JOURNAL OF MECHANICAL ENGINEERING

STROJNIŠKI VESTNIK

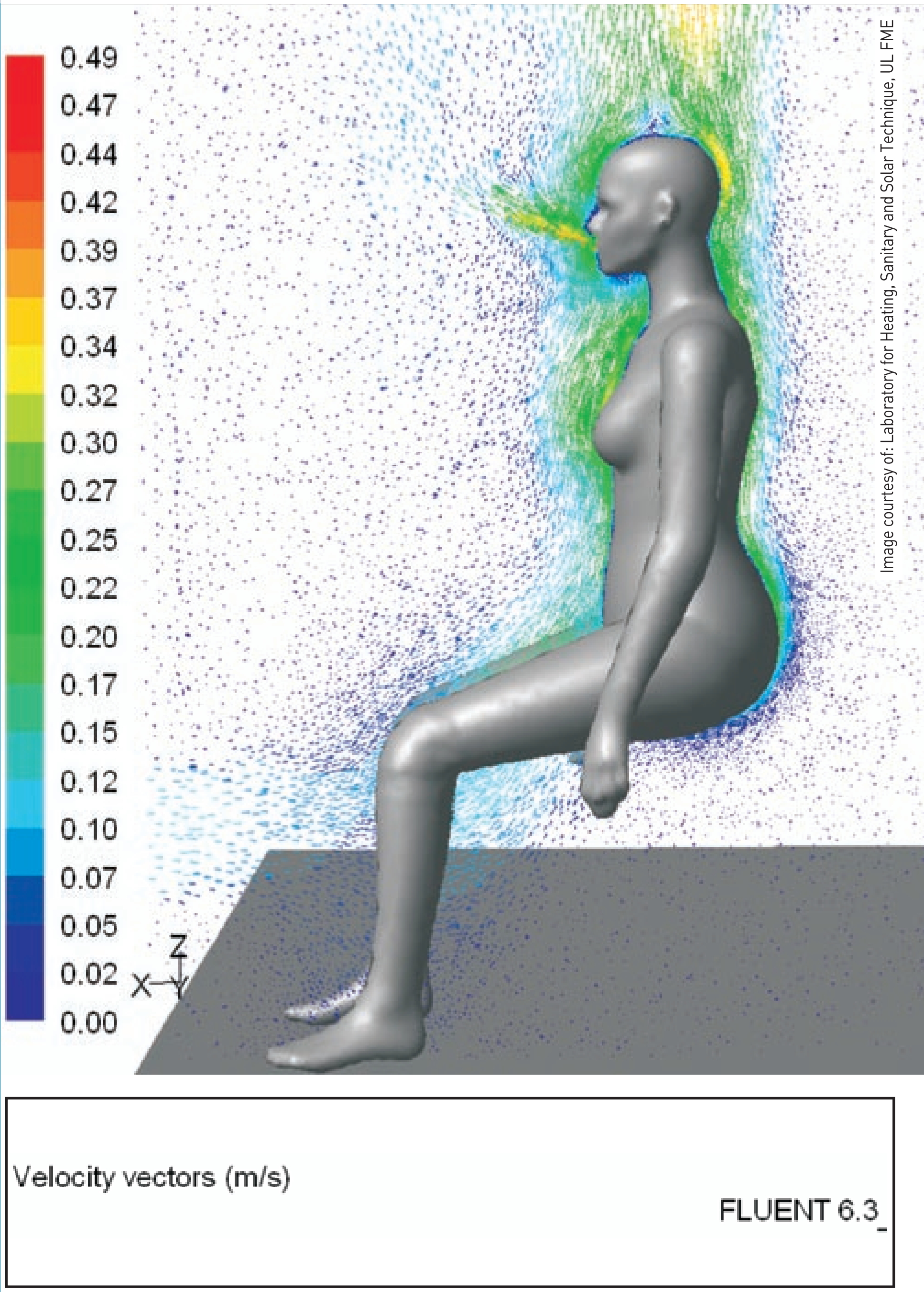


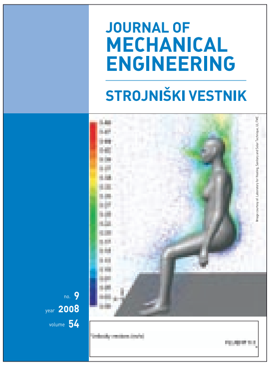
Image courtesy of: Laboratory for Heating, Sanitary and Solar Technique, UL FME

no. 9
year 2008
volume 54

Strojniški vestnik - Journal of Mechanical Engineering
ISSN 0039-2480

Editorial Office
University of Ljubljana
Faculty of Mechanical Engineering
Journal of Mechanical Engineering
Aškerčeva 6
SI-1000 Ljubljana, Slovenia
Phone: 386-(0)1-4771 137
Fax: 386-(0)1-2518 567
E-mail: info@sv-jme.eu
http://www.sv-jme.eu

Founders and Publishers
University of Ljubljana
- Faculty of Mechanical Engineering
University of Maribor
- Faculty of Mechanical Engineering
Association of Mechanical Engineers of Slovenia
Chamber of Commerce and Industry of Slovenia
- Metal Processing Association



Cover plate: Figure represents vector velocity distribution around the sitting human body and respiration area during the exhalation in a space with displacement ventilation. Exhaled air flow of the normal breathing cycle is strong enough to penetrate through the thermal plume around the body.
(Courtesy of the Laboratory for Heating, sanitary and Solar Technique, Faculty of Mechanical Engineering.)

Print
Littera Picta, Medvode, printed in 600 copies

Yearly subscription

companies	100,00 EUR
individuals	25,00 EUR
students	10,00 EUR
abroad	100,00 EUR
single issue	5,00 EUR

SV-JME is indexed in *SCI-Expanded*, *Compendex* and *Inspec*.
The journal is subsidized by the Slovenian Research Agency.

Strojniški vestnik - Journal of Mechanical Engineering is also available on http://www.sv-jme.eu, where you access also to papers' supplements, such as simulations, etc.

Contents

Strojniški vestnik - Journal of Mechanical Engineering
volume 54, (2008), number 9
Ljubljana, September 2008
ISSN 0039-2480

Published monthly

Papers

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, 579-587
UDC 697

Paper received: 19.02.2008
Paper accepted: 07.07.2008

Relative Decrease of Tracer Gas Concentration as a Measure of the Ventilation Effectiveness

Simon Muhič[1] - Mitja Mazej[2] - Vincenc Butala[2,*]
[1] Sineco d.o.o., Ljubljana, Slovenia
[2] University of Ljubljana, Faculty of Mechanical Engineering, Slovenia

An analysis of the ventilation effectiveness measured on a prototype system for local air-conditioning named PERMICS (Personal Microclimate System) was made based on simultaneous measurements of velocity field and of tracer gas concentration using the decay method. A new parameter based on a relative decrease of tracer gas concentration in the first minute of system operation dC(1) was introduced. The newly defined parameter has been verified by simulation results from commercial computational fluid dynamics (CFD) software. The usefulness of the parameter is the possibility to make quick measurements of the local efficiency of personalized ventilation systems.

Keywords: air distribution, air conditioning, ventilation, efficiency

0 INTRODUCTION

Heating, ventilation and air-conditioning (HVAC) systems are mainly designed to provide a healthy and comfortable indoor environment for the occupants of closed spaces. In recent time indoor air quality and thermal comfort of the occupants have been drawing more and more attention [1]. People have also become more aware of their satisfaction with the thermal environment and perception of the air-quality as well as of the sick building syndrome (SBS) [2] and different building related health complaints, such as allergies, headaches and fatigue. Poorly ventilated spaces are the main cause of SBS [3], which depends on different influencing parameters, such as the type of ventilation and HVAC system, the hygienic quality of the inlet air and classical physical factors in environment. These parameters interact to influence people's health conditions and feeling.

Decreased volume flow rates of fresh air into the building consequents much worse indoor air quality. This was coinciding with the appearance of more and more interior pollutants from numerous sources that represent potential health risk, such as new building materials, furniture, laser printers, photocopiers, detergents, as well as people themselves and their activities. After the last energy crisis it was found that indoor air quality also has an economic impact. There were savings in spite of increased ventilation rates which entailed the increased energy use. Namely, buildings with SBS are more expensive because of decreased productivity, absence of work and consequently higher health care costs of employees, as there is a strong connection between these and indoor environment [4] to [6].

Different studies carried out in Slovenia show dissatisfaction of people with the indoor environment mainly in mechanically ventilated buildings [7] to [10] and also the significance of psychological factors in the evaluation of indoor environment parameters [7], [10] to [12]. Further studies show that displacement ventilation is very useful in achieving good air quality, especially when heated sources of contaminants are present [13]. However, this type of ventilation could be at the same time problematic due to the draught and a large vertical temperature gradient [14] and [15]. Furthermore it has also been shown with analysis that up to 50% of occupants may still be dissatisfied with the thermal environment from displacement ventilation [16]. The gained conclusions from these studies indicate the need for new, more qualitative ventilation and air-conditioning systems for indoor environments. Considering the influencing parameters, a new approach, based on the philosophy of excellence for future air-conditioned environments was proposed by Fanger [17]. The main idea of this approach is based on narrowing the air-conditioned space from the whole room space to

*Corr. Author's: Address: University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, Slovenia, vincenc.butala@fs.uni-lj.si

the local space within the occupants' breathing zone using novel personalized ventilation (PV) system. This system has a local inlet of fresh air positioned near the occupants' breathing zone and serves gently a small amount of cool and clean air close or directly into the breathing zone of each individual where it is needed and without causing a draught. Appropriately designed PV system makes possible to achieve high local ventilation efficiency and high rates of personal air in inhaled air with a small amount of fresh personal air. At the same time very satisfactory thermal comfort for each occupant is achieved. This concept also enables a small degree of mixing of polluted and fresh air, which is the main problem in classical ventilation systems.

Research on different personalized ventilation applications evaluated numerous advantages of the system and confirmed high rates of personal air in inhaled air, good air quality and thermal comfort in the majority of cases [18] to [23].

1 PERSONALIZED VENTILATION SYSTEM - PERMICS

The concept of PERMICS for workplaces is mainly based on an analysis of other PV and local air-conditioning systems as well as on measurements from local air cleaning devices [24] and [25]. PERMICS is designed as an individual unit for use in offices with several employees, who are sitting in the same place for longer periods of time, which serves fresh air directly at the work area with individually regulated microclimate conditions. The system is designed to be applied in conjunction with total-volume ventilation and air-conditioning, especially in spaces with high heat and/or pollutant sources, due to the draught risk from larger amounts of air or lower air temperatures. The total-volume ventilation and air-conditioning system in this way assures approximately homogenous parameters for indoor air overall, while the local personalized ventilation assures the fresh air distribution within the breathing zone of the sitting occupant at the work area to fulfil individual preferences. PERMICS can be connected to the central air-conditioning system in different ways for example using a flexible duct from the wall or floor at the back side of an office desk. The system consists of two air distribution elements with air ducts, mounted on an office desk with dimensions 800 x 1600 mm and a height of 765 mm, supplemented with a partition wall at the back of the desk with a height of 800 mm above desk level (Fig. 1). Air distribution elements are located within the microclimate zone of the work area and connected with the air duct, which is separated into two parts leading to the elements, at the back side of the partition wall.

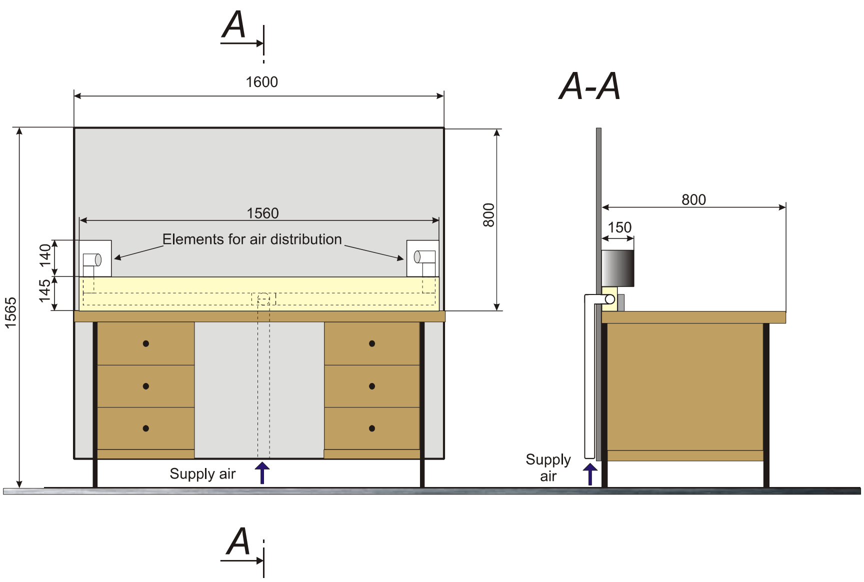


Fig. 1. *Scheme of PERMICS*

2 EXPERIMENTAL METHOD – MEASUREMENTS AND SIMULATIONS

The measurements of ventilation efficiency of PERMICS with seated manikin in the test chamber with dimensions 4.36 x 4.11 x 2.97 m were made using the decay, or tracer step-down method [28] and [29]. The scheme of the experimental device is shown in Figure 2. Seated manikin was fixed in an upright position with a nose height of 1.10 m during the entire measuring procedure. The air supply rate for the personalized ventilation system was regulated using a frequency controlled supply fan, while the exhaust fan for extracting air worked under constant operating conditions for the entire experiment. The personalized ventilation was the only clean air supply in the test chamber. The outlet for extracting air was placed under the ceiling of the test chamber at coordinates (2.2; 2.8; 2.93) m.

In the experiment several different operating regimes of the PERMICS in terms of the amount of supply air and settings of inlets were tested. Altogether eighteen different measurements with variations in air flow rates, angles of inlet and meshed material covering inlet were made. In all cases isothermal conditions were simulated in the test chamber. The temperatures of the air in the test chamber and of the fresh supply air as well as the mean radiant temperature were equal. The seated manikin was thermally inactive (not heated) so there was no influence of a thermal plume on the air distribution in the breathing zone.

On-line measurements of volume flow rate and temperature of supply air were performed using into the supply duct built rotating vane anemometer and thermocouples. Carbon dioxide (CO_2) concentration was measured using a system with infrared absorption sensor at four locations, namely in fresh supply air, at the inlets of PERMICS, at the manikin head and at the outlet from the test chamber. The CO_2 concentration was measured successively at four locations at time intervals of 1 min using a switching valve. In order to decrease measurement errors, every fifth minute the measuring system was “washed up” with fresh air, since every measurement cycle then starts from the same concentration level of CO_2. In this way it is possible to obtain a concentration reading at a single location every 5 min, which is in order for measuring ventilation efficiency. For every measurement CO_2 was injected into the chamber with the mixer turned on for 20 min to achieve a uniform initial tracer gas concentration of about 3000 ppm in the whole chamber. The first concentration reading was obtained exactly 60 secs after turning the fans on. All results were calculated as concentration of CO_2 over concentration of fresh air.

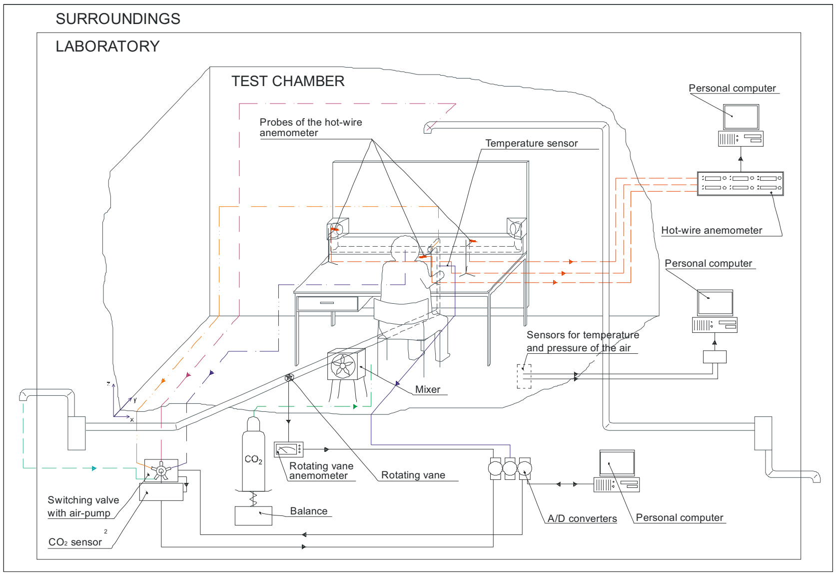


Fig. 2. *Scheme of experimental device*

Temperature and relative humidity of the air at different locations as well as the barometric pressure in the chamber were measured using an integrated chamber measuring system to verify isothermal conditions. Air velocity and turbulence intensity measurements were performed using a hot-wire anemometer HW3D-ED during the experiment at three locations, namely at the manikin head, at desk coordinates (80; 0; 110) cm (Fig. 3), and in the middle of the inlet surface of the left distributional element.

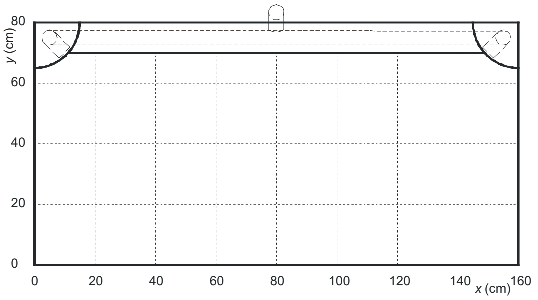


Fig. 3. *Coordinates at the desk, z coordinate is the same for whole chamber*

3 RESULTS AND DISCUSSION

The obtained measurement results were analysed in accordance with the literature [26] to [29], using different indexes for assessing ventilation efficiency. The nominal time constant of the ventilation system τ_n (Eq. 1) is defined as the ratio of the room volume (V) to the volume flow rate (Q) and represents the shortest possible air-change time that takes to replace the air in the room:

$$\tau_{\mathrm{n}} = \frac{V}{Q} \tag{1}$$

Average mean age of air in the room τ_m is defined as the ratio of the second and the first statistical moment of the frequency distribution:

$$\tau_{\mathrm{m}} = \frac{\int_0^\infty t \cdot C_{\mathrm{e}}(t)dt}{\int_0^\infty C_{\mathrm{e}}(t)dt} \tag{2}$$

Local mean age of air τ_L at the seated manikin head is calculated as a ratio of the first statistical moment of the frequency distribution and the initial concentration in the room:

$$\tau_{\mathrm{L}} = \int_0^\infty \frac{C_{\mathrm{p}}(t)}{C(0)} dt \tag{3}$$

The air-change efficiency ε_a is calculated as the ratio between the shortest possible time that it takes to replace the air τ_n and the average time that it takes to replace the air in the room, which is equal to twice the average air age:

$$\varepsilon_{\mathrm{a}} = \frac{\tau_{\mathrm{n}}}{2\tau_{\mathrm{m}}} 100 \tag{4}$$

The local air-change index ε_L is calculated as the ratio between the shortest possible air-change time τ_n and the local mean age of air τ_L:

$$\varepsilon_{\mathrm{L}} = \frac{\tau_{\mathrm{n}}}{\tau_{\mathrm{L}}} 100 \tag{5}$$

The results of defined ventilation efficiency parameters during measurements with variable air supply flow rate are presented in Table 1. The lowest average mean age of air in the test chamber was 72.0 min at the first measurement M_01.

Table 1. *Parameters at variable air supply flow*

		M_01	M_03	M_06	M_08	M_09
Q	l/s	9.5	7.25	7.58	8.49	6.22
v_{head}	m/s	0.56	0.24	0.5	0.52	0.24
Tu_{head}	%	15.0	43.2	28.1	21.8	30.3
$v_{120,40}$	m/s	1.37	0.26	0.29	0.45	0.18
$Tu_{120,40}$	%	10.8	36.86	36.55	28.97	44.64
T_{in}	°C	24.2	22.1	19.2	22.4	21.1
$C(0)$	ppm	2766	3150	2946	3110	2641
τ_L	min	54.5	75.8	74.5	62.7	84.3
τ_m	min	72.0	101.1	96.7	84.0	110.3
τ_n	min	92.1	120.8	115.5	103.1	140.6
ε_L	%	168.94	159.36	155.1	164.53	166.8
ε_a	%	64.03	59.74	59.73	61.38	63.75

Hypothesis about connection between analysed variables was tested computing Pearson's correlation coefficients with a test of significance for the measured and calculated parameters. Pearson's correlation coefficients between the measured and calculated variables, computed using statistical software SPSS [30] and [31], are presented in Table 2. Significant connections are marked with an asterisk sign (*). Strong correlations were discovered between the inflow rate of fresh air and the mean age of air, as well as between turbulence intensity at the desk coordinate (120; 40; 100) cm $Tu_{120,40}$ and local air age at the head of seated manikin. A significant connection was found out between the local air-change index and air velocity and turbulence intensity at the manikin's head.

A new index based on the relative decrease in tracer gas concentration in the first minute of system operation dC(1) is defined as:

$$dC(1) = \frac{C(0) - C(1)}{C(0)} = \frac{\Delta C(1)}{C(0)} \quad (6)$$

Pearson's correlation coefficients between the ventilation effectiveness variables and the index dC(1) were calculated (Table 3). Strong correlation exists between dC(1) and measured air velocity and turbulence intensity as well as between dC(1) and the calculated local air-change index and local air quality. A new index dC(1) thus combines both velocity field and air quality parameters.

The dependence between the local air-change index ε_L and dC(1) for all measurements is shown in Fig. 4. Superior to other regression models is cubic regression model with the determination coefficient (Eq. 7).

$$\varepsilon_L(dC(1)) = 2431.3dC(1) - 12296dC(1)^2 + \\ +20090.8dC(1)^3 \quad (7)$$

Results of the measurements show that air distribution has a major influence on air quality in the breathing zone of the seated person, which is determined by the local air-change index and by the local age-of-air. Comparison between different operating regimes shows that with a small amount of laminar air flow equal air quality parameters as with a larger amount with higher values of turbulence intensity may be achieved, because there is no actual mixing of air in the laminar flow case as fresh air is able to push old air out of the breathing zone.

In the next step the operating conditions from the experimental analysis of the PERMICS were simulated using commercial CFD package CHAM PHOENICS. Numerical simulation was carried out in two stages because of the nature of the problem.

Table 1. *Table of correlation coefficients (* correlation is significant at 0.05; ** correlation is significant at 0.01). P Corr is the Pearson correlation coefficient, Sig. is significance, and N is the number of measurements)*

		Q	v_{head}	Tu_{head}	$v_{120,40}$	$Tu_{120,40}$	τ_L	τ_m	ε_L	ε_a
Q	P Corr	1	.357	-.522(*)	.533(*)	-.652(**)	-.515(*)	-.938(**)	-.258	.213
	Sig.	.	.073	.013	.011	.002	.014	.000	.151	.198
	N	18	18	18	18	17	18	18	18	18
v_{head}	P Corr	.357	1	-.891(**)	.667(**)	.080	.368	-.407(*)	-.741(**)	.098
	Sig.	.073	.	.000	.001	.380	.066	.047	.000	.349
	N	18	18	18	18	17	18	18	18	18
Tu_{head}	P Corr	-.522(*)	-.891(**)	1	-.660(**)	.024	-.227	.620(**)	.677(**)	-.280
	Sig.	.013	.000	.	.001	.464	.182	.003	.001	.130
	N	18	18	18	18	17	18	18	18	18
$v_{120,40}$	P Corr	.533(*)	.667(**)	-.660(**)	1	-.582(**)	-.195	-.499(*)	-.251	.094
	Sig.	.011	.001	.001	.	.007	.219	.018	.157	.356
	N	18	18	18	18	17	18	18	18	18
$Tu_{120,40}$	P Corr	-.652(**)	.080	.024	-.582(**)	1	.823(**)	.474(*)	-.401	.185
	Sig.	.002	.380	.464	.007	.	.000	.027	.055	.239
	N	17	17	17	17	17	17	17	17	17
τ_L	P Corr	-.515(*)	.368	-.227	-.195	.823(**)	1	.427(*)	-.686(**)	-.051
	Sig.	.014	.066	.182	.219	.000	.	.038	.001	.420
	N	18	18	18	18	17	18	18	18	18
τ_m	P Corr	-.938(**)	-.407(*)	.620(**)	-.499(*)	.474(*)	.427(*)	1	.301	-.507(*)
	Sig.	.000	.047	.003	.018	.027	.038	.	.112	.016
	N	18	18	18	18	17	18	18	18	18
ε_L	P Corr	-.258	-.741(**)	.677(**)	-.251	-.401	-.686(**)	.301	1	-.131
	Sig.	.151	.000	.001	.157	.055	.001	.112	.	.303
	N	18	18	18	18	17	18	18	18	18
ε_a	P Corr	.213	.098	-.280	.094	.185	-.051	-.507(*)	-.131	1
	Sig.	.198	.349	.130	.356	.239	.420	.016	.303	.
	N	18	18	18	18	17	18	18	18	18

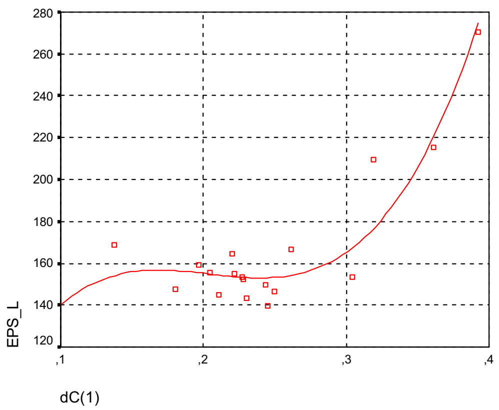


Fig. 4. *Scatter graph for local air-change index ε_L (EPS_L) and $dC(1)$ dependence at the head of seated person*

In the first part of the simulation a steady-state solution of the velocity and pressure field was calculated and then used in the second part of simulation. The second part was a transient simulation performed using a steady-state solution form the first part to determine the residence time and consequently the field of contaminant concentration. Therefore a new variable named $C1$ was defined, which represents contaminant concentration in the chamber. In both stages of numerical simulation the Chen-Kim turbulence model was used, which has been found the most suitable in this case [32]. Different supply flow rates were simulated using boundary conditions from the various measurements. The results of both measurements and simulations for $dC(1)$ in the breathing zone, the decrease of concentration in the first minute of system operation, $\Delta C(1)$, and the relative difference between measurements and simulations relative to measurements are presented in Table 4. The differences between measurements and simulations exist and are up to 26%, mainly due to the inaccurate determination of the velocity and pressure field in the chamber. The main reasons for these deviations in the determination of the velocity and pressure field are inaccurate boundary conditions as a result of a very complex inlet profile at the air inlets of PERMICS and turbulence modelling. Complexity of inlet profile at the air inlets disables accurate description of boundary conditions used in the CFD model.

Table 3. *Table of correlation coefficients (* correlation is significant at 0.05; ** correlation is significant at 0.01). P Corr is the Pearson correlation coefficient, Sig. is significance, and N is the number of measurements.*

		$dC(1)$
Q	P Corr	-.273
	Sig.	.137
	N	18
v_{head}	P Corr	-.635(**)
	Sig.	.002
	N	18
Tu_{head}	P Corr	.529(*)
	Sig.	.012
	N	18
$v_{120,40}$	P Corr	-.329
	Sig.	.091
	N	18
$Tu_{120,40}$	P Corr	-.318
	Sig.	.107
	N	17
τ_L	P Corr	-.448(*)
	Sig.	.031
	N	18
τ_m	P Corr	.380
	Sig.	.060
	N	18
ε_L	P Corr	.762(**)
	Sig.	.000
	N	18
ε_a	P Corr	-.405(*)
	Sig.	.048
	N	18

The results of the unsteady simulations for two cases are shown in Fig. 5. These simulated predictions may be accurate only if the velocity and pressure field are accurately determined. The difference between the measurement and simulation results of local air-change index was estimated by comparing simulations relative to measurements, using

$$\Delta\varepsilon_L = \frac{\varepsilon_{L,sim} - \varepsilon_{L,meas}}{\varepsilon_{L,meas}} 100 \qquad (8)$$

Table 4. *Results of unsteady simulations and measurements of tracer gas concentration decrease in the breathing zone of a seated person 1.1 m above the floor and the relative difference between measurements and simulations*

	$dC(1)$		$\Delta C(1)$ (ppm)		Relative difference regarding measurements (%)
	Simulation	Measurement	Simulation	Measurement	
M_01	0.173	0.137	478	379	-26.0
M_03	0.176	0.240	553	620	10.9
M_06	0.222	0.218	655	652	-0.4
M_08	0.186	0.220	579	685	15.5
M_09	0.211	0.235	557	689	19.2

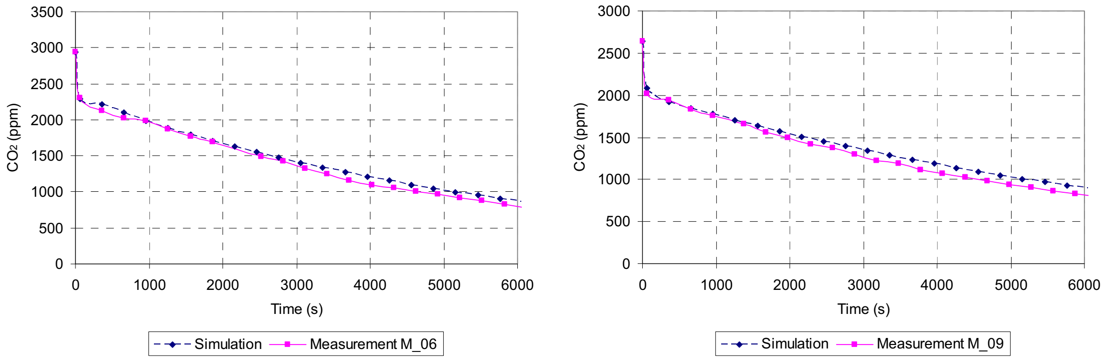


Fig. 5. *Trend of tracer gas concentration decrease for measurements and simulation for two cases M_06 and M_09 (Table 1)*

The maximum difference between measured and simulated local air-change index was 7.49% (Table 5). However, the relative decrease of tracer gas concentration, described with index dC(1), was confirmed by simulation results. Thus, dC(1) may be used for estimation of ventilation efficiency.

Table 5. *Local effectiveness of ventilation and the relative difference between the results predicted from the simulation and the measurements; local air age and the relative difference between the results predicted from the simulation and the measurements*

	$\varepsilon_{L,sim}$ (%)	$\varepsilon_{L,meas}$ (%)	$\Delta\varepsilon_L$ (%)
M_01	156.6	169.0	7.32
M_03	156.6	159.4	1.78
M_06	153.6	155.0	0.92
M_08	156.1	164.6	5.16
M_09	154.3	166.8	7.49

Comparison of the local air-change index with the typical values of different ventilation types (Table 6) shows that a local ventilation system is advantageous over a conventional ventilation system. It has a potential to improve the level of air quality in the breathing zone and to lower energy consumption for ventilation at the same time.

Table 6. *Ventilation effectiveness for different types of ventilation [32]*

Ventilation type	Air change efficiency (%)
Ideal complete mixing	50
Piston flow	100
Displacement flow	50-100
Short circuiting flow	0-50

4 CONCLUSIONS

The performed measurements and simulations of different operational regimes of PERMICS system show that a concept of personalized ventilation system is very effective. It was found from measurements that the newly defined index of relative decrease of tracer gas concentration in the first minute of system operation dC(1) is connected with velocity field as well with the ventilation effectiveness parameters. The main benefit of this parameter, verified by simulations of analysed operating conditions, is that it allows relatively accurate measurements of local air-change efficiency and makes them quick and easy in comparison with ordinary ventilation efficiency measurement procedures. The existing measurement procedure can lead to a large degree of uncertainty in measurements due to each successive reading bringing its own uncertainty. The newly defined parameter dC(1) has the advantage of direct measurement of ventilation efficiency in a much shorter time.

5 REFERENCES

[1] Butala V., Muhič S., Turk J., Molan M., Mandelc-Grom M. and Arnerič N. (2001) Indoor air quality and air distribution in occupied spaces-Final report. Research project No. L2-0528-0782-01, University of Ljubljana, Faculty of Mechanical Engineering.

[2] Indoor Air Facts No. 4 (revised, 1991). Sick Building Syndrome (SBS). U.S. Environmental Protection Agency / Office of Air and Radiation.

[3] World Health organization (1984) Indoor air quality research: EURO-reports and studies 103. WHO-Regional Office for Europe, Copenhagen.

[4] USEPA (1989) Economic impacts of indoor air pollution. Report to congress on Indoor Air Quality. Vol. II: Assessment and Control of Indoor Air Pollution, Office of air and radiation/United States Environmental Protection Agency (Chapter 5, EPA Publication No. EPA/400/1-89/001C).

[5] Wargocki P., Wyon D.P., Baik Y.K., Clausen G., Fanger P.O. (1999) Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads, Indoor Air 9, pp. 165–179.

[6] Wargocki P., Wyon D., Sundell J., Clausen G., Fanger P. (2000). The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity, Indoor Air 10, pp. 222–236.

[7] Butala V., Muhič S., Molan M. (2002) Diagnostic of IAQ problems in the central office of Slovenia Telecom, in: O. Seppänen, J. Säteri (Eds.), Healthy Buildings 2000, Espoo, Finland, pp. 181–186.

[8] Butala V., Novak P. (1997) Indoor air quality and energy use in Slovenia. Indoor+Built Environment, pp. 241–249.

[9] Butala V., Muhič S., Molan M., Mandelc-Grom M., Arnerić N. (2001) Indoor air quality and air distribution in occupied spaces. Final Report of the Research Project (in Slovenian). University of Ljubljana, Faculty of Mechanical Engineering.

[10] Muhič S., Butala V. (2004) The influence of indoor environment in office buildings on their occupants: expected–unexpected. Building and Environment 39(3). pp. 289-296.

[11] Muhič S., Butala V. (2002) Impact of CO2 concentration, temperature and relative humidity of air to the current feeling and health of well-being employees in air-conditioned and natural ventilated offices. In: Levin H, editor. 9th International Conference on Indoor Air Quality and Climate: Indoor Air 2002. Monterey, CA, USA. pp. 848-853.

[12] Butala V., Muhič S., Molan M. (2001) The correlation with indoor environment parameters and current feeling of employees in air-conditioned offices, in: Indoor Climate of Buildings'01, High Tatra, Slovakia, pp. 261–270.

[13] Brohus H., Nielsen P.V. (1996) Personal Exposure in displacement ventilated rooms. Indoor Air, 6, pp. 157-167.

