow monitoring of the printing process and they fill the D&K database via the mapping element (Figure 6)
- interfaces (Ixv and Iyv) transfer to the subject the relevant data about the agent operation and data on tasks that should be processed by the EWS.

All information in electronic form (orders, activities for obtaining the job, label data-recipes, etc.) is received by the VWS agent via the perceptor. The perceptor is, therefore, the entity that takes the relevant data from the network for the EWS represented by it on the network.

Zaznavanje vse prejete informacije pošlje naprej v element izvajanja, ki jih obdela. Osebek ima možnost vpogleda v še neobdelane podatke skozi vmesnik Ixv.

Rezultati obdelave elementa izvajanja razširjajo:
- po posledicah nazaj na mrežo (sporočila v fazah pridobivanja poslov, obvestila o delovanju ODS,
- v bazo podatkov in znanj (sl. 5).
- skozi vmesnik Iyv k informacijsko podprti usposobljeni osebi.

Mehanizem sklepanja z uporabo baze podatkov in znanj ter sprotnih podatkov izvajanja postopka svetuje pri sprejemanju odločitev.

V kraju Izlake so trenutno uvedena štiri mesta tiskanja in uvedenih pet mest naročanja (štiri mesta s prenosno strojno opremo in eno stalno mesto naročanja).

VDS za medsebojno komunikacijo uporabljajo inter/intra-omrežno (Wide Area Network - WAN / Local Area Network - LAN) infrastrukturo (sl. 6).

The perceptor forwards the data obtained to the executing element that processes them. The subject may take a look at the unprocessed data using the Ixv interface.

The results of the executing element processing are sent:
- back to the network via the effector (messages in job-gaining phases, notices on EWS operation),
- to the Data&Knowledge database (D&K, Fig. 5),
- through the Iyv interface to the IT-supported competent subject.

The inference mechanism supports decision-making using the D&K database and the online processing of data.

At the Izlake location there are currently four printing places and five ordering places (four places with mobile hardware and one stationary ordering place).

An internet/intranet infrastructure (Wide Area Network (WAN) / Local Area Network (LAN)) is used for the communication between VWSs (Fig. 6).

4 RAZPRAVA

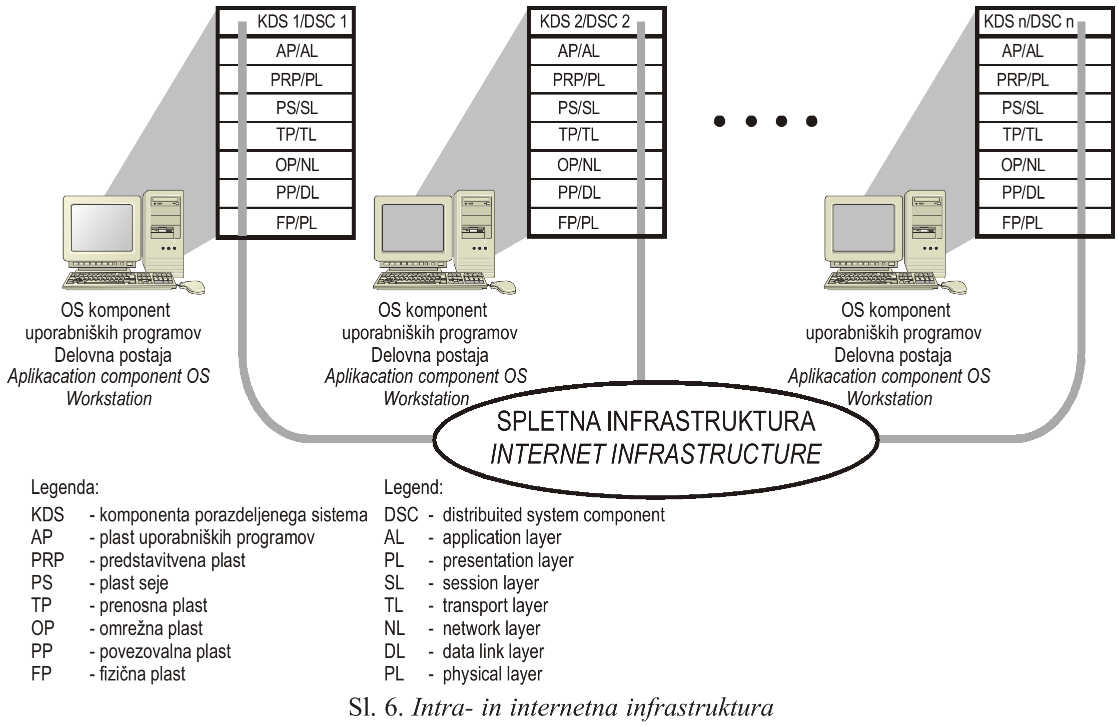
4 DISCUSSION

4.1 Orodja za izdelavo dejavnika

Pomembno vlogo pri gradnji dejavnih struktur v industrijskem okolju ima izbira delovnega

4.1 Agent building tools

When building agent structures in an industrial environment, the selection of the work and programming



Sl. 6. *Intra- in internetna infrastruktura*
Fig. 6. *Intranet / internet infrastructure*

in programskega okolja. Le to mora zadostiti naslednjim pogojem:
- stabilnosti delovanja,
- funkcionalni učinkovitosti,
- hitrosti in prilagodljivosti in
- ustrezni ceni.

Izbira med objektno usmerjenimi programskimi orodji je velika. Glavna merila pri izbiri orodij so a) zmožnosti razvojnega okolja (učinek razhroščevanja, pomoč pri pisanju kode, moč programskega jezika, preprostost programskega jezika), b) kakovost izhodne kode ter c) namen razvitih programskih enot.

Gibanje na ravni operacijskih sistemov se danes nagiba predvsem v korist Microsoftovih izdelkov družine Windows. Vse opaznejši pa postaja tudi operacijski sistem Linux, ki je plod razvoja računalniških zanesenjakov po vsem svetu in je prav zaradi tega skoraj brezplačen. V poslovnem svetu in v svetovnem spletu (WWW) so še vedno močno zastopani tudi opravilni sistemi družine Unix.

Še pred kratkim je bila Java glavni prevajalnik za izdelavo porazdeljenih uporab. Danes Javi predstavljajo alternativo objektno usmerjena orodja Visual Studio, C++ Builder, Delphi/Kylix in .NET, ki omogočajo pisanje programov na vseh ravneh programiranja (od gonilnika do povsem vizualno usmerjene uporabe). Odločitev o izbiri orodja ni preprosta, saj ima vsako orodje v primerjavi z drugimi na eni strani prednosti, na drugi strani pa tudi pomanjkljivosti.

4.2 Delovno okolje

Izbira delovnega okolja je vezana na izbiro predmetnega komunikacijskega modela. Med dvema glavnima alternativama, DCOM/COM+/.NET in CORBA dajemo prednost prvi alternativi. Razlogi so naslednji:
- jasna je strategija nadaljnjega razvoja,
- zrelost tehnologije in uvajanja,
- preprostost upravljanja in stabilnost delovanja,
- funkcionalnost, ki zadošča zahtevam po informacijski mreži porazdeljenih struktur ter
- cenovna ugodnost.

Tehnologija DCOM/COM+/.NET pomeni ključno tehnologijo sistemov Windows NT/200x in je že v osnovi vgrajena v opravilni sistem največjega proizvajalca tovrstnih izdelkov, Microsofta. Ta tehnologija je bila v preteklih letih predmet intenzivnega

environment is of crucial importance. The programming environment has to fulfill the following requirements:
- stable operation,
- functional efficiency,
- speed and adaptability,
- suitable cost.

There are several object-oriented programming tools available. The main criteria when selecting the tools are: a) the capacities of development environment (debugging efficiency, help at code generation, power of programming language, simplicity of programming language), b) the quality of the produced executable code, and c) the destination of the programming-entities developed.

At the operating system level the current trend is towards Microsoft Windows products. On the other hand, there is an ever-increasing use of the Linux operating system, which has been developed by a large number of computer enthusiasts from all over the world and for this reason it is almost free of charge. In the business environment and in the world wide web there are still many Unix-compatible operating systems.

Until recently, Java was the main compiler for the development of distributed applications. Today, there are several alternatives - object-oriented tools of Visual Studio, C++ Builder, Delphi/Kylix and .NET - which allow for the development of programs on all programming levels (from device driver to completely visually-oriented application). The selection of a particular tool is not a simple task, because each tool has some advantages and drawbacks in comparison with others.

4.2 Operating environment

The selection of operating environment depends on the selection of the object communication model. There are two main alternatives: DCOM/COM+/.NET and CORBA; we prefer the first one for the following reasons:
- clear strategy of further development,
- maturity of the technology and its implementation,
- simple management and stable operation,
- functionality that satisfies the requirements of the structures distributed over the information network,
- competitive price.

DCOM/COM+/.NET technology is the key element of Windows NT/200x systems, and it is already incorporated in Microsoft operating systems. This technology has been under intensive development in recent years and it reached its mature razvoja in je dobila zrelo podobo v operacijskem sistemu Windows 2000. Čeprav je CORBA starejša in ima trenutno več uporabnikov, so napovedi strokovnjakov skupine Gartner Group bolj v prid tehnologiji COM+/.NET, ki nadgrajuje tehnologijo DCOM. Prav zaradi te tehnologije predvidevajo tudi prevladujočo vlogo sistemov Windows 200x v okoljih strežniških sistemov. Z drugimi besedami, Microsoft po utrditvi položaja v namiznem računalništvu utrjuje svojo prevlado tudi v strežniških sistemih.

