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Vpliv kavitacijskih struktur na erozijo na simetričnem krilu v kavitacijskem predoru

The Influence of Cavitation Structures on the Erosion of a Symmetrical Hydrofoil in a Cavitation Tunnel

Brane Širok - Matevž Dular - Matej Novak - Marko Hočevar - Bernd Stoffel - Gerhard Ludwig - Bernd Bachert

Izvedena je bila vizualna in erozijska študija kavitacije na dvodimenzionalnem krilu v kavitacijskem predoru. Razvita je bila nova metoda vrednotenja kavitacijskih poškodb, ki temelji na računalniški vizualizaciji.

Z računalniško vizualizacijo je bila izvedena analiza kavitacijskih dogodkov nad krilom. Razvit je bil empirični model, ki povezuje moč kavitacijske erozije na površini krila in kavitacijske dogodke nad krilom. Empirični model omogoča opazovanje kavitacije v turbinskih strojih. Študija je del petega okvirnega evropskega projekta "Cavismonitor".

(Ključne besede: kavitacija, erozija, vizualizacija računalniško podprta, modeli empirični)

A study of the visual and erosion effects of cavitation was performed on a two-dimensional hydrofoil in a cavitation tunnel. A new method of erosion-damage evaluation was developed, based on computer-aided visualization.

Using computer-aided visualization, a statistical evaluation of the cavitation structures above the hydrofoil was made. An empirical model was developed that relates the intensity of cavitation erosion on the hydrofoil surface and the visual structures of the cavitation above the hydrofoil. An empirical model enables monitoring and control of cavitation in turbo-machinery. The study is a part of the European 5th Framework Project "Cavismonitor".

(Keywords: cavitation, erosion, computer-aided visualization, empirical models)

0 UVOD

Kavitacija v hidravličnih strojih povzroča nihanje, povečanje hidrodinamičnega upora, spremembe hidrodinamike toka, hrup, termične, svetlobne učinke in erozijo. Vsi učinki kavitacije povzročajo hidravlične izgube v pretočnem delu in zmanjšujejo moč in učinkovitost strojev. Naš namen je povezati vidne kavitacijske dogodke nad krilom v kavitacijskem predoru z erozijo na površini. V prispevku bo predstavljena povezava med časovno in prostorsko odvisnimi topološkimi strukturami in kavitacijsko erozijo na krilu.

Pojav kavitacije je tesno povezan z lokalnimi časovno spremenljivimi hidrodinamičnimi lastnostmi kakor sta lokalna kinetična energija toka in lokalni statični tlak. V primeru, da lokalni statični tlak pade pod vrednost pripadajočega uparjalnega tlaka kapljevine, se v opazovanem področju oblikuje dvofazni tok kapljevine in pare, ki v področju povečanega statičnega tlaka prek kondenzacije pare preide v enofazni kapljevinski tok. Ta pojav spremljajo tlačni utripi.

0 INTRODUCTION

When cavitation occurs in hydraulic machines it produces vibrations, increases the hydrodynamic drag, changes the flow hydrodynamics, produces noise, thermal and light effects, and most importantly, it causes cavitation erosion. All cavitation effects generate hydraulic loss in the flow tract and decrease the machine's efficiency and power. The purpose of this paper was to relate the visible cavitation structures above a single hydrofoil in a cavitation tunnel with the erosion on the hydrofoil's surface. A functional relationship between the visible space and time-dependent topological structures and the cavitation erosion on the surface of a hydrofoil will be presented.

The cavitation phenomenon is related to local time-dependent hydrodynamic characteristics such as the local kinetic energy of the flow and the local ambient pressure. In the cases where the local ambient pressure drops below the vapour pressure, a two-phase flow of liquid and vapour is formed, which transforms to a one-phase liquid flow in a region where the pressure is higher than the condensation pressure. This phenomenon is accompanied by significant pressure pulsation.

Metode raziskav kavitacije delimo na celovite in lokalne metode. Celovite metode temeljijo na energijskih razmerjih. Celovite metode so v celoti standardizirane in podprte z mednarodnimi priporočili. Uporabljajo se pri prevzemnih preskusih na modelih hidravličnih strojev, npr. vodnih turbin, vijakov in črpalk. Z lokalnimi metodami obravnavamo kavitacijo časovno in prostorsko. Med lokalne metode prištevamo računalniško vizualizacijsko metodo, merjenje akustične emisije ter merjenje nihanja mehanskih sestavov in utripov tlaka v pretočnem delu. Lokalne metode so namenjene predvsem kot dopolnilo celovitim metodam.

V nasprotju s študijo kavitacije v hidravličnih strojih potekajo temeljne raziskave kavitacije na hidrodinamičnih krilih v kavitacijskih predorih. Namenjene so ugotavljanju novih empiričnih odvisnosti, ki so usmerjene predvsem v napoved erozijskih učinkov na stenah pretočnega dela ([1] in [2]).

Cavitation is studied using integral and local methods. Integral methods are based on energy effects that are standardised and supported by international recommendations. Integral methods are used during the model testing of hydraulic machines like water turbines, propellers and pumps. Using local methods, information about the space and time behaviour of cavitation in hydraulic machines is obtained. Local methods are computer-aided visualization methods and measurements of the acoustic emissions and vibrations of mechanical structures. Local methods are mainly used as a supplement to integral methods.

In contrast to studies of hydraulic machines, basic studies of cavitation are performed on hydrofoils in cavitation tunnels. The goal of these studies is to set new empirical relations, mainly predicting the erosion effects on the walls of flow tracts. Visualization studies confirm a relationship between material erosion and the type of cavitation, which is characterised by the dynamics and geometrical structure of the vapour cloud above the surface ([1] and [2]).

1 KAVITACIJA

Kavitacijo delimo glede na obliko kavitacijskih pojavov v tekočini, glede na stopnjo ali režim kavitacije in glede na vzroke za nastanek kavitacije ([1] in [3]). Po obliki delimo kavitacijo na kavitacijo ločenih mehurčkov, kavitacijo v obliki žepa ali kavitacijskega oblaka in vrtinčno kavitacijo, ki nastaja na mestih velike obročne napetosti v tekočini. Z vidika kavitacijske erozije na hidravličnih strojih je najpomembnejša kavitacija v obliki žepa ali kavitacijskega oblaka, katerega kavitacijski mehurčki implodirajo nad trdno površino rotorskih lopatic stroja [1].

Množico lastnosti, ki vplivajo na nastanek, razvoj in vrsto kavitacije, delimo na hidravlične in geometrične lastnosti. Med hidravlične lastnosti sodijo hitrost, spremembe hitrosti, tlak in spremembe tlaka. Med geometrične lastnosti prištevamo obliko, usmerjenost in hrapavost telesa. Poglavitne značilnosti kavitacijskega stanja v odvisnosti od hidravličnih razmer toka opišemo z brezdimenzijskim kavitacijskim številom σ, ki vključuje primerjalni tlak p_∞, tlak uparjanja kapljevine p_v in hitrost toka v_∞ [1].

1 CAVITATION

Cavitation can be classified with regard to the shape of the cavitation structure in a fluid, to a stage or regime of cavitation, or according to its origin ([1] and [3]). With regard to the shape, cavitation can be classified as the cavitation of isolated bubbles, cavitation in the shape of a vapour pocket or to cloud cavitation and vortex cavitation, which appears at a location with high circumferential fluid tension. When observing the cavitation erosion of hydraulic machines, it is the shape of the vapour pocket or cloud cavitation that is the most important type. In the former case, cavitation bubbles implode above the solid surface of the rotor blades [1].

Parameters that have an influence on the appearance, growth and type of cavitation can be divided into hydraulic and geometrical parameters. The hydraulic parameters are flow velocity, velocity fluctuations, pressure, and pressure pulsations. The geometrical parameters are shape, orientation and roughness of an object. The basic properties of the cavitation condition as a function of the hydraulic conditions of flow are described with a non-dimensional cavitation number σ. This number includes the reference pressure p_∞, the vapour pressure p_v and the flow velocity v_∞ [1]:

$$\sigma = \frac{p_\infty - p_v(T_\infty)}{\rho v_\infty^2 / 2} \qquad (1).$$

Z uporabo kavitacijskega števila σ lahko opišemo kavitacijske razmere toka tekočine glede na razmere brez kavitacije, začetno stopnjo kavitacije in kavitacijo v različnih fazah. Z zmanjšanjem kavitacijskega števila σ se povečuje kavitacijska ogroženost. Poleg povečane hitrosti toka in zmanjšanja statičnega tlaka v tekočini vplivajo na kavitacijo tudi geometrijske značilnosti kot so ostri robovi obtekanega telesa, povečanje vpadnega kota

With the aid of the cavitation number σ one can describe the cavitation conditions of fluid flow for non-cavitating flow, cavitation start-up and cavitation at different stages of development. When the cavitation number σ decreases, the cavitation aggressiveness increases. Besides increased velocity and decreased static pressure of the fluid flow, geometrical parameters such as sharp edges, increased inclination angle and roughness of the surface of the submerged body also in povečana hrapavost površine. Hrapavost in nepravilnosti na površini telesa lahko delujejo kot viri kavitacijskih jeder.

Najpogostejša nezaželena posledica kavitacije je erozijska poškodba materiala, povzročena pri imploziji kavitacijskih mehurčkov v bližini trdne površine. Problem erozije materiala so intenzivno raziskovali že mnogi avtorji ([4], [5], [8] in [9]). Kolaps kavitacijskega mehurčka je proces, ki dela motnje in šoke z velikimi tlačnimi amplitudami v točki kondenzacije mehurčka. Če se ta dogodek odvija blizu trdne stene, nastanejo velike lokalne mehanske obremenitve v sestavi materiala. Ponavljanje te obremenitve zaradi množice mehurčkov, ki implodirajo, povzroča utrujanje materiala in »razkrajanje« materialne sestave na površini. Kakovostne študije dinamike kavitacijskih oblakov nakazujejo, da je kolaps mehurčkov v kavitacijskem oblaku agresivnejši od kolapsa posameznih mehurčkov [2]. Tlačna motnja nastane v trenutku, ko kavitacijski mehurčki v oblaku implodirajo in s tem povzročijo udarni val, ki se širi na vse strani. Če udarni val trči ob bližnjo steno, povzroči na njej močan tlačni udar velikosti nekaj deset MPa [4]. Velikost tega udara je primerljiva z mejo elastičnosti materiala. Drugi možni tip kavitacijske erozije se odvija z implozijo mehurčkov v neposrednem stiku s trdno steno v pretočnem delu. V tem primeru vpliva trdna površina na krogelno obliko mehurčka, ki postane nestabilen v svoji obliki. Opazovanja so pokazala, da lahko tako nastala asimetrija pri prehodu v področje z večjim tlakom zavzame obliko pospešenega curka kapljevine, usmerjenega skozi mehurček proti trdni steni [4]. Tako imenovani povratni mikrocurek (sl. 1) doseže veliko lokalno hitrost, ki povzroči udarni šok z veliko lokalno obremenitvijo materiala ([1] in [3]). V nadaljevanju se bomo usmerili predvsem v študijo mehanizma kolapsa množice mehurčkov v kavitacijskem oblaku, ki se s celovitimi parametri, to sta kavitacijsko število σ in vpadni kot na lopatico δ, spreminja po obliki in kinematiki kavitacijskega oblaka.

2 PRESKUS

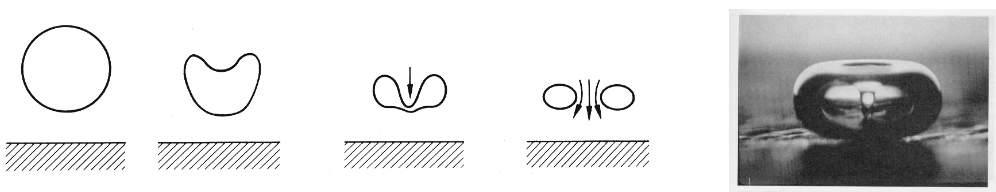
Eksperimentalno delo je obsegalo študijo kavitacije na simetričnem krilu v zaprtem kavitacijskem predoru. Delo je potekalo na Tehniški univerzi v Darmstadtu – v Laboratoriju za turbinske stroje in

have an influence on cavitation aggressiveness. Roughness and unevenness of the surface of the body can act as a generator of cavitation cores.

The most unwanted consequence of cavitation is erosion damage, which is caused by bubble implosion near the solid surface of a body. Cavitation erosion has been studied by many authors ([4], [5], [8] and [9]). Bubble implosion is a process that generates disturbances and shocks with high amplitudes of pressure in the position of a bubble's condensation. If this process occurs close to a solid surface, high local mechanical tensions in the structure of the material are generated. Repeated disturbances, caused by numerous bubble implosions, results in fatigue and damage to the material's structure. Qualitative studies of cavitation clouds' dynamics show that the collapse of bubbles in a coherent cavitation cloud is more aggressive than the collapse of a group of single bubbles [2]. A pressure disturbance occurs when cavitation bubbles in a cavitation cloud implode and generate a shock wave that propagates in all directions. If the shock wave collides with a nearby surface it causes a large pressure shock of the order of several 10 MPa [4]. The magnitude of the shock is comparable to the elastic limit of the material. The second possible type of cavitation erosion happens when bubbles implode onto the solid surface of a flow tract. The solid surface of the body acts on the spherical shape of the bubble, which becomes unstable. Investigations have shown that the developed asymmetry at the transition into the region of higher pressure takes the form of an accelerated fluid micro-jet, directed through a bubble towards the solid surface [4]. The so-called reverse micro-jet (Fig. 1) can reach a high local velocity, which causes a shock with high local tension of the material ([1] and [3]). In addition, the study will focus on the implosion mechanism of a group of bubbles in a cavitation cloud, which changes its kinematics and shape in accordance with integral parameters such as the cavitation number σ and the blade inclination angle δ.

2 EXPERIMENT

The experimental work included a cavitation study using a symmetrical hydrofoil in a closed cavitation tunnel of the Technical University Darmstadt, Laboratory for Turbomachinery and Fluid



Sl. 1. *Mehanizem nastanka mikrocurka in slika mikrocurka[1] in [2]*
Fig. 1. *Mechanism of micro-jet generation and a picture of a micro-jet [1] and [2]*

tekočinsko energetiko in na Turboinštitutu v Ljubljani. Kavitacijski preskus na simetričnem krilu je bil izveden na kavitacijskem predoru na Univerzi v Darmstadtu, kjer je bila opravljena tudi eksperimentalna analiza erozijskih poškodb na izbranih mestih površine krila. V izbranih delovnih točkah so bile posnete zaporedne digitalizirane slike topoloških sestavov kavitacijskih oblakov. Predprocesirano vizualizacijsko gradivo je bilo analizirano s programsko opremo na Turboinštitutu v Ljubljani. V sklepnem delu preskusa je bila opravljena večparametrična analiza erozije v odvisnosti od moči in lege kavitacije.

Power, and analyses at the Turboinstitut Ljubljana. The cavitation experiment on the symmetrical hydrofoil, as well as the experimental analysis of the erosion damage at specific locations on the hydrofoil, was performed at the University of Darmstadt. Successive images of topological structures of the cavitation clouds were captured at selected operational points. Pre-processed visualization material was analysed with the aid of software at the Turboinstitut Ljubljana. In the final part of the experiment a multi-parametric analysis of cavitation erosion versus the magnitude and position of cavitation was performed.

2.1 Kavitacija na simetričnem krilu v kavitacijskem predoru

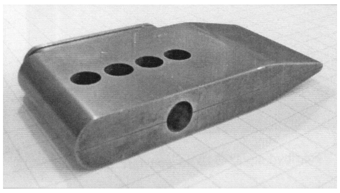
Pri preskusu je bilo uporabljeno simetrično krilo (sl. 2) s polkrožnim vpadnim robom dolžine 107,9 mm, širine 50 mm in debeline 16 mm. Kot primerjalna izmera je bila uporabljena debelina krila h = 16 mm. Oblika krila z ravnimi vzporednimi stenami je bila izbrana zaradi tehnologije vrednotenja erozije na nadzornih površinah – vzorcih.