[14] Melikov A.K., Nielsen J.B. (1989) Local thermal discomfort due to draft and vertical temperature difference in rooms

with displacement ventilation. ASHRAE Transactions 96, pp. 1050-1057.
[15] Pitchurov G., Naidenov K., Melikov A.K., Langkilde G. (2002) Field Survey of Occupants Thermal Comfort in Rooms with Displacement Ventilation. Roomvent, Copenhagen, pp. 479-482.
[16] Naydenov K., Pitchurov G., Naidenov G., Melikov A.K, (2002) Performance of Displacement Ventilation in Practice. Roomvent 2002. Copenhagen, pp. 483-486.
[17] Fanger Ole P. (2001) Human requirements in future air-conditioned environments. International Journal of Refrigeration 24, pp. 148-153.
[18] Čermak R., Majer M, Melikov A.K. (2002) Measurements and prediction of inhaled air quality with personalized ventilation, Indoor Air 2002, Monterey, pp. 1054-1059.
[19] Melikov A.K., Cermak R., Majer M. (2002) Personalized ventilation: evaluation of different air terminal devices. Energy and Buildings 34(8), pp. 837-844.
[20] Čermak R., Melikov A.K. (2003) Performance of personalized ventilation in a room with an under floor air distribution system: transport of contaminants between occupants. In: TK Wai, C Sekhar, D Cheong, editors. Healthy Buildings 2003, Singapore: Department of Building, National University of Singapore, pp. 486-491.
[21] Gori P., Grossi L., Vallati A. (2003) Personalized ventilation: experimental apparatus to evaluate high induction air terminal devices. In: TK Wai, C Sekhar, D Cheong, editors. Healthy Buildings 2003. Singapore: Department of Building, National University of Singapore, pp. 452-457.
[22] Kaczmarczyk J., Zeng Q., Melikov A., Fanger P.O. (2002) The effect of a personalized ventilation system on perceived air quality and SBS symptoms, Indoor Air 2002. Monterey, pp. 1042-1047.
[23] Yang J., Kaczmartczyk J., Melikov A., Fanger P.O. (2003) The impact of a personalized ventilation system on indoor air quality at different levels of room air temperature, Healthy Buildings 2003. Singapore, pp. 345-350.
[24] Gričar P. (1998) Local air-conditioning of working places. M.Sc. thesis (in Slovenian), University of Ljubljana, Faculty of Mechanical Engineering.
[25] Muhič S. (2001) Quality and distribution of air on the working places in closed spaces. M.Sc. thesis (in Slovenian), University of Ljubljana, Faculty of Mechanical Engineering.
[26] Etheridge D., Sandberg M. (1996) Building Ventilation: Theory and Measurement. British Gas, John Wiley & Sons.
[27] Mundt E., Mathisen H.M., Nielsen P.V., Moser A. (2004) Ventilation Effectiveness. REHVA Guidebook No. 2, Forssan, Finland.
[28] Sandberg M., Sjoberg M. (1982) The use of moments for assessing air quality in ventilated rooms. Building and Environment 19, pp.181–197.
[29] Sutcliffe H. (1990) A guide to air change efficiency. Technical note AIVC 28, Warwick, Air Infiltration and Ventilation Centre, United Kingdom.
[30] Grabec I. (1988) Probability and statistics (in Slovenian). Ljubljana, University of Ljubljana, Faculty of Mechanical Engineering.
[31] Rovan J., Turk T. (2001) Analysis of data with SPSS (in Slovenian). Ljubljana, University of Ljubljana, Faculty of Economics.
[32] Muhič S. (2004) Distribution and Quality of Air at the Local Air Condition. Ph.D. thesis (in Slovenian), University of Ljubljana, Faculty of Mechanical Engineering.
[33] Bronsema B., Björck M., Carrer P., Clausen G., Fitzner K., Flatheim G., Follin T., Haverinen U., Jamriska M., Kurnitski J., Maroni M., Mathisen H.M., Morawska L., Müller B., Nathanson T., Nevalainen A., Olesen B.W., Pasanen P., Seppänen O., Säteri J., Witterseh T. (2003) Performance criteria of buildings for health and comfort. Final Draft: ISIAQ CIB Task Group TG 42.

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, 588-606
UDC 658.5

Paper received: 26.05.2007
Paper accepted: 07.07.2008

Project Management of Product Development

Janez Kušar* - Lidija Bradeško - Jože Duhovnik - Marko Starbek
University of Ljubljana, Faculty of Mechanical Engineering, Slovenia

The market requires that companies continuously reduce their product and process development time and costs, in order not to lose their competitive advantage on the global market. Short product and process development time in combination with low costs and achievement of required quality can be obtained only by integrating project management methods with concurrent engineering elements.

Project management of orders combined with concurrent engineering elements allows for considerable reduction of development time, reduction of costs, and provides for a higher quality of order/product [1].

Order planning phase is very important in integrated product/process development. In the traditional product/process development, on average only 3% of total order development time is used for planning, while at the concurrent concept this time increases to about 20% [2].

The company which has decided for the integrated product/process development as a mode of its operation, first has to carry out organization and information redesign of its business process, as well as to make system and operation project management guidelines.

The paper presents an example of project management implementation in a company, the emphasis being on the development of planning procedure and project management of orders, as well as design of a project dossier.

Keywords: project management, orders management, project management office, dossier, cuncurrent engineering

0 INTRODUCTION

Mass production was prevailing production concept till the end of the 20th century, while today's companies favor a transition to project type of production [3]. This is not only the case in companies which manufacture special equipment for new investments – this transition can also be seen in companies which have used mass production traditionally, e.g. in automotive industry [4], so the companies nowadays have to deal simultaneously with continuous and project processes (Figure 1).

Continuous processes are carried out for an "indefinite period of time" - for an unknown customer; they are used (according to the market demand) for providing new quantities of previously developed products.

Project processes are carried out once or in standard repetitions; they are aimed at achieving precisely defined objective, for a known customer, and their duration is limited to a "definite period".

This paper is concerned only with market-oriented projects arising from known-customer orders. An order is an expression of a wish or requirement for supply or delivery of a specified product or service. The project-oriented way of implementation of such orders will be further dealt with as project management of orders.

1 INTRODUCTION OF PROJECT MANAGEMENT OF PRODUCT DEVELOPMENT

The company deciding for project management of orders has to perform four important steps:

Step 1: training of employees for project management of orders.

Step 2: organization and information changes in company operation.

Step 3: creation of system- and operational guidelines for project management of orders.

Step 4: definition of a method for planning and project management of orders.

*Corr. Author's Address: University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva 6, Ljubljana, Slovenia, janez.kusar@fs.uni-lj.si

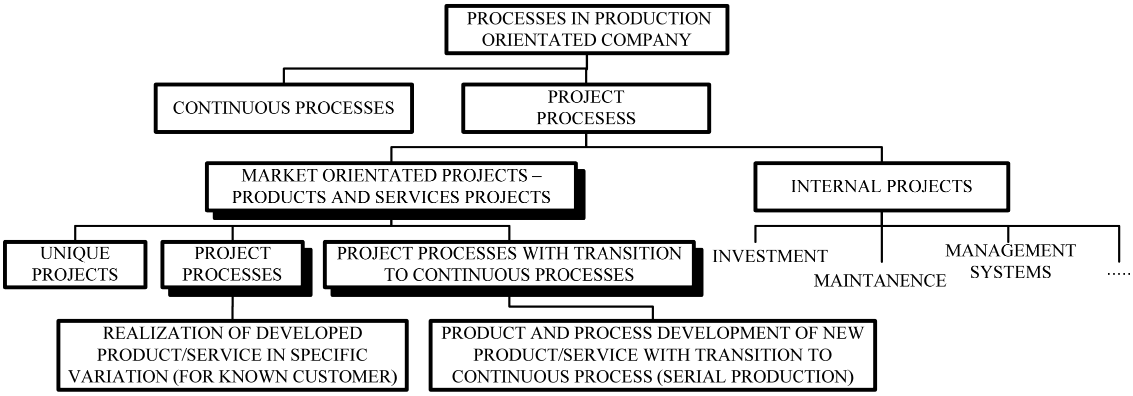


Fig. 1. *Processes in a manufacturing company*

1.1. Training of Employees for Project Management of Orders

Analyses of company personnel qualification for project management of orders reveal that this knowledge is insufficient [5]. For a successful use of project management it is necessary that a critical mass of employees be appropriately trained; these people will be project managers, project team members and heads of organizational units responsible for project management.

For project management of orders it is important to have the knowledge on: teamwork and team philosophy [6] and [7], project management [8], network planning techniques [9] and [10], concurrent engineering [2], organization of manufacturing systems for project management support [4] as well as IT and communication support of project management [11].

1.2. Organization and Information Changes in Company Operation

The implementation of project management of orders in a company requires considerable organizational and informational changes. In companies with traditional functional organization, a transition is usually made to a project-matrix organization [12] in which project teams take over competences and responsibilities (from functional units) for planning and project management of orders. By this organizational change, the functional units of the company become operators of project activities "only", responsible for observing deadlines and quality assurance.

By increasing role of projects in companies, the need for suitable technical and organizational support increases along with the selection of suitable labor forms. At the end of 1990's, a special organizational form appeared in companies: a project management office (PMO) [12]. This term is based on the fact that there is usually a multi-project environment in companies and project management is a mode of company operation.

The need for PMO appeared due to the requirement for employing unified project management methods and standards, as well as for achieving higher efficiency in the management of time, resources, costs, quality, risks and IT support.

PMO can be considered a critical link between strategic company management, which is responsible for managing the company, and the project management, which is responsible for managing projects [3], as presented in Figure 2.

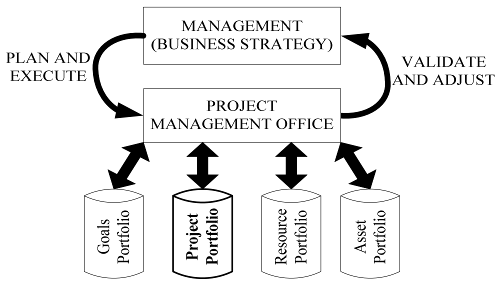


Fig. 2. *PMO as a link between strategy and project management*

PMO is not only professional, technical and administrative aid for project management of orders; it is also becoming an important service of strategic management of the company for synchronous coordination of various company portfolia, a source of information and its flow between strategic and project management, management of processes for data exchange and acquisition on project progress, as well as for harmonization of project portfolio with strategic plans of the company [3].

In order to make PMO operation successful it is necessary to ensure its position in the company organization scheme. Our experience shows [5] that project-matrix structure is the most suitable form; in this structure the PMO is responsible for project support on one hand, and to the company management on the other (Figure 3).

Strategic management has to form a special body for operational supervision of project management (and PMO) – a project board [7]. Several project boards may be established in the company for various projects.

It is suggested that the PMO be filled with the following personnel:

- PMO head (management of PMO and coordination with the company management and managers of functional units),
- project information system administrator (information support for projects and PMO),
- project process analyst (planning and management of projects and project portfolios),
- control analyst (project control),
- project management administrator (data acquisition and distribution).

PMO head has to have support of the company management and a sufficiently influential position in order to be able to coordinate the labor with functional units in the company.

A two-level structure is developed for organization of teamwork [1] and [13]. It consists of: project board (core team) and project teams for the implementation of a particular project (Figure 4).

The company management appoints the project board; it takes care of the planning and implementation of project management policy and strategy, and for guidance and coordination of project-team work.

Project board is permanent and heterogeneous, consisting of project managers and heads of organization units. The general manager or his deputy, who is in charge of the project management, usually manages the project board.

Project team is managed by the project manager. Permanent members of the project team are representatives of organization units, who work on the project throughout its duration. They are responsible for communication and information transfer between the project team and organizational units.

Project team can be extended with temporary members participating in the project for a limited time frame. In the integrated product development, the temporary members form sub-teams, which are responsible for activities in concurrent engineering loops [1] and [2].

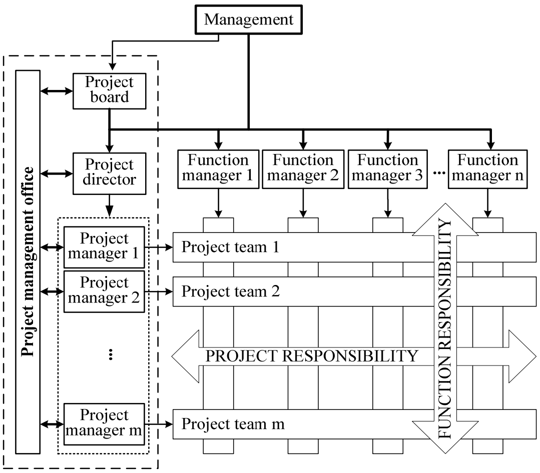


Fig. 3. *PMO location in the project-matrix organization*

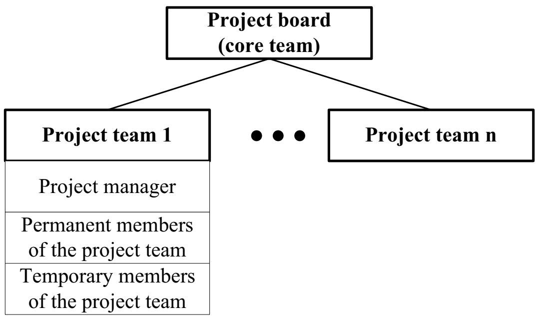


Fig. 4. *Organization of teamwork for integrated product development*

1.3. Creation of System- and Operational Guidelines for Project Management of Orders

Studies have shown that a company, which has decided to use project management of orders, has to develop system- and operational guidelines (Figure 5), which have to be harmonized with other system- and operational guidelines of the company.

For each project it is necessary to set up a project dossier – a data warehouse of all data/documents produced in the project lifetime. For easier survey, the project dossier is divided into folders with documents related to a particular process type (Figure 6). The project dossier has to be accessible to all project participants via the intranet.

1.4. Method for Planning and Project Management of Orders

The studies on introduction of project management of orders in companies have shown that the order management process has to be dealt with in a holistic manner. The data and experience obtained during tender preparation are an important source of information for the implementation project preparation.

Order management project therefore has to be carried out in two phases:
Phase 1: Planning and management of a tender.
Phase 2: Planning and management of implementation project.

1.4.1 Planning and Management of Making a Tender for an Order

A tender is made on the basis of customer inquiry or internal initiative in an organizational unit of the company. Company management should check whether the proposal is in accordance with objectives and strategies of the company. If it is, then the company management orders that a tender be made and appoints an ad hoc project team, which (on the basis of customer requirements and market analyses) obtains as much input data as possible and examines the history and experience on similar, reference projects.

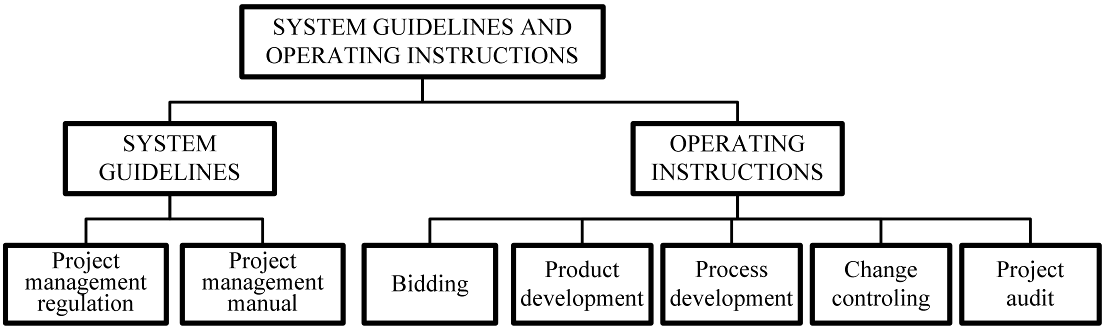


Fig. 5. *Overview of system- and operational guidelines for project management of orders*

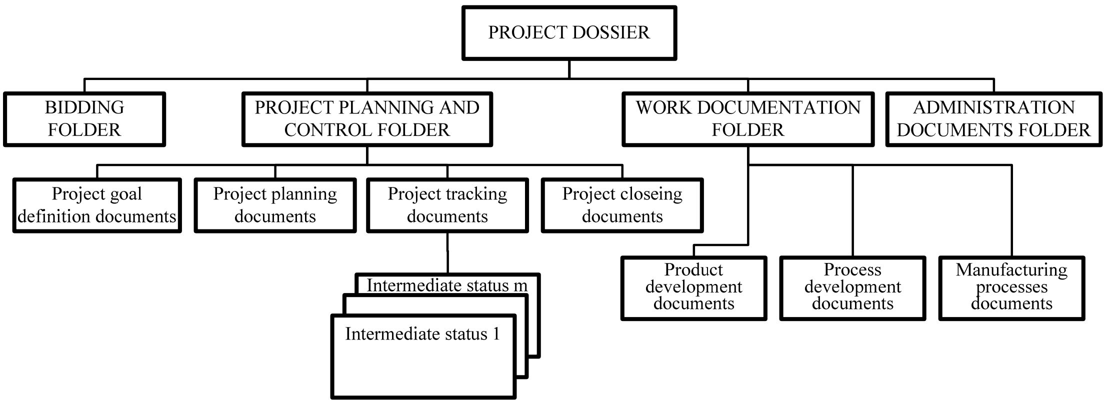


Fig. 6. *Contents of the project dossier*

The course of making a tender is presented in Figure 7.

Ad hoc project team is usually managed by the marketing-department representative. Its members are from development, technology, manufacturing and, when necessary, from other departments of the company. The future project manager is also a member of the ad hoc project team. The result of work of the ad hoc project team is an estimate of the economic justification and feasibility of the project, including risk analysis. If the estimated economic justification and feasibility of the project are promising, the tender is made in accordance with the customer requirements. The tender contains technical and financial data, as well as data on deadlines – the Gantt chart of the project tender.

If the tender is successful, a contract is signed, which defines: project deliverables, quality, deadline with milestones, costs and method of payment, supervision and report on the course of the project.

By signing the contract the foundations are made for planning and management of the implementation project.

1.4.2 Planning and Management of Implementation Project of an Order

Planning and management of the implementation project of an order consists of a logical sequence of all the activities needed for the preparation and implementation of the project, as well as the documents resulting from individual activities.

Planning and management of the implementation project of an order for new product development is similar to execution of a previously developed product, the difference being in individual activities.

Project manager and project team are responsible for the execution of planning and managing of implementation project.

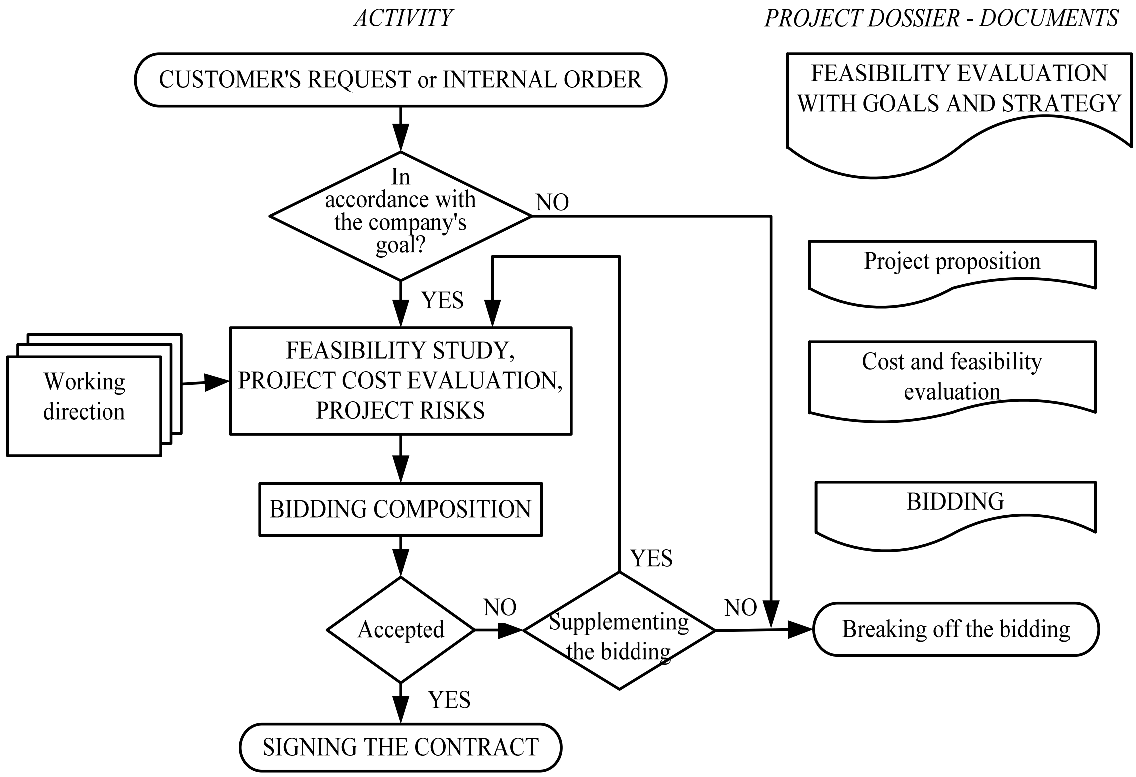


Fig. 7. *The course of making a tender*

Planning and management of implementation project of an order is carried out in four steps (Figure 8):
Step 1: definition of the objective of implementation project.
Step 2: planning of implementation project.
Step 3: execution and monitoring of implementation project.
Step 4: completion of the implementation project.

1.4.2.1 Definition of the Objective of Implementation Project of an Order

In order to define the objective of implementation project it is necessary to:

- order implementation project,
- define the implementation project.

Implementation project is ordered by the contracting authority - company management on the basis of the signed contract. Order of the project contains the data on: customer, project deliverables, project manager, project team composition, conditions for project implementation as regards on time, costs and resources.

Definition of the implementation project is made by the project team on the basis of a detailed study of the project and the book of customer requirements. Project definition consists of: summary of the project - tender; starting

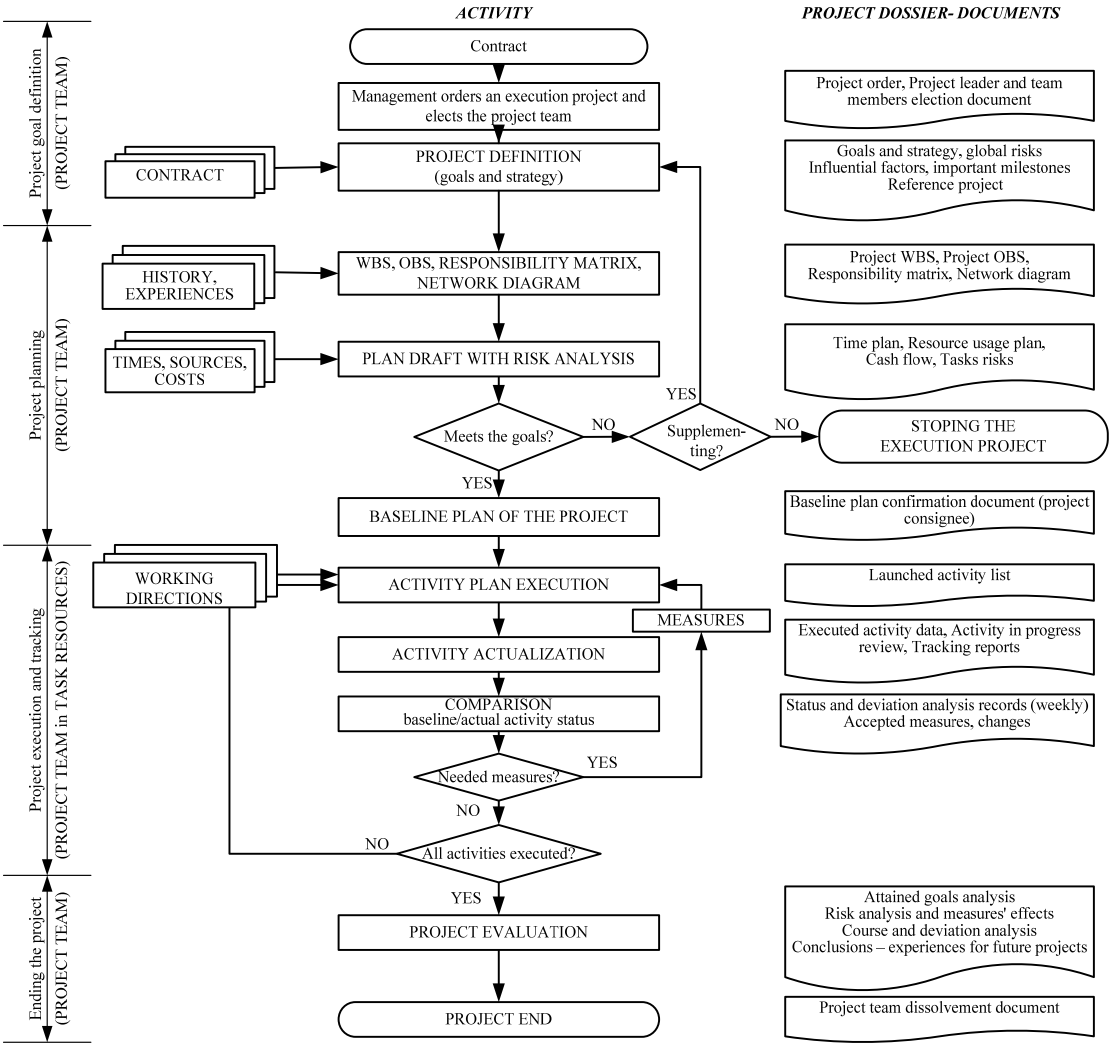


Fig. 8. *Steps in planning and management of implementation project of an order*

points for the project - tender documentation; general and specific objectives of the project; strategies for meeting the deadlines; scope of the project; data on project manager, his deputy and project team members; data on other project participants: suppliers, sub-contractors, customer, control; reference project; feasibility study; the way of ensuring the required resources; investment dynamics and ROI data; pre-calculation; milestones: external and internal; general risk assessment; the way of monitoring the project and reporting to the contracting authority and to the customer.

1.4.2.2 Planning of Implementation Project of an Order

Planning the implementation project is a responsibility of the project team, which has to make:

- work breakdown structure of the implementation project – WBS,
- organization breakdown structure of the implementation project – OBS,
- responsibility assignment matrix,
- network diagram of the implementation project,
- proposal of the plan of the implementation project: schedule, plan of resources and costs, risk analysis with measures, communication plan and plan for management of changes,
- basic plan of implementation project activities.

Work breakdown structure (WBS) represents a structured breakdown of the whole project [8], [10] and [14] into smaller and manageable tasks. WBS is important in terms of the management of time, costs and risks of the project [15]. WBS defines the scope of the project and all the activities necessary for project objectives completion.

WBS of the implementation project (Figure 9) consists of four main groups of tasks: definition of project objective, planning the project, implementation and monitoring of the project, and completion of the project.

The tasks listed comprise activities for all phases of the implementation project.

The "Implementation and monitoring of the project" task is – on the basis of the assembly structure of the product – divided into groups of parts, sub-groups and parts (PtBS – part breakdown structure).

The tasks defined within PtBS can be performed sequentially or parallelly [5].

Planning and manufacturing of components is treated in a process manner (PsBS – processes breakdown structure) (Figure 9).

Tasks (packages of activities) can be performed sequentially or parallelly [5].

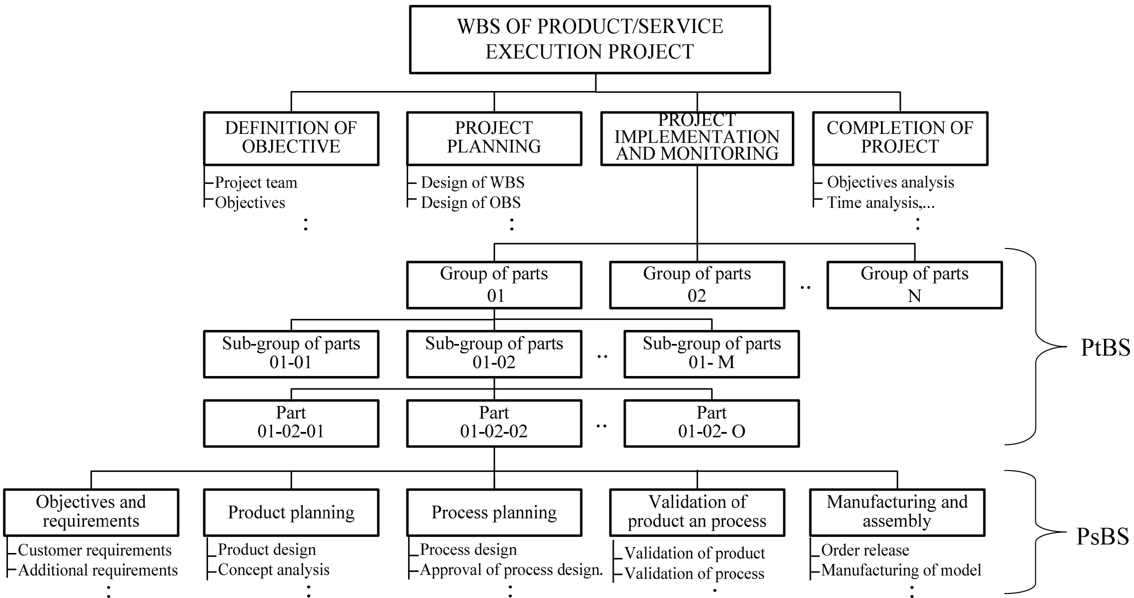


Fig. 9. *WBS of implementation project*

Organization breakdown structure (OBS) represents an organizational breakdown of the company organization units, which are responsible for the execution of WBS tasks/activities [16]. In addition to internal organizational units of the company, OBS also comprises external contractors (suppliers, sub-contractors, consultants, auditors).

The last OBS level consists of resources to be used for the implementation of project activities. An example of an OBS project is presented in Figure 10.

OBS is a temporary organizational structure whose lifetime is equal to the lifetime of the project. It is managed by the project manager and project team members.

If organizational units that are part of the OBS are on various locations, OBS may be organized as a virtual company (by using modern IT and communication means) [17].

Responsibility assignment matrix (RAS) links the project organizational structure (OBS) with the project labor structure (WBS). Responsibilities of operators from OBS versus tasks and activities in WBS are presented with symbols [16]. An example of RAS formation is presented in Figure 11.

Project network diagram is a set of mutually logically linked activities, which have to be carried out in a precisely defined logical sequence and interconnected. It can be made in a form of event- or activity network diagram. Preference is given to activity network diagrams

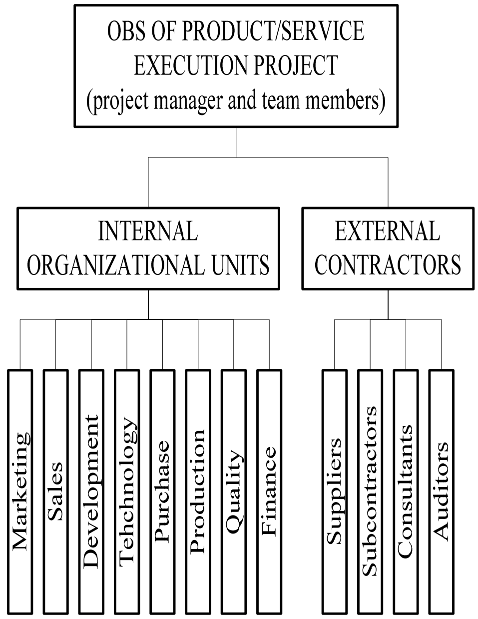


Fig. 10. *OBS of the project*

due to their simplicity and possibility of concurrent execution of activities (partial dependence) [9].

Links between activities in a network diagram can be (Figure 12).

Direct connections - observed activity has to be finished before new activities can start e.g. testing can only be carried out after the prototype has been made; the prototype has to be made before testing.

Responsibilities (OBS) / Product and process development phases (WBS)	OPERATORS IN THE COMPANY								EXT.OPERATORS			
	Marketing	Sales	Development	Technology	Supply	Manufacturing	Quality	Finance	Suppliers	Sub-contractors	Consultants	Auditors
Definition of project objectives	P		S				S	I			I	
Project planning		S	P	S	I	S	S		I	I		
Implementation and monitoring of the project	P		S	S	S	S	S	I	S	S		I
Project completion		P					S					

Legend:

P – primary responsibility
S – secondary responsibility
I – informational responsibility

Fig. 11. *Responsibility assignment matrix*

Partial connections (dependencies) - allow concurrent execution of two or more activities.

External connections - join activity of the observed project with activities of other projects.

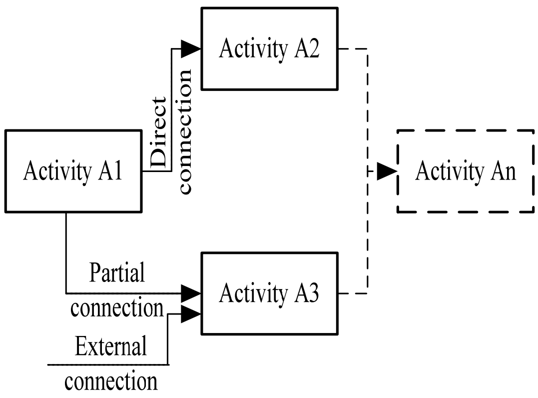


Fig. 12. *Project network diagram*

When defining links between project activities in project management of orders, extended with concurrent engineering elements, it is necessary to define the maximum partial overlapping and thus maximum overlapping of tasks defined in WBS on PtBS and PsBS levels.

Network diagram is a starting point for analyses of duration, resources and costs of the project. In view of preserving the prescribed links between project activities, the network diagram is an indispensable aid for monitoring the project progress.

Proposal of the implementation project plan with risk analysis is an output of the project team in the project design phase. It contains: schedule with milestones, resource load plan, plan of costs, and risk analysis of the project.

Schedule with milestones comprises: durations of activities, date of starting the project, starting and completion dates of activities including milestones, deadline for project completion, dates of milestones, critical paths and time slacks.

Resource load plan can refer to labor force, production means or materials. Each activity is allocated one or more resources.

Project manager and team members examine the resource load profile and if conflicts arise, they search for a suitable solution (in collaboration with PMO and managers of functional units at a project board meeting), which still assures the achievement of project objectives.

In resource analysis the PMO has to harmonize the project portfolio with the resource portfolio.

Project cost plan is made on the basis of: fixed costs of activities, fixed costs of project management, and variable costs of resources used for carrying out activities.

Project cost plan is acceptable if the planned total project costs do not exceed the costs approved when the project was ordered.

PMO has to harmonize the project portfolio with the company costs portfolio.

There are several methods available for risk analysis of implementation project activities [7] and [18]. An analysis of available methods has revealed that the most suitable tool for project management of products and services is the table of "critical success factors", as it represents an analytical aid to find, evaluate, reduce and remove risk. It is elaborated by the project team, which is responsible for planning and implementation of the project. Analyses should be as extensive as possible and they have to cover all possible problems.

Procedure for designing the table of critical success factors consists of risk analysis and risk management.

Risk analysis consists of the identification of problems or events, definition of the probability of their arising, evaluation of their consequences and incidences, and risk calculation [8].