4.3 Obremenitveno preverjanje porazdeljenega sistema

Obremenitveno preverjanje določi (overi) razmerje med ceno in postopkovno močjo sistema. Pri radodarnem dodajanju zmogljivosti (postopkovna moč, obseg spomina, prepustnost podatkovnih poti) se cena sistema hitro nedopustno poveča. Varčevanje pri ceni sistema (počasne povezave, skromnejše delovne postaje in skromnejši strežniki) pa povzroči, da s svojimi minulimi izkušnjami (nezadovoljstvo naročnikov) ne moremo pridobiti novih naročil kljub dobri zasnovi in uvajanju programskih rešitev. Zato je protokolirano obremenitveno preverjanje nujen del porazdeljenega informacijskega projekta.

5 SKLEPI

Nov postopek reševanja označevanja izdelkov, temelječ na vzorcu ZPPS, ima naslednje lastnosti:
- Sistem je modularno grajen in odprt za vse spremembe v prihodnosti. Predvidene spremembe omogoča modularna gradnja sistema, izvedbo nenačrtovanih sprememb pa omogočajo vgrajeni posplošeni uporabniški vmesniki.
- Upravljanje ter vzdrževanje sistema sta nezahtevna.
- Razmeroma nezahtevno je programsko uvajanje novih VDS in novih funkcij ODS.
- Uvajanje sistema v dejanskem proizvodnem okolju ne zahteva sprememb varnostnih nastavitev v informacijskem okolju.
- Neodvisnost od nadrejenih informacijskih sistemov hčerinskih podjetij in
- relativizacija oziroma nepomembnost fizičnih razdalj za delovanje informacijskega sistema tiskanja.

Rešitev je uvedena v proizvodnem okolju podjetja ETI d.d. Izlake na treh lokacijah, in sicer v Izlakah, Trbovljah in Kamniku.

state in the Windows 2000 operating system. CORBA is older and currently has more users. However, Gartner Group expert predictions favor COM+/.NET technology, which is an upgrade of DCOM technology. Just because of this technology, the dominant role of Windows 200x systems in server environments is foreseen. In other words, after establishing its main role in desktop computing, Microsoft is now strengthening its dominance in server environments, too.

4.3 Load verification of distributed system

Load verification determines (verifies) the relation between price and system processing power. With a generous addition of features (processor speed, RAM and disk size, data flow throughput), the system price increases very rapidly. If we over-economize the system price (slow connections, cheap workstations and weak servers), then because of our past references (unsatisfied clients) we cannot obtain new orders, in spite of good design and the implementation of programming solutions. Therefore, the load verification (using the proper protocol) is an essential part of a distributed IT project.

5 CONCLUSIONS

A new approach to product labeling, based on the CAMS paradigm, has the following characteristics:
- the system has been built from modules and it is open to changes in the future; it will be possible to make anticipated changes because of the modular system design, while generalized user interfaces will enable the realization of unplanned changes,
- the system is not difficult to manage and maintain,
- program implementation of new VWSs and new EWS functions is relatively easy,
- system implementation in a real manufacturing environment does not require changes of security settings in the information environment,
- independence from parent information systems in subsidiary companies,
- physical distance is not relevant for the operation of the printing information system.

This solution has been implemented in the distributed manufacturing environment of the ETI d.d. company, at the locations Izlake, Trbovlje and Kamnik (all places are in Slovenia).

Predstavljena izvedbena struktura VDS je preverjena v rešitvi porazdeljenega označevanja izdelkov z n mest naročanja označb in z m mest izdelave označb. Razviti in preverjeni so delovni moduli VDS (rokovnik, razlage meta-kode označevanja izdelkov, komunikacija s pristojno osebo, podatkovna baza označevanja, moduli odločanja v predvidenih okoliščinah). Celotna mreža VDS je preverjena delovno in obremenitveno.

The presented VWS structure has been verified in the solution of distributed product labeling; there are n places of label ordering and m places of label printing. Functional VWS modules have been developed and verified (organizer, product labeling meta-code interpreters, communication with competent persons, labeling database, decision modules in predictable circumstances). The whole VWS network has been verified in terms of functions and load.

Zahvala

Predstavljeno raziskavo in uvedbo sistema v industrijo je podprlo Ministrstvo za visoko šolstvo, znanost in tehnologijo RS, s pogodbo št. S2-782-020/20337/99 in sponzoriralo podjetje ETI d.d.

Acknowledgments

This research work has been supported by the Slovenian Ministry of Higher Education, Science and Technology, Grant No. S2-782-020/20337/99, and sponsored by ETI d.d.

6 LITERATURA
6 REFERENCES

[1] Peklenik J. (1995) Complexity in manufacturing systems, *Manufacturing systems*, 24(1): 17 - 25.
[2] Peklenik J. (1995) Complexity of manufacturing systems-subject oriented knowledge processing and control. V: Baskin, Arthur B.(ur), Kovacs G., Jacucci G.(ur) Cooperative knowledge processing for engineering design. Norwell, Massachusetts; Dordrecht: *Kluwer Academic publishers*, p.p. 17-40.
[3] Sluga A., Butala P. (1998) Structuring of the information system for distributed manufacturing, *Manufacturing Systems*, 27(2): 177-182.
[4] Raptis K., Spinellis D., Katsikas S. (2001) Multi-technology distributed objects and their integration, *Computer Standards & Interfaces*, 23(3): 157-168.
[5] Sluga A., Butala P. (1998) A pace toward a distributed manufacturing systems, *Proceedings of the 1st Int. Workshop on intelligent manufacturing systems (IMS-Europe)*, EPFL, Lausanne, CH, p.p. 277-290.
[6] Hagras H., Callaghan V., Colley M. (1999) An embedded agent technique for industrial control environments where process modeling is difficult, *Assembly Automation*, 19(4): 323 - 3

Naslova avtorjev: Franc Rotar
iWare d.o.o.
Izlake 40
1411 Izlake
franc.rotar@iware.si

prof. dr. Alojz Sluga
Univerza v Ljubljani
Fakulteta za strojništvo
Aškerčeva 6
1000 Ljubljana
alojz.sluga@fs.uni-lj.si

Authors' Addresses: Franc Rotar
iWare Ltd.
Izlake 40
1411 Izlake, Slovenia
franc.rotar@iware.si

Prof. Dr. Alojz Sluga
University Ljubljana
Faculty of Mechanical Eng.
Aškerčeva 6
1000 Ljubljana, Slovenia
alojz.sluga@fs.uni-lj.si

Prejeto:
Received: 20.9.2005

Sprejeto:
Accepted: 22.6.2006

Odprto za diskusijo: 1 leto
Open for discussion: 1 year

Strojniški vestnik - Journal of Mechanical Engineering 52(2006)9, 613-624
UDK - UDC 678:677
Strokovni članek - Speciality paper (1.04)

Izdelava politetrafluoretilenskih membran in njihovo laminiranje na tekstilne podloge

Producing Polytetrafluorethylene Membranes and Laminating Them on Textile Backings

Darko Drev
(Fakulteta za gradbeništvo in geodezijo, Ljubljana)

V prispevku so prikazani preizkusi izdelave politetrafluoretilenskih membran (PTFE) in njihovega laminiranja na tekstilno podlogo. Ker je osnovni postopek izdelave PTFE membran patentno zaščiten in je tehnologija izdelave težko dostopna ([6] in [7]), smo sami razvili ustrezne tehnološke postopke za izvedbo pilotnih preizkusov izdelave PTFE membran. Izdelani vzorci PTFE membran so bili primerljivi s tržnimi izdelki. Pri laminiranju smo naredili še korak naprej in razvili izdelke z enakimi prepustnostmi, kakršne so imele membrane pred laminiranjem. Naš inovativni postopek smo tudi patentirali [5].

(Ključne besede: membrane PTFE, izdelava membran, laminiranje, metode eksperimentalne)

This paper discusses a variety of experiments related to the manufacturing of polytetrafluorethylene (PTFE) membranes and laminating them on textile backings. Due to the fact that the PTFE membrane production process is protected by international patent law, making the PTFE technology somewhat inaccessible ([6] and [7]), the author of this paper used innovative production processes and techniques to conduct the pilot PTFE membrane production experiments. In the field of PTFE membrane lamination, another step forward was made by patenting an innovative production process [5].

(Keywords: PTFE membranes, production processes, laminating, experimental methods)

0 UVOD

Politetrafluoretilenske (PTFE) membrane so se pojavile na tržišču po letu 1970. Tehnologija izdelave PTFE membran, ki so na trgu poznane kot membrane GORE - TEX, izvira iz patenta družbe W.L. Gore and Associates, Inc., Newark, iz leta 1971 [6].

Politetrafluoretilenske membrane se že vrsto let masovno uporabljajo za izdelke široke porabe in industrijo. Pri izdelkih široke porabe so vgrajene v vodo-neprepustna oblačila in obutev. V industriji pa se uporabljajo za različne vrste filtrov za industrijsko odpraševanje ter tekočinsko filtracijo. Poleg tega so PTFE membrane zelo pogosto pomembna sestavina različnih naprav v medicini, farmaciji, zaznavalni tehniki, itn. PTFE membrane so zelo prepustne, saj je njihova struktura bistveno bolj odprta kakor pri drugih membranah. Odprtost strukture se spreminja

0 INTRODUCTION

Polytetrafluorethylene (PTFE) membranes first appeared in the international market in the 1970s. PTFE membrane production technology dates back to the 1971 patent of the Newark-based company W.L. Gore and Associates Inc [6].