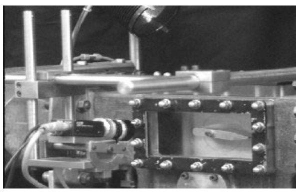
Krilo je bilo nameščeno v kavitacijskem predoru (sl. 2) s sklenjenim obtokom, tako da je bilo mogoče spreminjati tlak in imensko hitrost (kavitacijsko število – σ) v sistemu. Srednja hitrost v testni ravnini pred krilom je znašala v = 16 m/s, kar ustreza Reynoldsovemu številu Re = 256000. Med preskusom se je spreminjal podtlak v sistemu in vpadni kot krila δ v mejah od 0° do 7,5°.

2.1 Cavitation on a symmetrical hydrofoil in a cavitation tunnel

The experiment was performed on a symmetrical hydrofoil (Figure 2) with a circular leading edge. The hydrofoil was 107.9-mm long, 50-mm wide and 16-mm thick. The thickness of the hydrofoil (h = 16 mm) was used as a reference dimension. The shape of the hydrofoil with parallel walls was applied to suit a method for the evaluation of cavitation erosion on control surfaces (samples).

The hydrofoil was placed in a closed-circuit cavitation tunnel (Figure 2) so that the system pressure and nominal velocity (cavitation number σ) could be changed. The average velocity in front of the hydrofoil was constant (v = 16 m/s) at Re = 256000. During the experiment the system pressure and inclination angle δ (from 0° to 7.5°) were modified.





Sl. 2. *Krilo in preskuševališče*
Fig. 2. *Hydrofoil and test rig*

Na krilu so bili nameščeni štirje valjni vzorci na mestih, ki jih prikazuje slika 2. Kavitacijsko število se je spreminjalo z nastavljanjem podtlaka v kavitacijskem predoru tako, da je bil vstopni rob kavitacijskega oblaka nad določenim vzorcem na krilu. Izbrana so bila štiri kavitacijska števila za vsak vpadni kot krila δ. Integralne preskusne karakteristike so podane v preglednici 1.

Four specimens were placed in a hydrofoil, as shown in Figure 2. The cavitation number was set by changing the system pressure so that the leading edge of the cavitation cloud was located above a specific specimen on the hydrofoil. Four different cavitation numbers were chosen for each inclination angle. The integral experimental characteristics are shown in Table 1.

Preglednica 1. *Kavitacijsko število v odvisnosti od vpadnega kota krila in mesta najintenzivnejše kavitacije*
Table 1: *The dependence of the cavitation number on the hydrofoil inclination angle and the position of maximum cavitation*

δ	σ_1	σ_2	σ_3	σ_4
0°	1,59	1,38	1,22	1,16
2,5°	2,35	2,03	1,75	1,63
5°	3,25	2,71	2,43	2,19
7,5°	4,00	3,38	2,98	2,73

2.2 Ocenjevanje erozijskih učinkov kavitacije

Ocenjevanje erozijskih poškodb temelji na vrednotenju geometrijskih sprememb na površini vzorca. Vzorci so bili v krilo vstavljeni poravnano s površino in izpostavljeni toku (slika 2). Čas preskusa je bil 30 minut. Spremembe so se pokazale kot luknjice na površini valjnih vzorcev, ki so posledica erozije zaradi kavitacije. Pri preskusu smo uporabili vzorce premera 10 mm, narejene iz čistega bakra (sl. 3). Baker je primeren material zaradi mehanskih lastnosti, predvsem zaradi majhne trdote in majhne odpornosti na tlačne sunke, ki jih povzroči kavitacija. Luknjice na površini vzorca imajo premer velikostnega reda 10^{-5} m.

Moč erozijskih učinkov kavitacije je bila določena s štetjem luknjic. Sistem za vrednotenje erozije je sestavljen iz mikroskopa, digitalne (CCD) kamere ter vira svetlobe (sl. 3). Razvit je bil program vrednotenja, ki luknjice prešteje in oceni njihovo površino. Občutljivost vrednotenja oziroma velikost nadzornega elementa sta bili nastavljivi. Najboljši rezultati so bili dobljeni pri velikosti nadzornega elementa 18 µm, kjer področje – velikost nadzornega elementa ravno zajame luknjico povprečne velikosti. Program je upošteval prekrivanje dveh ali več luknjic. Da bi dobili reprezentativen nabor podatkov, je treba ovrednotiti dovolj veliko površino vzorca.

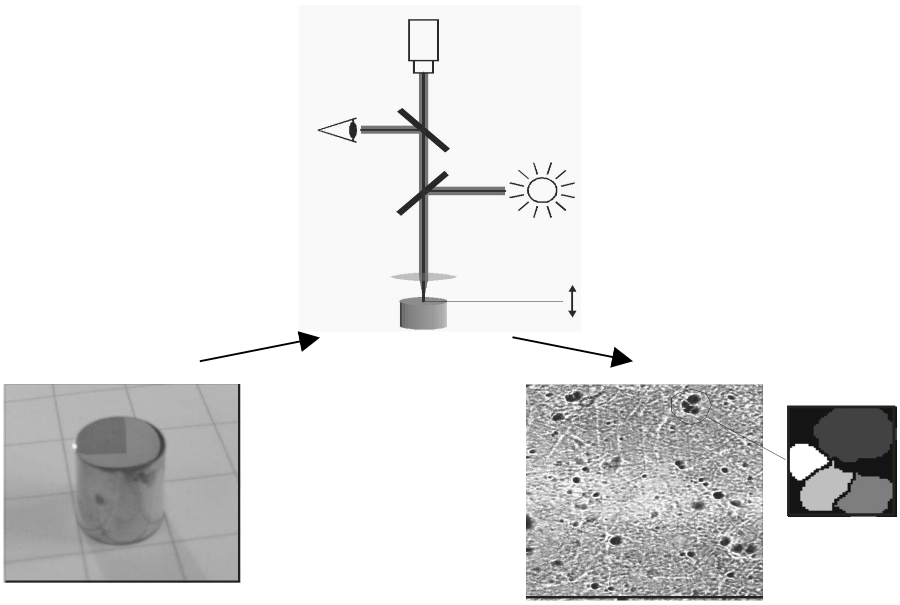
Količinska ocena poškodb kavitacijske erozije z metodo štetja luknjic je predstavljena v preglednici 2. Moč kavitacije količinsko podajata število N in površina luknjic A_d. Uporabljena metoda omogoča relativno medsebojno primerjavo vzorcev na krilu.

2.2 The method for evaluating cavitation erosion

The erosive aggressiveness of the cavitation condition can be quantified by the so-called pit-count method, i.e. a quantitative evaluation of the pits that are generated on the surface of a specimen. The specimens were mounted flush with the surface of the hydrofoil and exposed to cavitation (Figure 2). The exposure time was 30 minutes. Erosion effects are expressed as pits on the surface of the specimen. In the experiment, cylindrical specimens of 10-mm diameter, made with pure copper, were used (Figure 3). Pure copper is well suited because of its mechanical quantities, especially its low hardness, i.e. its low resistance to pressure shocks caused by cavitation. The pits have a diameter of 10^{-5} m order of magnitude.

The number and size of the pits in relation to the cavitation exposure time and the type of material gives us a quantitative measure of the erosive aggressiveness. The system for recording the pits consists of a microscope, a CCD camera, and an illumination source (Figure 3). Image-processing software was developed to determine the aggressiveness of the erosion by counting the number of pits and determining their size. The sensitivity of the evaluation, i.e. the magnitude of the control element, is optional. Investigations have shown that a control element with a diameter of 18 µm, where the control element covers a pit of average magnitude, offered the most plausible results. The software also considered the overlapping of two or more pits. In order to obtain a representative set of data, an appropriate surface area needs to be considered.

The quantitative evaluation of the cavitation erosion of the hydrofoil surface obtained by the pit-count method is shown in Table 2. The number (N) and the pit area (A_d) represent quantitative measures of the cavitation aggressiveness. The pit-count method allows a relative comparison of the specimens.



Sl. 3. *Sistem za vrednotenje kavitacijske erozije*
Fig. 3. *System for evaluating cavitation erosion*

Preglednica 2. *Podatki o poškodbah vzorcev pri strmini 5° (brez erozije na prvem vzorcu)*
Table 2. *Specimen erosion data for an inclination angle of 5° (with no erosion on the first specimen)*

σ / *specimen*	A_{ref} mm^2	A_d mm^2	N
3,25 / 1.	-	-	-
2,71 / 2.	24,75	1,64	2752
2,43 / 3.	24,53	1,14	2093
2,19 / 4.	24,54	0,97	1670

2.3 Ocenjevnje kavitacije z vizualizacijo

Kavitacija je viden pojav, zato ga lahko opazujemo z računalniško vizualizacijo. Kavitacijski oblaki, ki so predmet raziskave, oblikujejo skalarna polja moči svetlobe v prostoru in času. S pomočjo časovno zaporedne digitalizacije slik so nastale posamezne sočasne časovne vrste, ki popisujejo kavitacijske sestave.

Za vsak kavitacijski režim sta bili posneti dve seriji 500 slik s frekvenco zajemanja slik 25 slik/s. Prva serija predstavlja pogled na krilo od zgoraj, druga pa s strani. Signal iz video kamere je bil digitaliziran s kartico za zajemanje slik s 24-bitno barvno ločljivostjo v sistemu M-JPEG. Za nadaljnjo uporabo in analizo v programu za vrednotenje dinamičnih pojavov na digitalnih slikah Dynascan [7] je bila ločljivost zmanjšana na 256 odtenkov sivine.

Statistično vrednoteno vidno polje je bilo razdeljeno na 225 oken (sl. 4). Pri pogledu od zgoraj je bila velikost vsakega okna 15 × 15 točk, pri pogledu od strani pa je bilo okno veliko 5 × 5 točk. Za vsako okno je bila izračunana skalarna funkcija [7]:

2.3 Cavitation evaluation using the computer-aided visualization method

Cavitation is a visual phenomenon that can be observed with a computer-aided visualization method. The observed cavitation clouds form scalar patterns of grey-level intensity in space and time. With time-successive digitisation of the images, time series that describe the observed cavitation structures were generated.

Five hundred images of the top and side view were recorded for each respective cavitation condition (cavitation number) with a sampling frequency of 25 images/s. The camera signal was digitized using an image-capturing card with a 24-bit colour resolution in the M-JPEG system. For further analyses with Dynascan software [7], for quantification of the dynamic phenomena of digital images, the resolution was decreased to 256 grey levels.

The region of interest for the statistical evaluation (Figure 4) was divided into 225 observation areas (windows). Each window had a size of 15 × 15 pixels at the top view and 5 × 5 pixels at the side view. For each window a scalar function was calculated [7]:

$$A(k,t)=\frac{1}{225}\sum_{l=1}^{15}\sum_{m=1}^{15}E(l,m)........E(l,m)=\{0,1....255\} \qquad (2),$$

kjer E podaja lokalno, A pa povprečeno svetlost. Količinska ocena kavitacijske sestave na opazovanem območju krila v navpični in vodoravni smeri prečno na krilo je podana v obliki prostorskih topoloških porazdelitev skalarne funkcije:

where E is the local grey-level intensity and A is the average grey-level intensity. A quantitative evaluation of the cavitation structure in the observed hydrofoil area in the vertical and horizontal directions perpendicular to the hydrofoil is given in the form of space-distributed topological structures of the scalar function:

$$\overline{A}(k)=\frac{1}{N}\sum_{t}A(k,t)$$

in / and (3)

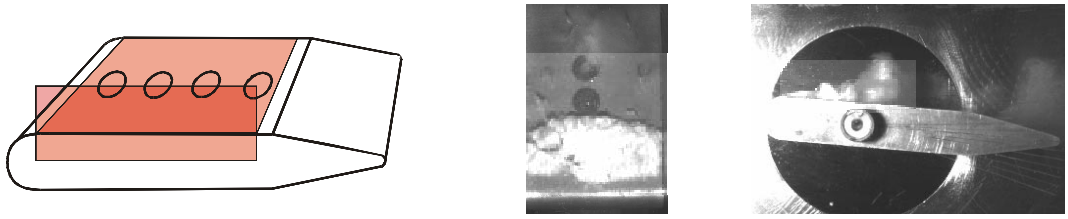
$$s(k)=\sqrt{\frac{1}{N-1}\sum_{t}\left(\overline{A}(k)-A(k,t)\right)^2}$$

kjer je $\overline{A}(k)$ povprečna jakost in *s(k)* standardno odstopanje moči svetlobe.

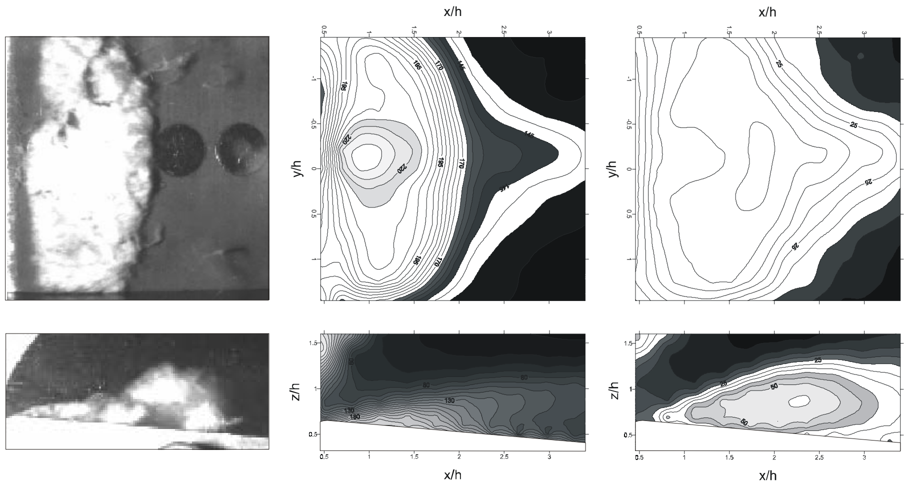
Z enačbami (2) in (3) so bile ocenjene lokalne karakteristike topoloških sestavov kinematike kavitacijskega oblaka pri različnih celovitih parametrih kavitacije, ki so določeni s preglednico 1. Lego in vrednost največje moči kavitacije je mogoče oceniti s slike 5. Oba parametra se znatno spreminjata s celovitimi

where $\overline{A}(k)$ is the average and *s(k)* the standard deviation of grey-level intensity.

With equations (2) and (3) the local characteristics or topological structures of the kinematics of the cavitation cloud under different cavitation conditions, given in Table 1, were evaluated. The position and the value of the maximum cavitation intensity can be evaluated from Figure 5. Both parameters change significantly when the integral



Sl. 4. *Lega opazovalnega polja pri pogledu od zgoraj in s strani*
Fig. 4. *Region of interest: top and side view*



Sl. 5. *Sliki kavitacije (levo), pripadajoča srednja vrednost svetlosti (v sredini) in standardno odstopanje vrednosti svetlosti (desno). Zgornja vrsta slik je pogled od zgoraj, spodnja pa s strani. Smer toka je od leve proti desni, hitrost toka v = 16 m/s, natočni kot δ = 5° in kavitacijsko število σ = 2,4.*
Fig. 5. *Cavitation figures (left), distributions of average grey level (middle), distributions of the standard deviation of grey level (right). The upper row of figures is a ground plan, and the lower the sideview. The flow direction is from left to right, flow velocity v = 16 m/s, angle of inclination δ = 5°, cavitation number σ = 2.4.*

parametri kavitacije. Lego lokalnih kavitacijskih ekstremov podajata v brezdimenzijski obliki y/h in x/h, kjer sta x in y koordinati v poldnevni ravnini krila, h pa je debelina krila. Na sliki 6 so prikazane porazdelitve srednje vrednosti svetlosti in standardno odstopanje svetlosti pri nespremenljivem vpadnem kotu $\delta = 5°$ za štiri kavitacijska števila, podana v preglednici 1.