During the identification of problems, all tasks and activities, which are defined in the project WBS, are analyzed. Potential problems of individual task are entered into the critical factor table (Table 1). If it is not possible to identify problems related to a particular task, the latter is omitted.

Quantitative risk analysis is defined by risk activity level, which is calculated on the basis of the following estimates:

- probability that a problem or risk event will arise,
- consequences of a problem or risk event,
- incidence of a problem or risk event.

Table 1. *Table of critical success factors*

Risk analysis						**Risk management**		
No.	Activity/ problem	Event probability *EP*	Consequence estimate *CE*	Incidence estimate *IE*	Risk factor *RF*	Measures *P* – preventive *C* – corrective	Responsibility	Signals
1.	Activity A	3	2	4	24			
:	:	:	:	:	:	:	:	:

Table 2. *Probability that a risk event (RE) will arise*

Estimate	Event probability *EP*
1	very small
2	small
3	middle
4	great
5	very great

Table 3. *Estimate of consequences (CE) of an event*

Estimate	Consequence estimate *CE*
1	very small
2	small
3	middle
4	great
5	very great

Table 4. *Event incidence estimate (IE)*

Estimate	Incidence estimate *IE*
1	never
2	very rarely
3	rarely
4	often
5	very often

An interval scale from 1 to 5 is used for the estimates [8] and [19].

Probability that a problem or risk event will arise is estimated by means of Table 2.

In order to estimate the consequences of a problem or risk event, Table 3 is used.

In [8] the risk is defined only by estimating the probability of a risk event arising and the estimated consequences. The paper deals with project management of cyclically recurrent projects, so experience derived from similar past projects can be used for estimating the incidence probability of a risk event.

Table 4 is used for estimating the incidence of a problem or risk event.

RF – risk factor for the problem identified is calculated by:

$$RF = EP \times CE \times IE$$

EP – probability that a problem or risk event will arise,
CE – evaluation of consequences if a problem or risk event arises,
IE – evaluation of incidence of a problem or risk event arising.

If the calculated risk factor $RF \leq 60$, the risk is considered normal; no measures need to be prepared in advance. If $RF > 60$, the risk is high and measures need to be prepared in advance.

The threshold value of 60 has been set on the basis of the Paret principle [20]: 20% of risks (high-risk-level activities) can cause 80% of problems or damage.

Risk management means definition of measures and responsibilities for risk prevention, and signals that warn us when a risky event might occur.

If the risk factor (*RF*) reaches the critical value (60), it is necessary to pay special attention to the problem. An additional analysis of possible sources of problems is made, and suitable prevention or corrective measures are predicted.

A table of critical success factors also has to contain the so-called signals, i.e. events signaling a new problem to responsible operators and thus allowing them to trigger a suitable measure(s).

Project manager, project team and operators of activities are responsible for the implementation of measures.

Project team forwards the finished proposal of a project plan to the contracting authority (company management or project board), which issues a decision on the confirmation of the baseline project plan, which consists a "copy" of project plan proposal, which does not change during implementation and monitoring of the project – it serves as a reference value for an analysis of deviations of actual project course from the planned course.

Change of the baseline project plan (elaboration of a new baseline project plan) must be confirmed by the contracting body.

1.4.2.3 Implementation and Monitoring of the Project

Project manager (via the project management office) takes care of activity plan implementation. Data on activities that have to start at a specified time are sent to team members (according to the responsibility assignment matrix) and thus to the competent organization units (included in the project OBS). Heads of these units take care of the elaboration of operative activity implementation plan within the planned date of start and end of activities, and for the elaboration of required documentation. Suitable system- and operating instructions are used for the implementation of activities.

Project manager is responsible for actual information on project status, i.e. periodical information retrieval on realization of activities. The project team members from individual organizational units are responsible for on-time actual data acquisition on activity realization.

Project manager and project team make a deviation analysis of the current project status in comparison with the basic project plan; they analyze reasons for deviations and search for solutions to continue the project.

PMO helps the project manager during project updating and deviation analysis. PMO performs a simulation of possible scenara, and on the basis of these the project manager suggests corrective measures. Problems that cannot be solved by the project team, are sent (together with a proposed solution) to the project board.

Project manager documents all measures adopted, including data on holders of their activities and results achieved.

Measures that influence other projects, always have to be analyzed by the PMO and confirmed by the project board.

1.4.2.4 Completion of the Project

After the project has been completed, the project manager and project team members perform project evaluation, which includes: analysis of objectives achieved, deviations of time, resources, costs, risk analysis and important conclusions for future projects. The project board confirms the project evaluation.

Project is completed when a total project dossier has been elaborated; it comprises full documentation on project planning and management, as well as technical documentation on project deliverables (see Figure 6). All these documents should be forwarded to the project management office for archiving. After the project dossier has been archived, the contracting body discharges the project manager and dissolves the project team.

2 CASE STUDY

Implementation of project management of orders in real life is presented in a case of a company which is a development supplier of components for automotive industry. Four groups of products are the most important in its production programme: gearshift mechanism, hand brake, pedal component and engine bonnet pivot. As a development supplier, the company participates in a development project already in a new car concept, and it cooperates with the car producer at least three years before the production starts. By selecting a supplier, the car producer makes an important decision, because the supplier should be a long-term reliable partner; on the other hand, the supplier is in a risky position, as it is not known in advance whether a particular car model will be a market success.

In 2004, the company management decided to introduce project management as a mode of company operation. They did it in four steps:

Step 1: Training of staff for project management.
Step 2: Organization and information changes.
Step 3: Creation of system and operational guidelines.
Step 4: Implementation of test project management of orders (As-Is / To-Be process).

2.1. Training of Project Management Staff

The company management found that for introduction of project management into the company, the employees do not have the required knowledge. In collaboration with the Centre of excellence for modern automation technologies on the Faculty of Mechanical Engineering in Ljubljana several seminars and workshops have been organized, where the employees obtained the required knowledge on project management, teamwork, creativity, communications and concurrent engineering. The seminar participants tested their newly obtained knowledge in solving actual problems in their company.

2.2. Organization and Information Setup

In the past, the company was organized according to the functional principle. Based on an analysis of a suitable company organizational form, the company management selected a balanced matrix company organization. The decision was based on the fact that project decision-making is equally divided between the project manager (regarding project management and achievement of goals) and heads of company functional units (for carrying out project activities and ensuring product quality).

A product and service project board was appointed, managed by the company executive director and consisting of project managers and functional unit heads.

A PMO was established for organizational and technical project management support. It was managed by the project management assistant to the executive director and it consisted of project management administrator, project control analyst, administrator and all professional project managers.

Fig. 13. *Car pedal component*

MS Project software was selected as a key tool for project management IT support. It was used together with MS Office software (Excel, Outlook), which will have to be linked with ERP and PLM system in the future. A question arises, which MS Project functions can be done by ERP system, and which tasks and project management processes should still be managed by MS Project. The implementation of web version of MS Project Server will also be analysed. A project management portal was established on the company's intranet; all project participants can obtain the project-related data on that site.

2.3. Creation of System- and Operational Guidelines

Company management organized the creation of system- and operational guidelines. Project team, responsible for project management implementation in the company, made project management rules, where project management system was defined, as well as a procedure for project planning and management, and the content of a project dossier. The project management rules were adjusted to the company quality management rules. As an aid to project managers and project team members, a project management handbook was made, which contained practical guidelines and templates of all documents appearing in folders and project dossier. For execution of individual processes (bid, product and process development and validation, test manufacturing) operational guidelines have been used that had already been made for the company quality management system, so they have been just harmonized with the project management rules.

2.4. Implementation of Test Project Management of Orders

Company management selected a product and process development order of a car pedal component (Figure 13) as a test project during the introduction of project management of orders. Contract for that project had already been signed; this was therefore an implementation project of an order.

Project team was appointed for the implementation of the project; its members were representatives from all the company functional units, and a senior project manager was elected as the project manager.

The project team carried out the project planning and management process in accordance with the procedures defined in chapter 2.4.

The implementation project plan of the car pedal component order was carried out in four

steps:
- Definition of project objectives.
- Project implementation plan.
- Project implementation and monitoring of the project.
- Completion of the project.

2.4.1 Definition of Project Objectives

In order to define the project objective, the project team carried out two creativity workshops. During the first workshop the team members learnt about their tasks, competences and responsibilities, and they thoroughly studied the tender documentation and subject of the contract.

During the second workshop the team members defined project objectives, suitable strategies, scope of the project, global risks, impact factors and identified the project participants.

2.4.2 Project Implementation Plan

According to the plan of introduction of project management, the company management decided to create two project implementation plans for product order:
- Using the existing way of order process implementation (As-Is)
- Using the project-management-of-orders system, extended with concurrent engineering elements (To-Be).

On the basis of the project definition, the project team made a project implementation plan in several creativity workshops.

Project team members first made the project WBS structure (Figure 14). For individual project phases they defined tasks, subtasks and work packages as shown in Figure 9; they also defined the required project activities. Altogether 340 activities were defined.

During the definition of implementation step activities and project monitoring, all processes, methods and procedures, defined by the APQP methodology for automotive industry, were precisely reviewed [21].

Afterwards, team members formed a project OBS (Figure 15); they included into it those functional units of the company, which would provide resources for the implementation of activities, as well as external suppliers and sub-contractors.

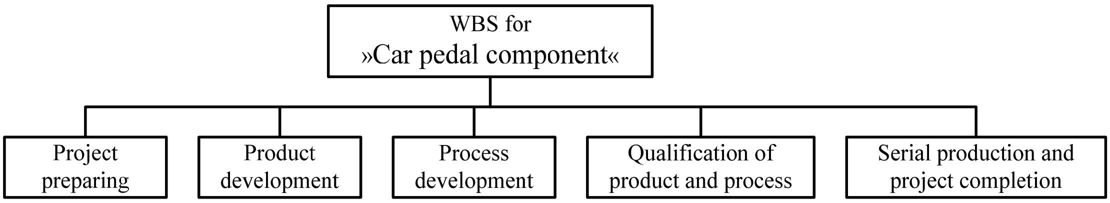


Fig. 14. *WBS for car pedal component*

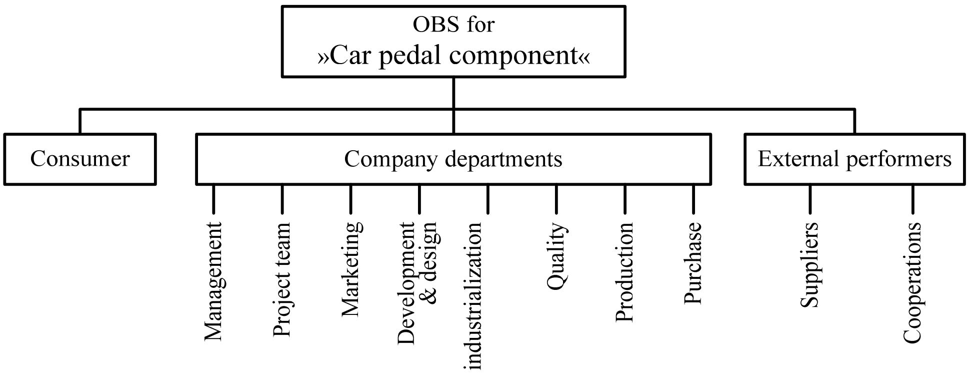


Fig. 15. *OBS for car pedal component*

Product and process development phases (WBS) \ Responsibilities (OBS)	Management	Project team	Marketing	Development & design	Industrialization	Quality	Production	Purchase	Cooperation	Suppliers
Project preparing	S	P	S	I	I					
Development and design of product		S	I	P	S	S		I		
Development and design of process		S		S	P	S	I	I	I	I
Qualification of product and process	I	S		S	S	P	S	S	S	S
Serial production and project completion		P				S				

Fig. 16. *Responsibilities assignment matrix for car pedal component*

Responsibilities assignment matrix was made for easier coordination between project management and functional-units management (Figure 16). The responsibilities were presented by symbols (P – primary, S – secondary, I – informational responsibility).

During project planning, the creation of a project network diagram was the most difficult and most critical task for the project team. Only the network diagram that realistically and logically defines dependencies between project activities can serve as a useful tool for further planning and management of project implementation. Project team members made activity card (label) for every activity. Then they logically connected activities into a network activity diagram (Figure 17). In this process they defined the As-Is order implementation project process as precisely as possible.

After the network diagram had been made, the project team members defined duration of each activity they allocated the required resources and defined the data required for cost analysis.

MS Project software was used for time-, resources- and cost analysis. A period of 644 days would be required for project implementation using the As-Is process.

During the risk analysis all project activities were checked, risk types were defined, risk levels were calculated and preventive and corrective measures were defined if necessary.

The output of the project team was a proposal of the implementation project plan with risk analysis. It was sent to the project board for confirmation. After the project has been confirmed its implementation could begin.

After the order implementation project had been made in accordance with the existing implementation process, the project team began designing an implementation project plan, which would, as far as possible, include elements of concurrent engineering.

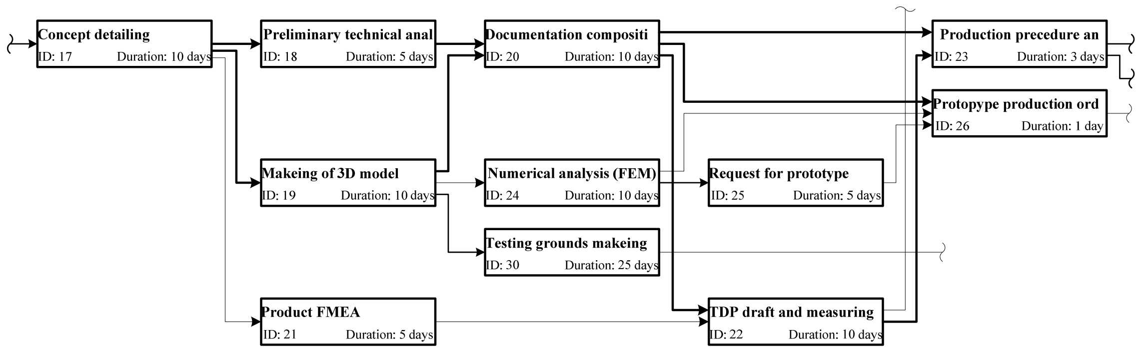
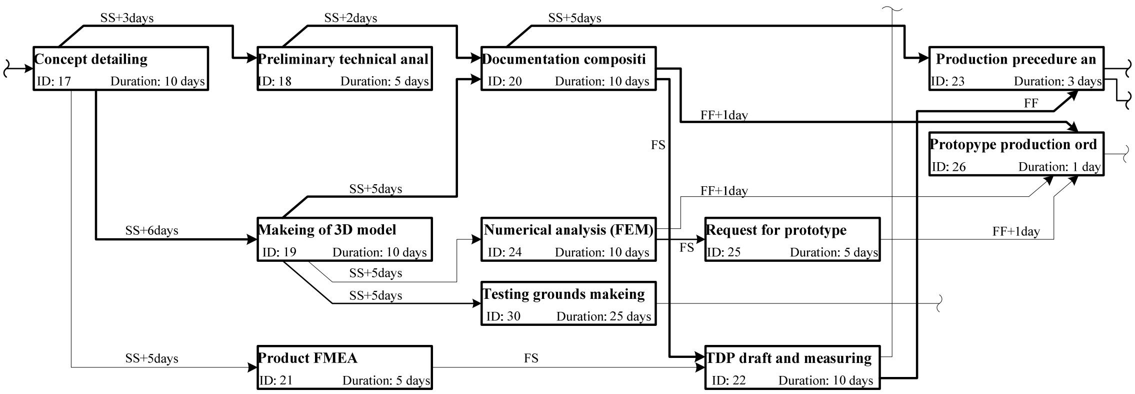


Fig. 17. *Part of network diagram for car pedal component (sequential engineering)*



Legende: SS – start to start; FS – finish to start; FF – Finish to finish

Fig. 18. *Part of network diagram for car pedal component (concurrent engineering)*

Procedure for designing implementation project plan is similar as in a classical project implementation, with the following important differences:

1. It is necessary to ensure as much as possible concurrency of process implementation, defined by the APQP methodology [21].
2. It is necessary to find which activities within processes can be executed concurrently, so that maximum overlapping is achieved, and to define the values of partial dependencies between network diagram activities.
3. It is necessary to define concurrent engineering loops.
4. It is necessary to form teams (sub-teams) for implementation of concurrent engineering loops.

It is obvious that by incorporating concurrent engineering elements, the project implementation changes because its processes overlap (APQP) and the network diagram structure changes, too – the goal is to achieve as high concurrency as possible. Because of a partial overlapping of interdependent activities, their execution time may even extend – without extending the project duration time. Incorporation of concurrent engineering elements does not influence the WBS and OBS project structures (Figure 18).

The process overlapping and partial dependencies between project activities require a high level of collaboration between the holders of responsibilities and operators of activities, so it is necessary to introduce concurrent engineering loops [1] and [2], as shown in Figure 19.

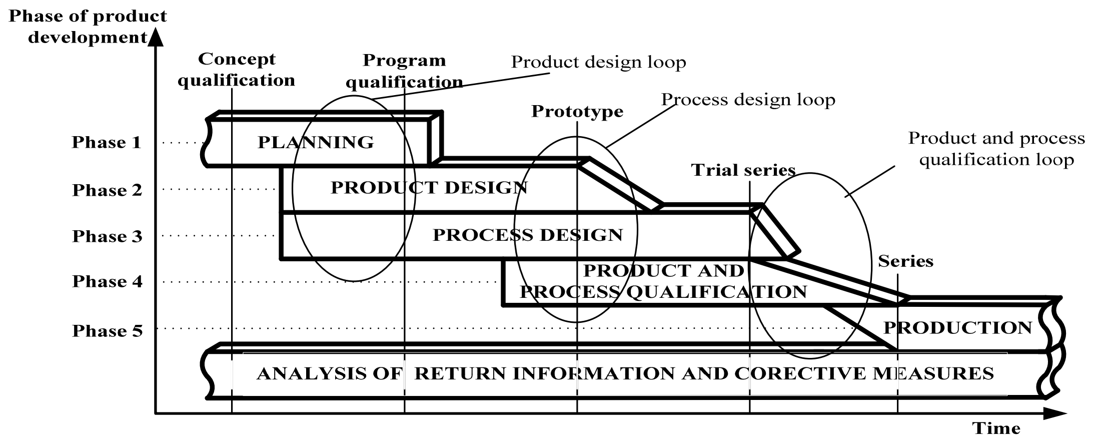


Fig. 19. *Concurrent engineering loops during product and process development for car pedal component*

Three concurrent engineering loops were defined for the car pedal component project:

- product development loop
- process development loop
- qualification of the product and process loop.

Within an individual loop, various activities are being carried out concurrently by resources from various functional units and by external contractors. To ensure on-line information exchange between operators of various activities, sub-teams are formed within the project team for implementation of concurrent engineering loops (Figure 20).

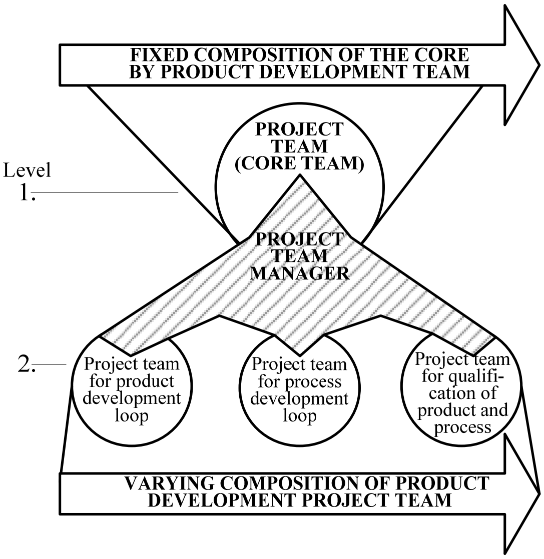


Fig. 20. *Team structures of concurrent engineering loops*

Loop teams consist of representatives (operators) from those functional units, which concurrently carry out activities of an individual concurrent engineering loop.

Loop teams do not have permanent members – they change depending on the loop for which the team is responsible or depending on the activities that will be carried out within this loop.

After all changes had been made, the project implementation time was reduced from 644 to 419 days, which is 35% reduction of project duration.

The company management was aware that project implementation on the basis of concurrent engineering elements is a very demanding process and its implementation is associated with a high risk. Nevertheless, they decided to implement this project in a new, more demanding way. They were aware that they have insufficient knowledge of concurrent engineering, so they asked the experts of the Centre of excellence for modern technologies on the Faculty of Mechanical Engineering in Ljubljana for technical assistance.

2.4.3 Implementation and Monitoring of the Project

According to the project plan, the project manager sends (in electronic form – using MS Outlook) to team members and functional unit heads the information about activities that should start with a special document containing data on planned activities, their duration and the planned date of beginning and completion. The same document has fields for entering dates of actual beginning and completion of activities.

A project team member from a particular functional unit is responsible for monitoring the implementation of activities and for current reporting on status of activities to the project manager, while functional unit head is responsible for the implementation of activities within the prescribed deadline and for achievement of the required quality. Reports on the implementation of activities are made once a week.

Project manager promptly stores the actual data into the MS Project software.

Project team makes a weekly snapshot of project status. It finds out which activities have been finished completely and which have been finished just partially. On the basis of these data a calculation of the current project status is made. By comparing it with the initial plan, the team members find which activities are delayed, which are carried out according to the plan and which are carried out faster. Also important are the analyses of critical activities, critical paths and the costs incurred so far. Problems and risks are identified (so called "status indicators" are an aid to the team members); they can be overcome by triggering an appropriate action plan made during risk analysis, and additional measures can be taken if necessary.

Project manager and team members are responsible for the implementation of measures. If a measure exceeds their competences, they forward it to the project board or to the company management. Project manager continuously keeps records of measure results.

Weekly results on current situation snapshot are published on the project management portal, listed by the whole project activities and separately by activities allocated to individual functional units of the company.

Project manager reports on the project status and on the measures taken at the project board meeting, where the project status is being harmonized with other current projects.

An analysis of all current projects, especially in terms of the used resources and costs, is prepared by the PMO.

According to the contract, the project status data are sent to the customer, who thus has an accurate overview of the project status and problems, and can participate in their solution.

2.4.4 Completion of the Project

Project is completed when all the project activities have been carried out and the objectives met. When the project has been completed, the project team made evaluation of project including:

- Meeting the deadlines and financial limits: project was completed within the agreed deadline and within the approved costs.
- Use of internal and external resources: there were great difficulties with internal resources associated with coordination of their involvement in other projects.
- Quality of project management and project deliverables: was in accordance with project management rules and with the customer's expectations, which was confirmed by two audits made by a reviser authorized by the customer.
- Overview of the planned and performed risk measures: there were many more preventive and corrective measures prepared than actually used.
- Experience obtained that is important for similar future projects: regular meetings of project team. Project team members have to be well prepared for a meeting – this is a precondition for short end effective meetings.

Likewise all other project dossier documentation, the final report was also published on the project management portal.

After the project has been completed, the company management dissolved the project team and appoints the sales department for execution of post-contract obligations.

2.5. Establishment of Multi-project Environment

After the analyses of the first results of planning and management of the test project, the company management decided that all new projects should be managed using the described procedure (one year later, more than 30 projects have been planned and managed in this way).

PMO is responsible for project coordination, especially for the use of common resources and cost management.

Every week PMO sends a report on cumulative status of all projects to the company management; the projects are classified in three categories:

- carried out according to the plan,
- carried out according to the plan with some discrepancies that are manageable,
- critical, whose discrepancies are difficult to control or even beyond control.

In each individual case the company management acts according to its strategy.

3 CONCLUSION

This paper deals with market-oriented and value-added projects and services, especially cyclically repeated projects, i.e. projects of implementing a previously developed project/service in a specific form, in accordance with the customer's requirements, and projects related to new product/process development, which are afterwards submitted to a mass production.

Introduction of project management into a company, as a mode of business process operation, is a demanding task, because it requires changes in the integration and focus of company functional units to the goals of the company. It is important that project objectives have higher priorities than functional unit priorities, and that project-friendly environment is created in a company.

It is proposed that project management be introduced in the company in four steps.

Before introducing project management into a company, the employees have to be trained to use new knowledge, methods and techniques required for project management – and change their way of thinking: from focus to the company goals, the employees have to focus to the customer/market goals ("customer is the king" principle). Project management requires continuous and on-line exchange of information, so it is important that employees learn to communicate in a way of giving and receiving the right information, at the right time and related to the task they perform. In practice, a problem of hiding information within the functional unit (or within an individual person) can still be found. It is therefore important that the company establishes a knowledge management system.

Success of introduction of project management also depends on organizational and informational changes. Authors of this paper propose that a transition from a functional to a balanced-matrix organization be made, with a possibility of further transition to a project-type organization. Our proposal can be justified by the fact that in this case an important advantage of functional units is retained. In these units specialist knowledge is concentrated, employees have permanent training available and they get to know modern trends in their field of speciality. Members of functional units participate in projects temporarily and during that time they give their maximum contribution to a successful project implementation. Working in projects, they gain experience, which they later transfer back to their functional units.

It is important that (especially in early phases – during project and process development) the best and most qualified personnel is involved, so that decisions are made as fast as possible and optimal from the quality and cost point of view.

In the company there are several projects running concurrently (even several dozens), so it is essential to set up a PMO, which supports the projects and provides management of the whole company project portfolio.

Project management procedures have been formalized by making system and operational guidelines for project management, where procedures for the implementation of individual project phases and the contents of required documents, which make a project dossier, are defined precisely.

The market requires as short delivery time as possible and the highest possible quality, so it is necessary to extend the order/service project planning and management methods with concurrent engineering elements. Concurrent engineering is based on teamwork, track and loop process of implementation and incorporation of concurrent engineering tools. IT and communication support are required for incorporation of concurrent engineering elements (ERP, PDM and PLM systems).

The proposed methodology of project management implementation, as well as planning and management of products/services was tested in a company, which is a development supplier of components for automotive industry. On the basis of the proposed methodology of project planning and management for products/services, the company management decided to create two versions of a project plan.

The results have shown that the version of project implementation, extended with concurrent engineering elements, has some essential advantages: shorter delivery time, higher quality, somewhat lower costs, simultaneous elimination of errors already in the concurrent engineering loops and not in later phases as in the sequential engineering. In spite of a higher risk, associated with the implementation of a project in this way, the company management decided to test the proposed new method and carry out the project in a new way. The customer agreed with that.

Insufficient capability and willingness of project participants for on-time, continuous and accurate communication and exchange of data and information turned out to be the main problem during project implementation.

Nevertheless, the results achieved have been encouraging, so further research will be focused mainly on the definition of criteria for formation of concurrent engineering loop teams, their internal and external information integration, and to methods for effective personal and technical communication.

4 REFERENCES

[1] Kušar J., Duhovnik J., Grum J., Starbek, M. How to reduce new product development time. *Robot. comput.-integr. manuf.*, 2004,vol. 20, no. 1, p. 1-15.

[2] Prasad B. *Concurrent Engineering Fundamentals, Integrated Product and Process Organization*, 1996, vol. I, Prentice Hall PTR, New Jersey

[3] Kendall I.G., Rollins C.S. *Advanced Project Portfolio Management and the PMO*, J. Ross Publishing, Inc., 2003.

[4] Fleischer M., Liker K.J. Concurrent Engineering Effectiveness: *Integrating Product Development Across Organisations,* Hanser Garden Publications, Cincinnati, 1997.

[5] Kušar J., Rihar L., Kisiček K., Starbek M. Experiences at Project Management Office Implementation. *Project network of Slovenia,* 2004, vol. 7, no. 4, p. 42-46 (In Slovene)

[6] Schlicksupp. H. *Creative Search for Ideas in a Company.* Watter der Gruyter, Berlin - New York, 1977 (In German)

[7] Cappels M. T. *Financially Focused Project Management,* J. Ross Publishing, Inc., 2004.

[8] PMBOK Guide, *A guide to the project management body of knowledge*, 3rd ed., Newtown Square: Project Management Institute, 2004.

[9] Meredith R.J., Mantel J.S. *Project Management,* A Managerial Approach (fifth edition), John Wiley &vSons, Inc., 2003.

[10] Badiru B. A. *Project management tools for engineering and management professionals,* Industrial Engineering Press, Instiute of Industrial Engineers, Norcross, Georgia, 1991.

[11] Bridges D., Crawford K. *How to startu pand rollout a project office*, http://www.systemcorp.com/framesite/downloads/startup_frame.html, 2. sept. 2002

[12] Block T.R., Frame J.D. *Today's Project Office: Gauging Attitudes*, PM Network, August 2001.

[13] Duhovnik, J., Starbek, M., Dwivedi, S.N., Prasad, B. Development of innovative products in a small and medium size enterprise. *Int. j. comput. appl. technol*., 2003, vol. 17, no. 4, p. 187-201.

[14] Badiru B. A. *Project Management in Manufacturing and High Technology Operations,* John Wiley & Sons, Inc., New York, 1996.

[15] Engineer J.S. *Progressive Manufacturing*, J. Ross Publishing, Inc., 2005.

[16] Turner J.R. The Handbook of project – based management, The McGaww-Hill Compnies, 1993.

[17] Brezovar A. *Process orientated organisation of production in virtual enterprices,* PhD Thesis, University of Ljubljana, 2005 (In Slovenian).

[18] Goodpasture C.J. *Quantitative methods in project management*, J. Ross Publishing, Inc., 2004.

[19] *Risk management guide for DOD acquisition sixth edition*, Department of defence, USA, 2006.

[20] Michalski J.V., King G.D. *Six sigma tools navigator,* Productivity press, New York, 2003.

[21] Stamatis D.H. *Advanced Quality Planning*, Productivity, Inc, USA, 2001.

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, 607-618
UDC 658.5

Paper received: 03.01.2008
Paper accepted: 07.07.2008

Assembly Initiated Production as a Prerequisite for Mass Customization and Effective Manufacturing

Zoran Anišić* – Cvijan Krsmanović
University of Novi Sad, Faculty of Technical Sciences, Serbia

The paper deals with a review of a complex IPS-DFA methodology with a purpose of rating and improving design characteristics regarding the aspect of the assembly process. The approach has to be applied at the level of the product assortment, basic product structure and at the component level, aiming to achieve two primary goals: rationalization of the part count and the optimization of handling and fitting parts, through the developed tools for assembly suitability enhancement. Comprehensiveness of the methodology, especially at the product assortment level, simultaneously enables increasing suitability for mass customization. The paper provides an insight into the results of circular pumps product family application with a special emphasis on the consequences concerning mass customization.

Keywords: product design, design for assembly, mass customization, concurrent engineering

0 INTRODUCTION

Mass customization and personalization are strategies developed to address the challenge by producing goods and services meeting individual customer need's with near mass production efficiency [15] and [18]. Today's turbulent markets, growing product variety, and opportunities for e-commerce require efficient approaches, like Agile Manufacturing, Just-in-Time, Build-to-Order and Mass Customization. Mass customization comprises the whole spectrum of methodologies that can benefit companies and the inevitably one is DFA due to extreme importance of assembly process and well designed production varieties for quick response to individual customers needs.

The product design process definitely plays a major role when planning and implementing mass customization. Managing the variety in the design domain is a challenging problem for manufacturers. Designing a family of products using a common platform approach instead of designing single products has gained momentum in various industries. Product families and common product platforms should help mass customizing companies to ensure economies of scale while serving all customers differently. Design for assembly (DFA) techniques and methodologies have been in use since the early 1980s, started with three independent DFA tools, representing a systematic approaches in solving the problem of products' suitability for assembling.

These tools are:

- *Boothroyd-Dewhurst DFA* [5];
- *Lucas DFA* [12];
- *Hitachi Assembly Evaluation Method,* [13].

To this day, number of researches have been made in the field of assembly suitability rating and enhancement and/but each of them covers a part of the problem [1], [14] and[17]. The applicability factor of DFA methods also has received considerable attention. There are many factors, like modularizing the product to fit the strategy, adjusting the optimum product structure, minimizing the part variety with the help of group technology principles and determination the optimum level of automation of operations to accomplish production solutions. Flowchart methods which avoid extensive mathematical analyses have been presented, such as the design for automatic assembly (DFA2), and concurrent engineering methodologies have proposed supportive measures, but there still remains the distinct separation which exists, in most companies, between the design departments and production system [10].

The basic aim of the IPS-DFA integrated methodology is to completely encompass all relevant aspects of assembly suitability from the standpoint of product, process and system designing. The paper presents the methodology for implementation of all available knowledge about the **assembly process** *(organisation, process and resources)* into a new product or in

*Corr. Author's Address: Faculty of Technical Sciences, Department for Industrial Engineering and Management, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, azoran@vts.su.ac.yu

an already existing product, enabling efficient and accurate assembly [3]. Built-in characteristics during the developing phase will lead toward the minimal expenses, short assembly times and working conditions suited to manual work. It has to be based on three principles IPS - *Integration, Parallelization and Standardisation,* generating the acronym of the full name **IPS-DFA methodology** [6]. Immediately follows the question, what does IPS-DFA methodology has to encompass. If the final goal is a **product designed for assembly** having all above-mentioned characteristics, it can be concluded that IPS-DFA methodology has to have three aspects of comprehensiveness:

- *The approach has to be applied at the level of the product assortment, structure of the complex product-representative and at the component level.*
- *The approach has to have complete mechanism for assembly suitability enhancement which consists of: developed analyses for design rating with the ability of weak point detection and the developed tools (procedures) for design improvement as a generator of ideas and suggestions.*
- *The approach has to be completely incorporated into the procedure of assembly process planning and system designing, therefore the conducted analyses and the results have to be adjusted to fit both needs.*

In addition, assembly is an operation that is executed relatively late in the manufacturing chain. Considering that most companies with large product variant numbers desire to give a product its final identity as late as possible in this chain, accomplishing this in the last operation that involves be a definite achievement. The final assembly is the last of the operations that involves making changes to the product itself would therefore be the natural choice for creating different variants of products.

Going from mass production to mass customization requires introduction a new strategy **AIP** *(Assembly-Initiated Production)* [9] providing short lead times through production. AIP is formed around the idea to assemble products from product modules on customer orders.

The total delivery time would be the time to process order + assembly time + shipping time. This gives a total delivery time considerably shorter than when manufacturing the entire product order.