As a consequence, PTFE membranes are usually referred to as GORE-TEX membranes. PTFE membranes have been used on a large scale for making a myriad of products for a number of years. In the case of consumer products, they have been used as the basic input materials in waterproof apparel and clothing production, and in the case of company-to-company products, they have mostly been used in the production of dust filtration systems, liquid filtration systems and sensors. The openness of the PTFE membrane structure makes it

Preglednica 1. *Različne vrste PTFE membran, ki nastanejo zaradi različne stopnje raztezanja*
Table 1. *Dependence of PTFE membranes characteristics on the level of biaxial stretching*

Velikost por Pore size μ	Debelina Thickness mm	Poroznost Permeability %	Pretok zraka * Air flow * ml/min cm^2	Prestop vode ** Water entry ** bar
0,02	0,08	50	2,3	24
0,2	0,06	78	72	2,75
0,45	0,08	84	190	1,35
1,0	0,08	91	370	0,48
3	0,025	95	930	0,13
5	0,025	95	3870	0,07
10 - 15	0,013	98	11300	0,03

* prepustnost zraka pri ΔP 0,01/air flow at ΔP 0.01
** najmanjša prepustnost vode/minimal water entry

od stopnje dvoosnega raztezanja v fazi izdelave. V preglednici 1 so podane glavne značilnosti PTFE membran [8].

Poleg velike odprtosti strukture imajo PTFE membrane veliko prednost pred večino drugih membran v kemijskih in fizikalnih lastnostih osnovnega polimernega materiala. PTFE je izredno kemijsko stabilen. Zelo odporen je tudi za povišano temperaturo, saj je obstojen še pri 350 °C do 400 °C. Poleg tega ima PTFE tudi hidrofobne in oleofobne lastnosti. Zaradi te lastnosti se na površini filtrirnega sredstva pogača ne nabira, temveč hitro odpade.

Postopek izdelave membran, ki je opisan v tem prispevku, ni potekal v optimalnih razmerah, ki so navedene v patentu, temveč v laboratorijskih in pilotnih razmerah na različnih krajih. Za laminiranje pa smo uporabljali različne vrste lepil ter tekstilne podloge, ki se najpogosteje uporabljajo za izdelavo filtrov za odpraševanje.

Pri postopku izdelave PTFE membrane so tudi mehčala, ki jih je treba na koncu odstraniti. Odstranijo se lahko toplotno z odparevanjem ali z ekstrakcijo. Toplotni postopek lahko kombiniramo z delnim toplotnim utrjevanjem. Toplotno utrjena membrana je zato mehansko stabilnejša od tiste, ki je brez toplotne stabilizacije. Pri toplotnem utrjevanju se sprostijo in uredijo napetosti med polimernimi verigami. Naši preizkusi so bili omejeni le na toplotno odstranjevanje molekul mehčala in delno tudi toplotno utrjevanje. Prepustnost membranske filtrirne snovi je odvisna tudi od debeline membrane in od tekstilnega materiala. Debeline membran se gibljejo med 0,1 in 0,01 mm. Lepila, ki se do takrat uporabljala, so po naših meritvah in ocenah zmanjševala prepustnost membran. Razlog za to je bila delna zamašitev membranske strukture z lepilom.

extremely permeable to air and other specific substances, and this openness of the structure depends on the level of biaxial stretching in production. Table 1 shows the main characteristics of PTFE membranes [8].

Aside from the structural openness effects, the chemical and physical characteristics of the PTFE polymer itself make PTFE membranes superior to other similar products. PTFE polymer has great chemical stability. It is also resistant to temperatures as high as 350 to 400^{0}C. Also, PTFE is hydrophobic and oleophobic, which enhances the cake release properties on the PTFE membrane filter, thus making PTFE membranes very suitable for use in filtration.

The PTFE-membrane production-process experiment that is described in this paper was not operated under the optimal conditions stated in the original 1971 patent, but rather under sub-optimal laboratory conditions. For the lamination process several types of glue and textile backing materials, mainly found in the production of filtration systems, were used.

Solvents are used in the PTFE membrane production process. However, they have to be removed at the end of the process either by thermic solvent removal techniques or by plain chemical extraction. The former can be conducted in combination with thermic membrane strengthening. In the thermic membrane strengthening process some inter-polymer-chain tensions are loosened or transformed. This enables such membranes to exhibit a superior mechanical stability. For the purpose of this paper, we limited our experiments to using thermic solvent removal techniques and some thermic strengthening techniques. The permeability of PTFE membrane filter media depends heavily on the

Z našim postopkom laminiranja smo ta problem odpravili. Izdelani laminati so imeli enake prepustnosti kakor PTFE membrane. Pri tem so morale biti prepustnosti tekstilnih nosilcev za filtrirne snovi bistveno večje kakor pri membranah. To pa ne velja za laminate v oblačilni in obutveni industriji, kjer gre pogosto za gosto tkane in zato slabo prepustne materiale.

1 EKSPERIMENTALNI DEL

1.1 Materiali in metode

Na tržišču je več proizvajalcev PTFE v obliki prahu, ki je primeren za izdelavo membran. Pri laboratorijskih in pilotnih preizkusih smo uporabili politetrafluoretilen podjetja Hoechst AG ter drsno sredstvo podjetja SHELL Industrial Chemicals [12]

Pri laminiranju smo preizkusili večje število različnih materialov, od katerih so bili nekateri opredeljeni kot lepila. Najboljše rezultate smo dobili z uporabo specialnih veziv na podlagi silikonov in fluorkarbonov. Pri tem posebej izdvajamo silikonsko vezivo proizvajalca DOW CORNING z oznako Q2-7406. V preglednici 3 so navedeni glavni tekstilni materiali, ki se uporabljajo pri izdelavi laminatov PTFE za industrijsko odpraševanje ter njihova obstojnost.

Pilotni preizkus laminiranja dvoosno raztegnjene PTFE membrane izdelovalca Tetratex Co smo izvedli na laboratorijski progi Werner Mathis, AG in industrijski pilotni progi ISOTEX, Inc. Laboratorijska pilotna naprava je omogočala delovno širino okoli 30 cm, pilotna proga ISOTEX pa delovno širino 160 cm. V obeh primerih smo imeli več možnosti nanosa lepila (z nanašalno glavo s podlogo in brez podloge, s sitom, z brizganjem, z nanašalnim valjem). Temperaturo sušenja je bilo mogoče uravnavati v temperaturnem območju od sobne temperature do 280 °C. Kot dodatni način segrevanja smo imeli še infra peč. V obeh primerih smo imeli na voljo tudi hladilne valje in kalander z nastavljivim pritiskom. Pri

membrane thickness, the type of textile backing material and the type of glue used in the lamination process. Membrane thickness is normally found to be in the range 0.01–0.1mm. The glue types, primarily found in the lamination process, usually deteriorate the membrane filter media's permeability. The innovative lamination process described here removes this problem.

1 EXPERIMENTAL PART

1.1. Input materials and methods

Hoechst AG polytetrafluorethylene and Shell Industrial Chemicals solvent were used in the laboratory and pilot experiments. PTFE films of our own production and Tetratex PTFE membrane were used in the lamination experiments [12].

For gluing, a variety of materials was used, of which only a few are officially marketed as glue products. The most favorable results were obtained by using a special silicone-based and fluorocarbon-based glue. In this experiment, the DOW CORNING Q2-7406 silicone-based glue provided by far the best results. Textile backing materials, mainly used in the production of filtration systems, were used. They are described in more detail in Table 3.

The former enabled a 30-cm work width and the latter a 160-cm work width. Both made possible various glue-adding techniques (coating head with base and without base, sieve cylinder, jetting, coating cylinder). The equipment was functional in the room-temperature to 280^{0}C drying-temperature interval. As an additional heating source an infra oven was used. Both production lines were equipped with cooling rolls and adjustable-pressure calenders. However, the ISOTEX industrial pilot production line was equipped with an automatic calender pressure control system, whereas the Werner Mathis laboratory production line allowed only manual pressure control. The latter also failed to provide a

Preglednica 2. *Nekatere surovine, ki so primerne za izdelavo PTFE membran*
Table 2. *Input materials used in the PTFE membrane-production experiment*

Izdelovalec Manufacturer	Surovine Material	Opomba Type
DU POINT Fluoropolymer Division	Teflon 669 N, 62 N, 636 N	PTFE
ICI Plastics Division	Fluon, CD1	PTFE
HOECHST AG Werk Gendorf	Hostaflon TF 2028, TF 2027, TF 2025	PTFE
SHELL Industrial Chemicals	Shellsol T, Shellsol K, Shell Sinarol II	drsno sredstvo solvent

Preglednica 3. *Tekstilni nosilniki za membranske filtrirane snovi in njihove lastnosti*
Table 3. *Filter-media production textile backing materials and their characteristics*

Nosilni material Fiber type	Delovna temp. Operating temp. °C	Odporen proti kislinam Resistency to mineral acids	Odporen proti alkalijam Resistency to alkalis	Odporen proti solem Resistency to salts	Odporen proti oksidantom Resistency to oxidizing agents	Odporen proti org. topilom Resistency to organic solvents	Odporen proti vodni pari Resistency to water vapor
polst (PES) poliester Polyester Felt	130	xxx	xx	xxx	xxx	xxxx	x
polst (PP) polipropilen Polypropilen Felt	90	xxxx	xxxx	xxxx	x	xx	
poliamid Nomex Nomex Felt	200	xx	xxx	xx	xx	xxx	xx
polivinilsulfid Ryton Ryton Felt	200	xxxx	xxxx	xxxx	xx	xxxx	xx
steklena tkanina glass fabric	260	xxx	xx	xx	xxxx	xxxx	xxxx
polst poliakrilnitril Polyacrylnytril Felt	130	xxx	xx	xxx	xxx	xxxx	xxx

x - neobstojen/unstable xxx - dobro obstojen/stable
xx - delno obstojen/partially stable xxxx - zelo obstojen/extremely stable

pilotni progi je bilo mogoče pritisk na kalandru krmiliti avtomatsko, pri laboratorijski progi pa le ročno. Na laboratorijski progi ni bil zagotovljen neprekinjen pretok materiala čez različne tehnološke faze, temveč je šlo za prekinjan postopek.