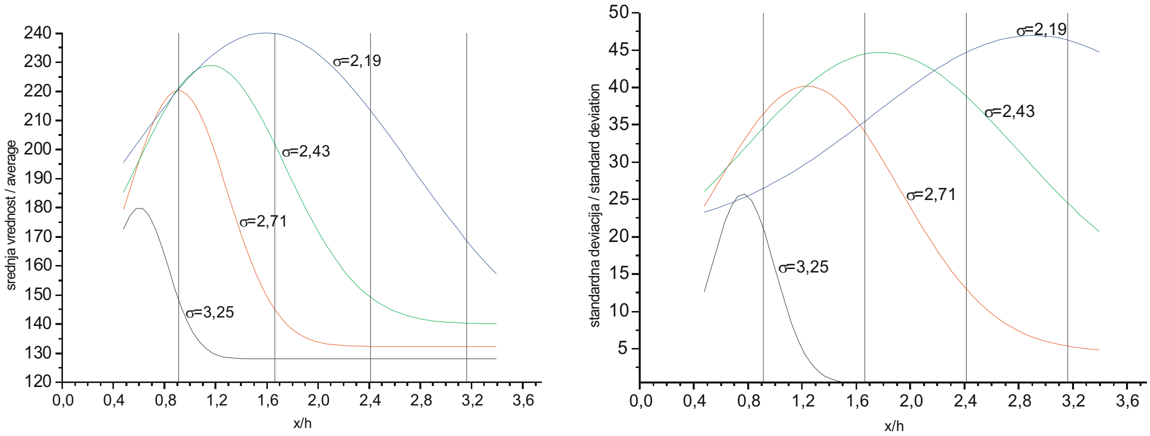
Srednja vrednost svetlosti A in standardno odstopanje svetlosti s pri nespremenljivem kavitacijskem številu σ popisujeta intenziteto kavitacije vzdolž krila. Moč kavitacije se povečuje vzdolž krila, doseže največjo vrednost in se zmanjša na prehodu ravnega dela krila v klinasto obliko krila. Lega in moč kavitacije, ki sta popisani s parametroma A in σ v odvisnosti od razdalje x/h, sta značilno odvisni od kavitacijskega števila σ. Z zmanjševanjem kavitacijskega števila σ se moč kavitacije povečuje, lega največjih vrednosti spremenljivk A in s pa se premika vzdolž krila.

Drug pomemben podatek o kavitacijskih razmerah na osamljenem krilu je odmik kavitacijskega oblaka od površine krila oziroma lega kavitacijskega oblaka nad krilom. Oddaljenost kavitacijskega oblaka od površine je določena iz diagramov lokalnih

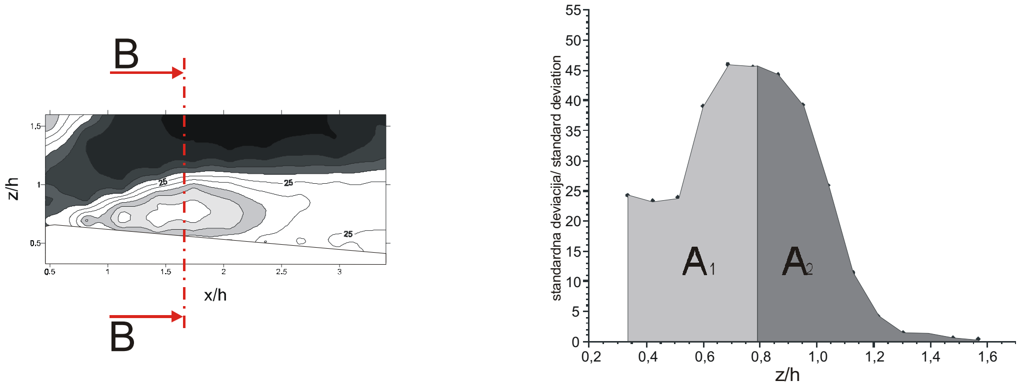
cavitation parameters are changed. The position of the local cavitation extremes is given in non-dimensional form, y/h and x/h, where x and y are the coordinates in the meridian plane of the hydrofoil, and h is the hydrofoil's thickness. Figure 6 shows the distribution of the average grey level and the standard deviation of the grey level at a constant inclination angle 5°, for four different cavitation numbers (Table 1).

The average grey level A and the standard deviation of the grey level s at constant cavitation number σ, describe the cavitation intensity along the hydrofoil. The cavitation intensity is increased along the hydrofoil in a streamwise direction, reaches its maximum value, and is decreased at the transition of the hydrofoil shape from straight to a wedge. The location and magnitude of the cavitation, described with the parameters A and σ, and their dependence on the distance x/h, are both dependent on the cavitation number σ. When σ is decreased, the cavitation intensity is increased, and the location of the maximum values of A and s is moved along the hydrofoil.

The second important parameter describing the cavitation conditions on the hydrofoil is the distance of cavitation cloud from the hydrofoil surface, i.e. its position above the hydrofoil. Its distance is determined from the side-view diagrams



Sl. 6. *Srednja vrednost in standardno odstopanje svetlosti v odvisnosti od x/h za vse režime pri natočnem kotu δ = 5°. Pokončne črte označujejo mesta, kjer so nameščeni bakreni vzorci.*
Fig. 6. *Distributions of the average grey level and the standard deviation of the grey level versus x/h for all flow conditions at an inclination angle 5°. Vertical lines denote positions of copper specimens.*



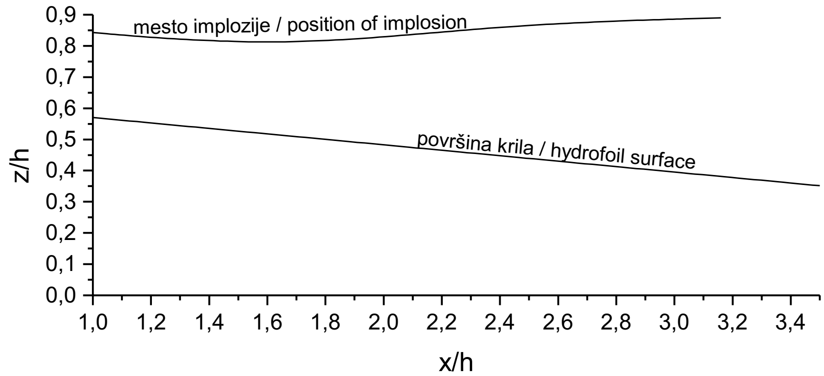
Sl. 7. *Mesto prereza x/h nad drugim vzorcem za kavitacijsko število σ_2 in diagram porazdelitve standardnega odstopanja σ pri nespremenljivi vrednosti x/h v odvisnosti od z/h*
Fig. 7. *Position of section x/h for second specimen – cavitation number σ_2, and graph of standard deviation of grey-level distribution at a constant value x/h versus z/h*

porazdelitev moč kavitacije pri pogledu s strani. Na sliki 7 je prikazana porazdelitev standardnega odstopanja svetlosti pri nespremenljivi vrednosti *x/h* v odvisnosti od *z/h.*

Za mesto implozije kavitacijskega oblaka je bila izbrana vrednost *z/h*, kjer je diagram porazdelitve standardnega odstopanja svetlosti *s* ploščinsko razdeljen na dva enaka dela ($A_1 = A_2$) (sl. 7). Brezdimenzijska oddaljenost mesta implozije *l* kavitacijskega oblaka od površine krila je bila določena z razliko mesta implozije in brezdimenzijsko višino krila na tem mestu. Pri tem ni bil upoštevan vpliv strmine krila δ. Mesto implozije kavitacijskega oblaka se pri nespremenljivem kavitacijskem številu σ vzdolž krila monotono odmika od površine krila, kar je posledica tokovnega polja okoli krila. Diagram mesta implozije kavitacijskega oblaka v odvisnosti od vrednosti *x/h* je prikazan na sliki 8.

of local cavitation intensity distributions. Figure 7 shows an example of the standard deviation distribution at a constant value *x/h* with its dependence on *z/h*.

The position of the cavitation-cloud implosion was determined with the value *z/h,* where the diagram of the standard deviation of the grey-level distribution *s* is divided into two areas of equal size ($A_1 = A_2$), Figure 7. The non-dimensional distance *l* of the cavitation-cloud implosion from the hydrofoil surface is determined by the difference between the position of the cavitation implosion and a non-dimensional height of the hydrofoil at that position. Because of the negligible error, the influence of the inclination angle δ, was not taken into consideration. The position of the cavitation-cloud implosion along the hydrofoil, at constant cavitation number σ, is moved away from the surface of the hydrofoil, influenced by the flow field around the hydrofoil. Figure 8 shows a diagram of the position of the cavitation-cloud implosion versus *x/h*.



Sl. 8. *Mesto implozije kavitacijskega oblaka v odvisnosti od vrednosti x/h*
Fig. 8. *Position of cloud implosion versus x/h*

3 ANALIZA REZULTATOV

Cilj raziskave je bila postavitev empiričnega - fenomenološkega modela odvisnosti med vizualnimi sestavami kavitacije nad krilom in izmerjenimi erozijskimi učinki na površini krila. Vizualne sestave kavitacije podajata standardno odstopanje svetlosti *s* (sl. 6) in mesto implozije kavitacijskega oblaka (sl. 7), erozijske učinke pa podatki iz preglednice 2.

Fenomenološki model temelji na predpostavki, da je jakost erozije sorazmerna moči spreminjanja kavitacijskega oblaka in obratno sorazmerna oddaljenosti kavitacijskega oblaka od površine krila. Intenziteto erozije izrazimo z A_d/A_{ref}. Napoved jakosti kavitacijske erozije za opazovani preskus podaja enačba:

3 ANALYSIS OF RESULTS

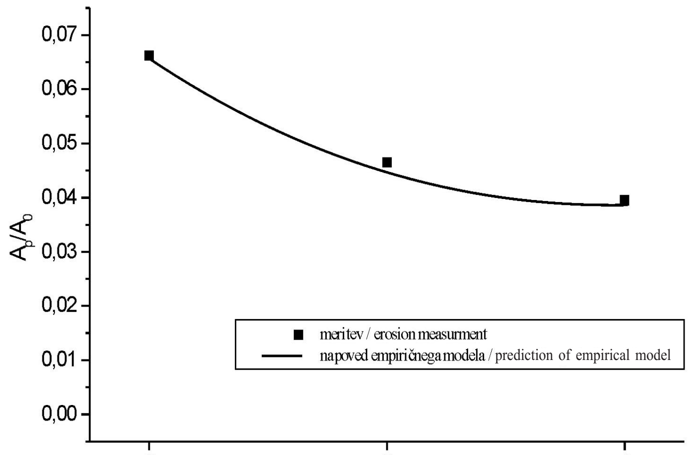
The aim of the research was to establish an empirical-phenomenological model of the relation between the intensity of cavitation erosion on the hydrofoil surface and the visual cavitation structures above the hydrofoil. The visual cavitation structures are given by the standard deviation of the grey level *s* (Fig. 6) and by the position of the cavitation-cloud implosion (Fig. 7). The erosion effects are given by the data presented in Table 2.

The phenomenological model is based on a presumption that the erosion intensity is proportional to the fluctuation intensity of the cavitation cloud and inversely proportional to the distance of the cloud implosion from the hydrofoil surface. Erosion intensity is expressed by the ratio A_d/A_{ref}. The prediction of the intensity of cavitation erosion for the observed experiment is given by:

$$\frac{A_d}{A_{ref}} = 0,016443\frac{s(k)^{0,070798}}{l^{0,898913}} \qquad (4).$$

Koeficienti v enačbi (4) so določeni z metodo najmanjših kvadratov odstopanja, modeliranih iz izmerjenih vrednosti. Ujemanje napovedi modela z eksperimentalno izmerjenimi vrednostmi za vsa tri mesta čepov na krilu prikazuje slika 9.

The coefficients in equation (4) are determined by the method of least squares for the deviation of the modelled and measured values. The agreement of the model prediction with the experimental values for all three specimen locations are presented in Figure 9.



Sl. 9. *Primerjava napovedi modela in eksperimentalnih vrednosti erozije na vzorcih*
Fig. 9. *Comparison of the empirical model prediction and the experimental data of specimen erosion*

4 SKLEP

V kavitacijskem predoru so bile pri izbranih celovitih karakteristikah izvedene meritve kavitacije na osamljenem krilu. Kavitacija na krilu je bila vrednotena z računalniško podprto vizualizacijo in z novo metodo za določanje kavitacijske erozije.

Na podlagi eksperimentalno dobljenih rezultatov kinematike kavitacijske sestave nad krilom in rezultatov erozije na opazovanih vzorcih površine krila je bil oblikovan pojavnostni model, ki napoveduje moč kavitacijske erozije.

Z razširitvijo študije na dejanska krila turbinskih strojev se odpira možnost oblikovanja pojavnostnih modelov napovedi erozije na rotorjih turbostrojev in uporabe računalniško podprte vizualizacije za opazovanje kavitacije na vodnih turbinah in velikih črpalkah.

4 CONCLUSIONS

In the cavitation tunnel we observed cavitation on the single hydrofoil at selected integral parameters. The cavitation was evaluated with the pit-count method and computer-aided visualization.

On the basis of the experimentally obtained results of the cavitation-structure kinematics above the hydrofoil, and the results of the erosion evaluation on the observed selected specimens of the hydrofoil surface, a phenomenological model was setup which predicts the magnitude of the cavitation erosion.

An expansion of the study to include real profiles of turbine machines opens up a possibility for developing phenomenological models for erosion prediction on turbomachinery rotors and the application of computer-aided visualization for cavitation monitoring on water turbines and large process pumps.

5 ZAHVALA

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6 LITERATURA
6 REFERENCES

[1] Young, F.R. (1999) Cavitation. *Imperial College Press*.

[2] Hofmann, M. et al (1999) Numerical and experimental investigations on the self–oscillating behaviour of cloud cavitation - Part 1: Visualization.- V: *3rd ASME / JSME Joint Fluids Engineering Conference* (San Francisco, CA 1999).

[3] Kern, I. (2000) Eksperimentalna raziskava dinamičnih parametrov na modelu Kaplanove vodne turbine, magistrsko delo, *Fakulteta za strojništvo*, Ljubljana.

[4] Diodati, P., G. Giannini (2001) Cavitation damage on metallic plate surfaces oscillating at 20 kHz, Ultrasonics Sonochemistry, Volume 8, *Issue 1*, January 2001, 49-53.

[5] Mann, B.S. (2000) High-energy particle impact wear resistance of hard coatings and their application in hydroturbines, *Wear*, Volume 237, Issue 1, January 2000, 140-146.

[6] Pham, T.M., F. Larrarte, D. H. Furman (1999) Investigation of unsteady sheet cavitation and cloud cavitation mechanisms, *Journal of Fluids Engineering*, Transactions of the ASME, Volume 121, Issue 2, 289-296.

[7] Širok, B., I. Kern, M. Hočevar, M. Novak (1999) Monitoring of the cavitation in the Kaplan turbine, *IEEE International Symposium on Industrial Electronics*, Volume 3, 1224-1228.

[8] Okada, T., S. Hattori, M. Shimizu (1995) A fundamental study of cavitation erosion using a magnesium oxide single crystal (intensity and distribution of bubble collapse impact loads), *Wear*, Volumes 186-187, Part 2, August 1995, 437-443.

[9] Caron, J.-F, M. Farhat, F. Avellan (1999) The influence of flow unsteadiness on erosive cavity dynamics, *Proceedings of the 1999 3rd ASME/JSME Joint Fluids Engineering Conference,* FEDSM'99, San Francisco, California, USA, 18-23 July (CD-ROM), *Published by American Society of Mechanical Engineers*, ISBN 0791819612, 1.

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Proizvodna strategija, podprta s teorijo proizvodnih virov: študij primera v podjetju Primat

An Operations Strategy Supported with Resource-Based Theory: A Case Study at the Primat Company

Krsto Pandža - Borut Buchmeister - Andrej Polajnar - Iztok Palčič

Zamisel o uporabi proizvodnje kot strateškega orožja za doseganje konkurenčnih prednosti je stara vsaj toliko kolikor proizvodnja sama. Vendar se vsebina raziskovalnega področja proizvodnih strategij glede na razvoj gospodarskega okolja močno spreminja. V teoretičnem delu prispevka je predstavljena teorija proizvodnih virov in njen potencial, da postane vodilna teoretična zamisel raziskovalnega področja proizvodnih strategij. V nadaljevanju je predstavljena raziskava, ki s svojimi izsledki prispeva k razvoju teorije proizvodnih virov. Štiri uspešna proizvodna podjetja so ponudila okolje za raziskavo. V prispevku je podrobneje predstavljen študij primera iz podjetja Primat. V razpravi so podane ugotovitve, ki so nastale na podlagi induktivne analize med vsemi štirimi študijami primerov.