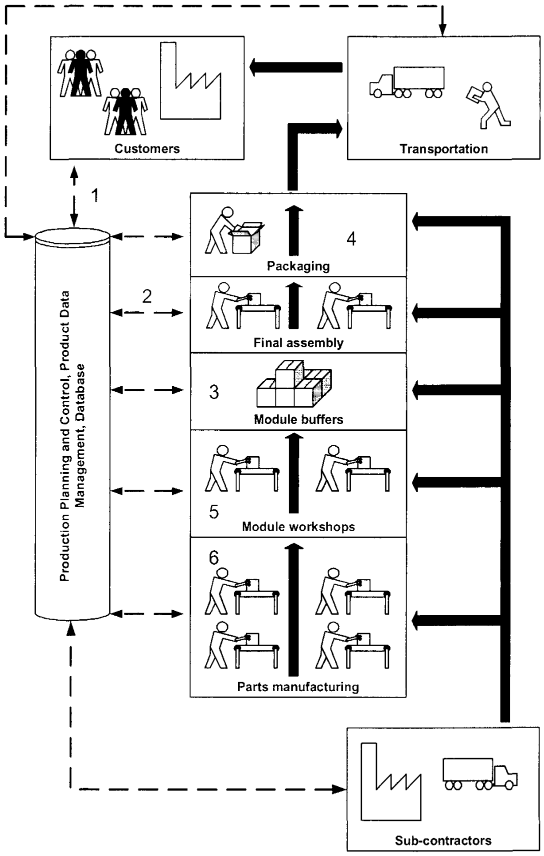


Fig. 1. *Assembly Initiated Production* [9]

Fig.1 describes the function of the AIP structure:

1. The customer order enters the computer system and is immediately available to the assembly.
2. The assembly will be able to see which orders there are in the system at an earlier stage. This will lead to a more responsive production with shorter lead-times.
3. One of the central concepts about AIP is the modularization of products. The modules and standard components will be stored close to the assembly. When an order is to be executed, components and modules will be taken from the storage and assembled into products.
4. The finished products are, after the assembly, packed and delivered to the customer. The process described so far will decide the lead time from order to delivery.

5. The module storage is set just before the module (assembly) working units. Modules are produced to keep the levels in the module storage at a preset value.
6. The demands placed upon manufacturing and ordering of components are basically the same as the ones placed upon modular working units.
7. The subcontractor's role in an AIP system will be evaluated in the scope of the project. Many of the demands set upon subcontractors will be generated by companies using AIP, regardless of what the final product is.

A modular product design is a part of the AIP strategy. Modularization is the decomposition of a product into building blocks (modules) with specified interfaces, driven by company specific reasons, called module drivers [7]. Analyzing module drivers, primary drivers for AIP are to be able to combine modules into products with different specification; different styling and that are sharing common units among variants. Basically, they are central building blocks of the AIP strategy. They make it possible to create product variants within the final assembly.

Second, to improve overall flexibility of the production, driver's carry-over of modules to new products, planned design changes, technical advancement during the product lifetime and the possibility to outsource are important. Standardization of parts that are not to be modules is included in the design process. There are also many different ways to easy production by designing the products to the specification of the manufacturing equipment. Use of design for X, including design for manufacturing and design for assembly methods will contribute to the overall flexibility and performance of the AIP system. **IPS-DFA methodology** provides answers on the most of the stated problems.

1 IPS-DFA METHODOLOGY

IPS-DFA methodology has been developed on the clearly defined principles stated in the introduction, which denote **comprehensiveness** of the methodology from three aspects, connecting *it with other IPS-DFX methodologies* in context of the wider concept of the IPS-DFX platform. The basic characteristic of the platform is the ***common data base*** in which the *integrated product and process development* starts and flows. It contains information about:

- *defined functional tasks,*
- *production system and environment,*
- *unique geometric model of the product*

as well as other necessary information which will be used during the developing phase.

Figure 2 illustrates the concept of comprehensive IPS-DFA methodology based on the principles within the frame of IPS-DFA platform, enabling simultaneous application of all available IPS-DFX methodologies.

IPS-DFA methodology transfers necessary data from the common data base, process them through developed procedure and returns the report with suggestions for corrections on the design. The integrated platform collates all returned suggestions for reconstruction from other methodologies, conforms them and equalizes existing differences, primarily on economic criteria but also on other general design evaluation criteria which could not be explicitly expressed through expenses.

Determined parameters are, according to the third aspect of *comprehensiveness,* ***integrated into the procedure of product planning and system designing,*** i.e. in documents that already exist enabling parallelism and **uniqueness.** After the application of the procedure for assembly suitability enhancement, the developed bases enable direct continuation of the process of product planning and system designing with significant shortening. The second aspect of comprehensiveness states that after the rating of the level of assembly suitability the obtained values be compared with the referent (margin) ones and to suggest concrete measures for assembly suitability enhancement, whereas all measures consist of formal procedures for enhancement, recommendations based on research work and knowledge base with examples, as an idea generator.

1.1. Assembly Suitability Indicators

In the context of the first aspect of **comprehensiveness,** detailed analysis of the influence of the production assortment, product structure and components on assembly process have been performed resulting in the list of necessary and sufficient number of indicators and parameters necessary for computing.

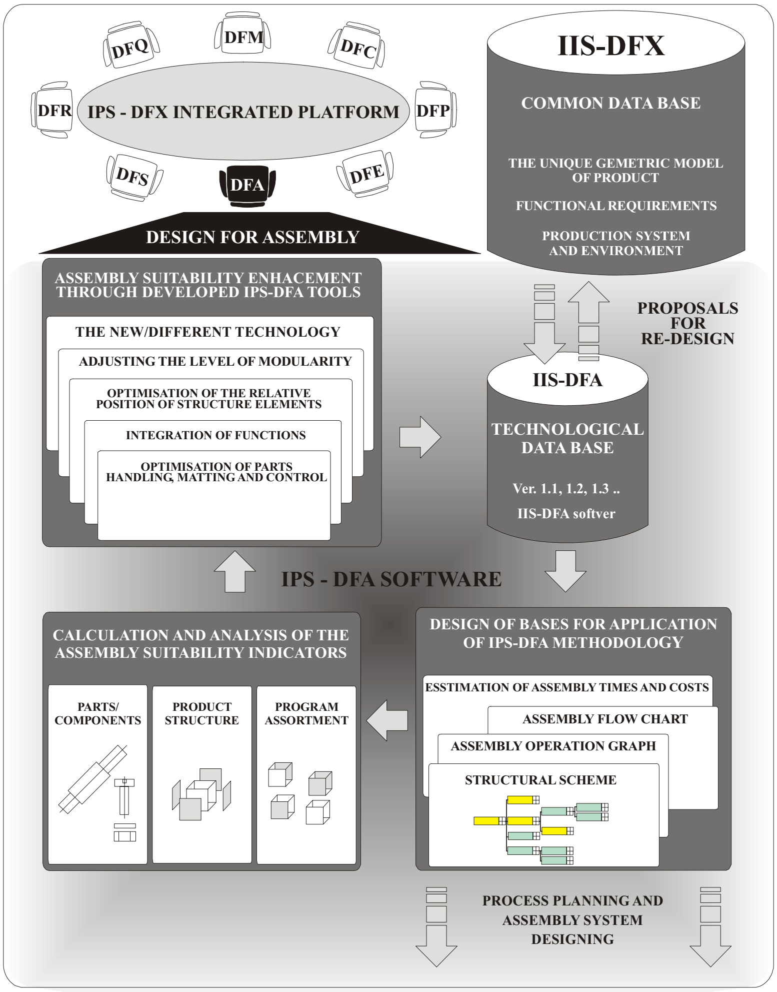


Fig. 2. *Concept of IPS-DFA methodology within the framework of IPS-DFX* [3]

1.1.1 Assembly suitability indicators at the production assortment level

A production program (assortment) is a group of similar products (p_1 - p_n) with the primary goal - fulfilment of a certain set of basic functional requirements (FRi), the most important background in the designing stage, as well as the fulfilment of the additional requirements as a result of the customers' individual demands, either technical or esthetical. The quality of designing, as a function of the production program structure, is generally defined as a maximum number of product variation p_1 - p_n that can be made with a minimum number of different parts $N_{P\text{tot}}$. All parts that make various product variations have to go through the assembly system in the assembly process. If the structure of the production program is too wide, the possible level of automation and mechanization is lower, even the product representative itself is optimally designed.

After completing the research, four indicators of the assembly suitability are at first established**,**

- Np_{tot} – total number of different parts in the production assortment,
- P_v – suitability of product variant development,
- P_a – automation suitability indicator,
- P_m – number of modules,

capable of presenting the quality of certain production assortment and highlighting weak points that may require designers intervention.

1.1.2 Assembly Suitability Indicators at the Product Structure Level

From the point of the product structure suitability, the most important fact is minimisation of the number of parts and interconnections between them that would lead to the shortest assembly times and costs. The efficiency of the product structure is usually estimated by the following characteristics:

- *number of parts that make the subassemblies and assemblies,*
- *number and orientation of insertion axes,*
- *structural product scheme,*
- *joining techniques,*
- *modularity, standardization...etc.*

In order to calculate the next four indicators at the product structure level, it is necessary to make a structural scheme of the product, assembly operation list and possible assembly sequence graph.

N_P – number of parts of the basic product variant,
P_{fs} – functional suitability of a product,
$P_{ext.}$ – number of additional subass. movements,
P_{bas} – minimum number and sequence of assembly operations.

2.1.3 Assembly Suitability Indicators at the Component Level

The analysis at the component level (considers the geometry, physical and chemical characteristics of a part, and thus determines if a part is suitable for exclusion, handling, orientation and positioning. The main objective is to determine the time and costs of the assembly operations using various methods and techniques.

These estimates can be made for manual, robotized and automated assembling based on DFA handling and joining empirical cases [5]. Assembly suitability indicators at the component level

P_{gt} - suitability for group technology
Σt_{ii} - assembly operation time,
T_M - costs of assembling operation.

1.2. Tools for Assembly Suitability Enhancement

IIS-DFA methodology also includes developed tools for assembly suitability enhancement. Their primary goal is to reduce the part number as the most effective measure, eliminating the complete assembly operation. If further rationalization is not possible, there is a tool for part optimization from the point of handling, insertation and control operations. Having in mind the previous discussion,

Fig. 3 shows developed tools organized in five levels. Each tool consists of three parts:

- *formal (analytic) procedures for enhancement,*
- *recommendations based on research work and*
- *knowledge base with examples, as an idea generator.*

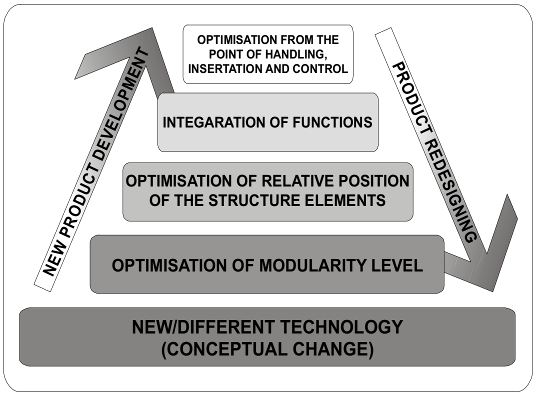


Fig. 3. *Application of the developed tools for assembly suitability enhancement in five levels*

The tools can be applied in process of new product designing or in process of redesigning the existing product.

2 APPLICATION OF THE IPS-DFA ON CIRCULAR PUMP'S PROGRAM VARIETY

Circular pumps production program consists of 14 basic product (Table 1). A total number of different parts in product assortment is 45.

Table 1. *Production program of circular pumps*

№	Product types	№	Product types
P1.	RS 15/50 P 130	P8.	RS 25/80 P 130
P2.	RS 15/60 P 130	P9.	RS 25/50 P 180
P3.	RS 20/50 P 130	P10.	RS 25/60 P 180
P4.	RS 20/60 P 130	P11.	RS 25/70 P 180
P5.	RS 25/50 P 130	P12.	RS 25/80 P 180
P6.	RS 25/60 P 130	P13.	RS 30/50 P 180
P7.	RS 25/70 P 130	P14.	RS 30/60 P 180

Fig. 4. *Circular pump representative – CAD model*

The basic variant, the one with the highest quantities is item No.3. RS 20/50 P130 consisting of 35 different positions (Figure 4).

Representing the whole production variety is of a vital interest, and it is enabled through creation of a structural scheme, with respect to the following rules. The structural scheme is generated for the most complex product (with the largest number of parts).

Initially generated structural scheme is progressively expanding, analyzing the whole assortment range from p_1 to p_n. During the process of structural scheme design regarding the whole production assortment, each part is classified into one of three groups:

- *Universal parts are parts that belong to each product variant (p1-p14),*
- *Poly-variant parts belong to the several product variants and*
- *Variant parts are explicitly addressed to one specific product variant.*

Figure 5 represents the structural scheme, generated for the circular pump's program variety.

According to IPS-DFA methodology (Figure 2), if the background documents are prepared and assembly suitability indicators calculated, the next step concerns an application of a specified number of iterations regarding the developed tools for design improvement - from Version 1 to Version 4.

In addition to, the structural scheme embracing the most needed parameters for assembly indicators calculation, the following backgrounds are also required: ASSEMBLY OPERATION GRAPH, ASSEMBLY FLOW CHART, ESTIMATION OF ASSEMBLY TIMES AND COSTS.

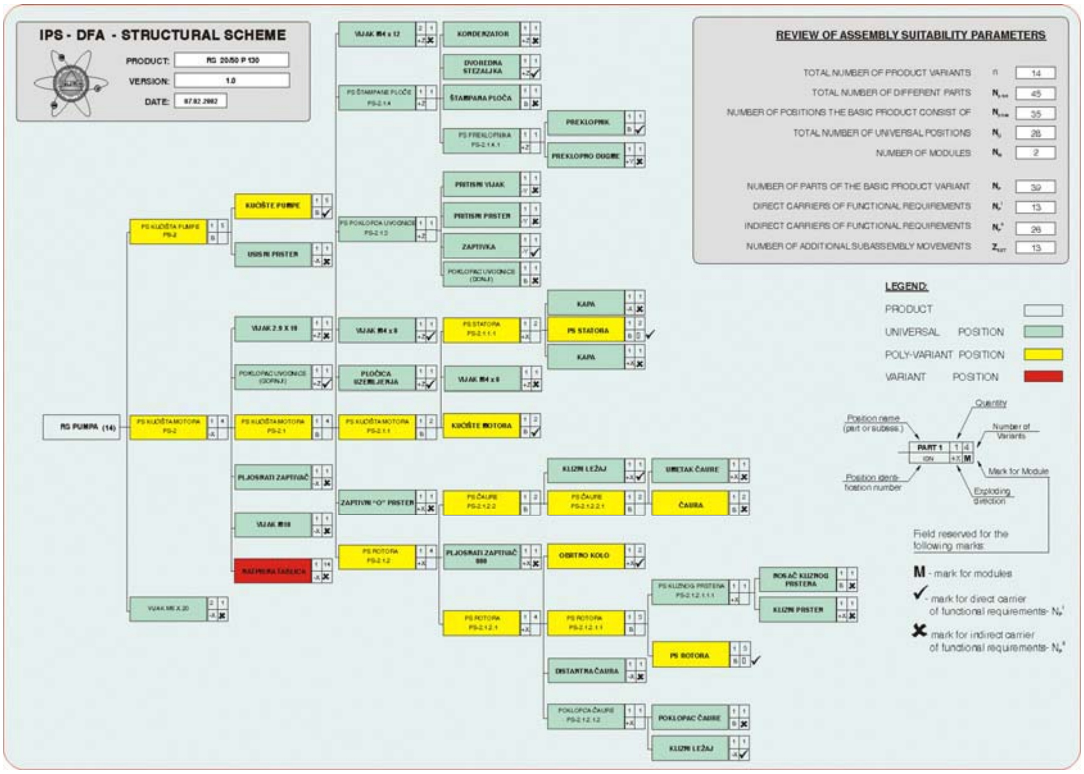


Fig. 5. *Structural scheme – representation of the product assortment*

2.1. Optimisation of Parts

The first measure for assembly suitability enhancement is a tool for optimisation of particular parts that are difficult to assemble, belonging to standard library parts or making the group of poly-variant parts. The results assume corrections on geometric features, material, surface quality, dimensions or tolerances (Figure 6).

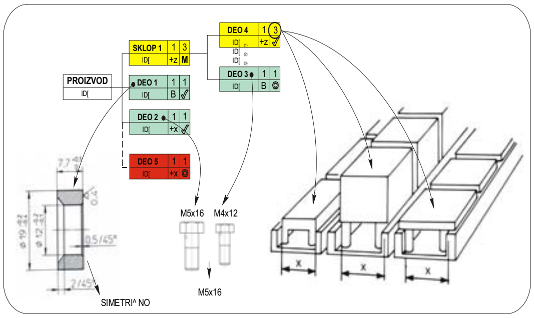


Fig. 6. *Optimization of parts*

The procedure starts with the identification of inconvenient surfaces on parts, concerning following operations *transport, orientation, positioning, joining, control, etc.,* and the main characteristic of the surfaces: functional (support, transfer forces, lead, etc.), connecting (touching or lying next to) or free (not functional or connecting) surfaces. The success of the procedure depends on a lot on the above mentioned surface character, allowing more or less freedom in making improvements toward assembly suitability and their acceptance (Figure 7).

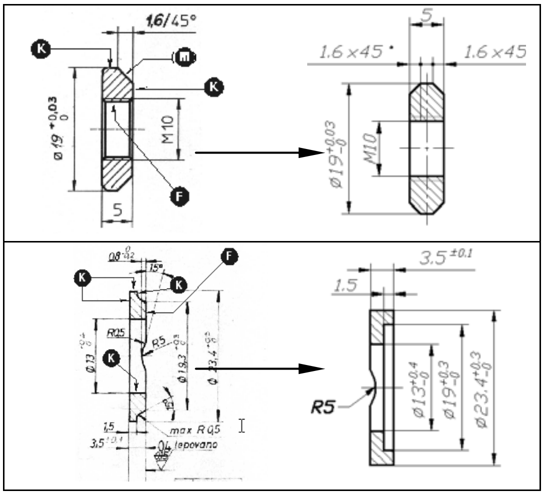


Fig. 7. *Examples of part optimisation*

2.2. Integration of Functions

The procedure prediction the possibility of making integration of two or more parts into one, depending on the efficiency of the given design solution. The integration is primarily related to parts *indirect carriers of functional requirements*, but can be applied without exception to parts *direct carriers of the functional requirements*. Although a strong line could not be drawn, the integration of functions is primarily related to the local (leaf) levels of the structures, to components or the simplest subassemblies. If the integration is successful, the *global structure of the product* will stay unaffected.

In order to make the integration of a certain number of parts, which will lead to elimination of assembly operation, a specific algorithm is developed for identification of parts suitable for integration (Fig. 8). Three fundamental reasons for differentiation have to be reconsidered of the given whole on the final number of elements. The creative thinking of the designer is stimulated through intentional and targeted questions for verification of each position in the design from the point of necessitation and justification for it's presence in the design. If passing through algorithm even one good reason is found for the existence of part as a separate entity, then it belongs to the group of elementary parts. On the contrary, the part belongs to a set of entities that's functions could potentially be transferred to part/parts in direct contact and perform the integration, physically eliminating it from the design.

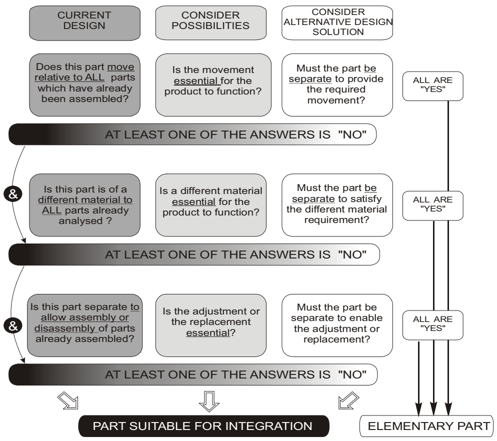


Fig. 8. *Algorithm for identification of parts suitable for integration*

Figure 9 shows the results obtained through integration of two or more parts in one.

2.3. Optimization of the relative Position of Structure Elements

The next step on the way to enhance assembly suitability is to vary the structure of the product, in order to optimise the relative position of elements (subassemblies). The achieved corrections will directly affect the structure: mating directions (±X, ±Y, ±Z), number of assembly flows, sequence of operations P_z, presence of the base component, the number of the extra operations P_{ext}, possibility of simultaneous performing the operations, minimum through output assembly time $t_{ct\ min}$, etc.

The procedure starts with the analysis of the structural scheme of the product and continues with the following:

- *Determination of the main assemblies and subassemblies through the desired level and symbolical representation,*
- *Symbolically represented main elements are varied in different spatial combinations,*
- *The most promising combinations that are not in collision with the defined functional requirements are going to be developed further,*
- *The choice of the optimum structure is based on the defined criteria,*

Figure 9 shows the reduction of few mating directions through changing the relative position of structure elements. Product shown on (Fig.9) (left) has 5 different matting directions (±X; ±Y; +Z), and after the reconstruction, the new design (Fig.9) (right) has only one matting direction (+X).

2.4. Optimization of the Modularity Level

Having in mind all disposable knowledge about the modularity and the consequences concerning assembly process, twelve basic features are highlighted as modularity drivers, if the existing number of modules is not satisfactory. The main features are organized in Table 2 to simplify the reconstruction of the product structure, recognizing and translating certain subassemblies into modules. The procedure starts with the matrix (Table 2) where the twelve modularity drivers are opposed to the complete product structure, including all building levels - subassemblies and parts.

Table 2. *Matrix of modularity drivers*

	ELEMENTS OF ***STRUCTURE***	ASSEMBLY S-1	SUBASSEMBLY PS-1.1	SUBASSEMBLY PS-1.2	PART D-1	ASSEMBLY S-2	SUBASSEMBLY PS-2.1
	NAME	*	**	**	**	*	*
1	CARRY-OVER	●					
2	TECHNOLOGICAL EVOLUTION			○			
3	PRODUCT PLANNING			○	⊘		
4	TECHNICAL SPECIFICATION						
5	STYLING						
6	COMMON UNIT						
7	PROCESS/ORGANIS ATION REUSE		●		⊘		
8	SEPARATE TESTING OF FUNCTION					○	
9	BLACK BOX						
10	SERVICE & MAINTANANCE						
11	UPGRADING						
12	RECYCLING						

Note: ●-3 points, ⊘-2 points i ○-1 points

The matrix is filled with the given symbols illustrating the importance of certain features and the possibility that a given subassembly or component becomes a module. It is important to emphasise that the success of the procedure is tightly connected to defined functional requirements for the given product FRi, because the module generation is one of the earliest stages in product developing process, preceeding the detailed definition of structure. Elements of the structure having the highest number of points in total are separated as the most serious candidates for modules and it remains to be reconsidered if there is some design or technological constraints.

2.5. Application of the New / Different Technology

The last level of product enhancement is the most radical one, and if it can be technically accomplished, it brings the largest benefit. The application of the new/different technology is

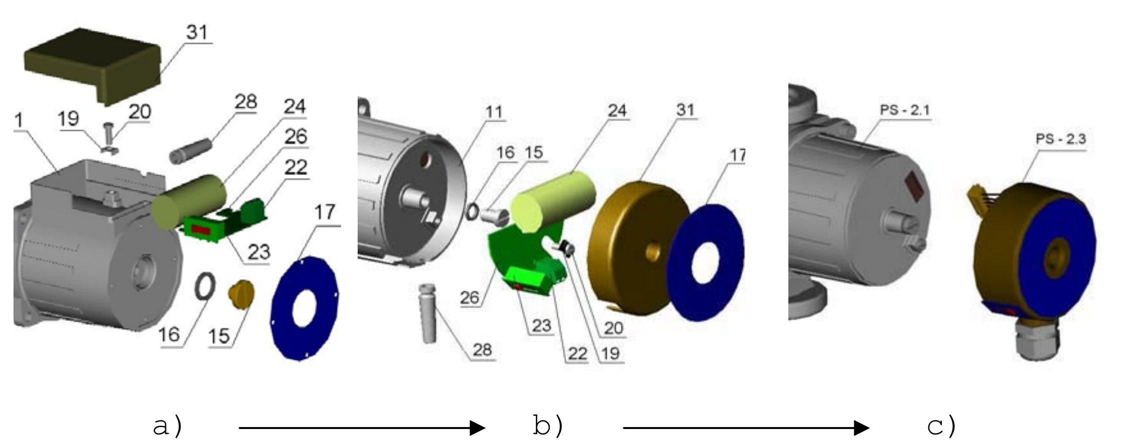


Fig. 9. *The results of applied tools for optimization of product structure and increasing the level of modularity*

connected to applied sciences as a result of the latest researches in fundamental sciences.

Morphological analysis is a methodology of a significant help in applying the new/different technologies. It is defined as an approach for systematical thinking and finding solutions for different problems. Morphological analysis enables the generation of possible developing alternatives in product designing.

2.6. Feedback Report - Proposals for Re-design

After the application of the developed tools for assembly suitability enhancement, it is to be expected that the number of proposals for re-design will follow. The proposals have to be clearly presented in the document “PROPOSAL FOR RE-DESIGN”, where the expected savings in assembly times and costs are particularly highlighted. Further, the proposals have to be critically analyzed if they cause negative consequences in some other aspects of the design, and if so, the proposal has to be rejected avoiding the additional efforts of other experts in the DFX team.

If the DFA expert, according to his professional knowledge and experience does not see any obstacles for implementation of the suggestion, the proposal has to be transferred to be verified by the DFX team, where two different cases may occur.

- *The proposal for re-design is not delayed in any aspect, and can be directly implemented in product design;*
- *The proposal for re-design is delayed by the expert team, sent for a detailed cost-benefit analysis, and followed by a renewed discussion about verification.*

The DFX expert’s team has to have as much iteration as necessary until none of participants has any objections to the proposal, so a consensus about the design reconstruction is achieved.

3 CONCLUSION

The developed IPS-DFA methodology completely came to the expectations, from the point of assembly suitability enhancement, since the established indicators connected with the developed tools enable a systematic improvement of certain detected weak points in the design, which has been confirmed in the number of case studies. After the process of re-designing has been completed, circular pump’s program variety structural scheme (Figure 10) clearly indicates the achieved simplifications concerning the part count and part variety reduction – smaller yellow boxes with poly-variant parts. Continuously monitoring indicators through developed on three levels, enables one to track every single change in the design and the consequences it has on the assembly process.

Table 3 briefly summarizes the accomplished achievements with the given assembly suitability indicators after each iteration has been performed (ver.1-ver.4).

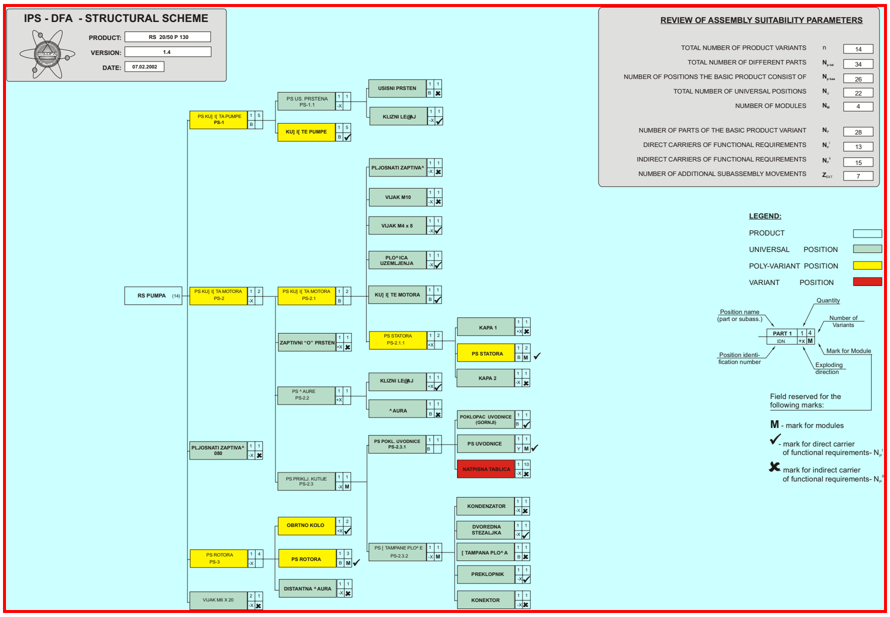


Fig. 10. *Simplified structural scheme depicting product family, after applying IPS-DFA*

Table 3. *Review of assembly suitability indicators after application of IPS-DFA*

No	SUITABILITY INDICATORS (Production Assortment)		Ver 1.4	Ver 1.3	Ver 1.2	Ver 1.1	Ver 1.0	Jed.
1.1	Total number of different parts in the production assortment	$N_{p\ tot}$	35	35	37	44	45	-
	Number of positions the basic product consist of	$N_{p\ bas}$	27	25	27	34	35	-
	Number product variants in the production program	n	14	14	14	14	14	-
1.2	Suitability of product variant development	$P_v=(N_{p\ totu}-N_{p\ bas})/n$	57%	71%	71%	71%	71%	-
	Total number of parts in the production program	N_U	23	18	20	28	28	-
1.3	Automation suitability indicator	$P_a=N_U/N_{p\ tot}$	66%	51%	54%	64%	62%	-
1.4	Number of modules	$P_m=N_m$	3	2	2	2	2	-
No	**SUITABILITY INDICATORS (Product Structure)**		**Ver 1.4**	**Ver 1.3**	**Ver 1.2**	**Ver 1.1**	**Ver 1.0**	**Jed.**
2.1	Number of parts of the basic product variant	N_P	29	28	30	39	39	-
	Direct carriers of functional requirements	N_P^I	13	13	13	13	13	-
	Indirect carriers of functional requirements	N_P^{II}	16	15	17	26	26	-
2.2	Functional suitability of a product	$P_{fs}=N_P^I/N_P$	45%	46%	43%	33%	33%	-
2.3	Number of additional subassembly movements	$P_{ext}=Z_{ext}$	7	5	11	13	13	-
2.4	Min. number and sequence of assembly operations.	$P_{bas}=T_{ct\ min}/T_{ct}$	133/42%	150/54%	168/49%	197/45%	197/45%	-
No	**SUITABILITY INDICATORS (Component level)**		**Ver 1.4**	**Ver 1.3**	**Ver 1.2**	**Ver 1.1**	**Ver 1.0**	**Jed.**
	Number of the universal assembly tasks	m_u	18	16	19	22	22	-
	Total number of assembly tasks in basic product	m	20	18	21	24	24	-
3.1	Suitability for Group Technology	$P_{GT}=m_u/m$	90%	89%	90%	92%	92%	-
	Assembly handling time	Σt_p^R	60.76	53.91	61.89	79.94	81.50	sec
	Assembly inserting time	Σt_o^R	221.00	183.50	241.50	284.50	298.00	sec
3.2	Assembly operation time	$\Sigma tii^R=\Sigma t_p^R+\Sigma t_o^R$	313.26	282.50	338.39	406.94	427.95	sec
	Costs of manual part handling	ΣT_p^R	3.96	3.56	4.03	5.20	5.31	din/kom
	Costs of manual part inserting	ΣT_o^R	14.39	12.73	15.72	18.52	19.40	din/kom
3.3	Costs of manual assembling operation	$T_M^R=\Sigma T_p^R+\Sigma T_o^R$	20.39	18.39	22.03	26.49	27.86	din/kom
	Costs of automated part handling	ΣT_p^A	20.72	17.87	29.51	29.30	27.72	din/kom
	Costs of automated part inserting	ΣT_o^A	36.59	34.08	47.77	46.94	44.87	din/kom
3.3	Costs of automated assembling operation	$T_M^A=\Sigma T_p^A+\Sigma T_o^A$	59.74	54.18	63.49	80.67	76.50	din/kom

At the program assortment level:

- *A total number of parts is decreased*
  $N_{du}^{IV}-N_{du}^{I}=45-35=10$ or 23%,
- *Product variant development suitability is increased by 14%,*
- *The possible automation level amounts to 66%,*
- *The number of modules is increased by one.*

At the product structure level:

- *A total number of parts of the basic product*
  $N_{D}^{IV}-N_{D}^{I}=39-29=10$ or 26%
- *Functional suitability of the basic product is increased by 45% - 33% = 12%,*
- *The number of additional assembly operations is decreased 13-7=5,*

- *The shortest possible assembly time of a product is also decreased from 197 s to 133 s*

At the component level:

- *The suitability for group technology application is very high 90%,*
- *The estimated manual assembly time is 427.95 s - 313.26 s =114.69s ≈ 2 min/item,*
- *The estimated manual assembly costs are decreased*
  0.43 €/item - 0.31 €/item = 0.12 €/item,
- *The estimated automated assembly costs are decreased*
  1.18 €/item – 0.92 €/item = 0.26 €/item

The achieved results concerning the IPS-DFA methodology application, in addition to the benefits regarding the assembly process, has another great impact on the production variety of circular pumps mass-customization. Figure 11 clearly indicates the obtained results at the production assortment level that mass customization can mostly benefit from. The 14 basic product variants now consist of less parts, component and variants. As a result, the desired customer order is easy to configure at the system entry.

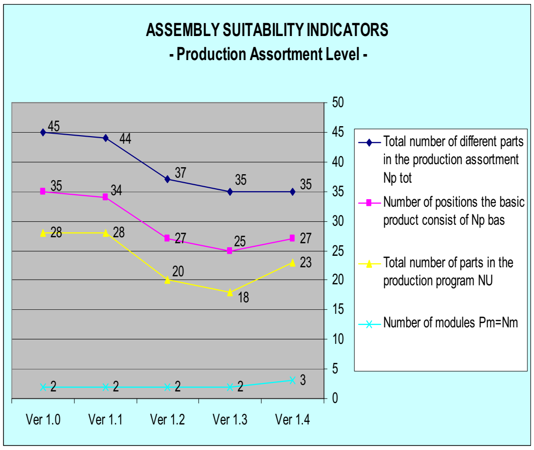


Fig. 11. *Increasing the program variety*

Additionally, the product is re-designed to be modular and the AIP concept can be easily applied to the production system designing, by forming three separate working units for subassembly of modules and one separate working unit for the final assembly (Figure 12). The automation level regarding final assembly can be manual or semiautomatic, while modules subassembly can be highly automated in separated assembly workshops. For example, the connecting box became a standardized module and it can be assembled with the highest automation level independently of the ordered variant.

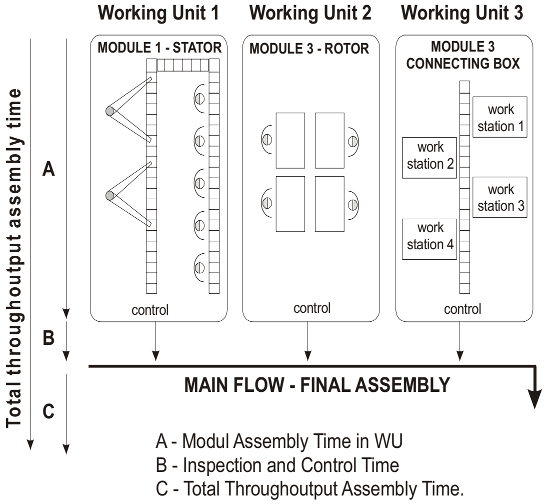


Fig. 12. *Circular pumps assembly system organized in separate working units*

It is important to emphasize in the conclusion, that IPS-DFA methodolgy and Mass Customization concept [4], [16] is directly in coordination with approach to design of *effective industrial system structures* [19], [20] based on principles of *group technology* and *product approach* in the designing of enterprise structure.