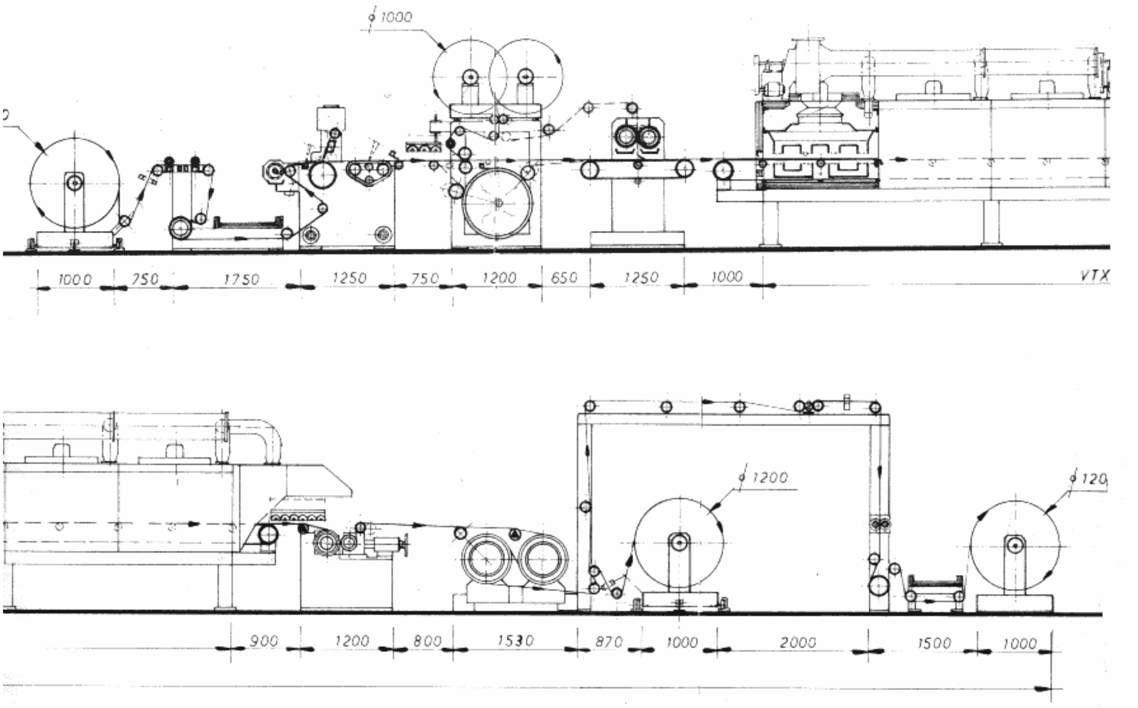
Pri industrijski pilotni progi ISOTEX je bil zagotovljen neprekinjen pretok materiala od faze odvijanja do navijanja z možnostjo natančne nastavitve hitrosti in strižnih sil na posameznih tehnoloških fazah. Pomemben del preizkusov so bili tudi postopki za testiranje. Del teh preizkusov smo izvedli sami (meritev prepustnosti zraka, učinkovitost laminiranja itn.), velik del pa pri zunanjih ustanovah. Fotografije z elektronskim mikroskopom so bile narejene na FNT Ljubljana, Oddelek za tekstil, nekateri preizkusi pa na IHTM ITR v Beogradu in pri BIA ustanovi v Bonnu.

Membranske filtrirne snovi iz PTFE imajo zmožnost zadrževanja veliko drobnejših delcev od običajnih filtrirnih snovi. To pomeni, da dosegajo višji filtracijski razred. Filtracijski razred označuje količino zadrževanega standardnega prahu. Za testiranje se uporablja kremenčev prah koncentracije

continuous material flow through the production phases. The former not only allowed for continuous material flow, but also for precise adjustments of the various production-environment parameters.

The testing of the produced materials was the core part of the experiments. The testing was partially conducted by the author (air-permeability measurements, lamination effectiveness measurements, etc) and partially by well-equipped research institutions. Specific measurements were conducted at the IHTM ITR Research Institute in Belgrade and at the BIA Institute in Bonn. The electron microscope photographs were produced at the Textiles Department of the University of Ljubljana’s Faculty of Natural Sciences and Engineering.

The PTFE-membrane filter-media particle-retention capability is far superior to that of other filter media. Formally, this means that they achieve a higher “filtration class”. This term is used to describe the amount of standard dust retained by the filter media. For testing purposes, flintstone dust with a concentration of 200 ± 50 mg/m^2 was used. Ninety



Sl. 1. *Industrijska pilotna proga ISOTEX*
Fig. 1. *ISOTEX Inc. industrial pilot-production line*

200 ± 50 mg/m^2. 90 odstotkov delcev ima velikost med 0,2 in 2 μm po Stokesu. Pri testiranju se filtrirna snov obremeni 60 min s testnim prahom pri določeni hitrosti zraka. Prenosni faktor se izračuna po naslednjem obrazcu:

percent of the dust particles had a Stokes value between 0.2 and 2 μm. The test involves the filter media being exposed to test dust at a specific wind velocity for 60 minutes. The transmission factor is then calculated according to the following formula:

$$D = \frac{(C_H - C_0)\,dt}{T(C_V - C_0)}.100\% \quad (1),$$

kjer so:
D = prenosni faktor (stopnja prepustnosti),
C_H = signal sipane svetlobe za filtrom,
C_v = signal sipane svetlobe pred filtrom.

Prenosni faktorji pri meritvah zaradi meje zanesljivosti niso doseženi, zato jih preračunavamo s statističnimi faktorji. Mejna vrednost prenosnega faktorja je:

where are:
D = transmission factor (permeability level),
C_H = light signal behind filter,
C_v = light signal before filter.

Due to the sub-optimality of its measurements, the transmission-factor values are adjusted using statistical parameters. The marginal value of the transmission factor is calculated as follows:

$$D_g = D + t \cdot s \quad (2),$$

kjer sta:
t = statistični faktor (95% statistične verjetnosti),
s = število stopnje prostosti.

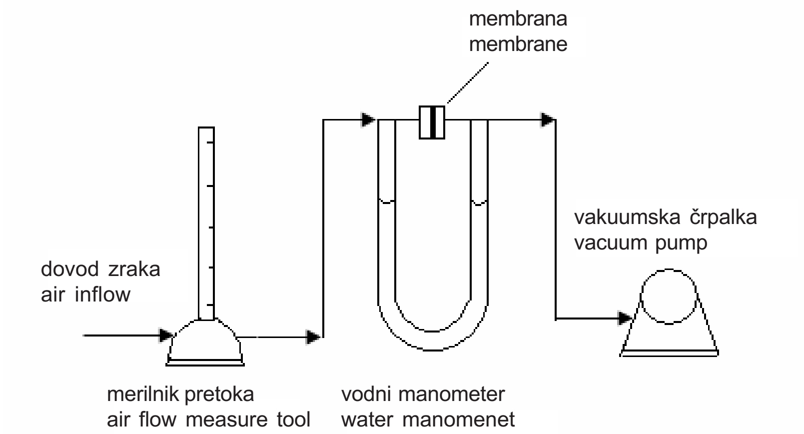
Za preizkušanje filtrov v navedenih razmerah smo uporabili pilotni testni kanal, ki je zgrajen tako, da ustreza predpisanim pogojem za določitev filtracijskih razredov ([12] do [14]). Pri tem smo

where are:
t = statistical parameter (95% probability interval)
s = degrees of freedom

A pilot test channel was used for the testing. The test channel was built according to the filtration-class determination standards ([12] to [14]). A standard flintstone dust with a standard

Preglednica 4. *Filtracijski razredi [16]*
Table 4. *Filtration classes [16]*

Filtracijski razred Filtration class	Opis razreda Class description	Mejne vrednosti za prenosni faktor D Transmission factor D marginal value
U	delci z MAK > 1 mg/m particles with MAK > 1 mg/m	5%
S	delci z MASK > 0,1 mg/m particles with MASK > 0.1 mg/m	1%
G	delci z MAK particles with MAK	0,5%
C	delci s KAK ali delci, ki povzročajo raka particles with KAK or carcinogen particles	0,1%
K	zdravju škodljivi delci health-hazard particles	filter razred S po DIN 24184 class S filters by DIN 24184



Sl. 2. *Shematski prikaz naprave za določevanje prepustnosti membrane za zrak*
Fig. 2. *The air-permeability measurement equipment*

uporabili standardni kremenčev prah s predpisano porazdelitvijo delcev.