(Ključne besede: strategije proizvodne, teorija proizvodnih virov, akumulacija sposobnosti, perspektive evolucijske)

The idea of using manufacturing as a strategic weapon to achieve competitive advantage is as old as manufacturing itself. The content of operations-strategy research, however, has changed a great deal due to the development of the economic environment. The theoretical part of this paper presents resource-based theory and its potential in becoming a leading theoretical concept for operations-strategy research. After that a case study is presented, the results of which add to the development of resource-based theory. Four successful manufacturing organisations provided the framework for the research. A case study of the manufacturing organisation Primat is presented in detail. The results of the inductive analysis of all four case studies are also presented.

(Keywords: operations strategy, resource-based theories, capabilities accumulation, evolution perspectives)

0 UVOD

Uspešnost in učinkovitost poslovnih procesov postajata ključnega pomena za uspešno poslovanje proizvodnih podjetij. Proizvodni procesi so integralni del poslovnih procesov. Še več, proizvodni procesi se vedno bolj obravnavajo kot celotna veriga dejavnosti, ki jo je treba upravljati, da izdelek zadovolji vrednote kupca. Proizvodni menedžment[1] se zato uveljavlja kot eno najpomembnejših področij organizacije in upravljanja. Znanstveno raziskovanje razmerja med proizvodnimi procesi in doseganjem konkurenčnih prednosti proizvodnega podjetja je zaokroženo v okviru raziskovalnega področja proizvodnih strategij.

Tradicionalna zamisel proizvodnih strategij, ki temelji na kompromisih med konkurenčnimi kriteriji, tj. prilagodljivostjo, stroški, kakovostjo, zanesljivostjo in hitrostjo dobav ter inovativnostjo,

0 INTRODUCTION

The success and efficiency of business processes are of key importance for the successful operations of manufacturing organisations. Manufacturing processes represent an integral part of business processes. What is more, manufacturing processes have been treated as a chain of activities that should be managed if the product is to meet customers' demands. Operations management[1] has therefore become one of the most important fields of management. Relationships between an organisation's operations processes and the attainment of competitive advantages are studied within the scientific field of operations strategy.

The traditional concept of operations strategy, which is based on trade-offs between competitive criteria such as flexibility, innovativeness, costs, quality, reliability of deliveries and speed of deliveries, has re-ostaja kljub spremembam v industrijskem poslovnem okolju izjemno robusten [1]. Najpomembnejša strateška odločitev v zvezi s proizvodnimi procesi je izbira ravni konkurenčnih kriterijev, s katerimi bodo podprte konkurenčne prednosti podjetja. Odločitve o izbiri konkurenčnih kriterijev terjajo kompromise, saj se nekateri konkurenčni kriteriji medsebojno izključujejo [2]. Kljub svoji robustnosti pa tradicionalna zamisel proizvodnih strategij vse teže razlaga dogajanja v sodobnem poslovnem okolju. Tradicionalna zamisel sama zase ne more pojasniti in razložiti uspeha ali neuspeha proizvodnega podjetja ([1] in [3]). Začne se iskanje nove zamisli, ki bo ponudila teoretični okvir področju proizvodnih strategij.

Z uveljavitvijo sodobnih proizvodnih zamisli, ki so temeljito zamajale nekatere predpostavke tradicionalne zamisli proizvodnih strategij, so poskušali nadomestiti zamisel proizvodnih strategij. Začetek devetdesetih postreže z zamislijo vitke proizvodnje [4]. Najpopularnejšim organizacijskim tehnikam, združenim pod imenom vitka proizvodnja, se pridružijo še proizvodne zamisli, to so agilna proizvodnja, fraktalno podjetje in množinska prilagodljivost.

Omenjene zamisli zavračajo heterogenost proizvodnega podjetja, kot temelj strateškega obnašanja v podjetju. Proizvodna podjetja so heterogena glede na vire in sposobnosti, zato proizvodna strategija še vedno pomeni biti predvsem zmožen delati drugače od konkurence. Iskanje nadomestila za proizvodne strategije v sodobnih proizvodnih zamislih pomeni ponovno vračanje v obdobje *taylorizma*, ko obstaja *le en* najboljši način za obvladovanje proizvodnih procesov [5].

Zamisel vitke proizvodnje izhaja iz okolja japonske avtomobilske industrije. Še več, gre za zamisel, ki je nastala na podlagi raziskovanja poslovne prakse v *Toyoti*. Ni težko ugotoviti, da zamisel, ki temelji na specifičnosti avtomobilske industrije in celo enega samega primera, ni prenosljiva v vsa poslovna okolja.

Vodilni avtorji zamisli agilne proizvodnje [6] in [7], fraktalnega podjetja [8] in množinske prilagodljivosti [9], poskušajo naštete zamisli predstaviti kot generično strategijo z namenom, postaviti skrajno prilagodljiv sistem, ki naj bi bil imun za stroške, povezane z rastjo kompleksnosti. Takšen sistem bi naj bilo mogoče doseči predvsem z uporabo napredne proizvodne tehnologije in sodobnih informacijskih sistemov. Avtorji sicer priznavajo, da sama tehnologija še ni dovolj [6]. Dodajajo še kopico sodobnih poslovnih procesov, to so strateške zveze, ploščenje organizacijske strukture in osredotočenost na ključne kompetence. Tako te zamisli pomenijo predvsem lepljenko večine sodobnejših poslovnih zamisli, ki so se pojavili v sodobni literaturi o menedžmentu.

Sodobnim proizvodnim zamislim ne gre odrekati pomena, ki ga imajo za afirmacijo proizvodnih

mained extremely robust in spite of changes in the industrial business environment [1]. The most important strategic decision with respect to manufacturing processes is the selection of competitive criteria that will support the competitive advantages of an organisation. Decisions about the selection of competitive criteria require compromises as some competitive criteria exclude each other [2]. In spite of its robustness, the traditional concept of operations strategy is becoming increasingly inadequate when it comes to explaining events in the modern business environment. On its own, the traditional concept cannot explain and remedy the success, or lack of success, of a manufacturing organisation ([1] and [3]). A new concept is being searched for that will offer a theoretical frame for the field of operations strategy.

The creation of modern manufacturing concepts has utterly shaken some of the assumptions about the traditional operations-strategy concept: it was to be replaced by something else. The beginning of the nineties featured the concept of lean production [4]. To most popular organisational techniques under the joint term of lean production were added such manufacturing concepts as agile manufacturing, fractal organisation and mass customisation.

These concepts reject the heterogeneity of a manufacturing organisation as the basis for strategic behaviour in the organisation. Manufacturing organisations are heterogeneous with respect to resources and capabilities; operations strategy thus still means to be capable of working differently than one's competitors. In the modern manufacturing concept, searching for a replacement for operations strategies means returning into the era of *taylorism* with only *one* best way to manage manufacturing processes [5].

The concept of lean production comes from the Japanese automobile industry. What is more, the concept is based on a study of business practices in *Toyota*. It is not hard to understand that a concept which focuses specifically on the car industry is not transferable to all business environments.

The leading authors of agile manufacturing [6] and [7], fractal company [8] and mass customisation [9] try to present their concepts as a generic strategy with the aim of establishing an extremely flexible system that should be immune to costs arising from complexity. Such a system could be attained, especially with the use of advanced manufacturing technology and modern information systems. The authors admit, however, that technology itself is not sufficient [6]. They add a bundle of modern business approaches, such as strategic alliances, the empowerment of the organisational structure and focusing on key competences. These concepts thus represent a mosaic of the most recent business concepts that have appeared in modern management literature.

Modern manufacturing concepts should not be denied the important role they play in the affirmaprocesov, vendar same zase ne morejo postati zamenjava za proizvodno strategijo. Proizvodne zamisli niso same sebi namen, pač pa sredstvo, ki odpira nove priložnosti. Vsaka od proizvodnih zamisli mora biti prilagojena specifični situaciji podjetja in njegovemu položaju v poslovnem okolju. Ali povedano drugače, biti mora v okviru proizvodne strategije podjetja.

Nov teoretični okvir, na katerem bo temeljilo raziskovalno področje proizvodnih strategij, mora omogočiti razlago dogajanja v sodobnih proizvodnih podjetjih. Približati se mora statusu paradigme, kakor jo definira Kuhn [10]. Paradigma identificira in definira raziskovalna vprašanja, s katerimi se bodo spopadli raziskovalci s področja proizvodnih strategij. Teorija proizvodnih virov, ki se je uveljavila na področju strateškega menedžmenta in na področju teorije industrijskih organizacij, se pojavlja kot teoretični okvir, znotraj katerega bo temeljilo področje proizvodnih strategij. Raziskovalna vprašanja, s katerimi so se spopadli raziskovalci v okviru raziskave, predstavljene v tem prispevku, izhajajo iz teoretične zamisli teorije proizvodnih virov.

1 TEORETIČNO OZADJE

Bistvo teorije proizvodnih virov se kaže v trditvi, da je konkurenčni položaj podjetja definiran s skupkom edinstvenih virov in sposobnosti ter odnosov med njimi [11]. V njenem osrčju je predpostavka o heterogenosti podjetij. Ne obstajata namreč dve enaki podjetji. Vsako se ponaša s svojo edinstveno bazo virov in sposobnosti. Tudi isti vir bo v različnih podjetjih različno učinkovit. Viri in sposobnosti so nemobilni ali omejeno mobilni. Podjetje, ki v svoji bazi nima vira ali sposobnosti, potrebnih za dosego konkurenčne prednosti, jih ne more kar preprosto (brez stroškov) prenesti iz baze drugega podjetja.

Literatura teorije proizvodnih virov intenzivno opisuje lastnosti, ki jih morajo imeti viri in sposobnosti, da postanejo temelji konkurenčne prednosti ([12] do [14]). Biti morajo redki, neposnemljivi, nepregledni, kompleksni in historično odvisni.

Pozornost teorije proizvodnih virov je bila ob njenih začetkih usmerjena k raziskovanju pomena virov, ki jih je predstavljala kot specifično premoženje za podjetje. Ti viri so lahko oprijemljivi ali neoprijemljivi. Mednje sodijo tehnologija, patenti, avtorske pravice, individualno inženirsko znanje, ekspertno razvojno - tehnološko znanje, sloves. V zadnjem času se pozornost teorije proizvodnih virov preusmerja iz proučevanja statičnih virov k proučevanju dinamičnega procesa razvoja sposobnosti [15]. Sposobnosti pomenijo procese, ki omogočajo, da podjetja učinkovito in uspešno izbirajo in izvajajo dejavnosti, potrebne za

tion of manufacturing processes, yet they cannot, by themselves, become a replacement for operations strategy. Manufacturing concepts are not intended for themselves, rather they are a means to open up new possibilities. Every manufacturing concept needs to be adapted to the specific situation of an organisation and its position in the business environment. In other words, it should feature in the context of an organisation's operations strategy.

A new theoretical frame for operations-strategies research should make it possible to explain the events in modern manufacturing organisations. It should approach the status of a paradigm, as defined by Kuhn [10]. The paradigm identifies and determines the research questions that will be tackled by scholars from the operations-strategy field. Resource-based theory, which was created within the fields of strategic management and industrial organisation theory, has become a theoretical frame within which the operations-strategy field will be placed. The research questions tackled by the authors of the research presented in this paper result from the theoretical context of resource-based theory.

1 THEORETICAL BACKGROUND

The essentials of resource-based theory lie in the assertion that the competitive position of an organisation is determined by the sum of its unique resources and capabilities, and the relationships between them [11]. It is centred on the presumption of the heterogeneity of organisations, i.e. that two equal organisations cannot exist. Each organisation is characterised by its unique resource base and capabilities. The same resource will result in different levels of productivity in different organisations. Resources and capabilities are either immobile or of limited mobility. The organisation that lacks a resource or the capability necessary to achieve a competitive advantage, cannot simply adopt, without costs, the resources or capabilities of another organisation.

The literature on resource-based theory describes in detail the features that resources and capabilities should possess to become the fundamentals for a competitive advantage ([12] to [14]). They should be rare, inimitable, non-transparent, complex and path-dependent.

In the beginning, the attention of resource-based theory was focused on studying the importance of resources, which, according to the theory, meant the specific assets of an organisation. These resources can be either tangible or intangible. They encompass technology, patents, copyright, engineering knowledge, expert R&D knowledge, technological knowledge and image. Lately, the attention of resource-based theory has shifted from the study of static resources to the study of the dynamic process of capabilities development [15]. Capabilities represent the processes that enable the organisation to effectively and successfully select and implement the activities that are necessary to meet cuszadovoljevanje potreb kupcev izdelkov ali storitev [16]. Sposobnosti so tiste kombinacije virov in procesov, ki pomenijo temelje konkurenčne prednosti za izbrano podjetje, ki posluje v določenem poslovnem okolju [17].

Viri in sposobnosti so integralni del proizvodnih procesov, zato teorija proizvodnih virov s svojo introvertiranostjo pomeni ustrezen teoretični okvir za raziskovalno področje proizvodnih strategij. Gagon [18] poudarja, da je teorija proizvodnih virov lahko teoretični okvir za razlago vsebine, ki na področju proizvodnih strategij povzroča največ nesoglasij. Teorija proizvodnih virov odpravlja reaktivno in obrambno vlogo proizvodnje, ki jo ta zaseda v hierarhiji strateškega načrtovanja. V nasprotju s tradicionalno zamislijo ne obravnava statičnih odločitev med konkurenčnimi kriteriji. Poudarja dinamične poti, s katerimi proizvodno podjetje prehaja na različne proizvodne ravni [3]. Hayes in Pisano [19] poudarjata strateško prilagodljivost podjetja, ki omogoča spreminjanje narave kompromisov in doseganje različnih kombinacij konkurenčnih kriterijev v nekem obdobju. Teorija proizvodnih virov osvetli uporabo sodobnih proizvodnih zamisli v novi luči. Sodobnih proizvodnih zamisli, ki so se uveljavile kot najboljša praksa, teorija proizvodnih virov ne predstavlja kot splošno rešitev za proizvodne probleme, ampak jih predstavlja kot dokaz, da podjetje, ki metodično razvije sposobnosti in zavestno išče priložnosti za njihovo uporabo na trgu, lahko doseže izrazito konkurenčno prednost.

Kljub popularizaciji teorije proizvodnih virov na področju proizvodnih strategij ([17] do [22]), sta njena uporabnost in sposobnost opisovanja poslovne stvarnosti odvisna od pojasnitve nekaterih nedorečenosti. Raziskovalci intenzivno opisujejo značilnosti, ki jih morajo imeti sposobnosti, da postanejo temelj konkurenčne prednosti. Predstavljajo primere, ki dokazujejo pomen sposobnosti v proizvodnih podjetjih. Proučevanje procesa, kako se sposobnost akumulira, pa ostaja zunaj raziskovalne agende. Raziskovalci predpostavljajo, da podjetja *že kako* razvijejo sposobnosti, ki s svojim pomenom pomenijo na trgu temelj konkurenčne prednosti. Obravnavanje sposobnosti skozi statično perspektivo ima za posledico, da se sposobnost predstavlja kot nekaj, kar je že po definiciji vredno na trgu. Kako sposobnost doseže razvojno stopnjo, ki ji zagotavlja vrednost na trgu, pa ostaja nepojasnjeno.

Motivi za raziskavo, predstavljeno v tem prispevku, so izhajali iz želje, pojasniti dinamiko procesa akumulacije sposobnosti. Vsebino raziskave lahko predstavimo v dveh splošnih raziskovalnih vprašanjih:

- Kakšen je mehanizem, po katerem poteka dinamični proces akumulacije sposobnosti v proizvodnem podjetju?

tomers' needs, when it comes to buying either products or services [16]. Capabilities are those combinations of resources and processes that represent the fundamentals of competitive advantage for a selected organisation operating in a certain business environment [17].

Resources and capabilities are an integral part of manufacturing processes, therefore resource-based theory, with its introversion, represents a theoretical basis for operations strategy research. Gagon [18] argues that resource-based theory can represent a theoretical frame for the explanation of the content, which is the source of most conflicts in operations strategy. Resource-based theory does away with the reactive and defensive role of manufacturing in the hierarchy of strategic planning. Unlike traditional concepts, resource-based theory does not place static decisions among competitive criteria. It stresses dynamic ways that raise a manufacturing organisation to different manufacturing levels [3]. Hayes and Pisano [19] point to the strategic flexibility of an organisation that allows it to vary the nature of trade-offs and to achieve different combinations of competitive criteria in a definite time period. Resource-based theory puts the use of modern manufacturing concepts in a new light. It does not take modern manufacturing concepts that have proved to be the best practice as a general solution for manufacturing problems, but as a proof that an organisation can achieve a competitive advantage as long as it systematically develops capabilities and willingly seeks opportunities to use them on the market.