4 REFERENCES

[1] Andreasen, M., Kahler, S., Lund, T. (1988): *Design for Assembly*, JFS Public, ISBN 0-387-15435-5, UK.

[2] Anderson, D.M.(1997): *Agile Product Development for Mass Customization*, JIT, Build-to-Order, and Agile Manufacturing, Agile Product Development for Mass Customization, McGraw-Hill.

[3] Anišić, Z. (2002): *Investigation of the Effects of Integrated Product Development on Technological Assembly Structures and Determining the Optimal Level of Automation*, PH.D. thesis, Faculty of Technical Sciences, University of Novi Sad.

[4] Anišić, Z. (2006): Some Results of the Implementation of the MC Concept in Small Companies, *Annals of the Faculty of Engineering Hunedoara 2006*, vol.4, no.2, p. 127- 136, ISSN 1584-2665.

[5] Boothroyd, G., Dewhurst, P. (1983) *Design for Assembly*, Handbook, University of Massachusetts, Amherst, USA.

[6] Bullinger, H.J. Warschat, J. (1996): *Concurrent Simultaneous Engineering Systems*, Springer-Verlag, London, Berlin, Heilderberg, New York, ISBN 3-540-76003-2.

[7] Erixon, G.(1998): *MFD-modular function deployment, a systematic method and procedure for company supportive product modularization*, PH.D. thesis, The Royal Institute of Technology, Stockholm.

[8] Huang, G.Q., Mak, K.L.(1998): The DFX Shell: A Generic Framework for Applying 'Design For X' (DFX) Tools, *International Journal of Computer Integrated Manufacturing,* vol.11, no. 6, p.475-484.

[9] Karlsson, A.:(2002). Assembly initiated production – a strategy for mass customisation, utilising modular, hybrid automatic production systems, *Journal of Assembly Automation,* vol.22, no. 3, p.239-247, ISSN 0144-5154

[10] Krsmanović, C., Simić, M. (2002): Multifunctional and Intelligent Technical Systems – Fundamentals of Development and Design, 12th Scientific Conference on Industrial Systems, Vrnjacka Banja, 2002, Proceedings, vol.1, p.373 – 380

[11] Krsmanović, C. (2004): A Simulation Approach to Design as a Base for Product Quality and System Effectiveness Assurance (in Serbian), 3rd Conference About Construction, Shaping and Design, Novi Sad, May 2004, Proceedings, vol. 1, p. 39 – 44.

[12] Lucas Engineering System Ltd. (1995), University of Hull, Design for Assembly/ Manufacture Analysis Practitioners Manual, Version 10.5

[13] Miyakawa, S., Ohashi, T., Iwata, M.(1990): The Hitachi New Assemblability Evaluation Method, Transactions of the north American Manufacturing Research Institution, NAMRI Conference XVIII, Pennsylvania State University, Dearborn.

[14] Onori, M. (2002): Product Design as an Integral Step in Assembly System Development, Viewpoint, *Journal of Assembly Automation*, vol.22 no.3, ISSN 0144-5154

[15] Piller, F. Walcher, D. (2006): Toolkits for idea competitions: A novel method to integrate users in new product development, *R&D Management*, 36 (2006) 3: 307-318.

[16] Pine, B.J. (1993): *Mass Customization*, Boston: Harvard Business School Press.

[17] Rampersad, K.H. (1996): Integrated and Assembly Oriented Product Design, *Journal of Integrated Manufacturing Systems*, Vol.7, p.5-15, ISSN 0957-6061

[18] Tseng, M.M., Piller, F.T. (2003): *The Customer Centric Enterprise: Advantages in Mass Customization & Personalization*, Springer: New York/Berlin 2003.

[19] Zelenović, D., Ćosić, I.(1991) : *Assembly Systems*, (in Serbian) Nauka, ISBN 86-7621-045-4, Beograd, YU.

[20] Ćosić, I., Anišić Z. (2003): Methodology For Assembly Suitability Enhancement as a Part of Integrated Product Development, Ed. Katalinić, B.: *DAAAM International Scientific Book,* Vienna, Austria: DAAAM International Vienna, , ISBN 3-901509-30-5. p. 137- 148.

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, 619-627
UDC 681.5:007.52

Paper received: 05.12.2007
Paper accepted: 07.07.2008

Uncalibrated Visual Servo Control with Neural Network

Rok Klobučar[1,*] - Jure Čas[1] - Riko Šafarič[1] - Miran Brezočnik[2]
[1] University of Maribor, Faculty of Electrical Engineering and Computer Science, Slovenia
[2] University of Maribor, Faculty of Mechanical Engineering, Slovenia

Research into robotics visual servo systems is an important content in the robotics field. This paper describes a control approach for a robotics manipulator. In this paper, a multilayer feedforward network is applied to a robot visual servo control problem. The model uses new neural network architecture and a new algorithm for modifying neural connection strength. No a-prior knowledge is required of robot kinematics and camera calibration. The network is trained using an end-effector position. After training, performance is measured by having the network generate joint-angles for arbitrary end effector trajectories. A 2-degrees-of-freedom (DOF) parallel manipulator was used for the study. It was discovered that neural networks provide a simple and effective way of controlling robotic tasks. This paper explores the application of a neural network for approximating nonlinear transformation relating to the robot's tip-position, from the image coordinates to its joint coordinates. Real experimental examples are given to illustrate the significance of this method. Experimental results are compared with a similar method called the Broyden method, for uncalibrated visual servo-control.

Keywords: robots, neural networks, visual servoing, parallel manipulator

0 INTRODUCTION

An animal's brain develops accurate sensory-motor coordination in the face of many unforeseen changes in body dimensions, strength of the muscles, and placement of the sensory organs. This is accomplished, for the most part, without a teacher [1]. Can this skill be implemented in to a robot's control system? This paper presents some new architecture regarding artificial neural network for visual servo control.

Visual servo algorithms have been extensively developed in the robotics field over the last ten years [2]. Vision is a useful robotics sensor since it mimics an animal's sense of vision [3]. Visual control of robots allows for non-contact measurements of the environment, as opposed to the traditional encoder and end limit switches [4]. Owing to the reduction in hardware costs and the increase in computing power, the focus of vision research has turned to introducing visual data into the control-loop of a robot. Using visual data within the control-loop is termed as 'visual servoing' [5]. Visual servoing is the fusion of many areas such as image processing, kinematics, dynamics, motion control, and real-time computing. The task during visual servoing is to control a robot when moving within its environment using vision.

The robot controller is required to solve the inverse kinematics problem in order to move the robot tip to a desired point or along a desired path. This problem involves the computation of a sequence of links angles that will position the robot tip at the desired location.

The computational complexity involved when numerically solving of the inverse kinematics problem, and the capability of neural networks to approximate arbitrary functions, has attracted many researchers into applying neural networks to this problem [6]. Most of these approaches use known solutions for forward kinematics or inverse kinematics problems in order to generate input-output patterns for the neural network training process.

A lot of authors have presented uncalibrated visual servoing and several groups have shown how image Jacobian itself can be estimated online from the measurements of robot and image motions. Hosoda and Asada [7] present an uncalibrated visual servoing for static targets using a fixed camera. Jägersand [8] takes the approach of a nonlinear least-squares optimization method using a trust-region method and Broyden estimation. Pieprmeier [9] develops a dynamic Broyden Jacobian estimation for a moving target, where a steady camera is used within the workspace.

*Corr. Author's Address: University of Maribor, Faculty of Electrical Engineering and Computer Science, Smetanova ulica 17, SI-2000 Maribor, Slovenia, rok.klobucar@uni-mb.si

Our task is to build a system for robot control that is completely independent of robot kinematics, camera calibration, and robust to external modifications. This paper proposes a visual servo-control with artificial neural network serving as a robot kinematics approximator. Our proposed method is compared with the Broyden algorithm for visual servoing, as developed by Jagersand [10].

The key attribute of neural networks is their ability to serve as a general nonlinear model. Thousands of data points are fed through a black box until the output of the network converges into the true system. It has been shown [11] that any function of practicable interest can be closely approximated arbitrarily with a neural network having enough neurons, at least one hidden layer, and an appropriate set of weights. The computation high speed and general modelling capability of neural networks are very attractive properties for nonlinear compensation problems, as indeed robot control problems are.

This paper proposes a method for IBVS (Image Based Visual Servoing) based on a neural network for solving nonlinear (dynamic and kinematic) systems, which takes control over the robot's joints in order to position the end effector into the static point or to track the moving target along an unknown trajectory. This paper is organized as follows. Section 2 discusses major classes of visual systems. Section 3 describes a manipulator control scheme. Section 4 describes Broyden's estimation and the definition of the feature Jacobian. Section 5 describes a visual servo control algorithm with artificial neural network. The experimental system and experimental results are shown in section 6. Finally section 7 summarizes the paper.

1 FUNDAMENTALS OF VISUAL SERVOING

One of the most basic design issues in any vision-based robotic system is the open or closed loop control. Many industrial systems use open-loop control. Open-loop control may be termed as a "look and move" kind of action, wherein, at each step, the system halts its action, processes the visual information and then executes the next step. Open-loop control may be used in cases where the vision processing system is too slow for real-time control.

Closed-loop control requires the visual data to be used as a feedback signal in the manipulator control and requires vision processing with acceptable speed and delay factors for real-time applications. Closed-loop control also allows visual data to compensate manipulator positioning inaccuracies and sensor noise.

Visual servo control systems typically use one of two camera configurations: end-effector mounted, or fixed in the workspace [12]. The first one is often called an eye-in-hand configuration. In this case, often constant relationship between the pose of the camera and the pose end-effector exists. The second configuration has the camera fixed in the workspace. In this case, the camera image of the target is independent of the robot's motion, unless the camera is connected to the second robot.

Classical approaches to visual servoing are position-based and image-based systems.

During position-based control, features are extracted from the image during iteration of the control loop and evolving of an estimate of the target's pose with respect to the camera. This error signal is computed as the difference between the current and desired poses. The advantage of position-based control is that it is possible to describe tasks in terms of positioning as Cartesian coordinates and the disadvantage is that it is often highly calibration-dependent. Hutchinson, Hager and Corke [3] contend that a key issue in position-based visual servo is the estimating of quantities to parameterize the feedback. Hence, it follows that position-based visual servoing is closely related to the problem of recovering scene geometry from the camera. Figure 1 shows position-based control.

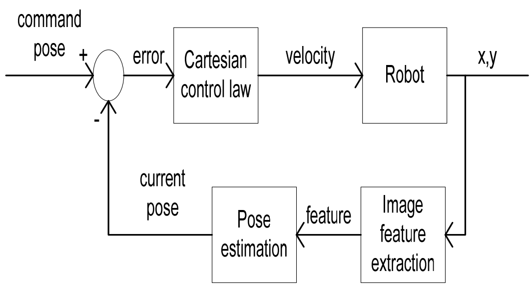


Fig. 1. *Position based control*

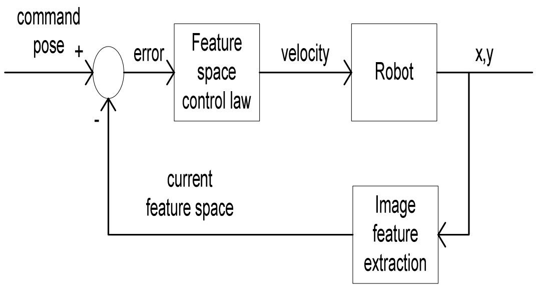


Fig. 2. *Image based control*

Image-based control consists of specifying the positioning task directly from the image without an estimation of the target's pose. Figure 2 shows image based control. Feedback is computed from the image plan, and the error is computed as the difference between the desired feature vector and the current feature vector. Elements of the task are therefore specified in the image space rather than the world space. i.e in pixles rather than Cartesian coordinates [5]. The task of the image-based control is to reduce an appropriate error function. The error function is defined within the image parameter space and input to the robot is in the task space. The feature Jacobian captures these relationships, and it is a linear transformation from image feature parameters to changes in the robot's position.

The main advantage of image-based control over position-based control is that no camera calibration is needed.

2 MANIPULATOR CONTROL SCHEME

The objective is to move the robot tip of robotic manipulator towards a target point. Movement of the robot's arm is achieved by generating the control signals through the use of visual information and a neural network.

This method is evaluated by experiment using a 2DOF planar robot manipulator built at the Institute for Robotics, University of Maribor. The camera is fixed within the workspace and can provide positional information of the robot's tip and the target in the robot's workspace. Figure 3 shows the robot and the visual system model.

The robot's forward kinematics is given by the following equation:

$$\vec{x} = L \cdot \begin{bmatrix} \cos(q_1) + \cos(q_2) \\ \sin(q_1) + \sin(q_2) \end{bmatrix}, \tag{1}$$

where q_1, q_2 are the robot's joint angles, and $\vec{x}$ is a vector of the robot's tip coordinates in the Cartesian coordinates. Figure 4 shows the corresponding manipulator and its coordinate system.

$L = 0.415m$ is the length of the robot's link. The robot has four equal length links. The control system for our robot visual servoing experiment consists of two personal computers. The image processing node and the robot controller is interconnected by the 100 Mbit/s Ethernet. UDP (User Datagram Protocol) is used for exchange data between the PC control nodes. The robot controller is implemented with a DSpace DS1102 motion controller board which executes joint servo-control algorithms at 1ms period. The image processing node acquires the image from the camera, extracts the image features and executes the visual control algorithms. We employed a professional CCD camera. With a full image resolution 640x480, the AVT PIKE F-032B/C offers up to 202 fps and is, thus, particularly suited for fast applications in industrial image processing and product automation. The AVT FireGrab library for grabbing the image and computer vision, and the Gandalf numerical algorithm library were used as written in C language [13].

The relationship between the robot's joint angles and the robot's tip coordinates in the camera image is a non-linear function. The following section presents the known Broyden [8], [10] and [14] method, for uncalibrated visual servo-control.

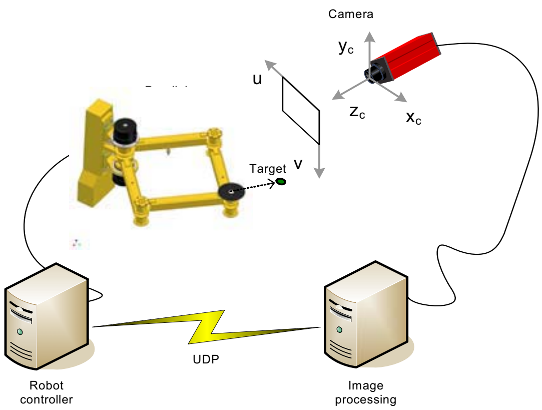


Fig. 3. *Experimental system*

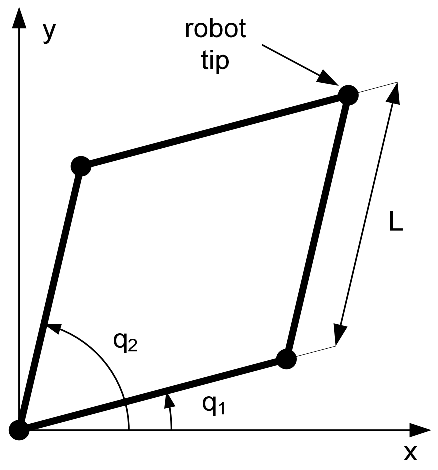


Fig. 4. *Planar 2DOF manipulator*

3 THE BROYDEN ALGORITHM

The visual servoing problem has been formulated as a nonlinear least-squares problem [10], [9], and it could be solved using quasi-Newton methods, which consider the linear model, at each iteration:

$$L_k(x;B_k) = F(x_k) + B_k(x - x_k)\,. \tag{2}$$

The model approximates F(x) in the neighbourhood of x_k and computes x_{k+1} as a solution of the linear system $L_k(x;B_k) = 0$. Quasi-Newton methods can be summarized as methods based on the equation:

$$x_{k+1} = x_k - B_k^{-1}F(x_k)\,, \tag{3}$$

followed by computation of B_{k+1}. For the pure Newton method B_k the Jacobian of F is evaluated at x_k, that is a n x m matrix such that entry (i,j) is $\partial F_i / \partial x_j$:

$$B_k = J(x_k) = \nabla F(x_k)^T\,. \tag{4}$$

Broyden [14] proposed a class of quasi-Newton methods based on secant equations, imposing the linear model L_{k+1} to exactly match the nonlinear function at iterates x_k and x_{k+1}, that is

$$L_{k+1}(x_k) = F(x_k), \quad L_{k+1}(x_{k+1}) = F(x_{k+1}). \tag{5}$$

Subtracting these two equations and defining $y_k = F(x_{k+1}) - F(x_k)$ and $s_k = x_{k+1} - x_k$ we obtain the classical secant equation:

$$B_{k+1}s_k = y_k\,. \tag{6}$$

If the dimension n is strictly greater than 1, there are an infinite number of matrices B_{k+1} satisfying(6). Applying the "least-change secant update", proposed by Broyden, leads to the following updated formula

$$B_{k+1} = B_k + \frac{(y_k - B_k s_k)s_k^T}{s_k^T s_k}\,. \tag{7}$$

3.1. The Control Scheme

The relationship between the velocity in the robot's joint space $\dot{q}$ and velocity of its end-effector $\dot{x}$ is called a robot Jacobian [15]:

$$\dot{x} = J_R\dot{q} \tag{8}$$

Similarly, the relationship between the velocity of a robot end-effector $\dot{x}$ and the velocity in the image feature space $\dot{f}$, is called image Jacobian:

$$\dot{f} = J_I\dot{x}\,. \tag{9}$$

A feature Jacobian J (10) is a compound of the robot Jacobian J_R and the image Jacobian J_I:

$$J = J_R J_I \tag{10}$$

The relationship between the velocity in a robot joint space and velocity in an image feature space is given by (11):

$$\dot{f} = J\dot{q}\,. \tag{11}$$

The visual algorithm determinates the joint's velocities $\dot{q}$:

$$\dot{q} = J^+ K\mathrm{e}\,, \tag{12}$$

where J^+ is the inverse of the feature Jacobian, K is a gain, and $e = f^d - f$ is the error signal that is obtained by comparing the desired and current image features' parameters. To obtain a vector norm we have to divide (the vector) by its length and thus we get a vector of length 1. The direction of the vector remains unchanged. The same vector is then multiplied with a gain. We norm a vector and multiply it with the gain only in the case where the length of the vector itself surpasses the given gain.

If the equation (12) is multiplied by J we get:

$$J\dot{q} = JJ^{+}Ke . \quad (13)$$

If the equation (13) is combined we get:

$$\dot{f} + Kf = Kf^{d} . \quad (14)$$

The Feature Jacobian J is obtained by the estimation process. The Broyden algorithm can be used for on-line estimation of the Feature Jacobian. The update equation of its estimate $\hat{J}$ is given by,

$$\hat{J}_{k+1} = \hat{J}_{k} + \left(\Delta f - J_{k}\Delta q\right)\Delta q^{T}\left(\Delta q^{T}\Delta q\right)^{-1} . \quad (15)$$

This method has proved to be successful. Jägersand [8] demonstrates the robust properties of this type of control and Piepmeier [9] develops a dynamic Broyden Jacobian estimation for moving target tracking.

Next section presents our proposed neural network method for uncalibrated visual servoing. Neural network has the capability to solve non-linear mapping, like direct and inverse kinematics and dynamics of the robot mechanism. Details of the learning and structure of the neural network will be presented in the next section.

4 NEURAL NETWORK STRUCTURE

Let us assume the proposed architecture of the neural network. A four-layered feedforward neural network is used (Figure 5).

It is described by the following equations:

$$\mathrm{net\_OJ}^{1}_{j} = \sum_{a=1}^{i} w^{1}_{j,a} \cdot \mathrm{in}_{a},$$
$$\mathrm{OJ}^{1}_{j} = f\left(\mathrm{net\_OJ}^{1}_{j}\right),$$
$$\mathrm{net\_OJ}^{2}_{k} = \sum_{a=1}^{j} w^{2}_{k,a} \cdot \mathrm{OJ}^{1}_{a},$$
$$\mathrm{OJ}^{2}_{k} = K_{1} \cdot f\left(\mathrm{net\_OJ}^{2}_{k}\right),$$
$$\mathrm{net\_OJ}^{3}_{m} = \sum_{a=1}^{k} w^{3}_{m,a} \cdot \mathrm{OJ}^{2}_{a},$$
$$\mathrm{OJ}^{3}_{m} = f\left(\mathrm{net\_OJ}^{3}_{m}\right),$$
$$\mathrm{net\_OJ}^{4}_{n} = \sum_{a=1}^{m} w^{4}_{n,a} \cdot \mathrm{OJ}^{3}_{a},$$
$$\mathrm{OJ}^{4}_{n} = K_{2} \cdot f\left(\mathrm{net\_OJ}^{4}_{n}\right). \quad (16)$$

Each layer has a sigmoid function between 0 and 1 for its output. Equation (17) represents this sigmoid function, as shown in Figure 6:

$$f\left(\mathrm{net}\right) = \frac{1}{1+e^{-\mathrm{net}}} \quad (17)$$

The network computes all angles between the links in one step, using the desired and actual end-effector location as the network input. The network is trained by the back-propagating of a two errors equations (18). K1 and K2 are the adjustable output scale factors. K1 is set between -π/2 and π/2, this being the output limit. K2 is set between 0 and 640. It presents the range of image resolution. Initial weights have been set randomly between 0.004 and -0.004. The learning rate for the first η1 and the second η2 layer has been set at 0.4 and for the third η3 and the fourth η4 layer has been set at 0.9:

$$\vec{e}_{A} = \left(\vec{x}_{R} - \vec{x}_{D}\right),$$
$$\vec{e}_{B} = \left(\vec{x}_{D} - \vec{x}_{O}\right). \quad (18)$$

The first error is the location error which is calculated from the desired and the actual position of the robot's tip. The second error is the location error that is calculated from the actual and the estimated positions of the robot's tip.

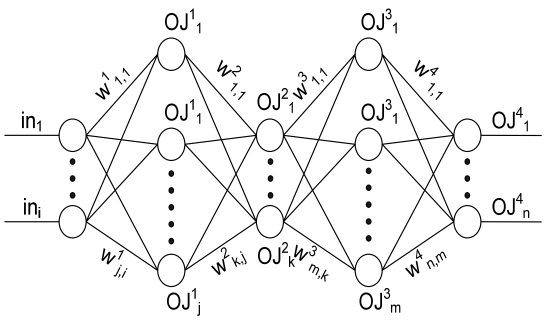


Fig. 5. *Neural network*

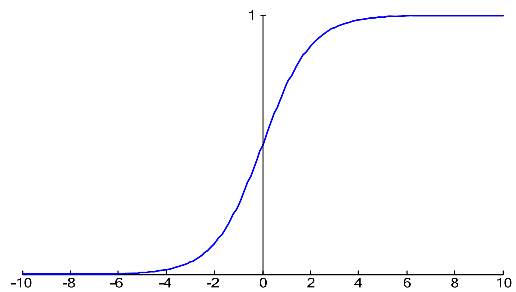


Fig. 6. *Sigmoid function*

The back-propagation for error $\vec{e}_A$ and $\vec{e}_B$ is described by:

$$\sigma_m^3 = \sum_{a=1}^{n} w_{n,m}^4 \cdot e_{B,n},$$
$$\sigma_k^2 = \sum_{a=1}^{m} w_{m,k}^3 \cdot \sigma_m^3,$$
$$\Delta w_{m,k}^3 = \eta_3 \cdot \sigma_m^3 \cdot {OJ_m^3}' \cdot OJ_k^2,$$
$$\Delta w_{n,m}^4 = \eta_4 \cdot e_{B,n} \cdot {OJ_n^4}' \cdot OJ_m^3, \quad (19)$$

$$\sigma_m^3 = \sum_{a=1}^{n} w_{n,m}^4 \cdot e_{A,n},$$
$$\sigma_k^2 = \sum_{a=1}^{m} w_{m,k}^3 \cdot \sigma_m^3,$$
$$\sigma_j^1 = \sum_{a=1}^{k} w_{k,j}^2 \cdot \sigma_k^2,$$
$$\Delta w_{j,i}^1 = \eta_1 \cdot \sigma_j^1 \cdot {OJ_j^1}' \cdot in_i,$$
$$\Delta w_{k,j}^2 = \eta_2 \cdot \sigma_k^2 \cdot {OJ_k^2}' \cdot OJ_j^1. \quad (20)$$

It is important, that this algorithm uses a new neural architecture. The architecture of the neural network is separated into two parts. The first part estimates the inverse kinematic while the second estimates the forward kinematic of the robot and the transformation to the camera image. Both neural networks are executed within the same step. It is important to know that this method also provides the capability of changing the camera's position within the executions of the tasks. Figure 7 shows the depicted architecture.

Unlike the forward kinematic problem, the inverse kinematic problem usually does not have a unique solution. Several joint positions may provide an identical end-effector position. In order to achieve appropriate results, neural networks require correct data preprocessing, architecture selection and network training.

Algorithm starts with random weights. The outputs of IKM NN (inverse kinematic model neural network) are actual joint coordinates, which are the result of random weights. The outputs of FKM NN (forward kinematic model neural network) are the estimated values of the robot tip's Cartesian coordinates.

We used the error BP (back-propagation) supervised learning technique. The first error is the difference between the estimated output values for the FKM NN and the actual values of the robot tip's Cartesian coordinates. The error BP technique helps to set up the weights for FKM NN. Learning for the IKM NN is executed within the same step. The second error is the difference between the actual values of the robot tip's Cartesian coordinates in the camera image and the desired Cartesian coordinates of the robot tip. The error BP technique helps to set up the weights through the FKM NN the IKM NN. Figure 8 represents the learning process while the figure 9 represents the execution process. Vector $\vec{q}$ represents the actual joint-angles. Vector $\vec{x}_{RC}$ represents the desired position in the camera frame. Vector $\vec{x}_{DC}$ represents the actual values of the robot tip in the image frame. Vector $\vec{x}_D$ represents the actual values of the robot tip's Cartesian coordinates.

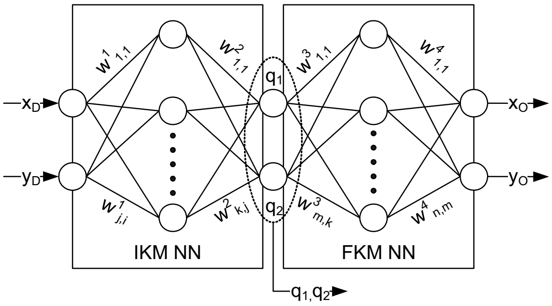


Fig. 7. *Neural network sheme*

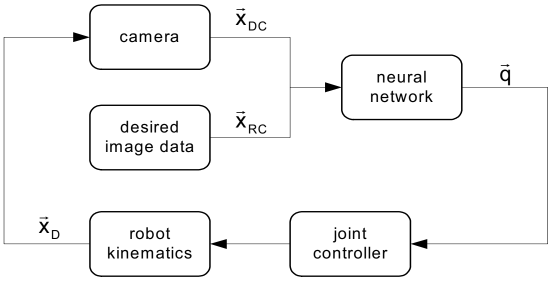


Fig. 8. *Block diagram of the learning process*

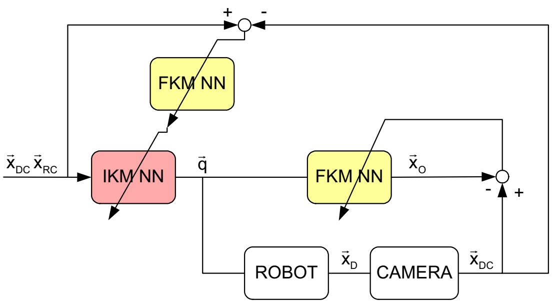


Fig. 9. *Block diagram of the execution process*

5 EXPERIMENTAL RESULTS

The work presented in this paper is based on a real experiment using neural network and visual servo-control. The experimental task was compared with the known Broyden method.

The algorithm starts with random weights chosen between the limits 0.004 and -0.004. It could happen that, at the beginning when the initial weights are chosen, the robot's tip does not reach the target, so the algorithm should be started more often. When the robot's tip reached the first target, the first approximation of robot FKM was achieved and the weights for FKM NN had the first good approximation. The FKM NN weights were set better for each of the following targets. More targets in the robot's workspace brought better results, thus better FKM approximation. The algorithm was trained with 100 random targets in the robot's workspace. Then we froze up the weights for FKM NN. Only the IKM NN stayed active, which was then used for controlling the robot's tip and used for minimizing the distance between the target and the robot's tip. Figure 10 shows the trajectory of the robot's tip. When the FKM NN is learned and the weights are set, we could use it for robot tracking and robot positioning, without any camera calibration or known robot-kinematics.

The camera resolution was 640x480, the camera's frame rate was 200 f/s, thus the sampling time of the algorithm execution was 5 ms. The camera was positioned 1 m above the robot, thus the size of pixle was approximately 1.5 mm.

Figure (10) shows the start of the algorithm with random weights. This sample presents appropriately chosen weights. The initial robot tip's position is marked with "0" while the target point is marked with "1". The dotted line presents the robot in the goal position. The curve presents the trajectory of the robot's tip in the learning phase. The initial weights ware set-up randomly thus causing the problem that the robot's tip during the so-called "virgin" learning did not always find the target and the IKM computed by the neural network was badly approximated by the neural network. However, if the first approximation of IKM is achieved the robot's tip finds the target. Better results are given using more targets. It can be compared with teaching a baby to stand on his legs. How many times do children fall before they can stand up and walk without assistance? After crawling for a few weeks they achieve sufficient balance to stand on legs with the support of a wall. It is important to know how many senses a human being has. It all helps to set up the initial weights, which are used in future life.

Figure 11 shows robot tracking. The initial robot tip's position is marked with "0" and the corresponding robot joint-angles have the following values q_1 = -30°, q_2 = 60°. The initial target-point's position is marked with "1", and the consequent positions are marked "2", "3", and "4". The target points' positions were generated in the following order "1"-"2"-"3"-"4"-"1". When the robot's tip reached the target, the target-point was moved to another position in order to provide travelling of the robot's tip through the whole robot work-plane. The position of the target-point determined the corners of a square in the image plane. The linear interpolation generated the reference trajectory within the image. The trajectory tracking speed was set to the following value 0.1 pixle/sample time. This is the difference between reference and actual trajectories.

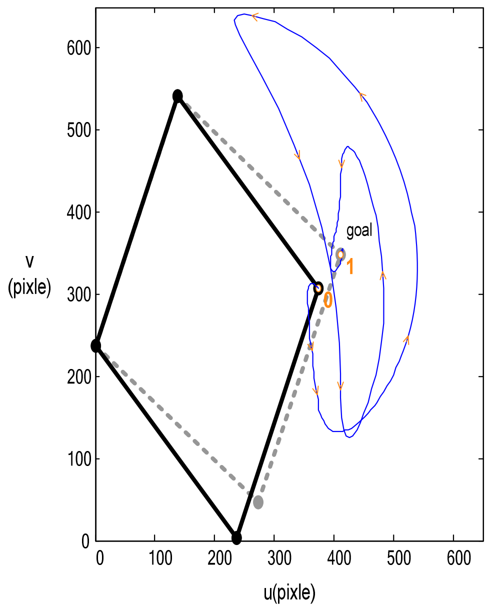


Fig. 10. *Virgin learning trajectory*

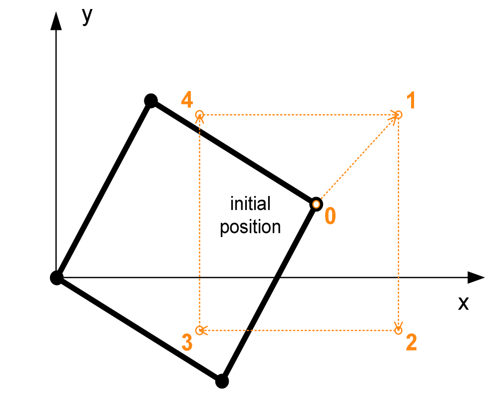


Fig. 11. *Target movement*

Figure 12 shows the experimental results for robot-tracking obtained by the Broyden method (a,b) and the proposed method (c,d). Figures 12(b,d) show the experimental results for u and v feature error tracking's for both algorithms.

Both methods yield reliable results. Broyden methods needs initial movements to initialize the first Jacobian approximation. Our proposed method with neural network needs initial learning to set up weights and to estimate the system. Tests for both methods were carried out on the same test-bed under the same conditions.

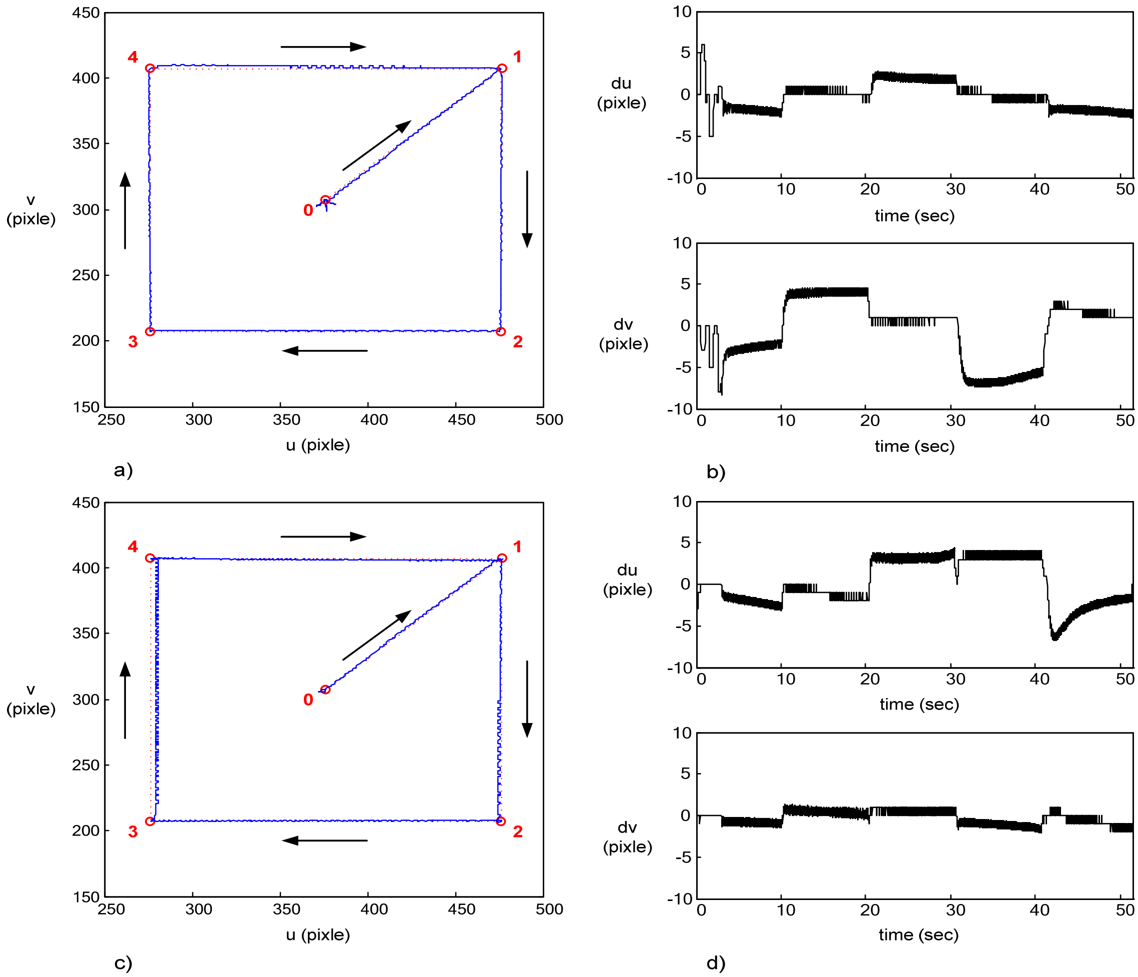


Fig. 12. *Experimental results for robot tracking: a) and b) Broyden method, c) and d) proposed method with neural network*

image contour : solid line – robot's tip, dotted line – reference, circle – target point

u-v error feature tracking: solid line – difference between reference and actual trajectories

6 CONCLUSION

This paper describes a scheme for the control of robot manipulators based on visual information. The learning control approach discussed is flexible, in that it is easy to apply within a robot control system and can be modified to accommodate system changes. Many learning control approaches involve learning to perform a particular movement. Our research focused on the robot control with two degrees of freedom and one camera. However, we predicted that the neural network algorithm would be able to be used on robots with more degrees of freedom and more cameras.