Prepustnost zraka in vode smo testirali na napravah, ki sta shematsko prikazani na slikah 2 in 3.

1.2 Eksperimentalni del

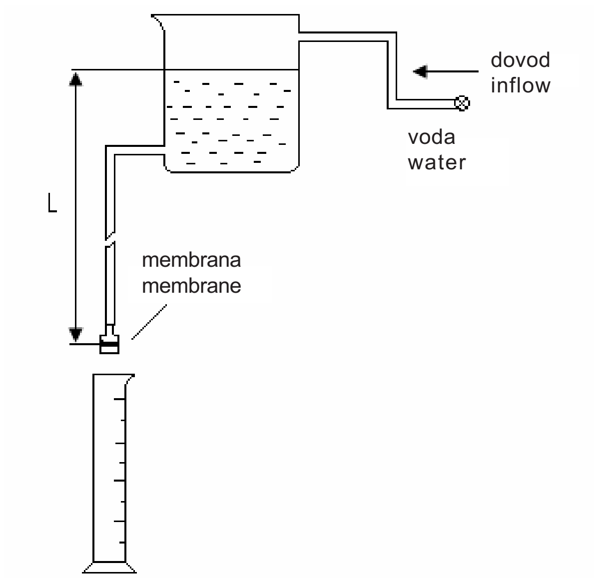
Postopek izdelave PTFE membran, ki je prikazan na sliki 4, je obsegal naslednje tehnološke faze:
- tehtanje komponent (75 do 77% prahu PTFE, 23 do 25% drsnega sredstva),
- ovlaženje prahu PTFE z ustreznim drsnim sredstvom,
- homogenizacijo navlaženega materiala (24 ur pri sobni temperaturi),
- oblikovanje predoblikovanca ustreznega prereza z iztiskanjem,
- oblikovanje folije s kalandriranjem (0,1 do 0,5 mm),
- dvoosno raztezanje folije,
- odstranjevanje drsnega sredstva s folije,
- utrditev folije.

concentration was used.

Air- and water permeability was tested with the use of the equipment shown schematically in Figures 2 and 3.

1.2 Experimental part

PTFE membrane production process, shown in Figure 4, involved the following phases:
- material weighing (75 to 77% PTFE dust, 23 to 25% solvent),
- combining PTFE dust with solvent,
- homogenizing the combined material (24 hours at room temperature),
- designing a preform with a suitable profile by extrusion,
- designing the film by calendering (0.1 to 0.5 mm)
- biaxially stretching the film,
- removing the solvent from the PTFE membrane,
- strengthening of the PTFE membrane.



Sl. 3. *Shematski prikaz naprave za določevanje prepustnosti membrane za vodo*
Fig. 3. *The water-permeability measurement equipment*

Postopek laminiranja PTFE membran na tekstilno podlogo (sl. 5) pa je obsegal naslednje tehnološke faze:
- odvijanje tekstilne podloge,
- nanos lepila na tekstilno podlogo,
- odvijanje PTFE membrane,
- kaširanje (laminiranje) PTFE membrane na tekstilno podlogo,
- sušenje,
- kalandriranje,
- navijanje laminata.

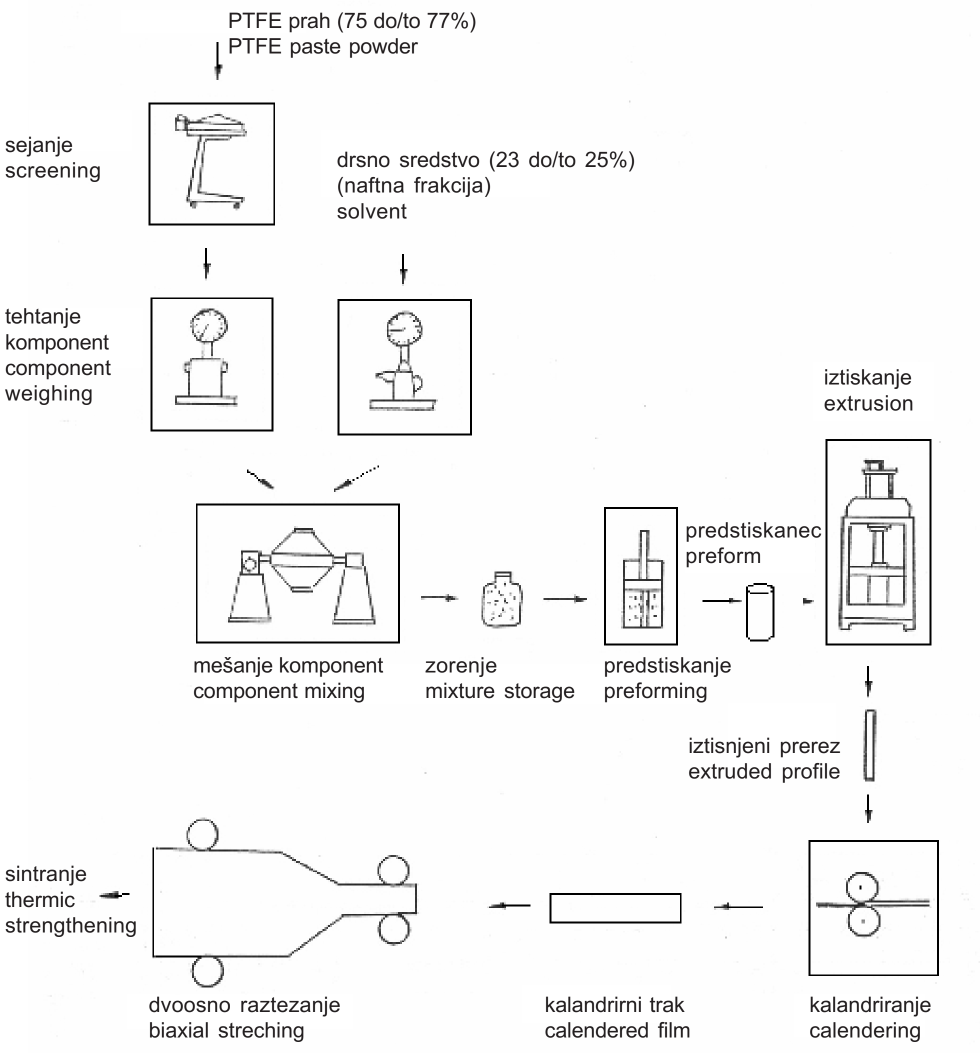
Pri pilotnih preizkusih smo nastale folije le ročno raztezali in toplotno utrjevali. Za izvedbo pilotnih preizkusov laminiranja membran na tekstilne podloge pa smo uporabljali PTFE membrano izdelovalca Tetratec Co. Filtracijske zmožnosti te membrane in laminata na podlagi poliestrske polsti so podane na slikah 8 in 9. Pri tem nismo dosegali popolnih razmer za oblikovanje PTFE membrane, ki so navedeni v patentu [6].

Na sliki 6 je prikazana membrana PTFE, ki smo jo izdelali v pilotnih razmerah. Raztegnjena je le v eni smeri v nasprotju z industrijsko izdelano na sliki 7, ki je dvoosno raztegnjena, toplotno stabilizirana in kaširana na poliestrsko polst. Obe fotografiji na elektronskem mikroskopu sta bili izdelani na FNT Ljubljana, Oddelek za tekstil. S slike 7, kjer gre za vzorec svetovnega izdelovalca podjetja GORE-TEX, je jasno razvidno, da je del membranske strukture zaprt z lepilom. Ta problem smo uspešno razrešili z našim postopkom. Nanesli smo tanek sloj lepila na

The process of applying PTFE lamination to textile backings, which is shown in Figure 5, involved the following phases:
- unrolling the textile backing,
- adding glue to the textile backing,
- unrolling the PTFE membrane,
- laminating the PTFE membrane to the textile backing,
- drying,
- calendering,
- laminate rolling.

Laboratory pilot experiments provided us with PTFE films from which membranes could be made via biaxial stretching. Such films have a relatively weak permeability. The pore size depends on the biaxial stretching level. This makes the stretching phase the most difficult and sensitive phase of PTFE membrane production. For example, to obtain 96% membrane permeability a temperature of 316°C and a stretch velocity of 1000% per second are needed [6].