In spite of the popularity of resource-based theory in the field of operations strategy ([17] to [22]), its applicability and capability to describe business reality depend on the want of clearness and precision. Scholars describe in detail features that capabilities should possess to become the basis of a competitive advantage. They present examples showing the importance of capabilities in manufacturing organisations. The study of the capability-accumulation process, however, is not put on the research agenda. Scholars presume that an organisation s*omehow* develops the capabilities that are important on the market as a source for competitive advantage. When capabilities are studied through the results arising from a static perspective they are presented as being valuable on the market, by definition. It remains unexplained, however, how capability achieves a level that would ensure the company's value on the market.

The motivation for the research presented in this article originated in a wish to explain the dynamics of the capability-accumulation process. The contents of the research can be grouped into two general research questions:

- What is the mechanism of a dynamic capability-accumulation process in a manufacturing company?
- Is the capability in the accumulation process al-

- Ali je sposobnost v procesu akumulacije vedno pomembna in vredna v poslovnem okolju?

2 METODOLOGIJA

Štiri uspešna slovenska proizvodna podjetja so ponudila okolje za poglobljeno raziskavo. Raziskava je potekala v podjetjih Primat d.d., Eti d.d., Gorenje d.d. in v strateški poslovni enoti Sava Print iz podjetja Sava d.d. V okviru tega prispevka je nemogoče predstaviti vse študije primerov, zato je v poglavju Rezultati predstavljen študij primera iz podjetja Primat. Ugotovitve, predstavljene v poglavju Razprava, so pridobljene na podlagi induktivne analize med vsemi štirimi študijami primerov.

Raziskava je izvedena v skladu s procesom induktivnega oblikovanja teorije [23]. Objekt raziskave je proces akumulacije sposobnosti. Zanj je značilna kompleksnost, slaba strukturiranost in dinamična historična odvisnost. Uporabljena metodologija študija primerov je ustrezno orodje za spopad s takšnim pojavom. Godfrey in Hill [24] poudarjata, da so kakovostne metodologije, kakršne so študije primerov in etnografske raziskave, najboljši način za proučevanje značilnosti strategij, na katerih temelji teorija proizvodnih virov. Postopek induktivnega oblikovanja teorije in izbrana metodologija študija primerov ustrezata, saj mora pojasnitev rezultatov zagotoviti opis in razlago dinamike procesa akumulacije sposobnosti in ne rigoroznega definiranja vzročno-posledičnih razmerij.

V raziskavi je uporabljena razvojna in vzdolžna perspektiva. Večina empiričnih raziskav s področja proizvodnih strategij uporablja prečno perspektivo. Uporaba evolucijske in vzdolžne perspektive, uporabljene v pričujoči raziskavi, pomeni pomemben metodološki prispevek k raziskovanju na področju proizvodnih strategij. Logika in mehanizem procesa akumulacije sposobnosti se zaradi dinamične historične odvisnosti ustrezneje proučuje skozi vzdolžno perspektivo. Van de Ven [25] predlaga definiranje teorije procesa, ki jo uporabljajo raziskovalci pri svoji raziskavi. Proces akumulacije sposobnosti je na podlagi induktivne pojasnitve dogajanja v podjetjih opisan kot življenjski cikel. Lastnosti posamezne faze življenjskega cikla je mogoče opisati z evolucijsko teorijo procesa.

Izvedba raziskave je od raziskovalcev zahtevala, da v podjetju identificirajo sposobnost, sledijo procesu akumulacije sposobnosti, razumejo poslovni okvir, v katerem je identificirana sposobnost vredna in pomembna na trgu, in opredelijo posredna merila za spremljanje razvoja sposobnosti. Winter [26] poudarja, da je sposobnosti mogoče posredno meriti z za podjetje specifičnimi merili izvedbe, ključnimi kriteriji ali celo vrednotami.

Intervjuji, poslovna dokumentacija in opazovanja so bili metode zbiranja podatkov,

ways important and valuable in the business environment?

2 METHODOLOGY

Four successful Slovenian manufacturing organisations offered to provide a framework for an in-depth field research. The research was performed in the following joint-stock companies: Primat, Eti, Gorenje, and in the strategic business unit Sava Print, a part of Sava, also a joint-stock company. It is impossible to present all four case studies in this article, therefore only the case study of Primat will be presented in the Results section. The findings in the Discussion section were obtained with the inductive analysis of all four case studies.

The research was performed with inductive-theory building [23]. The object of the research was the capability-accumulation process. This process is characterised by complexity, bad structure, idiosyncrasy and path-dependency. The applied case-study methodology was an appropriate tool to tackle such a phenomenon. Godfrey and Hill [24] point out that qualitative methodology, such as case studies and ethnographic research, present the best way to study the idiosyncratic characteristics of strategies on which the resource-based theory is grounded. The inductive approach to design the theory and the selected case-study methodology are adequate because the interpretation of results must ensure the description and dynamics of the capability-accumulation process and not the rigorous definition of cause-consequences relationships.

Evolution and longitudinal perspective are used in the research. The majority of empirical investigations from the field of operations strategy use transversal perspectives. The application of evolution and longitudinal perspective in this research represents an important methodological contribution to the research into operations strategies. The logic and mechanisms of the capability-accumulation process are studied through the longitudinal perspective due to path-dependency. Van de Ven [25] suggests defining the process theory used by scholars in their research. The capability-accumulation process is described as a life cycle of an organisation due to the inductive interpretation of events. The characteristics of the individual phases of a life cycle can be described with the process-evolution theory.

The research required from scholars to identify capabilities, study the capability-accumulation process, understand the business context within which the identified capability is valuable and important on the market, and set indirect measures to study capability development in an organisation. Winter [26] argues that capabilities can be indirectly measured with specific performance measurements, key criteria and even the values of an organisation.

Interviews, business documentation and observations were all methods for collecting the necesuporabljenih v raziskavi. Intervjuji s ključnimi osebami v podjetjih so običajno trajali 2 do 3 ure. Vsi intervjuji so bili posneti. Poslovna dokumentacija in arhivski dokumenti so bili ob intervjujih drugi vir podatkov. Uporaba več različnih virov je izboljšala notranjo veljavnost raziskave. Za raziskavo je bila pomembna vsa poslovna dokumentacija, ki je omogočala spoznavanje kompleksne poslovne stvarnosti, in tista, ki kakovostno kakor tudi količinsko podpira podatke, pridobljene z intervjuji. Tretji vir zbiranja informacij so opazovanja, ki pa so bila vključena zgolj v študiju primera iz podjetja Primat. Pri tem velja omeniti, da je bil raziskovalec štiri leta neposredno vključen v operativne dejavnosti podjetja. Raziskava v okviru tega študija primera ima zato zelo izrazito etnografsko komponento.

Analiziranje podatkov in zamisli so potekali v skladu z značilnostmi induktivnega oblikovanja teorije. Gre za iterativni proces zbiranja podatkov, analiziranja in interpretacije. Iterativni krog se ne konča s prvo interpretacijo. Tej sledi ponovno preverjanje ali zbiranje novih podatkov na podlagi novih spoznanj.

3 REZULTATI

Primat d.d. je podjetje, ki v zadnjih letih, z 290 zaposlenimi, stalno ustvarja dobiček. Za ugodne poslovne rezultate v zadnjih letih gre zahvala predvsem proizvodnemu programu varnostne opreme. Ob njem so Primatovi izdelki zaokroženi še v programu kovinskega pohištva, ki zagotavlja 30 % prihodkov od prodaje in programu skladiščne opreme, ki prispeva 10% prihodka.

V podjetju identificirana sposobnost hitrega razvoja izdelkov po naročilu je učinkovita predvsem v poslovnem okviru, v katerem mora podjetje hitro razviti izdelek ustrezne varnostne stopnje po naročilu kupca. Mehanska varnost je opredeljena z ustrezno varnostno stopnjo. Ta ne pomeni zgolj neke najmanjše tehnične ravni, ki jo mora zagotoviti izdelek, kar je značilno za overitve v mnogih industrijskih panogah. Varnostna stopnja, ki jo ugotovi neodvisen preskuševalni laboratorij in zanjo izda potrdilo, pomeni pomembno konkurenčno merilo, s katerim podjetje pridobiva naročila na trgu. Poslovni okvir, v katerem je identificirana sposobnost najuspešnejša in najučinkovitejša, predstavlja tržni segment blagajn za bančne avtomate, ki zagotavljajo skoraj 30% celotnega prihodka podjetja.

Bančni avtomat je zapleten izdelek, ki ga sestavljajo finomehanske komponente za poslovanje z gotovino, računalniško krmilje z elektronskimi komponentami in blagajna, v kateri se nahaja gotovina. Za proizvajalca bančnega avtomata pomeni blagajna, ki zagotavlja mehansko varnost, nabavni izdelek. Proizvajalec blagajne je dobavitelj proizvajalca bančnega avtomata. Takšna povezava zahteva od

sary data for the research. Interviews with key people in the organisation lasted 2-3 hours on average. All the interviews were recorded. Besides interviews, business documentation and archival documents were also used as a source of data. The use of different sources enhanced the internal validity of the research. For the research all the business documents that led to an understanding of business reality were important, as were those which supported the data obtained in interviews, either qualitatively or quantitatively. The third source of data collection was observation; it was, however, only used in the case of Primat. It should be pointed out here that for a period of four years the researcher was directly involved in the operative activities of the organisation. Within this case study, the research thus bears a clear ethnographic component.

The analysis of data and conceptualisation were performed in agreement with the characteristics of inductive-theory generation. This was an iterative process of data collection, analysis and interpretation. The iterative cycle does not end with the interpretation of the initial data. The repetition of verifications and the collection of new data based on new findings necessarily follow.

3 RESULTS

The joint-stock company Primat, which has 290 employees, has recently been making a profit. Favourable business results in the last years are due, in particular, to the manufacturing of safety equipment. The company also manufactures metal furniture, which accounts for 30 % of the sales revenue, and warehouse equipment, which accounts for 10 % of the revenue.

The company's capability to quickly develop products to order is efficient, especially in such a business context in which the organisation, by order of a buyer, must quickly develop a product with a suitable safety level. The mechanical safety of a product is determined by the safety level. According to certificates in numerous industrial branches, the safety level is the minimum technical level that a product must guarantee. In contrast, the safety level established by an independent laboratory and the subsequently issued certificate, represent an important competitive measure that ensures the company's orders on the market. The business context, within which Primat's capability is most successful and efficient, is the market segment of strongboxes for automatic teller machines (cash dispensers), which accounts for almost 30 % of the total income of the organisation.

An automatic teller machine is a complex product consisting of fine mechanical components to manipulate cash money, a computer control consisting of electronic components, and a strongbox containing cash. The strongbox, which ensures the mechanical safety, is a purchasing product for a producer of automatic teller machines. The manufacturer of strongboxes is his supplier. Such trading conditions proizvajalca mehanske varnosti ustrezen nabor sposobnosti in virov.

Narava poslovanja pri dobavljanju blagajn proizvajalcu bančnih avtomatov je, glede na tipologijo proizvodnih procesov, sestavljena iz dveh korakov. V prvem koraku gre za razvoj po naročilu. Proizvajalec blagajne mora razviti izdelek ustrezne varnostne stopnje. Izmere definira naročnik. Problem razvoja se ne skriva neposredno v izmerah blagajne. Kar zadeva njih, bi lahko bil proces definiran kot prilagajanje standardne izvedbe po naročilu. Problem se skriva v zagotavljanju varnostne stopnje. Za preskuševalni laboratorij gre za popolnoma nov izdelek, ki ga je treba znova preskušati. Proizvajalec blagajne se torej sreča z izzivom, prilagoditi že znane rešitve novim zahtevam ali razviti nove rešitve in kombinacije. Imeti mora izvedeniško znanje na področju zagotavljanja mehanske varnosti, da lahko hitro in učinkovito najde rešitev za konstrukcijo blagajne. Pri tem pomaga poznavanje preskuševalnih procesov, ki jih uporabljajo preskuševalni laboratoriji. Hiter razvoj prototipov terja obvladovanje napredne proizvodne tehnologije, predvsem računalniško podprtega konstruiranja in računalniško krmiljenih obdelovalnih sistemov ter dobro organizacijo prototipne delavnice. Še tako dobro strokovno znanje in obvladovanje sodobne tehnologije pa ne bi bilo dovolj, če se podjetje ne bi bilo pripravljeno hitro odzivati in prilagajati zahtevam kupca.

Uspešno razvit in preverjen izdelek pa še ne pomeni konca poslovne zgodbe. Ta se v svojem tržnem pomenu šele prav začenja. Uspešen razvoj po naročilu je potreben pogoj za pridobitev posla. Po podpisu pogodbe preide proizvodni postopek razvoja po naročilu v proizvodni postopek, ki je nekakšna mešanica med izdelavo po naročilu in izdelavo na zalogo. Slednji pa zahtevajo drugačne sposobnosti. Zagotoviti je treba kakovost procesa izvedbe naročil, obvladovati stroške serijske proizvodnje, zagotavljati zanesljivost in hitrost dobav ter obvladovati nabavne poti.

V Primatu so pridobili sposobnosti, ki so potrebne za obvladovanje procesov po načelu izdelave po naročilu in izdelave na zalogo. Vendar se sposobnosti, ki ga razlikujejo od konkurence, skrivajo v razvoju po naročilu. Štirje meseci od začetnega povpraševanja do uspešne overitve izdelka, kar so dosegli v Primatu, pomenijo za industrijsko panogo resnično malo časa. Tisti, ki je zmožen razviti blagajno ustrezne varnostne stopnje v štirih mesecih, ima sposobnost, ki je v tem poslovnem smislu predstavlja konkurenčno prednost.

Sposobnost hitrega razvoja izdelkov z zahtevano varnostno stopnjo po naročilu kupca je dandanes na trgu priznana. Vendar je svojo vrednost na trgu dosegla v življenjskem ciklu, opredeljenim z evolucijsko dinamiko. Pandža in Polajnar [27] strukturirano predstavljata kronologijo dogajanja.

require from a producer of technically safe products a set of capabilities and resources.

In supplying strongboxes to the producer of automatic teller machines, business operations are done in two steps, regarding the typology of the operations processes. The first step is the development of the product to order. The strongbox manufacturer must develop a product with a certain safety level. The product's dimensions are set by the buyer. The problem of product development does not lie in the product's dimensions. With respect to them, the process could be defined as an adaptation of standard types to order. The problem lies in ensuring safety levels. The strongbox is a completely new product that must be tested anew by the testing laboratory. The strongbox producer is therefore faced with the challenge to adapt known solutions to new requirements or to develop new solutions and combinations. He should possess expert knowledge in the field of mechanical safety assurance to find quick and efficient solutions for designing the strongbox. The knowledge of testing procedures used by testing laboratories is of great help. The rapid development of prototypes requires a knowledge of up-to-date manufacturing technology, especially that of computer-supported design and CNC systems as well as good organisation of a prototype workroom. Expert knowledge and the application of modern technologies, however, would not be sufficient if the company were not willing to respond and adapt to the customer's demands.

A successfully developed and certified product is, however, not the end of the business story. The commercial part of it is still to come. The successful development of a product to order is a prerequisite to arrange a deal. After signing the contract, the process of product development to order is transformed into a process that is a mixture between manufacture to order and manufacture to stock. The latter, however, requires different capabilities. It is necessary to ensure the quality of the order-realization process, manage mass-production costs, ensure the reliability and speed of deliveries, and master the purchasing channels.

Primat has acquired the capabilities required for mastering production processes to order and to stock. However, capabilities that distinguish Primat from its competition lie in the development to order. It cannot be denied that four months from the initial demand to the successful certification of the product is an extremely short period of time. A company that is capable of developing a strongbox of a suitable safety level in a four-month period possesses a capability that represents a competitive advantage in this business context.