Achieving successful results for machine vision and robotics in unstructured environments, without using any a-priori camera or kinematic models, has proven hard yet there are many such environments where robots would be useful [8].

A new approach is introduced for the dynamic control of a parallel manipulator. This algorithm uses a completely new neural architecture. The training procedure of the neural network does not require known solutions for the inverse or forward kinematic problems. The neural algorithm can successfully estimate the robot's inverse kinematics and forward kinematics without any prior information, while carrying-out a 2 DOF parallel manipulation task.

7 REFERENCES

[1] Kuperstein, M. Generalized neural model for adaptive sensory-motor control of single postures. In: Proceedings of the IEEE International Conference on Robotics and Automation (1988), pp. 140–143.

[2] Espiau, B., Chaumette, F., Rives, P. A new approach to visual servoing in robotics. IEEE Transactions on Robotics and Automation, 8(3):313-326, 1992.

[3] Hutchinson, S., Hager, G., Corke P. A tutorial on visual servo control, IEEE Transactions on Robotics and Automation, (5), pp. 651–670, 1996.

[4] Soria, A., Garrido, R., Vazquez, R. Improving visual servoing control with high speed cameras, Electrical and Electronics Engineering, 2004.

[5] Lee, P., Dean, T., Yap, A., Walter, D., Kitchen,L., Barnes, N. On- Board Vision Using Visual-Servoing for RoboCup F-180 League Mobile Robots. RoboCup 2003.

[6] Gazit, R. Widrow, B. Backpropagation through links: a new approach to kinematic controlof serial manipulators, Intelligent Control, 1995.

[7] Hosoda, K., Asada, M. Versatile visual servoing withoutknowledge of true Jacobian, in Proc. IEEE/RSJ/GI Int. Conf.Intelligent Robots and Systems, Munich, Germany, Sept. 1994, pp. 186-193.

[8] Jägersand, M. Visual servoing using trust region methods and estimation of the full coupled visual-motor Jacobian, in Proc. IASTED Applications of Robotics and Control, 1996.

[9] Piepmeier J. A., McMurray G. V., Lipkin H. Uncalibrated dynamic visual servoing. IEEE Transactions on Robotics and Automation, 2004, 20(1), p.143-147.

[10] Jagersand, M., Nelson. R.C. On-line estimation of visual-motor models using active vision. In ARPA Image Understanding Workshop, p.677–682, 1996.

[11] Hornik, F. Multilayer feedforward networks are universal approximators, Neural Networks, vol. 2, pp. 359–363, 1989.

[12] Jägersand M., Nelson R. Adaptive Differential Visual Feedback for uncalibrated hand-eye coordination and motor control TR# 579, U. of Rochester 1994.

[13] http://gandalf-library.sourceforge.net/

[14] Broyden, C.G. A class of methods for solving nonlinear simultaneous equations, Mathematics of Computation 19, p. 577-593, 1965.

[15] Qingjie Zhao, Zengqi Sun, Hongbin Deng: Robot Visual Servoing Based on Total Jacobian. ASIAN 2004, p.271-285.

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, 628-638
UDC 658.34.17

Paper received: 04.07.2007
Paper accepted: 07.07.2008

A Device for Simulating the Thermoregulatory Responses of the Foot: Estimation of Footwear Insulation and Evaporative Resistance

Mitja Babič[1,*] - Jadran Lenarčič[1] - Leon Žlajpah[1] - Nigel A. S. Taylor[2] - Igor B. Mekjavić[1]
[1] Automation, Biocybernetics, and Robotics, Jožef Stefan Institute, Ljubljana, Slovenia
[2] School of Health Sciences, University of Wollongong, Australia

A sweating thermal foot manikin was developed for evaluating the thermal and evaporative resistance of footwear. The sweating thermal foot manikin can be programmed to simulate physiological patterns of conductive, convective and evaporative heat loss. The manikin can simulate the initiation and magnitude of human non-evaporative and evaporative heat loss based on core and skin temperatures. The system comprises a computer controlled system for regulating the heaters in each of the 16 segments of the foot, as well as the sweating function provided by peristaltic pumps. Each of the 16 segments is autonomous: its heating and sweating responses are controlled independently, thus the calculation of the heat exchange can also be determined for each segment separately. Results of the footwear evaluation were compared to the results obtained for identical footwear with foot manikins from other laboratories.

Keywords: human foot, thermal manikin, sweating, foot wear, physiological simulation system

0 INTRODUCTION

Selection of appropriate protective clothing and footwear in extreme conditions is very important and requires biophysical evaluation [1] to [4]. Inappropriate footwear is the main cause for freezing and non-freezing cold injury of the feet. Ensuring that footwear meets minimum biophysical standards is therefore essential in preventing cold injury. The aim of the presented work is biophysical evaluation of footwear for different climates [5] and [6].

A copper thermal manikin was build in 1940 [7] to estimate thermal characteristic of clothes and footwear. The current development of thermal manikin is focused in the development of manikins which simulates parts of the human body, e.g. foot [8] and [9], hand [10], head [11].

A manikin system for the evaluation of thermal and evaporative resistance of footwear is presented in this paper.

1 CALCULATION OF THERMAL RESISTANCE

To estimate and compare different footwear we need some type of comfort measuring tool, which includes mechanical and ergonomic comfort. The primary measurement tools for estimating thermal footwear comfort are thermal resistance per unit of surface and permeability of water vapor, or sweat evaporation.

1.1 Physical Background

We can take a body in a shape of cylinder with length L and constant intersection A (Fig. 1 a).

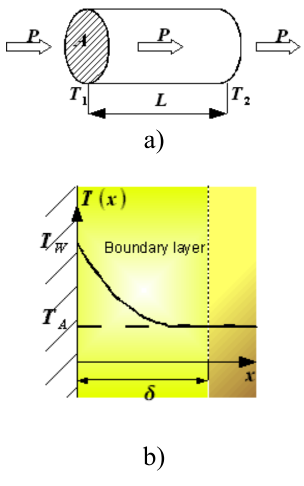


Fig. 1. *Heat transfer (see text for details)*

*Corr. Author's Address: Automation, Biocybernetics, and Robotics, Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia, mitja.babic@ijs.si

Heat flux P is directly proportional to the difference of temperature T_2 - T_1 and to intersection A and inverse proportional to the length L [12]. Dependence of different materials is defined with the parameter λ (material thermal conductivity), which gives

$$P / A = -\lambda \, \partial T / \partial L \,. \tag{1}$$

Good temperature conductors (e.g. metals) have thermal conductivity values between 60 and 300 W/mK. Substances which have small values of thermal conductivity are heat insulators, e.g. air, mineral wool, etc [12]. The best thermal insulator is calm air (λ around 0.025 W/mK).

We can express the heat transfer flux from wall to air with equation (2). The temperature drop from air temperature T_A to wall temperature T_W is carried out in a thin boundary layer (Fig. 1b); the thickness of the boundary layer is δ [12].

$$P / A = \alpha (T_W - T_A) \tag{2}$$

The proportional factor α (dimension W/m^{2}K) is called convection ratio. It depends on physical characteristic of wall, air, and on viscosity and speed of air near the wall [12].

Equations (1) and (2) can be expressed in the form of equation (3), so that wall and boundary layer have thermal resistance $R = L/\lambda A + 1/\alpha A$. T_I is the wall inner side emperature and T_O is the air temperature at the wall outer side.

Thus the measure for estimating the footwear quality is thermal resistance R.

In the following section the basic equations

$$P = (T_I - T_O) / R \tag{3}$$

for calculating the thermal resistance per unit of surface I ($I = RA$), measure unitm^2 K /W, of each segment of manikin and the total resistance per unit on surface of the whole manikin will be carried out in the form of equation (4).

$$I = A(T_I - T_O) / P \tag{4}$$

1.2. Thermal Resistance per Unit of Surface

Thermal resistance per unit of surface for each manikin segments can be expressed as

$$I_{T,i} = \frac{\left(T_{S,i} - T_A\right) \cdot A_{M,i}}{H_{T,i}} \tag{5}$$

where $I_{T,i}$ is the segment i thermal resistance per unit of surface, $T_{S,i}$ is the segment i skin temperature, T_A is the ambient (air) temperature, $A_{M,i}$ is the area of segment i and $H_{T,i}$ is the given power to segment i (loss).

The total thermal resistance per unit of surface can be compounded from segments resistances per unit of surface

$$I_T = A_M \left(\sum_i \frac{A_{M,i}}{I_{T,i}} \right)^{-1} \tag{6}$$

where A_M is the total area of the manikin and $A_{M,i}$ is the area of segment i.

When thermal resistance per unit of surface is estimated, the air temperature is lower than skin temperature ($T_A < T_{S,i}$, $\forall i = 1,...,16$). Normally a temperature gradient around 20 °C is keept. Greater temperature gradient requires more power. The intention is to improve system resolution and accuracy.

1.3. Estimation of Evaporative Resistance per Unit of Surface in Isothermal Conditions

The evaporative resistance per unit of surface for each manikin segments can be expressed as

$$I_{E,i} = \frac{\left(p_i - p_A\right) \cdot A_{M,i}}{H_{E,i}} \tag{7}$$

where $I_{E,i}$ is the evaporative isothermal resistance per unit of surface of segment i, p_i is the partial water vapor pressure of segment i (in saturation), p_A is the ambient (air) partial vapor pressure, $A_{M,i}$ is the area of segment i and $H_{E,i}$ is the given power to segment i (loss).

The total evaporative resistance per unit of surface can be compounded from segments evaporative resistances per unit of surface

$$I_E = A_M \left(\sum_i \frac{A_{M,i}}{I_{E,i}} \right)^{-1} \tag{8}$$

where A_M is the total area of the manikin and $A_{M,i}$ is the area of segment i.

The partial saturation vapor pressure at temperature T is calculated from the empirical relation [13]

$$p_{sat}(T) = 133.3 \cdot \exp\left(18.6686 - \frac{4030.183}{T+235}\right) \quad (9)$$

For ambient (air) partial vapor pressure we can write

$$p_A = p_{sat}(T_A) \cdot (RH_A / 100), \quad (10)$$

where RH_A is the relative humidity of air. For each segment relative humidity is supposed to be RH_i = 100%, so the partial water vapor pressure for segment i is

$$p_i = p_{sat}(T_i). \quad (11)$$

Estimation of evaporative resistance per unit of surface in isothermal conditions must assure that the temperature of air is equal to skin temperature ($T_A = T_{S,i}$, $\forall i = 1,...,16$). Under these circumstances, the heat transmission is dependent only on evaporation. It means that the given heat power $H_{E,i}$, to segment i, is equal to the process cooling evaporative power on skin.

1.4. Estimation of evaporative resistance per unit of surface in nonisothermal conditions

Evaporative resistance per unit of surface for each segment of the manikin on nonisothermal conditions can be expressed as

$$I_{S,i} = \frac{(p_i - p_A) \cdot A_{M,i}}{(H_{S,i} - H_{T,i})} = \frac{(p_i - p_A) \cdot A_{M,i}}{(H_{S,i} - \frac{(T_{S,i} - T_A) \cdot A_{M,i}}{I_{T,i}})}, \quad (12)$$

where $I_{S,i}$ is the evaporative non isothermal resistance per unit of surface of segment i, p_i is the partial water vapor pressure of segment i (in saturation), p_A is the ambient (air) partial vapor pressure , $A_{M,i}$ is the area of segment i, $T_{S,i}$ is the segment i skin temperature, T_A is the ambient (air) temperature, $I_{T,i}$ is the thermal resistance per unit of surface of segment i (previously measured) and $H_{S,i}$ is the given power to segment i (loss).

The total evaporative resistance per unit of surface can be computed from segments evaporative resistances per unit of surface

$$I_S = A_M \left(\sum_i \frac{A_{M,i}}{I_{S,i}} \right)^{-1}, \quad (13)$$

where A_M is the total area of the manikin and $A_{M,i}$ is the area of segment i.

When evaporative resistance per unit of surface in nonisothermal conditions is estimated, the air temperature is lower than skin temperature ($T_A = T_{S,i}$, $\forall i = 1,...,16$). Normally a temperature gradient around 20 °C is keept.

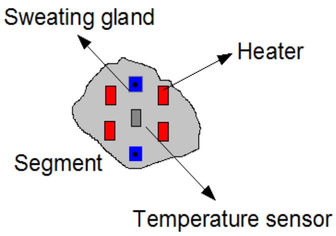
2 SYSTEM DESCRIPTION

Fig. 2 shows the foot manikin system. The system is composed of a personal computer, electrical control system, sweating system and the thermal foot manikin [8] and [9]. Hereafter each part will be shortly described.

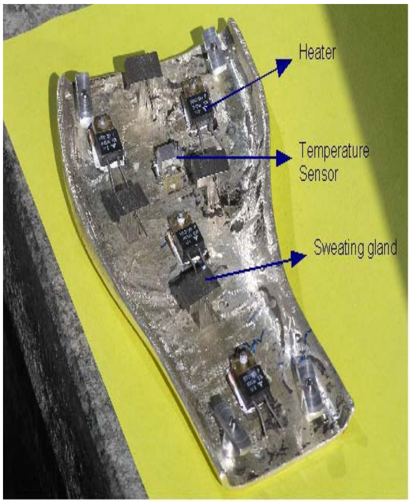
Fig. 2. *Foot manikin system*

2.1. Foot manikin

The foot manikin is composed of 16 segments. Segments are made of the alloy of silver and copper (approximately 95±5%), because silver has high thermal conductance, which causes optimal heat flux conduction from heaters to the measured material, whose resistance is measured. Also silver segments tend to have a homogeneous temperature distribution on the whole segment. Each segment has one temperature sensor, which measures the segment skin temperature $T_{S,i}$, heaters for the segment temperature control and artificial sweating glands, which simulate the human sweating. The segment model is shown in Fig. 3a.



a)



b)

Fig. 3. *a) Segment model b) Realized model of the foot sole*

The measurement and control process treats each segment as an autonomous part. Based on the temperature sensor data, the control algorithm controls the heaters in order to reach the desired segment temperature. With the control of sweating system the sweating glands wet appropriately the manikin segments. Segments thermal resistances per unit of surface calculations are based on the data obtained from the skin temperature sensors ($T_{S,i}$), the ambient (air) temperature sensor (T_A) and the control algorithm calculated power (H_i), given to the heaters.

The model part of the foot sole is shown in Fig. 3b. With the appropriate distribution of heaters and sweating glands a homogeneous sweating and heating of the whole segment is obtained.

2.2. Control system

The control system can be divided into three parts: the software part, the electronics part and the sweating system.

2.2.1 Sweating system

The sweating system is made of two peristaltic pumps, artificial sweating glands and conveyance tubes. Artificial sweating glands are mechanical elements, through which pumps transfer water to the surfaces of manikin's segments. Sweating glands are on one side connected with pumps through conveyance tubes, which supply water; holes on the other side humidify manikin's segments. Pumps are controlled by the computer via serial communication. The pumps speed can be controlled to influence the flow of water through the sweating glands, what simulates the intensity of foot sweating. The software allows starting, stopping and changing the speed of the pumps. An algorithm which simulates the foot sweating depending on the foot skin temperature is integrated in the software [14] and [15], as $v_p = f(T_{S,i},...T_{S,n})$, where $v_{p,j}$ is the pump j speed (j=1,2) , $T_{S,i}$ is the segment i skin temperature and n is the number of segments, in our case 16.

2.2.2 Electrical control system

The electrical control system consists of the power supply, National Instruments (referred as NI) PXI platform and the power output.

The base of the system is the NI PXI platform and the NI PXI control unit, which are functioning in the Microsoft Windows XP environment. The PXI platform contains the following card.

The connection between the personal computer and the NI PXI platform is made of the NI CardBus 8310 card, which together with the CardBus-to-PCI bridge, provides a transparent link where all PXI modules appear as if they are PCI boards within the computer itself. This allows an easy communication with the selected PXI module.

Two NI 4351 cards acquire data from temperature sensors. The properties of the card are high accuracy, resolution and big CMRR factor (CMRR- common mode rejection ratio).

The foot manikin has 16 Pt 1000 resistance temperature detectors, which are supplied with current source of 1mA. The length of the connection cables form the foot manikin to the controller is more then 3m, so in order to increase the measurement accuracy reduction of cables length is needed. For that reason a three wire connection is used to connect the temperature detectors (Fig. 4a). In this configuration only wire resistance R_{L1} adds error to the measurement.

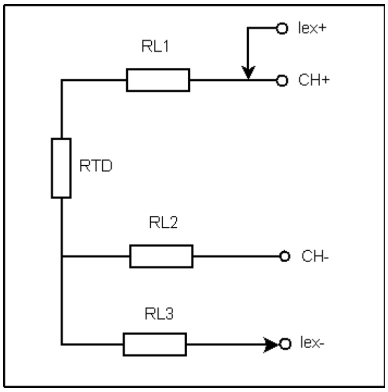
The NI 6221 card has digital inputs and outputs. With this card we control opto couplers, which turn the heaters on and off (Fig. 4b). For heating segments we use power resistors RTO 20, which principal property is that power-temperature characteristic negligible change with temperature change.

The last NI PXI card is a serial communication card. This card has four serial ports which are used to control the pumps.

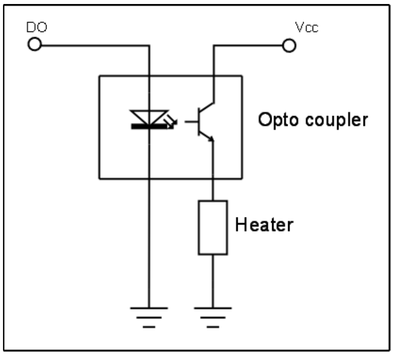
NI PXI supports various environments, between them also Microsoft Windows XP, which is used to build our software system.

2.2.3 Software environment

The manikin control system was built in the C++ programming language. Fig. 5 shows the measurement flow chart in real time. The system user can communicate with the software and hardware system in the graphical user interface. At the beginning the user has to define and configure the measurement. After the measurement starts the software communicates with the hardware through the NI PXI platform. From the acquired temperature sensors data and previously defined temperature references, the software algorithm controls the heaters. The software algorithm also controls through the NI PXI platform the pumps, which control the sweating glands in order to reach the desired sweating of the foot. After every sampling time the control process is repeated. The measured data are calculated and displayed on-line. The measurement stops automatically when some predefined reference condition is reached or the process is stopped manually.



a)



b)

Fig .4. *a) Temperature measurement b) Power output*

2.2.4 Control algorithm

Fig. 6 shows the flow chart of the control algorithm for one segment.

The control algorithm is composed of 16 PID regulators with anti-windup protection, which control 16 pulse width modulators (PWM) for control of the segment heaters. A proportional-integral-derivative (PID) control algorithm is given with equation (14).

$$u(t) = K_P e_P(t) + K_I \int e_I(t)\, dt + K_D \frac{de_v(t)}{dt} \quad (14)$$

PID is made with the parallel combination of *P*, *I* and *D* term. With the appropriate parameters tuning we influence the system response (*P, D*) and the steady-state error (*I*). Computer simulation in Matlab-Simulink

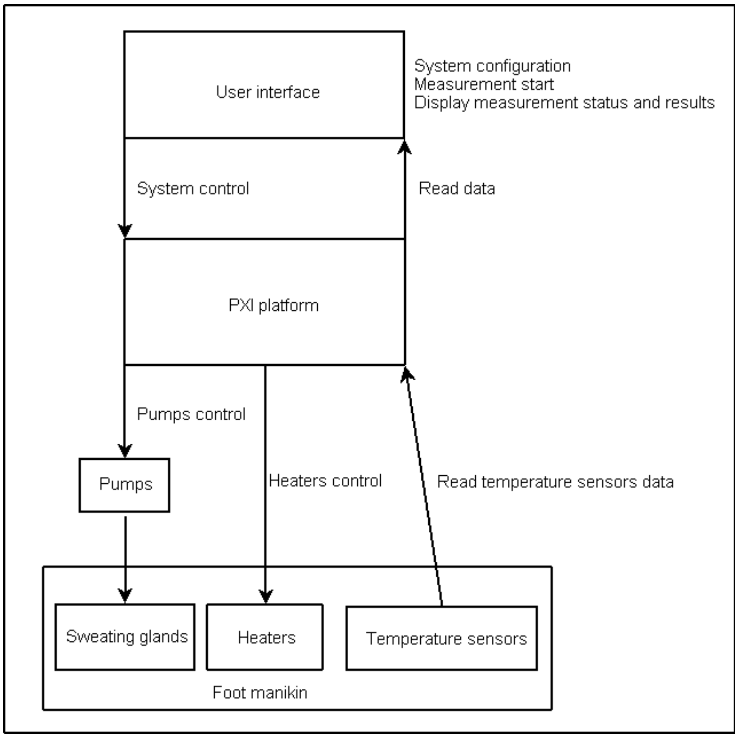


Fig. 5. *Chart of the measurement process*

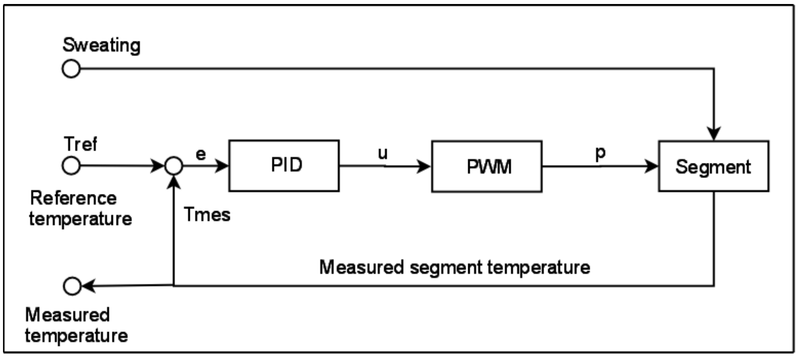


Fig. 6. *Control algorithm*

gives as the initial approximate values of *P, I, D* parameters. Finally, the parameters were fine tuned on the real system. We reach settling time lower than 3min and steady-state error lower than $\Delta T < \pm 0.5°C$.

On windup the control system goes in saturation during regulation, so the error is decreasing more slowly, as if saturation would not be present. The basic idea of anti-windup is to find out when the control system goes in saturation. At the time this happens it is necessary to stop the integration of the regulator I term, or respectively influence the I term in the way that the regulator will bring the control system near the saturation limit. Because the regulator is controlling the heaters with pulse width modulation, which has limit values between zero and one, it is necessary to adapt the control algorithm to these limits.

It is important to emphasize that the whole control algorithm is made programmatically, so the regulator is discretized and works with sampling time $T_s = 5s$.

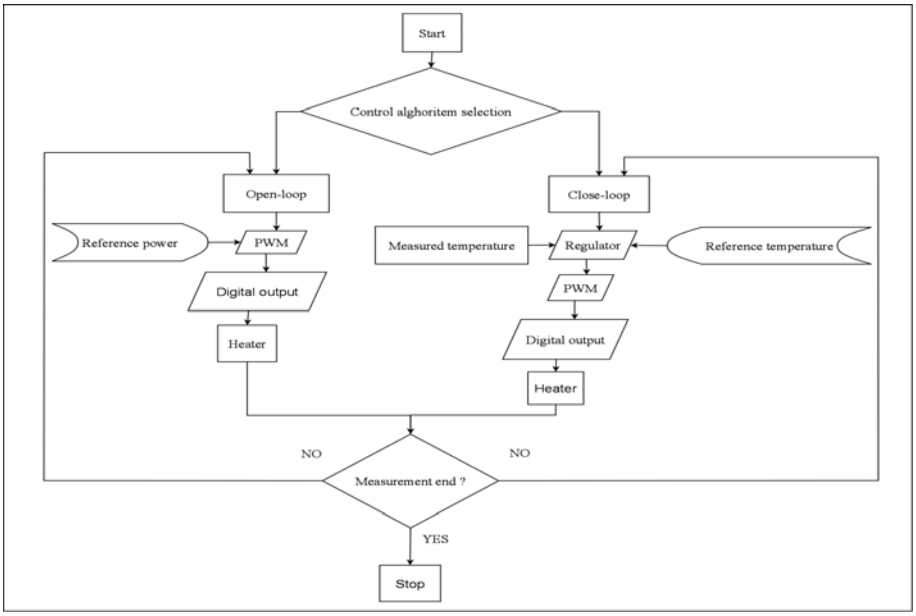


Fig. 7. *Control system algorithm*

Heaters are controlled with Pulse Width Modulation (*PWM*). Therefore the regulated heater power is directly proportional to the signal duty cycle

$$H_{\mathrm{i}} = H_{\mathrm{max,i}} \cdot \Delta t_{\mathrm{ON,i}} \ , \tag{15}$$

where $H_{\mathrm{max,i}}$ is the heater maximum power and 5s is the signal duty cycle.

In our system program timers are used for the generation of PWM signals. The standard timers accuracy is around Δt_{TIM} = (10 to 15) ms, with the use of multimedia timers the resolution can reach a limit of Δt_{TIM} = 1 ms. Because the sample time period is TS = 5 s, the minimum resolution of the PWM signal can be

$$\Delta PWM = \frac{\Delta t_{\mathrm{TIM}}}{T_{\mathrm{S}}} = 2 \cdot 10^{-4},$$

or expressed in heater power

$$H_{\mathrm{i}} = \frac{V_{\mathrm{CC}}}{R_{\mathrm{H,i}}} \Delta PWM_{\mathrm{i}} \approx \frac{(24\,\mathrm{V})^2}{45\Omega} \cdot 2 \cdot 10^{-4} = 2.56 \ \mathrm{mW},$$

where V_{CC} is the power supply voltage and $R_{\mathrm{H,i}}$ is the segment i heater resistance.

Beside the closed-loop control regulation the system also allows open-loop control regulation, which means constant heater power of the segment regardless to the segment temperature. From the given desired power of segment *i*, H_{i}, the system calculate the PWM signal duty cycle:

$$\Delta t_{\mathrm{ON,i}} = \frac{H_{\mathrm{i}}}{H_{\mathrm{max,i}}},$$

which controls heaters. With this method we can find out which is the steady state of the skin temperature at constant heating power for given footwear.

The sweating system is controlled with an open-loop algorithm. The pumps can be turned on or off. With pumps speed control influence the flow of water through the artificial sweating glands, what simulate the human foot sweating. If we want to change the flow of water through each sweating gland, we can achieve this with changing the tube diameter.

Fig. 7 shows the flow chart of the control algorithm. After the regulation type is chosen (closed-loop or open-loop) the selected algorithm is repeated in sampling time T_s = 5s. After some reference condition is reached, the measurement stops.

3 MEASUREMENT RESULTS

3.1. System Check Up

Some reference tests have been done to check the system behavior and to compare our manikin with other manikins. For this reason we did four tests with bare foot, sock, rubber boot and winter boot. We put the manikin in a climatic chamber on temperature T_A = 15°C, relative humidity RH_A = 50%, without wind. Dry test have been done with foot reference temperature set to T_F = 35°C. Test duration was 90 min, each test was repeated twice. The manikin result tests were checked and compared to the results from other laboratories manikins, which results were described by Kuklane et al. [16]. The test results are shown in Table 1.

Table 1 show that the thermal resistance per unit of surface increases, as expected. Values increase with more thermally insulated footwear. The values are near the mean values of other manikin's tests described in [16]. The results for bare foot and sock are near the mean values in [16], meanwhile for rubber boot and winter boot the values are lower than the expected values. The main reason was that the wear did not fit the foot well, which cause lose of power heat. All tests were repeated twice and the differences in the results were around ΔI = ±0.005 m^{2}K/W, which is the system accuracy and depends on the accuracy of sensors, program timers, etc.

3.2. Wind influence

Some test has been done to study the response of the foot manikin in the presence of wind. Simulation of wind was carried out with a fan. The results are shown in Fig. 8.

Fig. 8 show that the thermal resistance per unit of surface decreases, because the wind is cooling the foot and the regulator needs to increase the given power, to keep the foot on the same temperature.

Time course of relative measurement values for one segment (segment 5) is depicted in Fig. 8c (Tsrel-temperature skin, Irel-thermal resistance per unit of surface, HArel-heat flux per unit of surface).

Total thermal resistance per unit of surface without wind is

$$\Delta I_{NW} = 0.107 \text{ m}^2\text{K/W}$$

and with wind is

$$\Delta I_{W} = 0.067 \text{ m}^2\text{K/W} .$$

3.3. Influence of wind and sweating

The last test shows the influence of wind and sweating on the foot with sock. The measurement results are shown in Fig. 9.

Fig. 9 shows that sweating is cooling and wetting the sock, what results in the need of more power from the system to maintain the reference temperature and causes the thermal resistance per unit of surface to decrease.

Time course of relative measurement values for one segment (segment 5) is depicted in Fig. 9c (Tsrel-temperature skin, Irel-thermal resistance per unit of surface, HArel-heat flux per unit of surface).

Total thermal resistance per unit of surface are

$\Delta I_{PNW} = 0.065$ m^{2}K/W for pumps without wind,

$\Delta I_{PW} = 0.039$ m^{2}K/W for pumps with wind and

$\Delta I_{PNW} = 0.061$ m^{2}K/W for pumps without wind.

Table 1. *Comparison of thermal resistance per unit of surface derived for bare foot, sock, rubber boot and winter boot. Results are compared to those reported by Kuklane et. al. (2005)*

Footwear	Measured I_M m^{2}K/W	Reference I_R m^{2}K/W
Bare foot	0.0843	0.090
Sock	0.112	0.120
Rubber boot	0.139	0.170
Winter boot	0.189	0.225

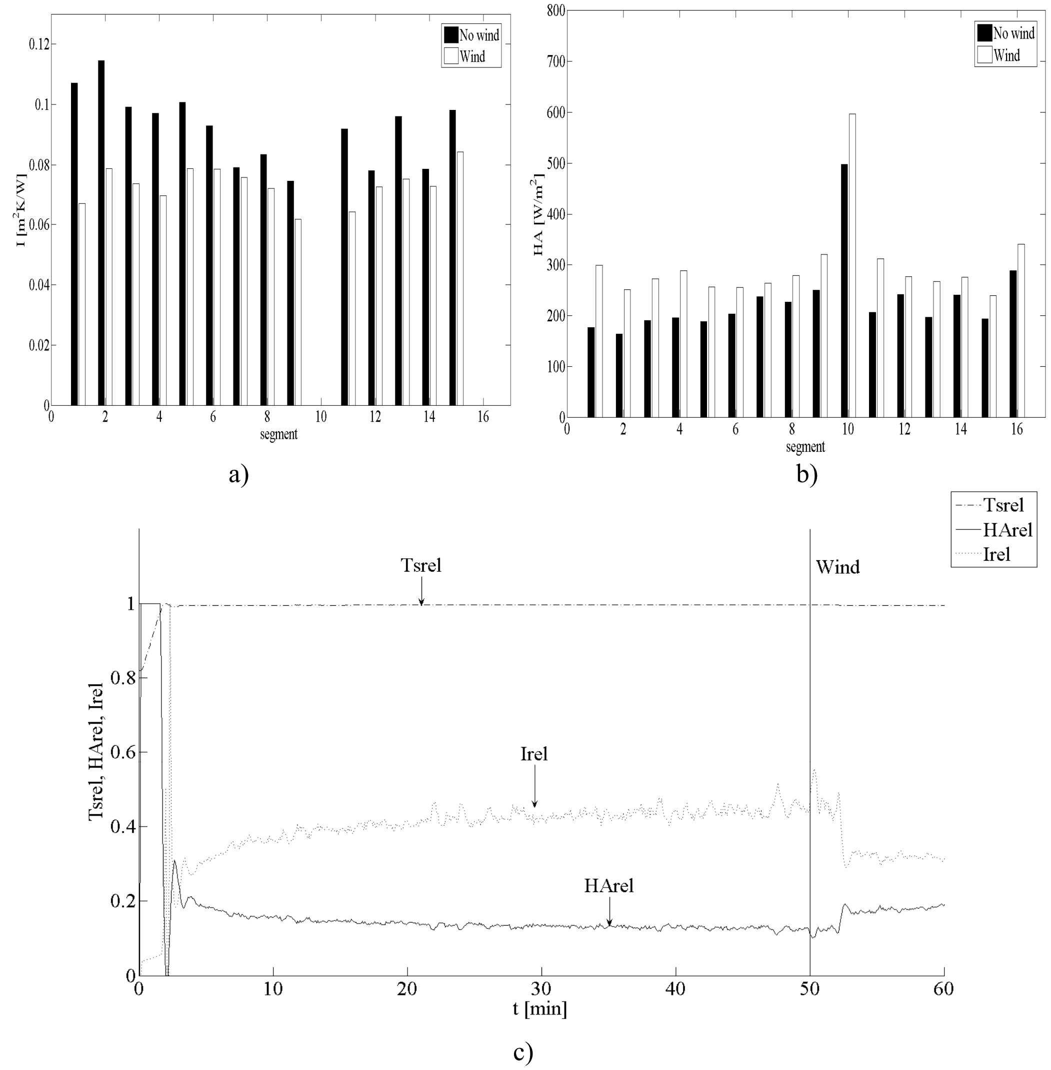
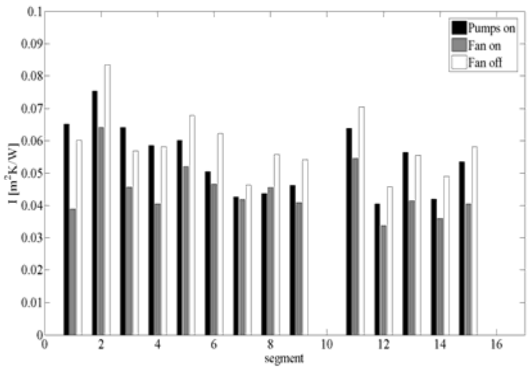


Fig. 8. *Influence of wind on thermal resistance per unit of surface (sock) thermal resistance per unit of surface b) heat flux per unit of surface c) time course of relative measurement values*

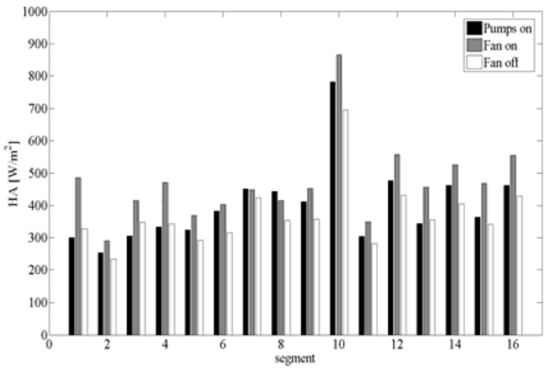
3.4. Studying the characteristics with infra-red camera

Fig. 10 shows two pictures obtained with infra-red camera when the foot is heated from 15°C to 35°C. Fig. 10a shows the foot at the temperature near 30°C, in Fig. 10b the temperature is around 35°C, which is the steady state.