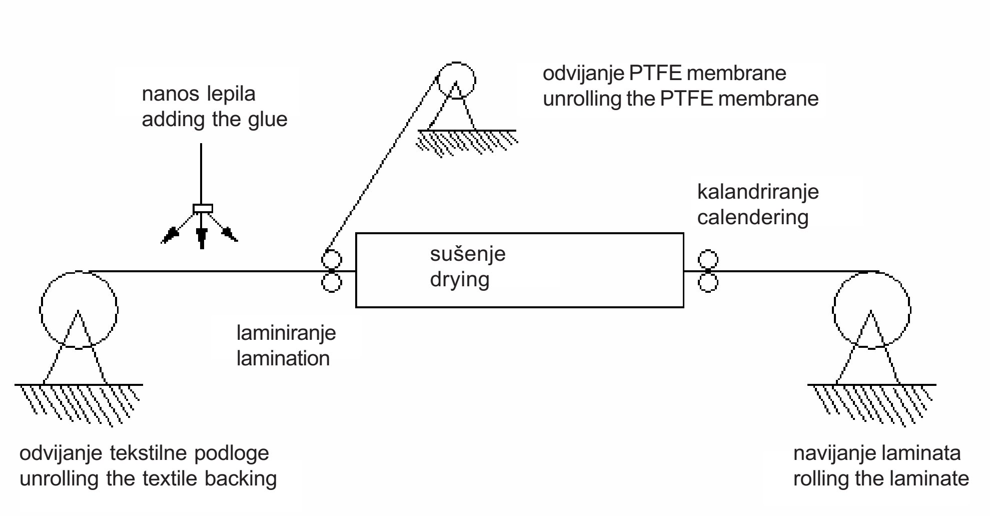
In our experiment, both the stretching and thermic strengthening were conducted manually. Figure 6 shows a PTFE membrane produced in our pilot experiment. This membrane is stretched only in one direction. One example of commercially produced membranes (a GORE-TEX sample) that are biaxially stretched, thermically strengthened and laminated to polyester felt is shown in Figure 7. Both electron microscope figures were produced at the Faculty of Natural Science and Engineering in Ljubljana. In Figure 7 we see that the commercially



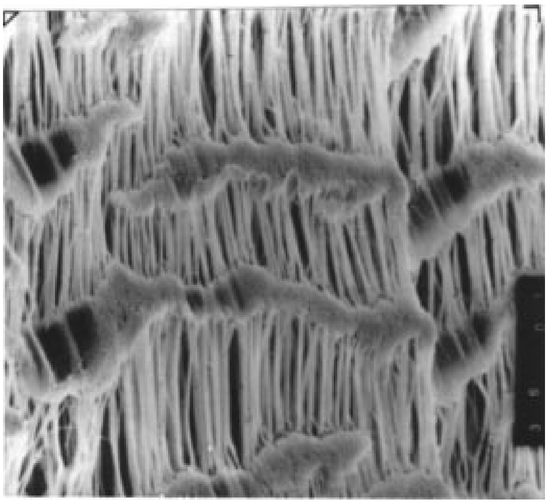
Sl. 4. *Shematski prikaz postopka izdelave PTFE membran*
Fig. 4. *The PTFE membrane-production process*

tekstilna vlakna v podlogi in na to kaširali PTFE membrano. Lepilni sloj med PTFE membrano in tekstilno podlogo je bil zato omejen le na stik membrana – vlakno. Glavni problem za uresničitev našega inovativnega postopka kaširanja PTFE membrane na tekstilno podlogo je bilo iskanje ustreznega lepila. PTFE je oleofoben in hidrofoben material, ki se zelo težko lepi. Po analiziranju vzorcev PTFE laminatov svetovnih izdelovalcev smo ugotovili, da so verjetno nanašali lepila na površine točkovno (s sitom) in po laminiranju lepila še dodatno zamrežili. Eno izmed verjetnih lepil, ki se je takrat uporabljalo, je bilo narejeno na podlagi poliuretanov. Morda so se uporabljala še kakšna druga lepila in drugi postopki. Pri vseh laminatih, ki smo jih našli na

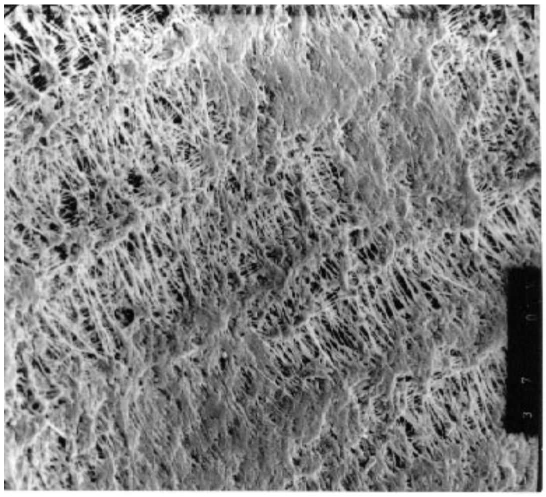
produced membrane has a part of its mechanical structure filled with glue. This problem was successfully removed using our innovative production process. We added a thin glue layer to the textile backing material fibers and then laminated the PTFE membrane on it. The glue layer between the PTFE membrane and the textile backing was, in this way, reduced to being in contact only with the membrane and the fibers. The air-flow and water-entrance measurements testing for the PTFE membrane on PES Felt 500 g/m^2 provided results that differ from those in the official manufacturer catalogues. The main concern with regard to the realization of our innovative lamination process was finding the right type of glue material. PTFE is



Sl. 5. *Shematski prikaz izvedbe preizkusov laminiranja membrane PTFE na tekstilno podlogo*
Fig. 5. *The process of applying PTFE lamination to textile backings*



Sl. 6. *PTFE membrana, ki je raztegnjena samo v eni smeri (elekt. mikroskop, povečava 1900-krat)*
Fig. 6. *PTFE membrane, stretched in only one direction (electron microscope, magnified 1900 times)*



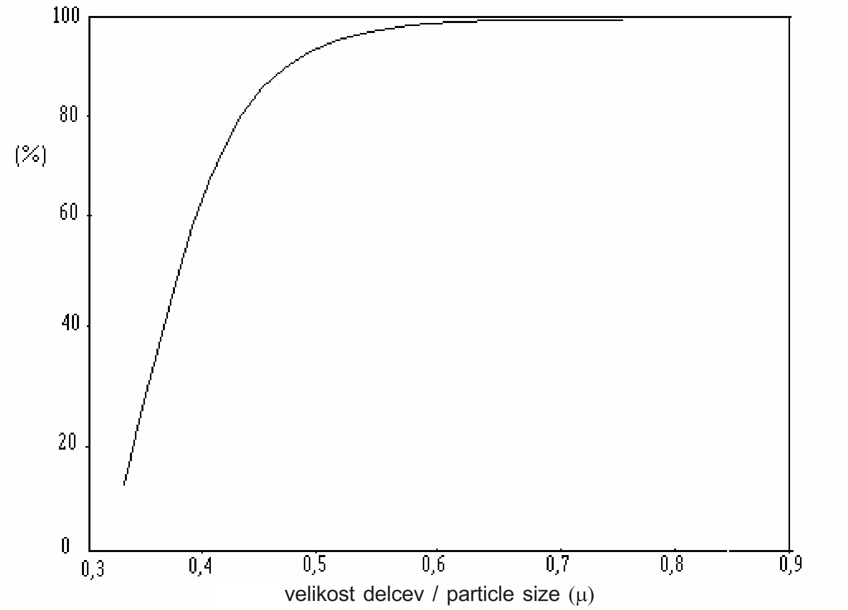
Sl. 7. PTFE *membrana na polsti PES 500 g/m²* *(elekt. mikroskop, povečava 190-krat)*
Fig. 7. *PTFE membrane on PES Felt 500 g/m², (electron microscope, magnified 1900 times)*

trgu, smo ugotovili delno zaprtje membranske strukture z lepilom. To kaže, da takrat niso uporabljali takšnega postopka laminiranja, ki je naveden v tem prispevku. Ker je tudi PTFE membrana vlaknaste strukture, gre v našem primeru za povezavo med PTFE vlakni in tekstilnimi vlakni iz podloge. Zaradi tega se v večini primerov prepustnost takšnih laminatov ne spremeni v primerjavi s čisto membrano. Pogoj za to pa je veliko večja prepustnost tekstilne podloge v primerjavi z PTFE membrano.

Na sliki 9 je podana zmožnost zadrževanja delcev kremenčevega prahu pri membranskem filtru TETRATEX (PTFE membrana + polst PES 500 g/m²)

oleophobic and hydrophobic, which makes it resistant to glue. All the laminates found on the market have part of their mechanical structure filled with glue. This shows that sub-optimal lamination processes were used in their production. Because the PTFE membrane has a fiber structure, both the PTFE membrane and the textile membrane are of similar structure. This leads to laminate permeability that does not differ significantly from the textile backing permeability provided the textile backing is more permeable than the PTFE membrane itself.

Figure 9 shows the particle retention capability of the PES Felt 500 g/m². It can be seen



Sl. 8: *Zmožnost zadrževanja standardnega prahu s preizkusno Tetratex membrano iz polsti PES 500 g/m² [8]*
Fig. 8. *Standard dust-particle retention capability in the case of PTFE membrane laminated to PES felt 500 g/m² [8]*

[8]. Pri testiranju pretoka zraka in vode skozi vzorec PTFE membrane na polsti PES 500 g/m² smo dobili rezultate, ki nekoliko odstopajo od podatkov iz kataloga izdelovalca PTFE membran.