Primat's capability to quickly develop products to order with a required safety level is nowadays recognized on the market. However, its value on the market was achieved in an evolutionary dynamic life cycle. The chronology of events is presented by Pandža and Polajnar [27].

Začetna faza procesa (1989-1991)

Na obnašanje podjetja v začetni fazi, ki jo opredeljuje razkorak med sposobnostmi, ki jih poslovno okolje zahteva, in sposobnostmi, ki jih podjetje obvladuje, vplivata dva segmenta. Strateški načrt, s katerim se je želelo podjetje ustaliti v poslovnem okolju, postavi okvir za akumulacijo izvedenska tehničnega znanja s področja mehanske varnosti. Vzporedno pa podjetje se odzove na spremenjene zahteve na trgu, ki narekujejo hiter odziv na zahteve kupcev, in si tako pripravi temelje za sposobnost hitrega razvoja izdelkov po naročilu kupca. V začetni fazi akumulacije sposobnosti v podjetju, sposobnosti hitre reakcije in razvijanja izvedenska znanja na področju varnostne opreme še niso povezovali. Združili sta se v evolucijskem razvoju.

Faza učenja (1991-1995)

Za obdobje učenja je v podjetju značilno zelo intenzivno akumuliranje izvedenska znanja s področja mehanske varnosti. Eksperimentiranje z materiali, konstrukcijskimi rešitvami in tehnološkimi procesi je pripeljalo do izvedenskih znanj. Ta so se akumulirala z intenzivno interakcijo med Primatom in preskuševalnimi laboratoriji. Ti so s svojo logiko preskuševalnih procesov narekovali razvoj tehničnega znanja, pa tudi nekaterih organizacijskih ukrepov in obenem predstavljali organ, ki izbira ponujene rešitve. Če so preskuševalni laboratoriji z overjenjem Primatovih izdelkov potrjevali obstoj sposobnosti, pa to ni mogoče trditi za druge dele poslovnega okolja. Kljub temu, da so se Primatovi izdelki začeli pojavljati v pregledih overjenih izdelkov, ki jih objavljajo preskuševalne ustanove, in se je krog mogočih kupcev povečeval, preglednica 1 pokaže, da so overjeni izdelki zgolj simbolično prispevali k prihodkom podjetja. Kljub neobstoju oprijemljivih finančnih učinkov ni bilo mogoče kar zamenjati strateške smeri. V podjetju so vztrajali na izbrani poti tudi zaradi tega, ker je poslovno okolje prek preskuševalnih laboratorijev potrjevalo vrednost akumuliranega tehničnega znanja.

Faza potrditve (1995-1996)

Posel z bančnimi avtomati pomeni prvo izrazito potrditev poslovnega okolja, da so v podjetju akumulirane sposobnosti dobile vrednost na trgu. Preglednica 1 prikazuje velik skok pri deležu prihodkov od preskušenih izdelkov mehanske varnosti. Skok je posledica prihodkov, pridobljenih s poslom z mednarodnim podjetjem, ki mu je Primat začel dobavljati blagajne za bančne avtomate. Za fazo potrditve je v Primatu značilno, da je podjetje hitro in odločno reagiralo na

Initial phase (1989-1991)

Two segments affect the behaviour of the company in the initial phase. This phase is characterized by the gap between the capabilities required by the business environment and those mastered by the company. The strategic plan with which the company wanted to position itself in the business environment was a framework for the accumulation of expert engineering knowledge in the field of mechanical safety. Simultaneously, the company reacted to the changing demands of the market that dictate a quick response to customers' demands. It thus prepared the foundations for the quick development of products to the buyer's orders. In the initial phase of capabilities accumulation, the company found no links between quick reactions and expert-knowledge development in the field of safety equipment. The two were only to be linked in the evolutionary development.

Learning phase (1991-1995)

The learning phase is characterized by the intensive accumulation of expert knowledge in the field of mechanical safety. Experimenting with materials, structural solutions and technological processes lead to the acquisition of expert knowledge. It was accumulated with intensive interaction between Primat and testing laboratories. With their testing logic, the laboratories dictated the development of engineering knowledge, but also made their influence felt in some organizational measures. The laboratories represented an authority for deciding on offered solutions. While the testing laboratories, by certifying Primat's products, confirmed the existence of capabilities, this cannot be said for other segments of the business environment. In spite of the fact that Primat's products started to appear in lists of certified products, which are regularly published by testing organizations, and the circle of potential buyers increased, spreadsheet 1 shows that the certified products only symbolically enhanced the company's income. In spite of the non-existence of tangible financial effects, the strategic orientation of the company could not be simply changed. The company persisted with the selected orientation also because the business environment, via the testing laboratories, confirmed the value of accumulated engineering knowledge.

Confirmation phase (1995-1996)

The business with the automatic teller machines was the first to gain a clear confirmation from the business environment that company's accumulated capabilities had gained value on the market. Spreadsheet 1 shows a great jump in the income share from products tested for their mechanical safety. The jump resulted from the income gained though cooperation with a multinational organisation to which Primat started to deliver strongboxes for automatic teller machines. The confirmation phase is characterized by the company's quick and determined reaction

Preglednica 1. *Merljivi podatek za oceno sposobnosti*
Table 1. *Quantitative data for capability performance measurement*

Leto Year	**Prihodki od prodaje overjenih izdelkov (DEM) Revenues from sales of certificated products (DEM)**	**Delež overjenih izdelkov v skupnih prihodkih od prodaje [%] Share of certified products in net revenues from sales [%]**
1991	*579.743*	*3,2*
1992	/	/
1993	*1.056168*	*7,7*
1994	*769.996*	*4,6*
1995	*1.017.737*	*6,3*
1996	*5.461.725*	*30,3*
1997	*5.756.398*	*27*
1998	*4.105.921*	*20*
1999	*8.452.888*	*35,8*

priložnost, ki se je pojavila na trgu. Eksperimentiranje z razvojem novih izdelkov in preskušanje v preskuševalnih laboratorijih, ki je bilo rezultat smotrne odločitve o doseganju primerljivosti izdelkov s konkurenti, je pripeljalo do akumulacije izvedenskega znanja. To se je ob poslu s proizvajalcem bančnih avtomatov zlilo s sposobnostjo hitrega reagiranja na zahteve kupcev, katere zametki so se pojavili v začetku devetdesetih kot nujna reakcija, ki jo zahteva poslovno okolje. Obe sta se v življenjskem ciklu zlili v sposobnost hitrega razvoja izdelkov z ustreznimi varnostnimi stopnjami po naročilu kupca.

Faza eksploatacije (1996-1999)

Za fazo eksploatacije je značilno, da podjetje uporablja že akumulirane sposobnosti pri poslovnih priložnostih, ki se pojavljajo na trgu. Poslu z mednarodnim podjetjem se pridružijo še drugi podobni posli. Podjetje poskuša z investicijami v proizvodno tehnologijo in organizacijske ukrepe vzdrževati raven akumulirane sposobnosti. V okviru razvoja družine blagajn Starprim v Primatu poskušajo razširiti uporabnost sposobnosti na tržni segment, v katerem akumulirana sposobnost ni tako značilna. Akumulacija sposobnosti ni več izrazito krmiljena s signali poslovnega okolja. V podjetju se zavedajo pomena akumulirane sposobnosti, zato jo z različnimi ukrepi in investicijami želijo dograjevati in vzdrževati.

Pobudna faza (1999-)

Za pobudno obnašanje podjetja je značilen odmik od preproste uporabe sedanjih sposobnosti za pojavljajoče se poslovne priložnosti k dejavnemu ustvarjanju priložnosti. Primat v odnosu do kupca blagajn za bančne avtomate nima več zgolj reaktivne vloge in mu podreja svoje sposobnosti, ampak mu na

to the opportunity that emerged on the market. Experimenting with the development of new products and the testing of products in testing laboratories, which was the result of a rational decision to attain comparability with competitors' products, led to an accumulation of expert knowledge. In doing business with the producer of automatic teller machines, expert knowledge mingled with the capability of a quick response to customers' demands, which originates from the necessary reaction demanded by the business environment at the beginning of the nineties. Expert-knowledge accumulation and the capability to respond quickly to customers' demands were combined with the capability to rapidly develop products with adequate safety levels to the buyer's demands.

Exploitation phase (1996-1999)

The exploitation phase is characterised by the company's exploitation of accumulated capabilities in business opportunities emerging on the market. Other business is added to the business with multinational organisation. With investments into manufacturing technology and with organisational measures, the company tries to maintain the level of accumulated capabilities. With the development of the family of Starprim strongboxes, Primat tries to expand capability applicability to the market segment in which accumulated capability is not as characteristic as in the first one. The accumulation of capabilities is no longer controlled by signals from the business environment. The company is aware of the importance of accumulated capability, therefore it is trying to maintain and upgrade it with different measures and investments.

Proactive phase (1999-)

The proactive phase is characterized by the shift from simple exploitation of the existing capabilities for emerging business opportunities towards the active generation of opportunities. Primat no longer plays a reactive role, subordinating its capabilities to the buyer of strongboxes for automatic teller machines, but acpodlagi že akumuliranih sposobnosti dejavno predlaga mogoča poslovna sodelovanja. V Primatu so med prvimi v Evropi overili blagajno za bančne avtomate V. varnostne stopnje, čeprav zanjo niso dobili neposrednega naročila.

tively suggests possible business cooperation based on accumulated capabilities. Primat was among the first companies in Europe to certify a strongbox for an automatic teller machine of the 5th safety level, although the company has not received a direct order.

4 RAZPRAVA

4 DISCUSSION

Namen raziskave je bil zagotoviti opis procesa akumulacije sposobnosti. Kompleksnost in dinamična historična odvisnost proučevanega pojava omejujeta možnost matematičnega opisa proučevanega procesa. Kljub temu je v tem članku predstavljen matematični opis, brez ambicij po rigoroznem matematičnem modeliranju odnosov med spremenljivkami.

Razlaga rezultatov raziskave je pokazala, da je dinamiko procesa akumulacije sposobnosti mogoče opisati kot življenjski cikel, sestavljen iz petih faz:

The aim of this discussion was to set a stylised mathematical description of the capability-accumulation process. The complexity and path-dependence of the studied event limit the possibility of its mathematical description. The mathematical description presented in this article has no ambition to rigorously model mathematical relationships between the variants.

The interpretation of the research results shows that the dynamics of the capability accumulation process can be described as a life cycle consisting of five phases:

$$\{CAP\} = \sum_{i=1}^{5} \{P_i\} \quad (1),$$

pri čemer sta CAP proces akumulacije sposobnosti in P_i faze življenjskega cikla. Obstoj različnih faz, s katerimi je opisan obravnavani proces, je mogoče prepoznati na podlagi empiričnih podatkov.

Proces akumulacije sposobnosti vsebuje logiko razvoja, ki ga usmerja od faze do faze. Vsaka faza je definirana s prejšnjo. Na ta način je zajeta historična odvisnost procesa:

where CAP is the capability accumulation process and P_i are the phases of a life-cycle. The existence of different phases, with which the studied process is described, can be identified with empirical data.

The capability accumulation process contains development logic which directs it from one phase to another. Each phase is determined by the previous one. Path-dependence is thus ensured:

$$\{P_i\} = f\left(\{P_{i-1}\}\right) \quad (2).$$

Proces akumulacije sposobnosti je mogoče predstaviti kot kumulativno in vezano zaporedje faz, ki si sledijo, pri čemer vsaka prispeva k naslednji fazi. Vsaka faza torej izhaja iz prejšnje. Vsaka faza je tudi kompleksnejša glede na akumulirane sposobnosti.

Faze se medsebojno razlikujejo po vplivu, ki ga imajo različni vplivni dejavniki na razvoj akumulacije sposobnosti. Te je mogoče predstaviti kot vplivne dejavnike podjetja, označene z indeksom *f,* in vplivne faktorje poslovnega okolja, označene z indeksom *m*. Dimenzije faz življenjskega kroga so predstavljene z vektorjem:

The capability accumulation process can be presented as a cumulative and linked sequence of phases that follow one another, with each one adding to the next one. Each phase thus results from the previous one and is more complex with respect to accumulated capabilities.

Phases differ according to the effect of different influential factors on the capability-accumulation process. These can be represented as organisation-oriented impact factors described with the index *f*, and market-oriented impact factors described with the index *m.* The dimensions of the life cycle phases are represented with the vector:

$$\{B\} = \left\{C_f, R_f, CU_m, c_m, S_m, T_m\right\} \quad (3),$$

pri čemer so C_f sposobnosti podjetja, R_f viri podjetja, CU_m kupci, c_m konkurenti, S_m dobavitelji in T_m razvoj tehnologije.

Vpliv posameznih dejavnikov na faze procesa akumulacije sposobnosti je predstavljen z utežnim vektorjem:

where C_f are the capabilities of the organisation, R_f are the resources of the organisation, CU_m are the buyers, c_m are the competitors, S_m are the suppliers and T_m is the technological development.

The influence of individual factors on the phases of the capability-accumulation-process phases is presented with the vector

$$\{I\} = \{\alpha, \beta, \gamma, \delta, \varepsilon, \zeta\} \quad (4),$$

pri čemer so α koeficient vpliva akumuliranih sposobnosti podjetja, β koeficient vpliva virov podjetja, γ koeficient vpliva kupcev, δ koeficient vpliva konkurentov, ε koeficient vpliva dobaviteljev in ζ koeficient vpliva tehnološkega razvoja. Vrednosti utežnega vektorja se od faze do faze spreminjajo. Zapišemo lahko:

where α is a coefficient of the impact of capabilities accumulated in the organisation, β is a coefficient of the impact of resources of the organisation, γ is a coefficient of the impact of buyers, δ is a coefficient of the impact of competitors, ε is a coefficient of the impact of suppliers, and ζ is a coefficient of the impact of technological development. The value of the weight vector changes from one phase to another. Thus we can write:

$$\{P_i\} = \{B\} \cdot \{I_i\} \quad i = 1,\ldots 5 \tag{5}$$

Vplivni dejavniki v posameznih fazah različno vplivajo na postopek akumulacije sposobnosti.

Koeficienti vpliva niso medsebojno neodvisni. Med koeficienti vpliva podjetja prihaja do sinergijskih učinkov pri prehodih iz ene faze v drugo. Isto velja tudi za koeficiente vpliva poslovnega okolja. Mogoče je definirati dva sistema, kar omogoči dvodimenzionalno predstavitev obravnavanega procesa:

Impact vectors differently affect the capability-accumulation process in different phases.

Impact coefficients are not mutually independent. Synergistic effects occur among organisation-oriented impact factors in passing from one phase to another. The same is true for market-oriented impact factors. Two systems can be determined, which enables a two-dimensional representation of the studied process:

$$S_f = (\alpha, \beta) \tag{6}$$

$$S_m = (\gamma, \delta, \varepsilon, \zeta) \tag{7}$$

pri čemer sta S_f sistem vplivnih koeficientov podjetja in S_m sistem vplivnih dejavnikov poslovnega okolja. Med koeficienti obeh sistemov prihaja do sinergijskih učinkov, ki jih predstavljata sinergija vplivnih dejavnikov podjetja σ_f in sinergija vplivnih dejavnikov okolja σ_m.