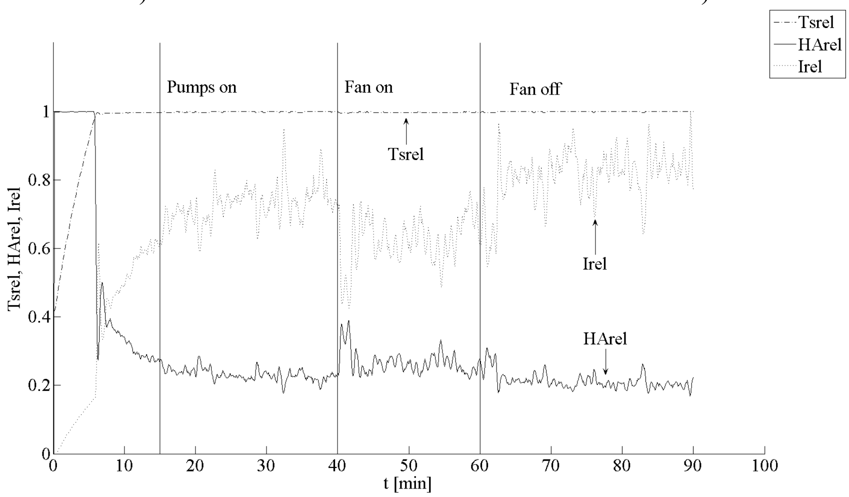
Fig. 10 shows that the segments are heating homogenously. Leg is filled with silicone rubber inside, which mechanically connects segments together. Silicone rubber is transferring warmth from one segment to another partially (dark lines between segments Fig. 10b). For an accurate analysis the system could be treat as a multivariable system, what could increase the difficulty of system analysis, control and calculations. The construction of our next manikins will be made in such a way that segments will be connected together mechanically with some holders. So they will be inside hollow, what will presumably reduce the heat transfer between segments.



a)

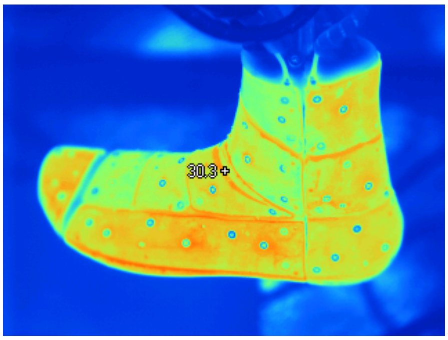


b)

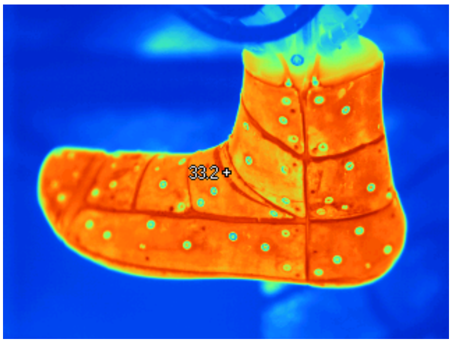


c)

Fig. 9. *Influence of wind and sweating (sock)*
a) thermal resistance per unit of surface b) heat flux per unit of surface c) time course of relative measurement values



a)



b)

Fig. 10. *Infra-red thermograms of the foot manikin at a) 30°C and b) 35°C*

4 CONCLUSION

A device for footwear quality estimation and physiologic simulation of the human foot was presented. The system calculates the thermal and evaporative resistance to estimate the quality of the footwear. The manikin can simulate thermal behaviors of the foot and sweating of the foot. There are many built-in functions for control of the foot heating and sweating.

The device construction, control system and the thermal resistance measurement are presented. Sixteen segments compose the foot manikin. Each segment is an autonomous part, in the sense of construction, control and calculation. The goal of using segments is that with segments we can test the quality of each part of the footwear, what is the base information for the manufacturer and user.

The test results are comparable with manikins from other laboratories.

5 REFERENCES

[1] Fourt L., Hollies N.R. (1970), Clothing. Comfort and Function. Marcell Dekker: New York.

[2] Hollies N.R., Goldman R.F. (1977), Clothing Comfort. Interaction of Thermal, Ventilation, Construction and Assessment Factors. Ann Arbor Science Publishers Inc.:Ann Arbor, Michigan.

[3] Newburgh L.H. (1968), Physiology of Heat Regulation and the Science of Clothing. Hafner Publishing Co.: New York.

[4] EN344 (1992), Requirements and test methods for safety, protective and occupational footwear for professional use [European Standard]. Brussels: European Committee for Standardization.

[5] Mekjavić I. B., Tomšič M., Rodman S. (2002), Determination of thermal insulation of hiking shoes. Medicinski razgledi 41, p. 183 - 186.

[6] Santee W.R. and T.L. Endrusick (1988), Biophysical evaluation of footwear for cold-weather climates. Aviation, Space and Environmental Medicine 59, p.178-182.

[7] Holmér I. (2004), Thermal manikin history and applications. European Journal of Applied Physiology, vol.92, no.6, p.614-618(5).

[8] Mekjavić I. B., Vrhovec B., Tomšič, M., Lenart B. (2005), Sistem za ovrednotenje dinamične toplotne izolacije obutve, (IJS delovno poročilo, 9273).

[9] Tomšič M. (2004), Izdelava modela noge za merjenja toplotne izolacije, (IJS delovno poročilo, 9066).

[10] Kuklane K., Nilsson H., Holmer I., Liu X. (1997), Methods for handwear, footwear and headgear evaluation. Proceedings of a European seminar on manikin testing. National Institute for Working Life, Stockhom, Sweden, February 1997.

[11] Bruhwiler P. A., Ducas C., Huber R., Bishop P.A. (2004), Bicycle helmet ventilation and comfort angle dependence. Eur. J. Appl. Physiol., 92, p. 698-701.

[12] Rudolf K. (1989). Visokošolska fizika I.del, DZS, Ljubljana.

[13] Buck, A. L. (1981), New equations for computing vapor pressure and enhancement factor, J. Appl. Meteorol., 20, p. 1527-1532.

[14] Taylor N. A. S., Caldwell J. N., Mekjavić I. B. (2006), The sweating foot : local differences in sweat secretion during exercise-induced hyperthermia. Aviat. Space Environ. Med., 77, p. 1020-1027.

[15] Machado-Moreira C.A., Smith F.M., Van den Heuvel A. M. J., Mekjavić I. B., Taylor N. A. S. (2008). Sweat secretion from the torso during passively-induced and exercise-related hyperthermia. Eur. J. Appl. Physiol. In press.

[16] Kuklane K., Holmér I., Anttonen H., Burke R., Doughty P., Endrusick T., Hellsten M., Shen Y., Uedelhoven W. (2005), Interlaboratory tests on thermal foot models. In: Tochihara, Y. and Ohnaka, T. (editors). Environmental Ergonomics - The Ergonomics of Human Comfort, Health, and Performance in the Thermal Environment.

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, 639-644
UDC 66.047

Paper received: 15.12.2007
Paper accepted: 07.07.2008

Results Research of Energetics Characteristics of Convection Drying

Slavica Prvulović[1] - Dragiša Tolmać[2,*] - Ljiljana Radovanović[2]
[1] Technical Faculty, Bor, Serbia
[2] Technical Faculty "Mihajlo Pupin", Zrenjanin, Serbia

Experimental and theoretic researches are presented in this paper and they are implemented on the real industrial equipment of convection dryer with pneumatic transport of material. The numeric values are given for optimum parameters of drying, energetic characteristics and balances as well as the coefficient of the heat transfer.

The heat transfer in these systems is accomplished based on the principle of direct contact of dryed material and warm air. Then, an intensive transfer of heat and mass is accomplished.

This paper presents the results of researches which can be useful in designing and construction of such dryers in the food and agri industry. It refers to the technological technical characteristics of the dryer, energetic balances and coefficient of heat transfer.

Keywords: energy balance, drying , numeric data, heat transfer

0 INTRODUCTION

In principle, convection dryers can be used for drying of meal-like and fine-kernel materials. Simple construction and relatively low consumption of energy has enabled successful application of convection dryers in the above stated industrial branches and starch. Application of convection pneumatic dryers is represented especially in the food industry in the factories for industrial processing of grains (processing of wheat and corn based on the wet milling).

Heat transfer systems of such of kind and likewise are introduced in literature [2] to [4], [6], [8], [9], [12], [14] and [18].

In these dryers, a continuous drying of loose materials is being made, the concentration being ck = (0.05 to 2) kg of material / kg of air. Average particle size of the drying material can be (0.05 to 2) mm. The initial moisture of the drying material can be w1= (35 to 40) %, and the remaining moisture after drying is usually w2 = (10 to 15)%. The specific consumption of energy is usually (3500 to 5040) kJ / (kg H_2O).

Efficiency of convection dryers is evaluated according to the thermal degree of utilization which is within the limits of (66 to 75)%, depending of the drying system (indirect or direct drying). The drying time in these dryers is very short, only several seconds, therefore they can be used for drying of the materials susceptible to high temperatures in the short drying period of time.

1 MATERIAL AND METHOD

Experimental research is made in the convection pneumatic dryer, Figure 1.

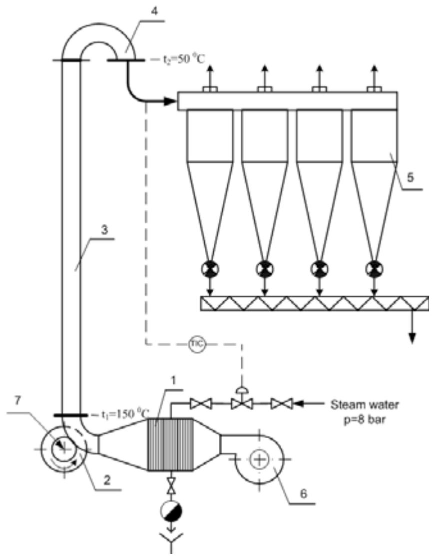


Fig. 1. *Scheme of experimental drying equipment (1 – heat transmiter, 2 – rotation dozer of moist material, 3 – dryer pipe, 4 – dryer head, 5 – cyclones, 6 – centrifugal ventilator, 7 – bringing of moist material))*

[*]Corr. Author's Address: University in Novi Sad, Technical Faculty "Mihajlo Pupin", Djure Djakovic bb, 23000 Zrenjanin, Serbia, tolmac@beotel.yu

Table 1. *Characteristics convection pneumatic drying*

Position	Name of equipment and characteristics
1	Heat transmiter, heat power Q = 2,5 MW
3	Dryer pipe, diameter d = 1250 mm, height 20 m
5	Cyclone separator, diameter Dc = 1750 mm, height: cylindrical part of the cyclone is 2620 mm, conical part of cyclone is 3500 mm
6	Centrifugal ventilator: V = 65000 $m_n^3h^{-1}$, p = 3500 Pa, N = 90 kW
7	Rotating dozer, N = 22 kW, n = 650 min^{-1}
4	Dryer head

Drying is performed in the direct contact of warm gases with the moist material. Based on that, the principle of direct drying is being represented here. The drying material is starch.

Dosing of moist material to the dryer is made through the rotation dozer (2) with the capacity of m_1 = 8000 kgh^{-1}, through the screw conveying system, as given in the scheme of experimental equipment in Fig. 1. In the Table 1, the characteristics of convection pneumatic dryer are given.

Moist material is being transported via hot air – the drying agent through the dryer pneumatic pipe (3), it passes through the dryer head (4) and goes to the cyclone separators (5) where separation of dried material is being made, and the hot gases exit with the help of ventilator (6), into the atmosphere (see Fig. 1). The dried material is being transported from the cyclone via screw conveyors and through a separate line of transport up to the material warehouse department.

During drying, the determined steam water is m_p= 3830 kgh^{-1}. Average values of the results of measuring the drying temperature and the material humidity are: t_1=150 °C, t_2=50 °C, w_1=36%, w_2= 13%.

Energetic balances show appropriate relations between the total invested energy, utilized energy and heat losses during the drying process. Based on the above, the energetic balances can be useful when showing the dryer condition diagnosis. According to the Lambić [6], Prvulović [10], Tolmać [17].

The discrepancy in the air enthalpy at the inlet and at the outlet of the dryer:

$$\Delta H = H_1 - H_2 = c_p\left(t_1 - t_2\right) \tag{1}$$

Quantity of evaporated water (kgh^{-1}):

$$W = m_1\left(1 - \frac{100 - w_1}{100 - w_2}\right) \tag{2}$$

Total heat quantity:

$$\dot{Q}_U = \dot{Q}_w + \dot{Q}_S + \dot{Q}_g \tag{3}$$

$$\dot{Q}_U = m_p \cdot r \quad kJh^{-1} \tag{4}$$

Quantity of drying air:

$$V_L = \frac{\dot{Q}_U}{\Delta H} \tag{5}$$

Specific consumption of energy:

$$q = \frac{\dot{Q}_U}{W} \tag{6}$$

Thermal degree of utilization:

$$\eta_T = \frac{t_1 - t_2}{t_1} = \frac{\dot{Q}_U - \dot{Q}_g}{\dot{Q}_U} \tag{7}$$

Total heat power of drying:

$$Q_U = h_u\, A\, \Delta\, t_{sr} \tag{8}$$

Total coefficient of the heat transfer:

$$h_u = Q_U \,/\, (A\ \Delta t_{sr}) \tag{9}$$

Heat for drying, i.e. its convective part consists of the heat for water evaporation (Q_w) and heat for heating of the drying material (Q_s), meaning, without heat losses (Q_g):

$$\dot{Q}_{conv} = \dot{Q}_W + \dot{Q}_S \tag{10}$$

During convective drying the following equation of the heat transfer is applied as well:

$$\dot{Q}_{conv} = h_c A \Delta t_{sr} \tag{11}$$

2 RESULTS AND DISCUSSION

Experimental research on the convection pneumatic dryer, Fig. 1, was aimed to determine the energetic balance, specific consumption of energy, thermal degree of utilization and other relevant parameters of drying, according to the reference by Prvulović [9]. The results of the energetic balance are being given in the Table 2. The total heat force of drying of Q_d = 2180 kW, is being acquired as well as the specific consumption of energy q = 3710 kJ kg^{-1}, of evaporable water. According to Heβ [2], Prvulović [8] and Tolmać [18], a specific consumption of energy in convection drying amounts (3650 to 5040) kJ kg^{-1}, of evaporable water. According to the data from reference Islam [3], specific consumption of energy amounts q = (3642 to 5283) kJ kg^{-1}, of evaporable water.

Based on the results of energetic balance and results of the drying parameters measuring, according to the reference by Prvulović [9], a total coefficient of the heat transfer is determined to be during convection drying h_u = 295 Wm^{-2}K^{-1}, Table 3. Based on the results of research, the mass air flow amounts 0.450 kg s^{-1}m^{-2}, the drying capacity is 5885 kgh^{-1}, and the air temperature at the dryer inlet is 150°C. According to the literature Lin [5], the mass air flow is 0.289 kgs^{-1}m^{-2}, the drying capacity is 1152 kgh^{-1}, at the drying temperature of 90°C.

According to the research by Heβ [2] and Tolmać [12], on the convection pneumatic dryer, the value of the total coefficient of heat transfer during drying of corn starch is 308 Wm^{-2}K^{-1}, and during drying of potato starch the coefficient of heat transfer is 295 Wm^{-2}K^{-1}.

The objective of this part of research is to determine the character of heat transfer in such complex dynamic model, considering that the heat transfer comprises a phenomenon of heat transfer by convection, conduction and radiation.

Based on the results of research, the value of the coefficient of heat transfer by convection has been determined, Table 4.

Table 2. *Energetics balance of convection pneumatic dryer*

Energetics drying parameter	Sign	Measure unit	Energetics value parameter
Air temperature at the inlet of dryer	t_1	˚C	150
Quantity of evaporable water	W	kgh^{-1}	2115
Total heat quantity	Q_u	kJh^{-1}	7.846650
Drying heat power	Q_d	kW	2180
Energy specific use	q	kJkg^{-1}	3710
Quantity of drying air	V_L	m$_n^3$h^{-1}	60358
Specific quantity of evaported water		kgm^{-2}h^{-1}	26.90
Specific quantity of evaported water		kgm^{-3}h^{-1}	86.20
Air temperature at the outlet of dryer	t_2	˚C	50
Thermal degree of utilization	η_T	%	67

Table 3. *Total coefficient of heat transfer (h_u)*

Drying heat power	Volume of pipe drying place	Drying surface*	Middle log. difference of temperature	Total heat transfer coefficient
Q_d	Vk	A	Δt_{sr}	h_u
kW	m^3	m^2	^oC	$Wm^{-2}K^{-1}$
2180	24.53	7850	94	295

*According to [2], [9], [14] drying surface is equal to interior surface of drying pipe (A = d π h ; d = 1,25 m - pipe diameter ; h = 20 m - pipe height).

Table 4. *Coefficient of heat transfer by convection (h_c)*

Heat power for water evaporation	Heat power for material heating	Heat power of heat transfer by convection	Surface drying	Mean logarithmic difference of temperature	Coefficient of convection heat transfer
Q_w	Q_s	Q_{conv}	A	Δt_{sr}	h_c
kW	kW	kW	m^2	^0C	$Wm^{-2}K^{-1}$
1	2	3	4	5	6
1482	66	1548	78.5	94	210

Based on the results of research of energetic balance and the results of measuring the temperature of the drying agent, the total coefficient of the heat transfer is being determined in the convection dryer in the amount of h_u = 295 $Wm^{-2}K^{-1}$, and the coefficient of the heat transfer by convection h_c = 210 $Wm^{-2}K^{-1}$. The effects of the heat losses during drying are expressed through the separate value $h_u - h_c$ = 85 $Wm^{-2}K^{-1}$, so called coefficient of the heat transfer for the heat losses together with the outlet air and the heat transfer by conduction and radiation through the dryer pipe. In such a way the effects of the heat transfer are being determined as well as the basic parameters of the heat transfer.

A coefficient of heat transfer under the dynamic conditions of the dryer operation (non-equal dosing of material to be dryed, oscillations in the initial moisture content, temperature of drying, heat flux, etc.) depends on the greater number of different values which characterize the heat transfer. The objective of this part of research is to determine the character of heat transfer in such complex dynamic model, considering that the heat transfer comprises a phenomenon of heat transfer by convection, conduction and radiation.

3 CONCLUSION

Energetic balance of the dryer can serve in evaluation of energetic condition of the dryer as well as in reviewing of the possibility of rational consumption of energy. This paper presented the experimental and theoretic research of relevant parameters of drying on the convection pneumatic dryer in the agri and food industry. Based on the analysis of energetic balance, the heat force of drying has been determined Q_d = 2180 kW, specific consumption of energy q = 3710 $kJkg^{-1}$ of evaporable water, as well as the thermal degree of utilization η = 67%.

Specific consumption of energy and quality of dried material are basic data which characterize the results of drying on the convection dryer. Following and control of these parameters in the drying process, the optimum consumption of energy is provided as well as the quality of dried material. A significant share of the energy during drying is forwarded to transfer of heat to the material, necessary for evaporation of moisture and heat for breaking of connection forces of moisture with the basis of the material to be dried.

The results of research can be used also for: determination of dependence and parameters of the heat transfer during convection drying, as well as in designing and development of convection dryers. The acquired results of research are based on the experimental data from the industrial dryer. Based on that, the results of research have a value of use, i.e. they are useful to the designers, manufacturers and beneficiaries of these and similar drying systems as well as for the educational purposes.

4 NOMENCLATURE

h_u	$Wm^{-2}K^{-1}$	total coefficient of heat transfer
h_c	$Wm^{-2}K^{-1}$	coefficient of convection heat transfer
H	$kJkg^{-1}$	enthalpy
t_1	°C	air temperature at the inlet of dryer
t_2	°C	air temperature at the outlet of dryer
C_p	$kJm_n^{-3}K^{-1}$	specific air heat
W	kgh^{-1}	quantity of evaporated water
m_1	kgh^{-1}	quantity of moist material
m_p	$kg\ h^{-1}$	quantity of water steam
w_1	%	the material moisture at the inlet of dryer
w_2	%	moisture of the dried material at the outlet of dryer
Δt_{sr}	°C	mean logarithm difference of temperature
Q	kJh^{-1}	heat quantity
A	m^2	drying surface
V_k	m^3	volume of dryer pneumatic pipe
r	$kJkg^{-1}$	specific heat of evaporation
q	$kJkg^{-1}$	specific consumption of energy
V_L	$m_n^3h^{-1}$	quantity of drying air
η_T	%	thermal degree of utilizatoin

5 REFERENCES

[1] Holman, J.P. (1981) Heat Transfer fifth edition, Mc Graw-Hill Book Company, New York

[2] Heß, D. (1984) Comparison of processing Economics of Different Starch Dryers, *Journal of Starch/Starke,* vol.36. pp. 369-373.

[3] Islam, M., Marks, B., Bakker - Arkema, F. (2004) Optimization of commercial ear-corn dryers, *Manuscript FP 04 007. Vol. VI. CIGR and EurAgEng publ.*

[4] Keey, R.B. (1972) Drying Principles and Practise, Pergamon Press, London

[5] Lin, Q., Bakker - Arkema, F. (1999) Capacity estimation of high temperature grain dryers- a implitied corelation method. vol. I. *CIGR and EurAgEng publ.*

[6] Lambić, M., Tolmać, D. (1997) Technical thermodynamics, Technical Faculty "Mihajlo Pupin", Zrenjanin

[7] Mak-Adams, V.H. (1999) Heat transfer, Science book, Belgrade

[8] Prvulović,S., Tolmać, D., Lambić, M. (2001) Determination of energetics characteristics of convection drying place on pneumatic transportation material, *Journal Process technic,* vol.1, pp.70-74. SMEITS, Belgrade

[9] Prvulović, S. (2004) Modelling the Mechanism for Heat Transfer at the Convective Drying and Establishing of Numerical Readers, Ph.D. Dissertation, University of Novi Sad

[10] Prvulović, S., Tolmać, D., Lambić, M. (2007) Convection Drying in the Food Industry, *Agricultural Engineering International the CIGR Ejournal,* vol.IX, no.9, pp.1-12, ASAE - American Society of Agricultural Engineering,.

[11] Tolmac, D., Lambic, M. (1997) Heat transfer through rotating roll of contact dryer, *Internacional Communications in Heat and Mass Transfer*, vol. 24, pp. 569-573. Pergamon, Oxford, United Kingdom.

[12] Tolmać, D. (1992) Analysis of economic work of convection starch dryers, *Journal Process technic* no.1, pp. 20-22, SMEITS, Belgrade

[13] Tolmać, D., Prvulović, S., Lambić, M. (2007) The Mathematical Model of the Heat Transfer for the Contact Dryer, Jnt. *Journal FME TRANSACTIONS*, vol.35, no.1, pp.15-22, Faculty of Mechanical Engineering, Belgrade.

[14] Topić, R. (1989) Basis in designing of dryers calculation and construction, Science book, Belgrade

[15] Tolmać, D., Lambić, M. (1999) The mathematical model of the temperature field of the rotating cylinder for the contact dryer, *International Cmmunications in Heat and Mass Transfer*, vol.26, no. 4, pp.579-586. Pergamon, Oxford, United Kingdom.

[16] Tolmać, D., Prvulović, S. (2007) Rationalization of energy consumption and utilization of waste heat in the corn fiber dryer, *29th International Conference of CIGR*, *"Rational Use of Energy in Agriculture"*, Procedigs, pp.83-90, Olsztyn, Poland, 2007.

[17] Tolmać, D. (2005) Machines and apparatuses, Technical faculty "Mihajlo Pupin", Zrenjanin

[18] Tolmac, D. (2005) Systems energetic parameters for starch drying in grain industry, Journal Energetic Teshnologies, Vol.2, No.(1-2), pp.11-13. Solar Energy Society "Serbia Solar".

[19] Webb, R.L. (1994) Principles of Enhanced Heat Transfer, John Wiley, New York.

[20] Wiset, L., Srzednicki, G., Driscoll, R., Nimmuntavin, C., Siwapornak, P. (2001) Effests of High Temperature Drying on Rice Quality. vol. III. *CIGR and EurAgEng publ.*

Instructions for Authors

From 2008 Journal of Mechanical is published only in English language with Slovenian abstracts. Authors are entirely responsible for language correctness. If reviewer estimates that language is poor, Editorial can require native English proof-reading with certificate from the author once again.

Papers can be submitted electronically on Editorial's e-mail or by post.

Papers submitted for publication should comprise:

- Title, Abstract, Keywords,
- Main body of text
- Tables and Figures (graphs, drawings or photographs) with captions,
- List of References and
- Information about the authors, corresponding author and his full address.

For papers from abroad (in case that none of authors is Slovenian) Editorial will provide Slovenian translation of the Abstract.

Papers should be short and should comprehend 8 to 12 pages.

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 or experimental methods used.
- 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 generalizations 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 and do not duplicate the Abstract.
- 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.

THE LAYOUT OF THE TEXT

Texts should be written in Microsoft Word format. Paper must be submitted in electronic version by e-mail or by post on CD.

Do not use the 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.

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).

Meaning of symbols and units belonging to symbols should be explained in each case or quoted in special table at the end of the paper before References.

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 or JPG. However, graphs and line drawings should be prepared as vector images, e.g. CDR, AI.

All Figures should be prepared in black-and-white technique, without borders and on white grounding. All Figures should be sent separately in their original formats.

When labeling axes, physical quantities, e.g. t, v, m, etc. should be used whenever possible to minimize 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.

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. In addition to the physical quantity, e.g. t (in italics), units (normal text), should be added in square brackets. Each column should have the title line. Tables should not duplicate information that is already noted anywhere in the paper.

Acknowledgement

Acknowledgement for co-operation or help can be included before References. Author should state the research (co)financer.

The list of references

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

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

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

[3] Muhs, D. et al. Roloff/Matek mechanical parts, 16th ed. Wiesbaden: Vieweg Verlag, 2003. 791 p. (In German). ISBN 3-528-07028-5

ACCEPTANCE OF PAPERS AND COPYRIGHT

The Editorial Committee 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.

The corresponding author must, in the name of all authors, 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.

Editorial does not return submitted materials. Unpublished material is not preserved and is not send anywhere else without author's consent.

Paper prepared for publishing will be send to authors in PDF format. Authors should make minor corrections if needed. With this author confirms paper for publishing.

PUBLICATION FEE

For all papers authors will be asked to pay a publication fee prior to the paper appearing in the journal. However, this fee only needs to be paid after the paper is accepted for publishing by the Editorial Board. The fee is €180.00 (for all papers with maximum of 6 pages), €220.00 (for all paper with maximum of 10 pages) and €20.00 for each addition page. Publication fee includes 25 separates of each paper send to corresponding author.

Vsebina

Strojniški vestnik - Journal of Mechanical Engineering
letnik 54, (2008), številka 9
Ljubljana, september 2008
ISSN 0039-2480

Izhaja mesečno

Povzetki razprav

Osebne vesti

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, SI 99
UDK 697

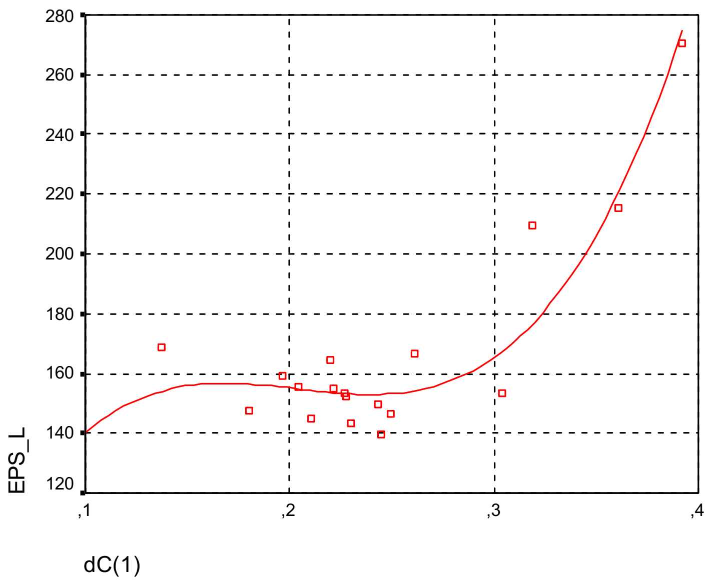
Prejeto: 19.02.2008
Sprejeto: 07.07.2008

Relativni padec koncentracije sledilnega plina kot merilo učinkovitosti prezračevanja

Simon Muhič[1] - Mitja Mazej[2] - Vincenc Butala[2,*]
[1] Sineco d.o.o., Ljubljana, Slovenija
[2] Univerza v Ljubljani, Fakulteta za strojništvo, Slovenija

Analizirali smo učinkovitost prezračevanja na prototipu sistema za lokalno klimatizacijo PERMICS (Personal Microclimate System) z uporabo sočasnih meritev hitrostnega polja ter polja koncentracij sledilnega plina z uporabo metode zmanjšanja koncentracije sledilnega plina. Pri tem je bil vpeljan in predstavljen nov parameter dC(1), ki temelji na relativnem zmanjšanju koncentracije sledilnega plina v prvi minuti delovanja sistema. Novo definirani parameter je overjen z rezultati opravljenih simulacij s tržnim paketom za računalniško dinamiko tekočin (CFD). Uporabnost parametra dC(1) je v možnosti hitre izvedbe meritev lokalne učinkovitosti na sistemih lokalnega prezračevanja in klimatizacije.

Ključne besede: razdeljevanje zraka, klimatizacija, prezračevanje, učinkovitost



Sl. 4. *Graf raztrosa indeksa lokalne izmenjave zraka pri glavi sedeče osebe*

*Naslov odgovornega avtorja: Univerza v Ljubljani, Fakulteta za strojništvo, Aškerčeva 6, Slovenija, vincenc.butala@fs.uni-lj.si

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, SI 100
UDK 658.5

Prejeto: 26.05.2007
Sprejeto: 07.07.2008

Projektno vodenje osvajanja izdelka

Janez Kušar - Lidija Bradeško - Jože Duhovnik - Marko Starbek
Fakulteta za strojništvo, Aškerčeva 6, Ljubljana, Slovenija

Trg zahteva od podjetij vedno krajše čase in nižje stroške osvajanja naročil, sicer bodo izgubila konkurenčno prednost na svetovnem tržišču. Kratke čase in nizke stroške osvajanja naročil, ob doseganju zahtevane kakovosti pa je mogoče doseči le z integriranim osvajanjem naročil, ki predstavlja povezovanje metod projektnega vodenja z elementi sočasnega inženirstva.

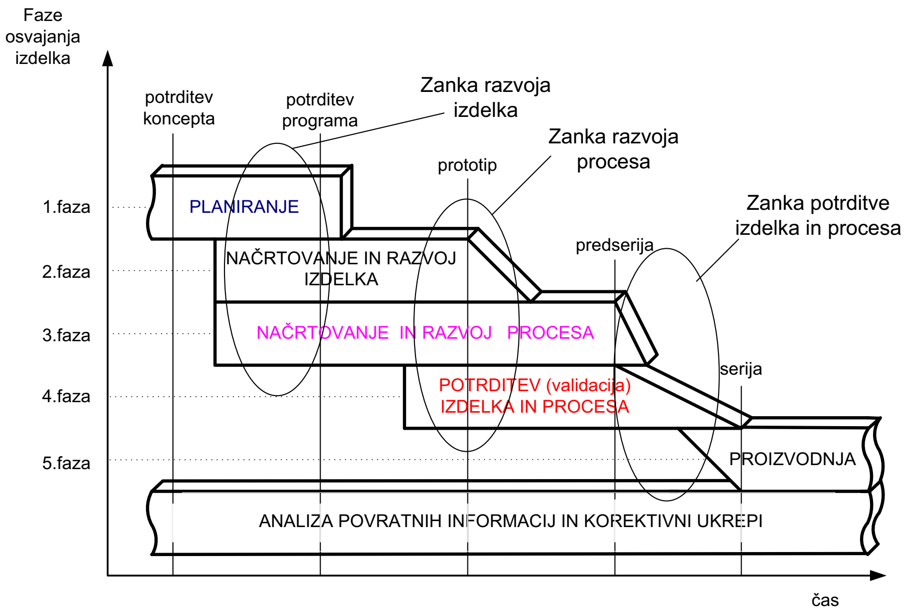
Projektno vodenje (PV) naročil z elementi sočasnega inženirstva omogoča bistveno skrajšanje potrebnega časa osvajanja naročil, znižanje stroškov in zagotavljanje večje kakovosti izvedenih naročil oz. izdelkov [1].

Pri integriranem osvajanju naročil je zelo pomembna faza načrtovanja naročil. Pri običajnem osvajanju naročil se porabi za načrtovanje v povprečju le 3% časa potrebnega za osvajanje naročil, pri zasnovi sočasnega osvajanja naročil pa se ta čas poveča na približno 20% [2].