2 SKLEP

Z laboratorijskimi in pilotnimi preizkusi smo dobili PTFE membrane ustreznih značilnosti, ki so primerljive s tržnimi izdelki. Z inovativnim postopkom laminiranja PTFE membrane na tekstilno podlogo pa smo obdržali prepustnost osnovne

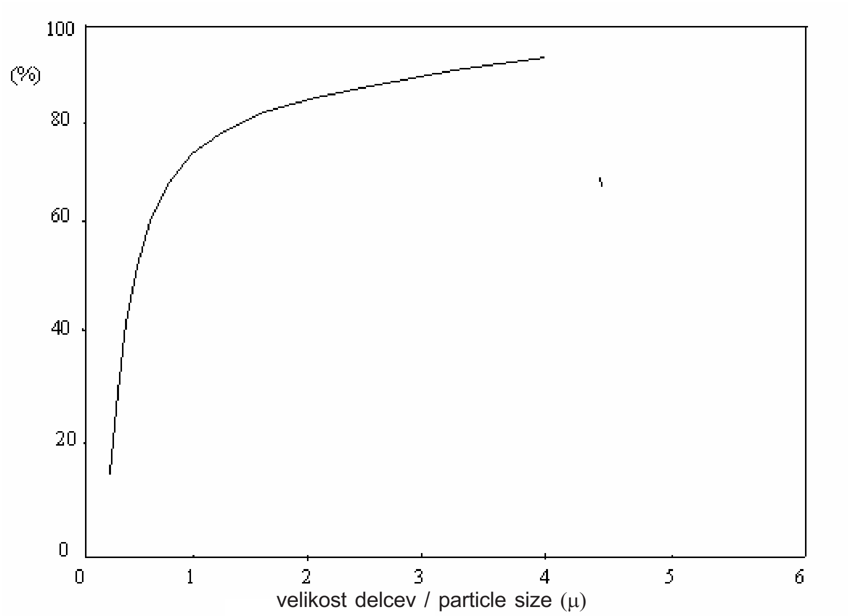
from the figures above that the test membrane filter media retains all the particles larger than 0.6 μm, while the PES Felt 500 g/m² laminated membrane retains all the particles in the 1–4 μm interval.

2 CONCLUSION

Our laboratory and pilot experiments have resulted in PTFE membranes that are of comparable quality to commercially marketed PTFE membrane products. The innovative PTFE membrane to textile backings lamination process succeeded in producing

Preglednica 5. *Pretok skozi filtrirne snovi*
Table 5. *Air-flow and water-entrance results*

Filtrirna snov Filter material	Pretok zraka (l/dm²) pri 20 mm vodnega stolpca Air flow (l/dm²) at 20 mm water level	Pretok vode (l/m² min) pri 0,35 bar Water inflow (l/m² min) at 0.35 bar
PTFE/polst PES 500 g/m² (iz kataloga) PTFE/PES felt 500 g/m² (catalogue data)	6,5 do/to 50	203 do/to 570
PTFE/polst PES 500 g/m² (naše meritve) PTFE/PES felt 500 g/m² (our measurements)	49	90 do/to 160
polst PES 500 g/m² PES felt 500 g/m²	77 do/to 93	2400
PTFE (testna membrana) PTFE (test membrane)	10	280
PTFE/polst PES 500 g/m² (naš vzorec) PTFE/PES felt 500 g/m² (our sample)	10	280



Sl. 9. *Zmožnost zadrževanja standardnega prahu s polstjo PES 500 g/m² [8]*
Fig. 9. *Standard dust-particle retention capability in the case of PES filc 500 g/m² [8]*

membrane in hkrati dosegli zadovoljivo adhezijsko zmožnost med membrano in tekstilno podlogo. To je po našem mnenju zanimiv tehnološki postopek, ki pa trenutno v Sloveniji nima ustreznih pogojev za uveljavitev. Predpostavljamo, da so takšen postopek kaširanja osvojili tudi proizvajalci tovrstnih materialov, saj je patent brez ustrezne zaščite na voljo že od leta 1994. Ne glede na to, da gre za razmeroma stare preizkuse, je po našem mnenju tematika še vedno dovolj pomembna. Izdelovalci tovrstnih materialov rezultatov tehnoloških raziskav ne objavljajo na znanstvenih simpozijih in strokovnih revijah, temveč le njihove uporabe. Gre namreč za specifična tehnološka znanja, ki jih ljubosumno skrivajo. Mnenja smo, da je obravnavana problematika kljub temu dovolj zanimiva tudi za znanstvene kroge, saj se m PTFE membranski filtri zelo pogosto uporabljajo v znanstvenih raziskavah, prikazana pa je tudi inovativna rešitev kaširanja, ki ne zmanjšuje prepustnosti PTFE membrane.

both a suitable membrane permeability and good adhesion between the textile backing and the membrane itself. We find our approach to be very suitable for industry-wide use. Due to the fact that this patent was first published in 1994, we assume that the main manufacturers have by now already started to implement this process into regular production. Although the experiments described in this paper were conducted over a decade ago, we find them to be of great industrial and research significance to this day. Membrane manufacturers do not usually present the results of their research in scientific journals or at conferences; rather they present only their applications and jealously hide the results. Although the topic of this article is mainly of significance to the chemical industry, we believe it is scientifically significant also for two reasons: (a) a new, innovative lamination technique that does not reduce PTFE membrane permeability is described and (b) PTFE membrane filters are very often an integral experimental part in many examples of scientific research.

3 LITERATURA
3 REFERENCES

[1] R.J. Schul, S.J. Pearton (2000) Handbook of advanced plasma processing techniques, *Springer Verlag* Berlin, Heidelberg, New York.
[2] J.Nentwig (2000) Kunststoff – Folien. Herstellung – Eigenschaften – Anwendung, *Hauser*, München.
[3] O.Schwarz, F.W.Eberling (2002) Kunststoffverarbeitung, *Vogel Bucherverlag*.

[4] H.Saechting, K.Oberbach (1998) Kunststoff – Taschenbuch, *Hauser*, München.
[5] D. Drev (1994) Nov način kaširanja PTFE membran in folij na tekstilno podlogo : *Urad za intelektualno lastnino Republike Slovenije*, patent št. SI-9200375 z dne 18. 10. 1994, Ljubljana.
[6] W.L.Gore and Associates Inc. (1975) Deutsches Patent, Auslegeschrift 2123316, P 21 23 316.9-16, Bekanntmachungstag 31.7.1975.
[7] R.W. Gore (1976) US Patent 3953556.
[8] Tetratec PTFE technologies begins construction of new headquartes and manufacturing facility (2000) *Donaldson Company, Inc.*
[9] W.R.Backer (2000) Membrane technology and applications, *Mc Graw – Hill*.
[10] H. Kirchenberger (1986) Spinnerei 2000, *Verlag Bondi*, Wien-Perchtoldsdorf.
[11] Podatki firme Tetratec Co.
[12] BIA – Hinweise Staubfiltermaterial 1/85
[13] DIN 24 184
[14] DIN 53 887
[15] S.Martin (2002) Filtration, Druckflüssigkeit und Reinheitsgrad in der Fluidtechnik, *Expert-Verlag*.
[16] M.D.Lechner, K.Gehrke, E.H.Nordmeier (1993) Makromolekulare Chemie, *Birkhäuser Verlag*.
[17] W.R.A.Vauck, H.A.Huller (2000) Grundoperationen Chemischer Verfahrenstechnik, *Wiley-VCH*.
[18] W.Michaeli (1999) Einführung in die Kunststoffverarbeitung, *Hauser*, München.
[19] M.C.Porter (1990) Handbook of industrial membrane technology, *William Andrew Publishing*.
[20] S.P.Nunes, K.V.Peinemann (2001) Membrane technology, *John Wiley & Sons Inc.*
[21] P.Albers, U.Lechner (1991) Zur chemische Fixierung von Silanen auf Feststoffoberflächen, Werkstofftechnik, *Carl Hauser Verlag*.
[22] C.Wargo, V.Kinney, J.Zahka (1994) Hard particle retention of PTFE membranes used for cemical filtration, *Semicon/Europa 94, Technical Conference*, April 12-13,1994 Genova.
[23] R.Mallouk, P.Branca, Composite membrane, US Patent 4902308.
[24] I.Tarsiche, E.Hoprtean, D.Ciurchea (199/) Least-squares analysis of ammonia diffusion through PTFE membranes, *Measurement Science Technology*, Volume 8, Number 11, 1997, pp. 1367-1371.
[25] R.A.Weker, M.A.Sabolefski (1995) Reactive membrane filter ring in microwave-assosted reaction, *Chemical&Engineering News*, 1995, Vol. 73, No. 25. pp.4.
[26] L. Bergmann (2003) Expanded PTFE membrane filtration media worldwide, *Filter Media Consulting Inc*.
[27] Z.Jianchun, H.Jizhi (2003) Processes technique of waterproof and permeable textile, *China Textile Press*.
[28] F.Liu, B.Yi, D.Xing, J.Yu, Z.Hou, Y.Fu (2003) Development of novel self-humidifying composite membranes for fuel cells, *Journal of Power Sources* 124 (2003) 81 – 89.
[29] K.Schwister (2005) Taschenbuch der Verfahrungstechnik, *Carl Hanser GmbH&Co*.
[30] K.N.Werner (2004) Membranfiltration und verwandte molekulare Separationsverfahren, *Fischer Verlag*.
[31] K.P.Müller (2003) Praktische Oberflächentechnik, *JOT Fachbuch*.
[32] E.Ruppelt (2003) Druckluft Handbuch, *Vulkan – Verlag GmbH*.

Avtorjev naslov: dr. Darko Drev
Univerza v Ljubljani
Fakulteta za gradbeništvo in geodezijo
Hajdrihova 28
1000 Ljubljana

Author's Address: Dr. Darko Drev
University of Ljubljana
Faculty of Civil Engineering and Geodesy
Hajdrihova 28
1000 Ljubljana, Slovenia

Prejeto:
Received: 20.9.2005

Sprejeto:
Accepted: 22.6.2006

Odprto za diskusijo: 1 leto
Open for discussion: 1 year

Osebne vesti - Personal Events

Prof. dr. Branko Gašperšič (1935-2006)

Zapustil nas je prof. dr. Branko Gašperšič, redni profesor na Fakulteti za strojništvo Univerze v Ljubljani, znanstvenik in mednarodno priznani ter uveljavljeni strokovnjak.