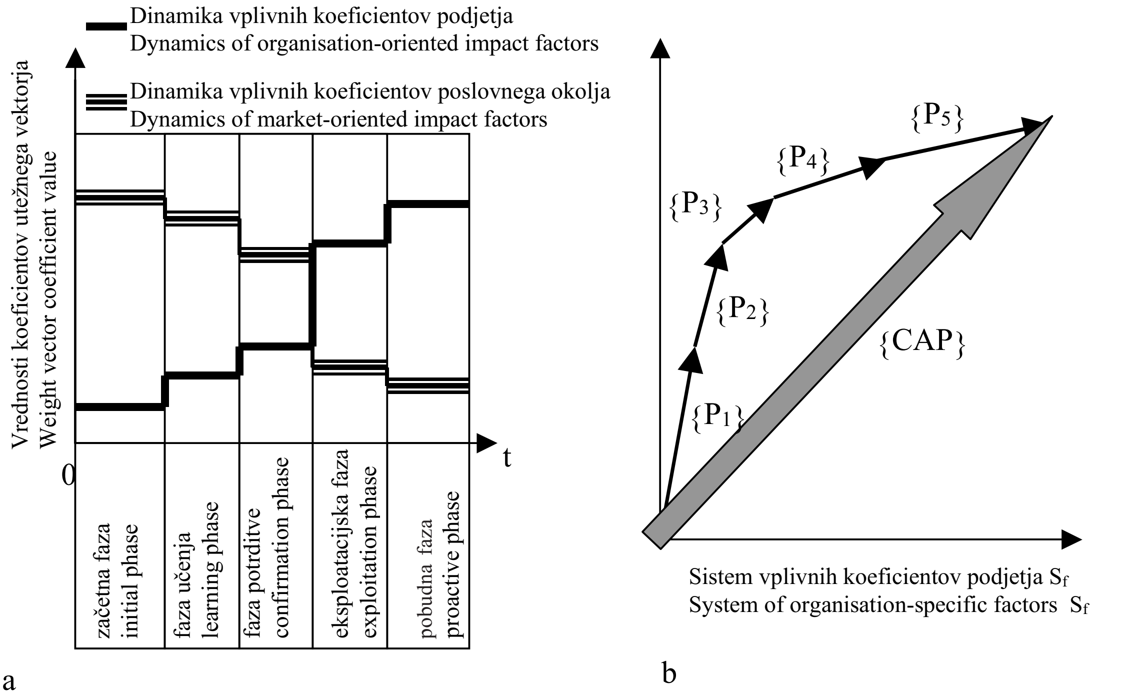
Empirični podatki dokazujejo, da vplivni dejavniki okolja izrazito usmerjajo proces akumulacije sposobnosti v prvih fazah. V zadnjih fazah procesa pa odločilno vlogo za usmerjanje procesa akumulacije sposobnosti pripada vplivnim dejavnikom podjetja. Ali drugače, sinergijski učinki med vplivi okolja so večji v prvih fazah procesa, v zadnjih fazah pa prevladujejo sinergijski učinki med viri in že akumuliranimi sposobnosti. Evolucijska dinamika vplivnih dejavnikov in njihov vpliv na postopek akumulacije sposobnosti so prikazani na sliki 1. Posamezni vplivni dejavniki imajo različne numerične ali simbolne vrednosti, pri čemer slika 1a predstavlja njihovo splošno gibanje.

V začetni fazi in v fazi učenja poslovno okolje izrazito usmerja postopek akumulacije sposobnosti. Gre za odzive na zahteve poslovnega okolja in jasne znake, da obstaja razkorak med zahtevanimi in sedanjimi sposobnostmi. Za fazo potrditve je značilno, da poslovno okolje potrdi ustreznost v evolucijskem procesu akumuliranih sposobnosti. V fazi eksploatacije podjetja zelo izrazito in ciljno usmerjeno dograjujejo in vzdržujejo na trgu potrjene sposobnosti. V pobudni fazi pa gradijo svojo strateško razpoznavnost na akumuliranih sposobnostih. Za zadnji dve fazi življenjskega kroga akumulacije sposobnosti je torej

where S_f is the system of organisation-oriented impact coefficients, and S_m the system of market-oriented impact coefficients. There are synergistic effects between both systems, i. e. the synergy of organisation-oriented impact factors σ_f and the synergy of business-oriented impact factors σ_m.

Empirical data show that the capability-accumulation process is clearly directed by market-oriented impact factors in the first phases. In the last phases of the process, however, a decisive role in directing the capability-accumulation process is given to organisation-oriented impact factors. Or, in other words, synergistic effects of the business environment are greater during the first phases of the process, while during the last phases, synergistic effects between resources and already-accumulated capabilities prevail. The evolution dynamics of impact factors and their influence on the capability-accumulation process are shown in Figure 1. Individual impact factors have different numerical or symbol values; Figure 1 presents their general movements.

In the initial and learning phases the business environment clearly directs the capability-accumulation process. The business environment reacts and gives clear signs that there is a gap between the required and the existing capabilities. The confirmation phase is characterized by the fact that the business environment confirms the adequacy of the capabilities accumulated in the evolution process. In the exploitation phase the organisation clearly and purposefully upgrades and maintains capabilities confirmed by the market. The last two phases of the capability-accumulation life cycle are characterised by the level of accumulated capabilities that deci-



Sl.1. *Evolucijska dinamika vplivnih koeficientov in njihov vpliv na postopek akumulacije sposobnosti*
Fig. 1. *Evolution dynamics of impact factors and their influence on the capability-accumulation process*

značilno, da raven že akumuliranih sposobnosti odločilno vpliva na postopek. Ali drugače povedano, sinergijski učinek med vplivnimi dejavniki podjetja usmerja postopek akumulacije sposobnosti.

Omenjene ugotovitve izzovejo dosedanja teoretična spoznanja. Avtorji s področja teorije proizvodnih virov predpostavljajo, da sta poslovno okolje in proces akumulacije sposobnosti neodvisna. Priznavajo edino, da morajo sposobnosti trgu ustrezati. Njihova perspektiva je izrazito statična in obravnava podjetja v ozkem časovnem obdobju. Obravnavanje procesa skozi vzdolžno perspektivo je pokazalo, da postopek akumulacije sposobnosti ni neodvisen od poslovnega okolja, saj ga v začetnih fazah življenjskega kroga zelo izrazito usmerja.

Raziskava v poslovnih okoljih je pokazala, da ima sposobnost različno vrednost v različnih fazah življenjskega cikla. Še več, v začetni fazi in v fazi učenja je vrednost sposobnosti, specifične za podjetje, manjša od sposobnosti, ki jo zahteva trg. Poenostavljeno je razmerje med gibanjem vrednosti sposobnosti, specifične za podjetje, in gibanjem vrednosti, ki jo zahteva trg, prikazano na sliki 2.

Če je mogoče predstaviti gibanje vrednosti za specifično sposobnost, je mogoče definirati proces akumulacije sposobnosti kot:

sively influences the process. Or, in other words, the synergistic effect between the organisation-oriented impact factors directs the capability-accumulation process.

These findings challenge previous theoretical issues. Scholars in the field of resource-based theory suggest that the business environment and the capability-accumulation process are independent. What they do acknowledge, however, is that capabilities must suit the market. Their perspective is explicitly static and transversal. It studies manufacturing organisations in a short time interval. Studying the process through a longitudinal perspective has shown that the capability-accumulation process is not independent of the business environment; what is more, it clearly directs it in the initial phases of a life cycle.

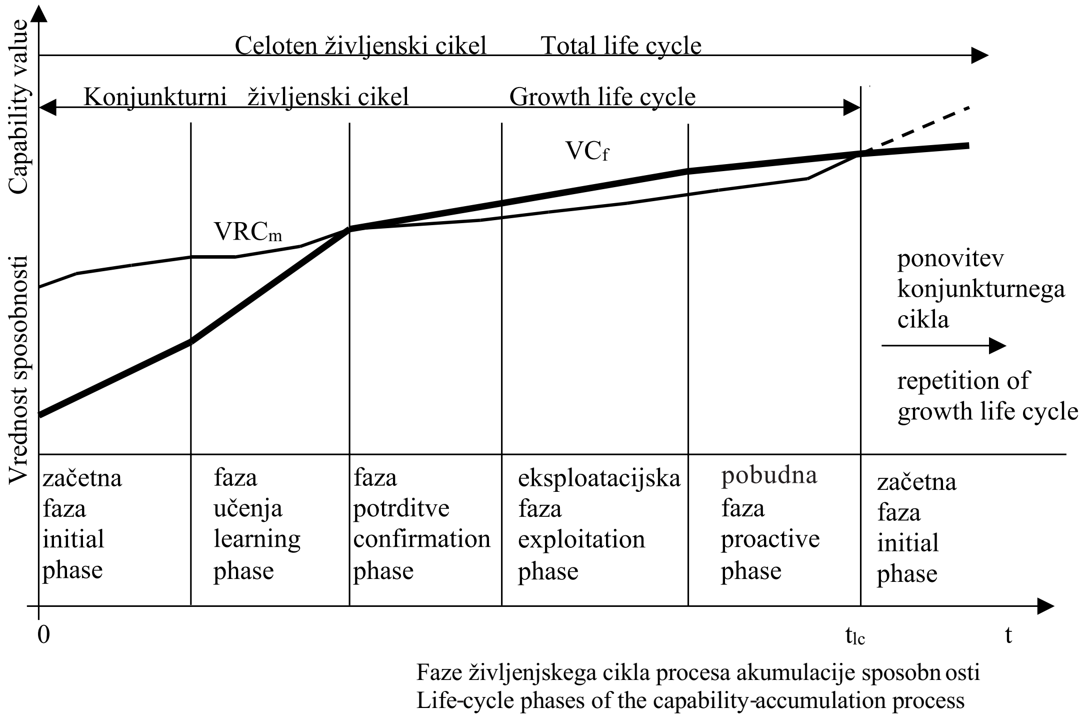
Research in business environments has shown that capability has a different value in the different phases of a life cycle. What is more, in the initial and learning phases, the organisation-specific capability value is lower than the market-oriented capability value. The relationship between the organisation-specific capability value and the market-oriented capability value is shown in a simplified way in Figure 2.

If variations of value can be represented as a specific capability, the capability-accumulation process can be defined as:

$$CAP = \int_{0}^{t_{lc}} VC_f \cdot dt \quad (8),$$

pri čemer pomeni VC_f predstavlja gibanje vrednosti za podjetje specifične sposobnosti in t_{lc} čas konjunkturnega življenjskega cikla. Podobno je mogoče zapisati zahtevano sposobnost trga:

where VC_f is the organisation-specific value movement and t_{lc} is the time of the growth life cycle. Similarly, the market-oriented value can be written as:



Sl. 2. *Življenjski cikel procesa akumulacije sposobnosti*
Fig. 2. *Capability-accumulation process life cycle*

$$RCAP = \int_0^{t_{lc}} VRC_m \cdot dt \qquad (9),$$

pri čemer je VRC_m gibanje vrednosti zahtevanih sposobnosti. Vsakokratno strmino krivulje lahko označimo kot koeficient dinamike poslovnega okolja. Mogoče je predpostaviti, da poslovno okolje stalno zahteva boljše sposobnosti. Večji koeficient dinamike poslovnega okolja pomeni, da v hitreje rastočih industrijskih panogah zahteve po sposobnostih hitreje naraščajo. Pomeni, da je vrednost sposobnosti odvisna od poslovnega okvira.

Razkorak med sposobnostmi podjetja in sposobnostjo, ki jo zahteva poslovno okolje, definiramo kot:

where VRC_m is a market-oriented capability value. Every inclination of a curve can be determined as a coefficient of business-environment dynamics. It can be anticipated that the business environment continually requires better capabilities. A higher coefficient of business-environment dynamics means that in faster-developing industrial branches the requirements for capabilities increase more quickly. The capability value is thus dependent on the business context.

A gap between organisation-specific capabilities and the capabilities required by the business environment is determined as:

$$\Delta C = VC_f(t) - VRC_m(t) \qquad (10).$$

Odvisnosti med razkorakom in značilnostmi posameznih faz je mogoče pojasniti takole:

The relationships between the gap and the characteristics of individual phases can be explained as follows:

$$\begin{cases} VC_f(t) - VRC_m(t) \le 0 \Rightarrow \text{prevladujoč vpliv koeficientov iz } S_m \text{ ali } \sigma_f \ll \sigma_m \\ VC_f(t) - VRC_m(t) > 0 \Rightarrow \text{prevladujoč vpliv koeficientov iz } S_f \text{ ali } \sigma_f \gg \sigma_m \end{cases}$$
$$\begin{cases} VC_f(t) - VRC_m(t) \le 0 \Rightarrow \text{prevailing impact of } S_m \text{ coefficients or } \sigma_f \ll \sigma_m \\ VC_f(t) - VRC_m(t) > 0 \Rightarrow \text{prevailing impact of } S_f \text{ coefficients or } \sigma_f \gg \sigma_m \end{cases} \qquad (11).$$

V začetni fazi in v fazi učenja, pri kateri obstaja razkorak med zahtevanimi sposobnostmi in sedanjo sposobnostjo, vpliva na postopek akumulacije sposobnosti poslovno okolje. Podjetje v teh fazah še ni akumuliralo sposobnosti, ki bi dosegale raven zahtevanih sposobnosti, zato se v

In the initial and learning phases, when there is still a gap between the required and the existing capability, the business environment affects the capability-accumulation process. In these phases the organisation has not yet accumulated the capabilities that would equal the level of the required capabilities, therefore the podjetjih odzivajo na zahteve poslovnega okolja. Od faze potrditve dalje, raven že akumuliranih sposobnosti odločilno vpliva na razvoj procesa. Podjetja se zavedajo pomena na trgu potrjenih sposobnosti.

Pojavi se logično vprašanje, kdaj se proces akumulacije sposobnosti konča in kaj se zgodi po pobudni fazi. Razlaga empiričnih podatkov je omogočila definiranje življenjskega cikla, katerega značilnosti zajamemo v predstavljenih fazah. Proučevan življenjski cikel je mogoče imenovati konjunkturni življenjski cikel, saj vrednost sposobnosti podjetja narašča in presega zahtevano vrednost. Konjunkturni življenjski cikel se lahko prekine, če se vrednost zahtevane sposobnosti hitro dvigne. Do takšnega pojava lahko pride ob prodoru konkurenta, ki je razvil sposobnosti obvladovanja nove tehnologije ali z organizacijskimi ukrepi izrazito dvignil svojo sposobnost. Sklepamo lahko, da je celotni življenjski cikel procesa akumulacije sposobnosti sestavljen iz zaporedja konjunkturnih življenjskih ciklov. Celoten življenjski cikel akumulacije sposobnosti se zaustavi samo v primeru propada podjetja ali s kakšno drugo dramatično spremembo.

Proučevanje zaporedja konjunkturnih ciklov procesa akumulacije sposobnosti je lahko smer nadaljnjih raziskav. Seveda pa bi bilo treba pri takšnih raziskavah obravnavati zelo dolga časovna obdobja.

5 SKLEPI

Namene pričujočega prispevka je mogoče predstaviti v dveh vsebinskih sklopih. V prvem, teoretičnem delu želimo predstaviti teorijo proizvodnih virov in njen pomen za raziskovalno področje proizvodnih strategij. Sporočilo prispevka je, da lahko teorija proizvodnih virov s svojo introvertiranostjo predstavlja teoretična zamisel, ki bo usmerjala raziskave na področju proizvodnih strategij. V drugem delu je predstavljena raziskava, ki je potekala v štirih slovenskih proizvodnih podjetjih. Spoznanja, pridobljena v induktivnem raziskovalnem procesu, prispevajo k novim spoznanjem na področju teorije proizvodnih virov. Vzdolžna perspektiva raziskave je omogočila opis akumulacije sposobnosti kot življenjskega cikla. V posameznih fazah procesa različni vplivni dejavniki različno vplivajo na postopek akumulacije sposobnosti. V začetni fazi in v fazi učenja na postopek izrazito vpliva poslovno okolje. V naslednjih fazah pa raven že akumulirane sposobnosti izrazito usmerja postopek. Izsledki raziskave dokazujejo, da sposobnost ni nekaj, kar je že po definiciji vredno in pomembno v poslovnem okolju, ampak to šele postane, ko njeno vrednost potrdi trg.

Raziskovanje akumulacije sposobnosti skozi vzdolžno in razvojno perspektivo lahko predstavlja pomembno smer raziskovanja na področju

organisation responds to the demands of the business environment. From the confirmation phase onwards, the level of accumulated capabilities decisively affects the process development. The organisation is aware of the importance confirmed by the market.

A logical question arises as to when the capability-accumulation process stops and what happens after the proactive phase. The interpretation of empirical data has enabled us to define a life cycle whose characteristics have been included in the presented phases. The studied life cycle can be designated as a growth life cycle, because of the value of the organisation's capability increases and surpasses the required value. The growth life cycle can be stopped if the value of the required capability rises quickly. Such a phenomenon can occur when a competitor penetrates the market because he has developed capabilities to master a new technology or has clearly increased his capability with organisational measures. We can conclude that the total life cycle of the capability-accumulation process consists of a sequence of growth life cycles. The capability-accumulation life cycle, in its totality, can fail only due to a total collapse of an organisation or some other dramatic change.