Podjetje, ki se odloči za integrirano osvajanje naročil kot načina poslovanja podjetja, mora najprej izvesti organizacijsko in informacijsko prenovo poslovnega postopka ter izdelati sistemska in delovna navodila projektnega vodenja.

V prispevku je prikazan primer uvedbe projektnega vodenja naročil v podjetje s poudarkom na izgradnji postopka načrtovanja in vodenja projektov naročil ter oblikovanja dosjeja projekta.

Ključne besede: projektno vodenje, vodenje naročil, projektna pisarna, dosje projekta, sočasni inženiring



Sl. 19. *Zanke sočasnega inženirstva pri osvajanju izdelka pedalni sklop*

*Naslov odgovornega avtorja: Univerza v Ljubljani, Fakulteta za strojništvo, Aškerčeva 6, Slovenija, janez.kusar@fs.uni-lj.si

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, SI 101
UDK 658.5

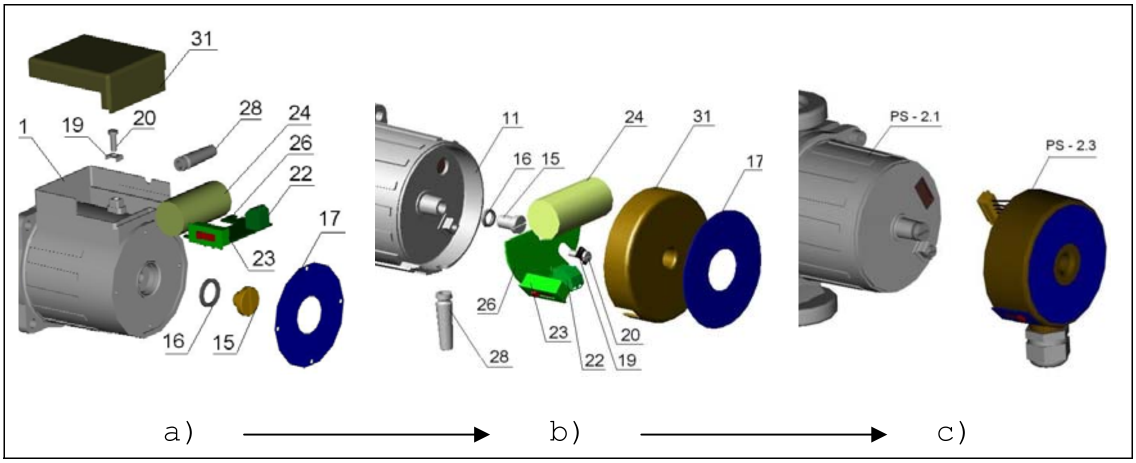
Prejeto: 03.01.2008
Sprejeto: 07.07.2008

Sestavna proizvodnja kot predpogoj za količinsko prilagajanje po meri in njena učinkovitost

Zoran Anišić* – Cvijan Krsmanović
Univerza v Novem Sadu, Fakulteta tehniških znanosti, Srbija

Pripspevek podaja pregled zahtevne metodologije IPS-DFA, namenjene vrednotenju in izboljševanju konstrukcijskih značilnosti z vidika postopka montaže. Pristop mora biti uporabljen na ravni izbire izdelkov, osnovne strukture izdelka in na ravni komponent z namenom doseganja dveh osnovnih ciljev: racionalizacije števila sestavnih delov ter optimizacije rokovanja in montaže sestavnih delov s pomočjo orodij, razvitih za izboljševanje primernosti za montažo. Celovitost metodologije, zlasti na ravni izbire izdelkov, hkrati omogoča tudi izboljšanje primernosti za masovno prilagajanje po meri. Prispevek podaja pregled rezultatov uporabe metodologije na družini rotacijskih črpalk, s posebnim poudarkom na učinke v zvezi s količinskim prilagajanjem po meri.

Ključne besede: snovanje izdelkov, konstruiranje za montažo, prilagajanje po meri, masovno prilagajanje, sočasni inženiring



Sl. 1. *Rezultati uporabe orodij*

*Naslov odgovornega avtorja: Fakulteta tehniških znanosti, Oddelek za industrijsko inženirstvo in menedžment, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia, azoran@vts.su.ac.yu

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, SI 102
UDK 681.5:007.52

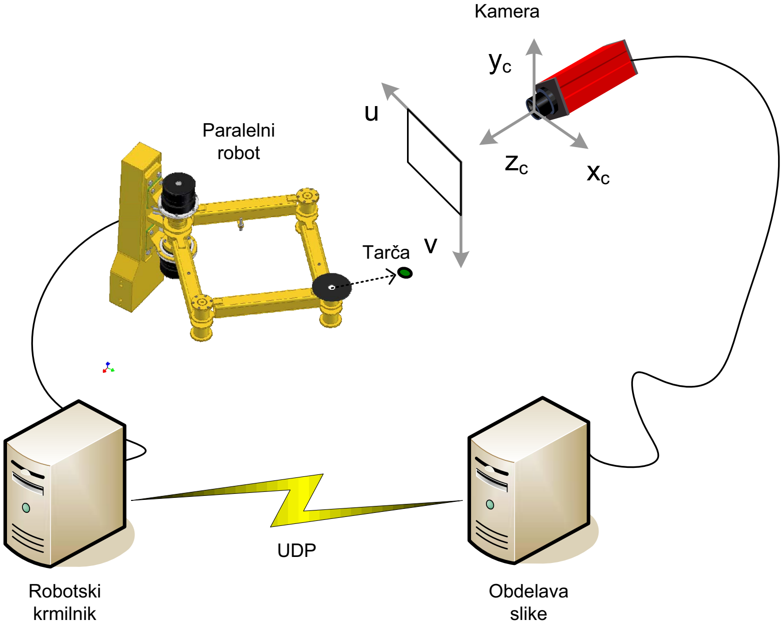
Prejeto: 05.12.2007
Sprejeto: 07.07.2008

Vodenje robota s pomočjo računalniškega vida in nevronske mreže

Rok Klobučar[1,*] - Jure Čas[1] - Riko Šafarič[1] - Miran Brezočnik[2]
[1] Univerza v Mariboru, Fakulteta za elektrotehniko, računalništvo in informatiko, Slovenija
[2] Univerza v Mariboru, Fakulteta za strojništvo, Slovenija

Raziskave s področja vodenja robota s pomočjo računalniškega vida so zelo pomembne. V prispevku je opisano vodenje robotskega manipulatorja. Za vodenje s pomočjo umetnega vida je uporabljena polno povezana usmerjena nevronska mreža. Uporabljena je povsem nova arhitektura nevronske mreže in nov algoritem nevronske mreže. Natančno poznavanje kinematike robota in kalibracija kamere nista potrebna. Nevronska mreža se uči s pomočjo vrha robota. Po učenju smo testirali natančnost nevronske mreže. Nevronska mreža je morala generirati notranje koordinate glede na zunanjo trajektorijo. Eksperiment je bil izveden na paralelnem manipulatorju z dvema prostostnima stopnjama. Pokazali smo, da lahko s pomočjo takšne arhitekture nevronske mreže robota opravlja zadane naloge. V prispevku je predstavljena uporaba nevronske mreže za ocenitev nelinearne transformacije med vrhom robota v sliki in notranjih koordinat. Eksperimentalni primeri potrjujejo zanesljivost predlagane metode. Eksperimentalne rezultate smo primerjali s podobno metodo, imenovano Broydenova metoda za nekalibrirano vodenje robota s pomočjo umetnega vida.

Ključne besede: roboti, nevronalne mreže, vizualizacijski servo sistemi, paralelni manipulatorji



Sl. 3. *Eksperimentalni sistem*

[*]Naslov odgovornega avtorja: Univerza v Mariboru, Fakulteta za elektrotehniko, računalništvo in informatiko, Smetanova ulica 17, 2000 Maribor, Slovenija, rok.klobucar@uni-mb.si

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, SI 103
UDK 658.34.17

Prejeto: 04.07.2007
Sprejeto: 07.07.2008

Naprava za simulacijo termoregulacijskih odzivov stopala: vrednotenje toplotne izolacije in izparilne upornosti obutve

Mitja Babič[1,*], Jadran Lenarčič[1], Leon Žlajpah[1], Nigel A. S. Taylor[2], Igor B. Mekjavić[1]
[1] Odsek za avtomatiko, biokibernetiko in robotiko, Institut Jožef Stefan, Ljubljana, Slovenija
[2] School of Health Sciences, University of Wollongong, Australija

V prispevku bo predstavljen sistem za simulacijo termofizioloških odzivov stopala, s katerim se lahko ovrednoti toplotne značilke obutve. Sistem uporablja kot mero za ovrednotenje toplotne značilke obutve termično in izparilno upornost. Model stopala omogoča simulacijo konduktivne, konvektivne in evaporativne izgube toplote na stopalu. Poleg primarne naloge merjenja toplotne karakteristike obutve, lahko model stopala uporabimo tudi za fiziološko simulacijo delovanja človeškega stopala. Vgrajene funkcije (sprememba potenja stopala v odvisnosti od temperature kože, sprememba temperatura kože v odvisnosti od toplotnega toka, itn.) omogočajo ugotavljanje in simulacijo delovanja človeškega stopala, kar je uporabno tudi v fiziologiji. Računalniško vodenje omogoča regulacijo moči grelnikov v vsakem od 16 delov stopala posebej, prav tako je možno vodenje potenja delov, ki ga zagotavlja krmiljenje peristaltičnih črpalk. Vsak del je avtonomen: neodvisno je vodenje gretja in potenja dela, prav tako lahko dobimo rezultate meritev za vsak posamezni del posebej. Dobljeni rezultati in raziskave so ovrednoteni s primerjavo rezultatov drugih laboratorijev.

Ključne besede: človeška noga, termični modeli, potenje, kakovost obutve, fiziološko simuliranje

Sl. 2. *Sistem toplotnega modela stopala*

*Naslov odgovornega avtorja: Odsek za avtomatiko, biokibernetiko in robotiko, Institut Jožef Stefan, Jamova cesta 39, 1000 Ljubljana, Slovenija, mitja.babic@ijs.si

Strojniški vestnik - Journal of Mechanical Engineering 54(2008)9, SI 104
UDK 66.047

Paper received: 15.12.2007
Paper accepted: 07.07.2008

Rezultati raziskave energetskih karakteristik konvekcijskega sušenja

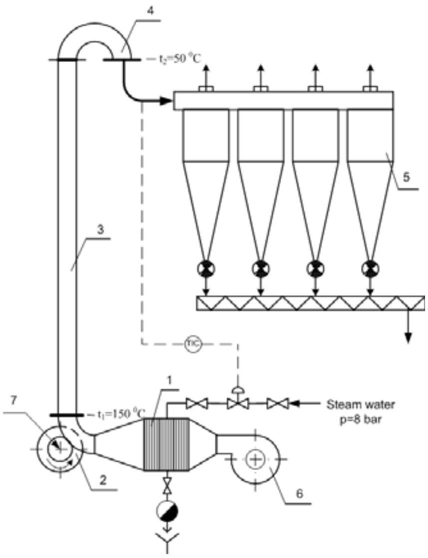
Slavica Prvulović[1] - Dragiša Tolmać[2,*] - Ljiljana Radovanović[2]
[1] Tehniška fakulteta, Bor, Srbija
[2] Tehniška fakulteta "Mihajlo Pupin", Zrenjanin, Srbija

V prispevku so predstavljene eksperimentalne in teoretične raziskave, ki so bile opravljene na industrijskem konvekcijskem sušilniku s pnevmatskim transportom materiala. Podane so numerične vrednosti optimalnih parametrov sušenja, energetske karakteristike, bilance in koeficient prenosa toplote.

Prenos toplote v teh sistemih poteka po načelu neposrednega stika suhe snovi in ogretega zraka. Tako je dosežen intenziven prenos toplote in snovi.

Prikazani rezultati raziskav so lahko koristni pri snovanju in konstruiranju tovrstnih sušilnikov v prehrambeni in živilskopredelovalni industriji. Delo obravnava tehnološko-tehnične značilke sušilnika, energetske bilance in koeficient prenosa toplota.

Ključne besede: energetske bilance, sušenje, numerični podatki, prenos toplote

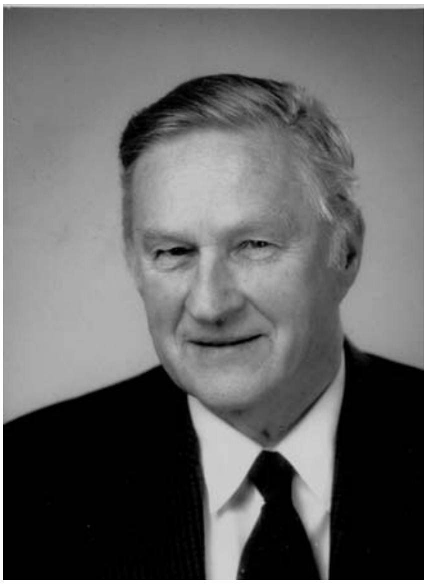


Slika 1. Shema eksperimentalne sušilne naprave
1- grelnik, 2-dozirnik, 3-cev, 4- glava
5-cikloni, 6- vetrilo, 7- vstop vlažne snovi

[*]Naslov odgovornega avtorja: Univerza v Novem Sadu, Tehniška fakulteta "Mihajlo Pupin", Djure Djakovic bb. 23000 Zrenjanin, Srbija, tolmac@beotel.yu

Osebne vesti

Podelitev »Zlatega doktorata« akademiku prof. Janezu Pekleniku



Zaslužnemu profesorju Univerze v Ljubljani, akademiku Janezu Pekleniku je 27. junija tega leta Tehniška univerza v Aachen-u v Zvezni republiki Nemčiji podelila "Zlati doktorat" za njegovo izredno uspešno znanstveno-raziskovalno delo.

Akademik Janez Peklenik je študiral na Fakulteti za strojništvo Univerze v Ljubljani. Po uspešno opravljenem študiju je odšel v Laboratorij za obdelovalne stroje Tehniške univerze v Aachen-u, ki je vodilna raziskovalna ustanova na področju proizvodnih tehnologij in sistemov. Tam je leta 1957 doktoriral na področju fizikalnih osnov brušenja. V svojem delu je razvil novo metodo merjenja temperature v brusilnem postopku in prvi uvedel statistični opis njegovih lastnosti. S tem je postavil raziskavam in razlagam zahtevnih tehnoloških postopkov nove temelje. Svoje raziskovalno delo je nato nadaljeval na področju avtomatizacije obdelovalnih sistemov ter leta 1961 postal docent na Tehniški univerzi v Aachen-u. Naslednje leto je bil povabljen kot gostujoči izredni profesor na Carnegie-Melon Univerzo v Pittsburgh-u, ZDA. Temu je leta 1964 sledila še izvolitev za rednega profesorja na Univerzi v Birmingham-u v Angliji, kjer je ustanovil prvo katedro za računalniško krmiljene obdelovalne sisteme na svetu. Z upoštevanjem naključnega značaja obdelovalnega postopka ter statistično obdelavo eksperimentalnih podatkov je postavil nova izhodišča za raziskovalno delo na področjih modernih proizvodnih tehnologij. Po dvajsetih letih znanstvenega in pedagoškega dela v tujini se je 1973 vrnil na Fakulteto za strojništvo Univerze v Ljubljani in ustanovil Katedro ter Laboratorij za tehniško kibernetiko, obdelovalne sisteme in računalniško tehnologijo. Pri nas je v študij strojništva uvedel modularno zasnovo in projektni način dela s študenti.

Akademik Peklenik je objavil preko 300 znanstvenih del s področja proizvodnih tehnologij, tehniških površin, strukturiranja in krmiljenja proizvodnih sistemov in ob svojem znanstveno-raziskovalnem delu vzgojil več kot 350 diplomiranih inženirjev, magistrov in doktorjev strojništva. Za znanstvene dosežke je prejel številna mednarodna in domača priznanja. Od Mednarodne akademije za proizvodno inženirstvo CIRP je prejel najprej Taylorjevo medaljo za mlade znanstvenike, nato pa še medaljo CIRP. Poleg tega je prejel še ameriško medaljo F. W. Taylorja, ki se podeljuje znastvenikom s področja proizvodnega inženirstva, in berlinsko nagrado Georga Schlesingerja. V Sloveniji je prejel Kidričevo nagrado, nagrado Republike Slovenije za življenjsko delo in bil imenovan za Ambasadorja znanosti Republike Slovenije. Akademik Peklenik je zaslužni profesor Univerze v Ljubljani ter častni profesor Univerze v Birmingham-u v Angliji ter Nanjinške Univerze za Aeronavtiko in Astronavtiko na Kitajskem. Je tudi redni član SAZU, ustanovitelj in častni predsednik Inženirske Akademije Slovenije, častni član mednarodne akademije CIRP, Evropske akademije in Ruske inženirske akademije. Naziv "Zlati doktorat" zaokrožuje nabor teh visokih domačih in mednarodnih priznanj.

akad. prof. dr. Igor Grabec

Prof. dr. Janez Kopač prejel medaljo za življenjsko delo

Hrvaško Združenje proizvodnega strojništva SHP – Hrvatska Udruga Proizvodnoga strojarstva – je prof. dr. Janezu Kopaču podelila plaketo in zlato medaljo za življenjsko delo. Fakulteta za strojništvo v Ljubljani in fakultete, združene v omenjeni povezavi, namreč že vrsto let sodelujejo predvsem na področju skupnega izvajanja raziskav in meritev na področju analize postopka odrezavanja ter posojanja merilne opreme za raziskave.

Prof. dr. Janez Kopač je plaketo prejel na podlagi sklepa sestanka članov SHP pod vodstvom predsednika prof. dr. Roka Cebala. Plaketo in medaljo so mu podelili ob odprtju mednarodne konference ICS 2008, ki je 18. junija potekala na Fakulteti za strojništvo in pomorstvo v Splitu. V utemeljitvi je med drugim zapisano, da so se za podelitev plakete in zlate medalje za življenjsko delo odločili na podlagi dolgoletnega sodelovanja prof. dr. Janeza Kopača s Fakulteto za strojništvo v Zagrebu (prof. dr. Toma Udiljak), Fakulteto za strojništvo Slavonski Brod (prof. dr. Ante Stoić) ter Fakulteto za strojništvo in pomorstvo Rijeka (prof. dr. Goran Cukor). Prof. dr. Janez Kopač je na omenjenih fakultetah predstavljal nova področja tehnike v obliki vabljenih predavanj (VHO – visoko hitrostno odrezavanje). Sodelovanje pa je potekalo tudi z izmenjavo raziskovalcev, izvajanjem meritev za raziskave, s posojanjem merilne opreme za raziskavo in podobno.

Prof. dr. Janez Kopač, sicer redni profesor, predstojnik Katedre za menedžment obdelovalnih tehnologij in vodja Laboratorija za odrezovanje – LABOD na Fakulteti za strojništvo v Ljubljani poudarja, da tovrstnega priznanja ne bi bilo, če laboratorij ne bi bil opremljen s sodobno merilno tehniko, ki na trgu dosega visoko ceno. V laboratoriju se zavedajo, da delo brez natančnih meritev ne more biti dobro opravljeno, zato so se odločili, da tehničnim fakultetam na Hrvaškem, ki tako dobre merilne opreme nimajo, priskočijo na pomoč. Študentje omenjenih fakultet tako za opravljanje meritev za doktorske naloge brezplačno uporabljajo naprave Fakultete za strojništvo v Ljubljani.

Tovrstno sodelovanje med fakultetami je običajno plod znanstev, ki se jih naveže na raznovrstnih konferencah, in je po Kopačevih besedah nekaj povsem običajnega, saj tudi študenti z ljubljanske Fakultete za strojništvo meritve za doktorske naloge pogosto opravljajo v tujini, kjer imajo še boljšo in sodobnejšo merilno opremo, kot jo imamo pri nas. Najpogosteje so to najuglednejši centri tehnike v Zahodni Evropi, in sicer Tehnično visoka šola v Aachnu in Fakulteta za visoko hitrostno odrezavanje v Darmstadtu v Nemčiji, v Franciji pa to sodelovanje poteka z inštitutoma v Clunyu in Metzu.

Poleg fakultet na Hrvaškem LABOD sodeluje na raziskavah s podiplomskimi študenti in opremo posoja tudi študentom Univerze v Rousseju v Bolgariji in Univerze v Gliwicah na Poljskem. Univerze in fakultete, ki intenzivno sodelujejo in si sposojalo opremo, se običajno predstojnikom kateder, ki omogočijo tujim podiplomskim študentom, da raziskave izvajajo v LABOD-u , zahvalijo za sodelovanje s podobnimi priznanji, kot je tokratna medalja za življenjsko delo. "Osebno mi priznanje pomeni zahvalo za vloženo energijo in čas ter priznanje, da kolegi z drugih fakultet radi sodelujejo z menoj," je še dodal Kopač.

prof. dr. Franci Čuš

Doktorati, magisteriji, specializacije in diplome

DOKTORATI

Na Fakulteti za strojništvo Univerze v Ljubljani so z uspehom zagovarjali svoje doktorske disertacije:

dne *07. julija 2008*: **Robert Rozman** z naslovom: "Model in lastnosti plazemskega oblaka pri laserski obdelavi materialov" (mentor: izr. prof. dr. Edvard Govekar);

Raziskali smo lastnosti plazemskega oblaka in njegov vpliv na laserski obdelovalni postopek pri obsevanju kovinskih površin z laserskim žarkom. V ta namen smo izdelali matematični model opisa fizikalnih pojavov, ki spremljajo nastanek plazemskega oblaka pri laserski obdelavi materialov. Pri tem smo nadgradili obstoječe modele iz literature ter tako znatno izboljšali ujemanje numeričnih rezultatov z eksperimenti. Glavni prispevek k izboljšanju numeričnih rezultatov je upoštevanje večkratnih ionizacij atomov, disociacije dvoatomnih molekul, sevanja plazme, absorpcije laserske svetlobe zaradi fotoionizacije in absorpcije laserske svetlobe na kondenziranih gmotah izparjenega materiala. Poleg tega je numerični model zasnovan zelo splošno, saj so vsi postopkovni parametri, ki jih potrebujemo pri reševanju numeričnega modela dostopni v literaturi in v specifikaciji laserskega sistema. Občasno se pojavijo le težave pri določitvi odbojnosti površine snovi za laserski žarek, zato smo razvili tudi novo metodo za določitev temperaturno odvisne odbojnosti površine snovi. Na osnovi numeričnih rešitev modela smo opisali nastanek plazemskega oblaka za dva primera. V prvem primeru je bila valovna dolžina laserske svetlobe A = 248 nm in dolžina bliska t_b = 30 ns, medtem ko je bila v drugem primeru valovna dolžina laserske svetlobe A = 1064 nm in dolžina bliska t_b = 200 μs. V obeh primerih se numerični rezultati dobro ujemajo z eksperimenti. Model smo uspešno uporabili tudi pri optimiranju postopka laserskega strukturiranja, ki se uporablja pri izdelavi pro¬totipov tiskanih elektronskih vezij. To kaže, da je model nastanka plazemskega oblaka zelo splošen ter primeren za širok nabor postopkovnih parametrov kot tudi za optimiranje laserskih obdelovalnih postopkov.

dne *08. julija 2008*: **Damjan Čelič** z naslovom: "Karakterizacija dinamskih lastnosti spojev sestavljenih struktur" (mentor: izr. prof. dr. Miha Boltežar);

Delo predstavi celostni pristop h karakterizaciji dinamskih lastnosti linearnih spojev v frekvenčnem prostoru in v ustaljenem stanju. Posamezne linearne podstrukture so numerično modelirane, rezultat redukcije, korelacije in izboljšav pa so veljavni modeli podstruktur v obliki končnih elementov. Na osnovi frekvenčnih prenosnih funkcij (FRF), pridobljenih z veljavnih numeričnih modelov, ter izmerjenih FRF, so identificirane dinamske lastnosti linearnih spojev. V identifikacijski postopek so poleg translacijskih vključene tudi rotacijske prostostne stopnje. Predstavljen identifikacijski algoritem je primeren za praktične uporabe, saj so meritve rotacijskih FRF na sestavu nepotrebne. Na osnovi identificiranih lastnosti spojev in FRF podstruktur se izvede rekonstrukcija odzivov na sestavu. Primernost predlaganega pristopa je demonstrirana na numeričnih in eksperimentalnih primerih.

dne *09. julija 2008*: **Miha Otrin** z naslovom: "Karakterizacija vibracij oplaščenih jeklenih vrvi" (mentor: izr. prof. dr. Miha Boltežar);

Delo predstavi celosten pristop k obravnavi dinamike prostorsko ukrivljenih oplaščenih jeklenih vrvi z medsebojnim stikom. Matematična modela ‚jeklene vrvi in oplaščenja sta postavljena po Euler-Bernoullijevi teoriji upogiba nosilca brez osne sile, za diskretizacijo pa so uporabljeni končni elementi. Vzbujevalna motnja je naključna v obliki kinematičnega pomika podpore oplaščenja in jeklene vrvi. Disipacija energije je predstavljena z dvema modeloma, proporcionalnim viskoznim dušenjem in strukturnim dušenjem. Za razpoznavo parametrov dušenja sta uporabljeni metoda z Nyquistovim diagramom in metoda z zvezno valčno transformacijo. Za razpoznavo frekvenčne odvisnosti dinamičnega modula elastičnosti jeklene vrvi in oplaščenja je razvita prilagoditvena metoda, ki upošteva izmerjene lastne frekvence in pripadajoče eksperimentalne modalne oblike. Stik med jekleno vrvjo in oplaščenjem je obravnavan po kazenski metodi z upoštevanjem trenja v tangencialni smeri stika.

Izdelana je metoda za obravnavo področja drsenja in mirovanja sočasnih točk v stiku. Pokazali smo, da z večanjem koeficienta trenja pomembno vplivamo na zniževanje prenosa vibracij. Numerični model jeklene vrvi z oplaščenjem predvidi, da dinamični modul elastičnosti jeklene vrvi nima večjega vpliva na velikost prenosa vibracij, kar je preverjeno tudi eksperimentalno. Z eksperimentalno overitvijo prenosa vibracij preko jeklene vrvi in oplaščenja se izkaže, da sta numerična modela primerna in uporabna za napoved njunega dinamičnega obnašanja.

Na Fakulteti za strojništvo Univerze v Mariboru sta z uspehom zagovarjala svoji doktorski disertaciji:

dne *04. julija 2008*: **Tomaž Vuherer** z naslovom: "Analiza vpliva mikro napak na trdnost pri utrujanju grobozrnatega TVP na zvarih" (mentor: doc. dr. Vladimir Gliha);

Nosilnost ciklično obremenjenih zvarnih spojev je odvisna od trdnosti najšibkejših mest. V primeru soležnih zvarov je najproblematičnejša mikrostruktura grobozrnatega toplotno vplivanega področja (TVP) na vznožju vara. Tu se pojavijo varilne zaostale napetosti in koncentracija napetosti. Mikro napake imajo vpliv na odpornost zvarov proti utrujenosti.

V tej raziskavi smo pripravili vzorce jekla, ki se lahko nahajajo na vznožju vara, z mikro napakami v različnih stanjih z uporabo simulacije temperaturnega cikla varjenja in s toplotno obdelavo v peči. Umetne mikro napake so bili odtisi Vickersove piramide in slepe izvrtine. Preizkušance smo rotacijsko upogibno obremenjevali z razmerjem napetosti $R = -1$.

Primerjali smo trdnost pri utrujanju treh martenzitnih jekel z mikro napakami in brez njih. Upoštevali smo lokalne in globalne zaostale napetosti.

Eksperimentalno smo raziskovali hitrost širjenja majhnih in velikih razpok. Analizirali smo mehanizme nastanka in zgodnjega širjenja razpok na jeklih v različnih stanjih. Nastanek razpok iz umetnih mikro napak, katerih velikost je primerljiva z največjimi mikrostrukturnimi enotami jekla, je funkcija lokalnih zaostalih napetosti zaradi priprave napak.

dne *04. julija 2008*: **Boštjana Žajdela** z naslovom: "Modeliranje usedanja prepustnih delcev v trdnokapljevitih zmeseh" (mentor: prof. dr. Matjaž Hriberšek);

V doktorski disertaciji je obravnavano gibanje kosmov v suspenziji, ki je delovna zmes na biološki čistilni napravi. Opravili smo analize odpadne vode biološke čistilne naprave Lendava z vzorčenjem. V eksperimentalnih raziskavah smo največjo pozornost namenili geometrijskim in sedimentacijskim lastnostim kosmov, ki so ključni parametri pri razvoju numeričnega postopka za simulacijo gibanja kosmov. Predstavili smo obsežne analize oblike kosmov, velikosti primarnih delcev in kosmov, poroznosti ter prepustnosti kosmov in gostote kosmov. Na osnovi rezultatov eksperimentalnih raziskav smo definirali in izračunali fizikalne parametre kosmov ob upoštevanju njihove poroznosti. Izmed teh sta zraven poroznosti najpomembnejša prepustnost in gostota kosmov, katerih vrednosti za različne velikosti kosmov predstavljajo najpomembnejši del izvedene raziskave.

Vsi ti parametri so potrebni za numerično modeliranje, s katerim smo izsledke eksperimentalnega dela prevedli v simulacijo dvofaznega toka tekočine pri usedanju kosmov. Eno fazo je predstavljala voda, ki smo jo opredelili kot zvezno fazo, drugo fazo pa so tvorili kosmi odpadne vode, ki smo jih opredelili kot dispergirano fazo. Numerično smo modelirali gibanje kapljevite faze z Eulerjevim načinom numerične obdelave na osnovi Navier Stokesovih enačb, medtem smo za gibanje disperzne faze uporabljali Lagrangeov način numerične obdelave. S primerjavo rezultatov numeričnih simulacij in meritev smo dokazali, da so izpeljani modeli poroznosti, prepustnosti in gostote kosmov pravilni in omogočajo natančno simulacijo gibanja kosmov v biološki čistilni napravi.

MAGISTERIJA

Na Fakulteti za strojništvo Univerze v Mariboru sta z uspehom zagovarjala svoji magistrski deli:

dne *14. julija 2008* **Anton Belšak** z naslovom: "Izvedba črpalnega sistema Žetale - Čermožiše z nabirnim vodohranom in povratno zanko" (mentor: izr. prof. dr. Andrej Predin);

dne *22. avgusta 2008* **Tadej Lozinšek** z naslovom: "Model vitke šest sigma v proizvodnji predelave aluminija" (mentor: prof. dr. Andrej Polajnar).

SPECIALIZACIJE

Na Fakulteti za strojništvo Univerze v Ljubljani je z uspehom zagovarjal svoje specialistično delo:

dne *4. julija 2008* **Roman Kurmanšek** z naslovom: "Projektno vodenje investicijskega vzdrževanja" (mentor: prof. dr. Marko Starbek).

Na Fakulteti za strojništvo Univerze v Mariboru so z uspehom zagovarjali svoja specialistična dela:

dne *10. junija 2008* **Tomislav Malgaj** z naslovom: "Optimizacija dela v oddelku obratovanja termoelektrarne brestanica" (mentor: prof. dr. Andrej Polajnar);

dne *22. avgusta 2008* **Boštjan Jakop** z naslovom: "Humanizacija dela na delovnih mestih oddelka za ekstrudiranje" (mentor: prof. dr. Andrej Polajnar);

dne *22. avgusta 2008* **Janez Kljun** z naslovom: "Merila za določanje uspešnosti na osnovi merjenja rezultatov dela" (mentor: prof. dr. Andrej Polajnar).

DIPLOMIRALI SO

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

dne *03. julija 2008*: Aleš HANŽEKOVIČ;
dne *10. julija 2008*: Roman HANŽEKOVIČ;
dne *28. avgusta 2008*: Peter GÖNCZ.

*

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

dne *11. julija 2008*: Filip AVBAR, Peter BABIČ, Mihael LISJAK, Robert MERHAR, Luka SLAPNIK, Aleš SMILJANIĆ.

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

dne *10. julija 2008*: Damir GAŠPARIĆ, Marko HRASTNIK, Aleš MIHELIČ, Anton ŠERBAK.

Navodila avtorjem

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

Članki morajo vsebovati:

- naslov, povzetek, ključne besede,
- besedilo članka,
- preglednice in slike (diagrami, risbe ali fotografije) s podnaslovi,
- seznam literature in
- podatke o avtorjih, odgovornega avtorja in njegov polni naslov.

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

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

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 rezultatov 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.

OBLIKA ČLANKA

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

Enote in okrajšave

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

Slike

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

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

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

Preglednice

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

Seznam literature

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

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

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

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

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 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.

Plačilo objave

Avtorji vseh prispevkov morajo za objavo plačati prispevek v višini 180,00 EUR (za članek dolžine do 6 strani), 220,00 EUR (za članek dolžine do 10 strani) ter 20,00 EUR za vsako dodatno stran. Prispevek se zaračuna po sprejemu članka za objavo na seji Uredniškega odbora. Po objavi prejme avtor članka 25 separatov članka.

Hidria is launching a new product range

Hidria is launching a new programme of integral thermo-solar solutions onto the market – solutions that contribute to the effective use of renewable sources of energy, reduce the impact on the environment and bring direct savings to the investor. With this innovative type of system, a well insulated house can be provided with up to 70% of its sanitary water requirements and 30% of its heating requirements. The system includes a complete range of solar collectors, solar sets, automation systems, thermal pumps, recuperators, sanitary water heaters, heat storage reservoirs and expansion tanks. The company also provides energy engineering.

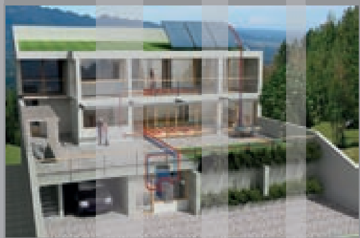
Package I - Hot sanitary water preparation with 70% energy saving

- heat storage tank 300 l
- preparation array with regulation
- solar energy collector with a 2 square meter surface (3 units)
- anti-freeze fluid
- expansion tank
- supporting structure

Package II: Solar package for the preparation of sanitary and process water

- 800 l heat storage tank with freshwater module
- preparation array with regulation
- solar energy collector (8 units)
- expansion tank
- anti-freeze fluid
- supporting structure

Our advantages are our own in-house trained experts, an individual approach and an excellent price to quality ratio.
We are also happy to assist in the preparation of any documentation you might need for state subsidies.



Hidria IMP Klima d.o.o.
BU Heat exchangers and
Renewable energy sources
Vojkova 58
1000 Ljubljana
Slovenia
T: +386 1 300 52 15
F: +386 1 436 76 19
E: collectors@hidria.com
www.hidria.com

The hottest solar sets in Slovenia!

Hidria is a Slovenian global corporation focusing on developing and selling systems for air-conditioning, heating and ventilation, automotive and handheld power tools industries. Hidria's newest solutions are **innovative solar power systems.**

New in offer: Photovoltaics

Hidria

9 770039 248001
ISSN 0039-2480

http://www.sv-jme.eu