Prof. dr. Branko Gašperšič je bil rojen 11. januarja 1935 v Kropi. Malo maturo in privatni izpit za tretji razred gimnazije je opravil v Radovljici. Nato se je šolal v Industrijski kovinarski šoli Litostroj v Ljubljani in leta 1954 končal srednjo tehnično šolo. Istega leta se je vpisal na strojni oddelek Tehniške fakultete v Ljubljani, kjer je diplomiral leta 1961. Takoj po diplomi je bil imenovan za rednega asistenta za področje termodinamike pri prof. dr. Zoranu Rantu, termodinamiku svetovnega slovesa, ki ga je usmerjal vsa leta podiplomskega študija. Tudi večino dela za doktorsko disertacijo je opravil pri prof. Rantu na Inštitutu za jedrsko in procesno tehniko v Braunaschweigu. Na Fakulteti za strojništvo v Ljubljani je bil leta 1972 izvoljen za docenta, leta 1979 za izrednega in leta 1984 za rednega profesorja.

Kot univerzitetni profesor je predaval izbrane vsebine s področij termodinamike in hladilne tehnike. S svojim temeljitim razčlenjevanjem snovi in s poglobljenim načinom reševanja zastavljenih nalog je pritegnil številne študente in jih vzgojil v sposobne inženirje. Iz vrst njegovih podiplomcev izhaja več imenitnih strokovnjakov in znanstvenikov. Njegov pedagoški opus obsega 10 doktorjev znanosti, 25 magistrov in 110 diplomantov. V pedagoško delo je vnašal sodobno strokovno raziskovalno zasnovo zahodnoevropskega tipa. Znanje, ki si ga je pridobil predvsem med podiplomskim študijem pri prof. Rantu, je nesebično prenašal na študente pri predmetih Termodinamika zmesi in Procesna tehnika. Pripravil je učbenik Prenos toplote v slovenščini, ki se še vedno uporablja kot temeljno učno gradivo na dodiplomskih in podiplomskih študijih v Sloveniji.

Znanstveno-raziskovalno in strokovno delo je gradil na temeljnih znanjih. Opravil je pionirsko delo na področju hladilnih stolpov v Sloveniji. Ustanovil je prvi Laboratorij za hladilno tehniko na univerzitetni ravni. V sodelovanju s slovensko industrijo toplotno procesnih naprav se je lotil zahtevnih nalog in jih uspešno reševal.

Slovenska inženirska javnost ga je kot cenjeno osebnost izbrala za dolgoletnega predsednika Društva strojnih inženirjev in tehnikov Ljubljana.

Za njegov bogat znanstveno-raziskovalni opus, ki obsega številne in kakovostne objave s področja hlajenja, termodinamike in prenosa toplote, so mu bila dodeljena številna priznanja. Nagrado Sklada Borisa Kidriča je prejel dvakrat. Prejel je plaketo in svečano listino ob 40-letnici študija strojništva, leta 1987 pa je bil odlikovan z redom dela z zlatim vencem. Slovensko društvo za hladilno in klimatizacijsko tehniko mu je podelilo posebno priznanje kot učitelju in mentorju številnim članom društva. Za izjemne zasluge pri razvoju znanstvenega in pedagoškega ustvarjanja mu je Univerza v Ljubljani leta 2004 podelila zlato plaketo.

Celih 16 let je bil sodelavec Instituta Jožef Stefan. Na Odseku za procesno in reaktorsko tehniko je pokrival termodinamični del raziskav energetskih sistemov.

Na fakulteti in univerzi so mu bile zaupane pomembne funkcije in zadolžitve v okviru različnih komisij in odborov. Od leta 1989 do 1991 je kot dekan vodil Fakulteto za strojnišvo Univerze v Ljubljani. V razvoj Fakultete za strojništvo je vložil veliko energije in daroval največjo vrednoto, celo svoje zdravje.

Zadnjih nekaj let je kljub bolezni posvečal veliko pozornost nekaterim zadevam, ki so bile pred tem zaradi preobilice dela in zadolžitev potisnjene v ozadje. Vzel si je čas tudi za drobne, na videz nepomembne stvari in za vsakogar.

Prof. dr. Branko Gašperšič je bil človek trdnih življenjskih načel, vedre narave in korekten ter kolegialen v medsebojnih odnosih. S svojim pedagoškim, raziskovalnim in mentorskim delom pušča za seboj neizbrisno sled zglednega učitelja, uglednega strokovnjaka in znanstvenika ter pokončnega poštenega človeka.

Dne 8. julija smo se v Kropi poslovili od Človeka z veliko začetnico. V sebi je združeval vrsto izjemnih lastnosti in je svoje tozemeljsko življenje bogato napolnil z redkimi in izjemnimi dosežki. Ni bil samo odličen strojnik in talentiran univerzitetni profesor s prirojeno pedagoško zagnanostjo, bil je tudi človek redkih naravnih darov, dobrosrčen, izjemno rahločuten in pošten ter zvest prijatelj.

V imenu vseh hvaležnih, ki nas je učil in nas vodil prek številnih strokovnih in življenjskih ovir,

prof. dr. Alojz Poredoš

Pisma uredništvu - Letters to the Editorial Board

Jure Smrekar - Janez Oman - Brane Širok

Statistični pristop k analizi hladilnih sistemov s hladilnimi stolpi na naravni vlek

Strojniški vestnik 51(2005) 11, 711-723

Razprava se nanaša na hladilni stolp. "Dosedanje analize delovanja hladilnih stolpov večinoma temeljijo le na poznavanju parametrov okoliškega zraka ter parametrov vstopne in izstopne hladilne vode."

Ta trditev ni resnična, ker so bile izvedene meritve in analize, med drugimi tudi hladilnega stolpa na naravni vlek TE Šoštanj III ([1] in [2]). Tako je že leta 1976 začel obratovati eksperimentalni hladilni stolp, v katerem je bil vgrajen prostorninski element pršišča TE Šoštanj III v naravni velikosti [3]. Postavljen je bil v Inštitutu Jožef Štefan pri reaktorskem oddelku IJS v Podgorici ([1], [3] in [6]). Posebej so bile izvedene še meritve povprečne toplotne in snovske prestopnosti pri kondenzaciji vodne pare z zrakom na filmu vode [2], poleg tega pa še prenos toplote in snovi ter padec tlaka pri protitoku filma vode in vlažnega zraka med navpičnima ploščama - laminarni in turbulentni tok zraka ([4], [5] in [7]). Raziskan je bil tudi sistem za pripravo dodatne hladilne vode pri toplotnih elektrarnah, IJS-DP-1032-76 [1].

Še posebna pozornost je bila posvečena vplivu hladilnega stolpa na okolico zaradi izločanja vlage na okolico. Zato smo obravnavali metode merjenja vsebine vodnih in velikost kapljic v toku nasičenega vlažnega zraka na izstopu iz hladilnega stolpa. Kapljice v nasičenem vlažnem zraku smo uparjali tudi tako, da smo zmesi zniževali tlak z dušenjem [1].

VIRI

[1] Fabjan, L., Petelin, S., Škerget, L.: Raziskave hladilnih sistemov pri izkoriščanju toplotnih energetskih virov z upoštevanjem njihovega vpliva na okolje. *IJS-DP-106/326-75*, Ljubljana 1975, 45 str.

[2] Gašperšič, B., Fabjan, L., Petelin, S. Škerget, L., Poredoš, A.: Hladilni postopki za toplotne elektrarne. *IJS-DP-106-/2012-76*, Ljubljana 1976, 1-64.

[3] Fabjan, L., Gašperšič, B.: Eksperimentalni hladilni stolp. *IJS-DP-1128*, Ljubljana 1976, 1-25.

[4] Petelin, S.: Termodinamični popis tokov vodnega filma in vlažnega zraka. *Fakulteta za strojništvo, Ljubljana* 1987. Doktorska disertacija, 118 str.

[5] Petelin, S., Gašperšič, B.: Prenos toplote in snovi pri protitoku vode in zraka. *XXIII Jugoslavenska konferencija ETAN-a*, Maribor 1979, 117/124.

[6] Fabjan, L., Gašperšič, B.: Rezultati meritev prenosa toplote in snovi v eksperimentalnem hladilnem stolpu. *XXIII Jugoslavenska konferencija ETAN-a*, Maribor 1979, 125/131.

[7] Petelin, S., Gašperšič, B.: Different one-dimensional mathematical models of current air and water flow. *Z. angew. Math. Mech.* 69 (1989) 6, T 635-T637.

Prof. dr. Branko Gašperšič

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.

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.

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].

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].

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

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.

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.

Podatki o avtorjih

Članku priložite tudi podatke o avtorjih: imena, nazive, popolne poštne naslove in naslove elektronske pošte.

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.

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.

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.

Author information

The information about the authors should be enclosed with the paper: names, complete postal and e-mail addresses.

ACCEPTANCE OF PAPERS AND COPYRIGHT

The Editorial Committee of the Journal of Mechanical Engineering reserves the right to decide whether a paper is acceptable for publication, obtain professional reviews for submitted papers, and if necessary, require changes to the content, length or language.

Authors must also enclose a written statement that the paper is original unpublished work, and not under consideration for publication elsewhere. On publication, copyright for the paper shall pass to the Journal of Mechanical Engineering. The JME must be stated as a source in all later publications.