The study of the growth life-cycle sequence of the capability-accumulation process can be a topic for further research. However, long time periods should be considered in such investigations.

5 CONCLUSIONS

The purpose of this paper is twofold. In the first, conceptual part we want to present the resource-based theory and its importance for the research of operations strategy. The article is designed to communicate the idea that resource-based theory, while being highly introverted, can represent a theoretical concept for directing research in the field of operations strategy. The research presented in the second part was performed in four Slovenian manufacturing organisations. The knowledge obtained in the research process makes a contribution to resource-based theory. The longitudinal perspective of the research has enabled us to describe capability-accumulation as a life cycle. In individual phases of the process, different factors differently affect the capability accumulation process. In the initial and learning phases, the process is clearly affected by the business environment. In subsequent phases, however, it is the level of accumulated capability that directs the process. The research findings prove that capability is not something that is valuable and important in the business environment only by definition, but that it becomes valuable when its value has been confirmed by the market.

The research into capability accumulation via the longitudinal and evolutionary perspective can significantly direct research in the field of operations proizvodnih strategij. Poznavanje dinamičnega procesa akumulacije sposobnosti lahko pomaga vodjem proizvodnih podjetij obvladovati proces, ki je zaradi zapletenosti, posebnosti in dinamične historične odvisnosti težko obvladljiv.

[1] Omeniti velja, da se v angleški terminologiji ime proizvodni menedžment vse bolj umika izrazu *operations management*. V okviru slednjega so dejavnosti, potrebne za fizično proizvodnjo izdelka, integrirane z dejavnostmi upravljanja nabavne in distribucijske mreže, uvajanja novih izdelkov, menedžmenta kakovosti, menedžmenta tehnologij in merjenja izvedbe. V slovenskem prostoru še ni poenotenja okoli izraza, ki bi opisoval vsebino, ki jo v angleški terminologiji opisuje beseda *operations*. Pojavljajo se termini npr.: procesni menedžment in izvedbeni menedžment. Zato je v slovenskem delu prispevka uporabljen izraz proizvodni menedžment, v angleškem prevodu pa *operations management*. Neenotnost v terminologiji dokazuje, da proizvodni menedžment kot znanstvena panoga še ni uveljavljena v Sloveniji. Slednje je seveda, glede na pomen proizvodnega menedžmenta, anahronizem, vendar je to že tema, ki izstopa iz okvira tega prispevka.

strategy. A knowledge of the dynamic-accumulation process can help managers of manufacturing organisations to master the process that is otherwise difficult to manage due to its complexity, idiosyncrasy and path-dependence.

[1] It should be noted here that in English terminology the term *manufacturing management* is being increasingly replaced by *operations management*. The latter encompasses the activities needed for the physical manufacture of the product and the management of purchase and distribution networks, new product introduction, quality management, technology management and performance measurement. In Slovene terminology no term has yet been found to describe the contents of the English term *operations*. There are terms such as *procesni menedžment* and *izvedbeni menedžment*. Therefore, the term *proizvodni menedžement* is being used in the Slovene part of the article, while *operations management* is being used in the English translation. This terminology gap shows that in Slovenia *operations management* has not yet become a scientific discipline. With respect to its importance, this is an anachronism, yet this topic is not within the scope of this article.

6 LITERATURA
6 REFERENCES

[1] Hayes, R. H., G. P. Pisano (1996) Manufacturing strategy: at the intersection of two paradigm shifts. *Production and Operations Management*, Vol.5, No.1, 25-41.

[2] Skinner, W. (1969) Manufacturing-missing link in corporate strategy, *Harvard Business Review*, May-June, 136-145.

[3] Clark, K.B. (1996) Competing through manufacturing and the new manufacturing paradigm: is manufacturing strategy passe? *Production and Operations Management,* Vol. 5, No. 1, 42-58.

[4] Womack, J., D. Jones, D. Roos (1991) The machine that changed the world. *Harper-Perennial*, New York.

[5] Hayes, R.H., G.P. Pisano, D.M. Upton (1996) Strategic operations: competing through capabilities. *New Yourk: Free Press*.

[6] Gunasekaran, A. (1999) Agile manufacturing: a fremework for research and development. *International Journal of Production Economics* 62, 84-105.

[7] Kidd, P.T. (1994) Agile manufacturing, forging new frontiers. *Addison – Wesley Publishing Company*.

[8] Warnecke, H.J (1993) The fractal company, a revolution in corporate culture. *Springer-Verlag*.

[9] Kotha, S. (1995) Mass customization: implementing the emerging paradigm for competitive advantage. *Strategic Management Journal* 16, 21-42.

[10] Kuhn, T. (1972) The Structure of scientific revolution. *University of Chicago Press*.

[11] Rumelt, E.P. (1991) How much does industry matter? *Strategic Management Journal* 12 (3), 167-185.

[12] Dierickx, I., K. Cool (1989) Asset stock accumulation and sustainability of competitive advantage. *Management Science*, Vol.17. No.1, 121-154.

[13] Barney, J. (1991) Firm resources and sustained competitive advantage. *Journal of Management*, Vol.17, No.1, 99-120.

[14] Grant, R. M. (1991) The resource based theory of competitive advantage: implications for strategy formulation. *California Management Review*, 33(3), 114-135.

[15] Teece, D.J., G.P. Pisano, A. Shuen (1997) Dynamic capabilities and strategic management. *Strategic Management Journal*, 18, 509-533.

[16] Collis, D.J. (1994) Research note: how valuable are organizational capabilities. *Strategic Management Journal*, Vol.15, 143-152.

[17] Slack, N., M. Lewis (2001) Operations strategy. *Financial Times Prentice Hall*.

[18] Gagnon, S. (1999) Resource-based competition and the new operations strategy. *International Journal of Operations & Productions Management*, Vol.19, No.2, 125-138.

[19] Hayes, R. H., G. P. Pisano (1994) Beyond world class: the new manufacturing strategy. *Harward Business Review*, January-February, 77-86.

[20] Roth, A.V. (1996) Neo-operations strategies linking capabilities-based competition to technology. In G.H. Gaynor (Ed.), The Handbook of Technology Management. *McGraw-Hill Publishing,* New York.

[21] Tranfield, D., S. Smith (1998) The strategic regeneration of operations by changing routines. *International Journal of Operations & Production Management* Vol.18, No.2, 114-129.

[22] Mills, J., K. Platts, M. Gregory (1995) A framework for the design of operations strategy process, a contingency approach. *International Journal of Operations & Productions Management* Vol. 15, No.4, 17-49.

[23] Glaser, B., A. Strauss (1967) The discovery of grounded theory: strategies of qualitative research. *London: Wiedenfeld and Nicholson*.

[24] Godfrey, P.C., C.W.L. Hill (1995) The problem of unobservables in strategic management research, *Strategic Management Journal*, Vol.16, 519-533.

[25] Van de Ven, A.H. (1992) Suggestions for studying strategy process: a research note. *Strategic Management Journal*, Vol. 13, 169-188.

[26] Winter, S.G. (2000) The satisfying principle in capability learning. *Strategic Management Journal*, Vol. 21, 981-996 .

[27] Pandža, K., A. Polajnar (2000) Capabilities accumulation process: a longitudinal case study in manufacturing organisation. In R. Van Dierdonck, A. Vereecke (Ed.), Crossing Borders and Boundaries: The Changing Role of Operations. *EurOMA Conference, Gent*, 503-210.

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Gradnja uporabniškega vmesnika na temelju programskega paketa MATLAB za študij sistemov

Building a User Interface Based on MATLAB for Control System Studies

Martina Leš - Boris Aberšek

Sodobna programska oprema ponuja visoko interaktivno kakor tudi učinkovito učno okolje za učenje teorije sistemov in simuliranj za mnoga področja študija tehnike. Predstavljeni prispevek opisuje razvoj in izvedbo učnega pripomočka za učenje teorije linearnih sistemov, ki povezuje skripta v elektronski obliki s primeri v Matlabu in Simulinku prek grafičnega uporabniškega vmesnika za obe različici Matlaba: 5 in 6. To je grafična uporaba, ki daje študentom dodiplomskega študija pregleden in preprost pripomoček pri učenju teorije linearnih sistemov v maternem jeziku. Študentom daje osnovo za samostojno učenje in učenje na daljavo. V prispevku smo se posebno posvetili predstavitvi grafičnega vmesnika in njegove strukture, kar smo ponazorili še s primerom. Na koncu smo opravili še analizo uspešnosti različnih metod poučevanja z računalnikom.

(Ključne besede: teorija linearnih sistemov, Matlab, orodja učna, vmesniki grafični, vmesniki uporabniški)

Software technology provides a highly interactive and powerful learning environment for system theory and simulation in some engineering disciplines. This paper describes the development and implementation of an educational tool for linear systems theory that connects electronic manuscripts with examples in Matlab and Simulink through a graphical user interface for versions 5 and 6 of Matlab. This is a graphical application that offers undergraduate students additional support by presenting linear systems theory in their native language. It provides students with a foundation for independent studies and distance learning. The main focus in this paper is given to the graphical interface structure, which is illustrated with an example. We conclude the paper with an analysis of different computer-assisted learning methods.

(Keywords: linear systems theory, Matlab, teaching tools, graphical user interfaces)

0 UVOD

Programska industrija ponuja dandanes učinkovita učna okolja za učenje različnih tehničnih vsebin. Poučevanje teorije sistemov je zapleten postopek, saj le-ta vsebuje veliko količino teoretičnega znanja in matematičnega ozadja. Posledica tega je, da se je velikega dela teorije sistemov zelo težko učiti brez vizualizacije. Vizualizacijo in simbolično računanje je mogoče opraviti v Matlabu, ki je interaktivni programski jezik za izvedbo znanstvenih in inženirskih izračunov, in izhaja iz *laboratorija za delo z matrikami* (Matrix laboratory). To pomeni, da večina operacij temelji na matričnih postopkih. Matlab ponuja tudi grafično okolje za izdelavo grafičnih uporabniških vmesnikov (GUV), ki omogoča gradnjo prijaznejšega okolja za uporabnika programov – lastnih uporabniških vmesnikov, pripomočkov in predstavitev. Uporabniški grafični vmesnik lahko pripomore pri organizaciji in omogoča

0 INTRODUCTION

The software industry provides a powerful learning environment for different engineering disciplines. The teaching of systems theory is a complex process because it contains a lot of theoretical knowledge and has a mathematical background. As a consequence, many concepts that are involved in systems theory are difficult to learn without visualization. The visualization and the symbolic computations can be done in MATLAB™, which is an interactive programming language for scientific and engineering computation, based on a matrix laboratory (Matrix laboratory). This means that most operations are organized as matrix operations. Matlab also provides a graphical user interface (GUI) tool, which makes it more user friendly and allows advanced users to build their own interfaces, tools and visual presentations. A GUI can help to organize and provide easier access to examples and additional lažji dostop do primerov in dodatnih uporab. Veliko število Matlabovih orodij nam daje sicer zelo dobro podporo pri reševanju različnih problemov, sintakse se je mogoče z lahkoto naučiti, toda veliko število funkcij (in število se nenehno povečuje) že povzroča neučinkovito uporabo. Da bi se izognili temu problemu, je treba skrbno organizirati primere in jih dobro dokumentirati. To je bila tudi osnovna zamisel, zaradi katere smo se lotili gradnje uporabniškega vmesnika, ki povezuje dodatno še skripta v elektronski obliki (predavanja in računalniške vaje).

V zadnjem desetletju so mnogi avtorji predstavili posamezne predmete, zapise in eksperimente z uporabo računalnika [1]. Mnogi uporabljajo World-Wide-Web kot servis za medmrežje in brskalnike (naprimer Internet Explorer ali Netscape) za navigacijo. Nekateri avtorji so predstavili tudi delo z virtualnimi inštrumenti, kakor npr. LabView ([2] in [3]), drugi spet simulacijska in animacijska orodja ([4] do [6]), toda le redki so predstavili program za celotni predmet ([7] in [8]). Večinoma je to posledica zelo obsežnega dela, ki je potrebno za pripravo takih predmetov.

Ker sestavljajo osnovo teoriji sistemov teoretična in matematična predznanja, je velik del leteh zelo težko razumeti brez vizualnih predstavitev, je bilo izdelano orodje za študente dodiplomskega študija, ki se praktično prvič srečajo z Matlabom, bodo pa nadaljevali s študijem tehnike in simuliranj. S tem smo pokrili najprej samo vse področje teorije linearnih sistemov. Uporabniški vmesnik in okolje smo pripravili v taki obliki, da ga je mogoče razširiti na podobne predmete.

1 POUČEVANJE TEORIJE LINEARNIH SISTEMOV

Tradicionalno poučevanje teorije linearnih sistemov poteka prek predavanj, v katerih učitelj razlaga teorijo in demonstrira tipične rešitve nekaterih primerov. Študentje širijo svoje teoretično znanje z računalniškimi vajami, za katere pa je potrebno večje teoretično predznanje kakor tudi matematična podlaga.

Na Univerzi v Mariboru so bila izdelana različna orodja, ki so jih uporabljali tudi študenti (npr. LSD, PADSIM, ASSO), saj so bila pripravljena v maternem jeziku. Razlog za uporabo drugih programskih jezikov, kot npr. Matlab, LabView, MatCad in drugih je bil v velikem razvoju in širitvi njihovih zmogljivosti, kakor tudi v njihovem poenotenju in vedno večji standardizaciji in splošni uporabi (tudi v industriji). Vedno več pozornosti pri regulacijah in simuliranjih dandanes posvečamo Matlabu in Simulinku, posledica pa je veliko primerov in funkcij, ki so na voljo v zadnjih letih.

applications. Many of Matlab’s toolboxes offer a lot of support for different problems. It is easy to learn Matlab’s syntax, but the number of designed functions is still increasing and this can lead to ineffective use. To overcome this problem, the examples should be well organized and documented. This was the basic idea: to build an additional user interface with links to manuscripts (lectures and computer exercises) in electronic form.

In the last ten years, many computer-based engineering courses, curricula and experiments have been presented [1]. Many of them use the World Wide Web as an Internet service and software interfaces (e.g. Microsoft Explorer or Netscape Navigator) for navigation. Some authors emphasize the use of virtual instrumentation, such as LabView ([2] and [3]), others use simulation and animation tools ([4] to [6]), but only a few complete courses have been presented ([7] and [8]). Mostly, this is a consequence of the extensive work needed for the preparation of the courses.

Systems theory consists of a lot of theoretical knowledge and a mathematical background. As a consequence, many concepts involved in control systems theory are difficult to understand without visualization. The Linear Systems Theory Education Tool is designed for undergraduate engineering students, who are generally working with Matlab for the first time, and will continue with engineering and simulation studies. It covers the full Linear Systems Theory course. The interface and the environment are organized in such a way that they can be extended to similar courses.

1 TEACHING CONTROL SYSTEMS THEORY

Traditionally, control systems theory is taught by a lecturer, who explains the theory and demonstrates typical solutions for some problems. The students broaden their theoretical knowledge with computer exercises, which require a lot of theoretical knowledge and a mathematical background.

At the University of Maribor some special control systems education tools, LSD, PADSIM, ASSO, prepared in Slovene, have been used in exercises. Another reason for using computing languages such as Matlab, LabView, or MatCad is the rapid development of different technical computing languages, their uniformity and use in many industrial applications. Increasing attention in control engineering has been given to Matlab and Simulink. As a result, many examples and functions have been prepared in recent years.

2 PROGRAMSKO ORODJE IN TEHNIČNI RAČUNALNIŠKI JEZIK

Računalniška simuliranja, simbolično računanje in vizualizacijo lahko naredimo z uporabo Matlaba. Ta interaktivni programski jezik omogoča preprosto odkrivanje napak, njegova orodja pa ponujajo veliko podpore inženirskemu delu. Študenti pri vajah pripravijo simuliranja in poiščejo rešitve v Matlabu za različne naloge s pomočjo učitelja ali demonstratorja. Ugotovili smo, da je tak postopek sprejemljiv za študente, čeprav imajo študenti probleme z novo sintakso in veliko količino funkcij in postopkov. Seveda je omejitev tudi licenčnina za Matlab, kar pa lahko same uredijo izobraževalne ustanove.

Naprednejši uporabniki lahko zgradijo lastne uporabniške vmesnike, pripomočke in vizualne predstavitve z uporabo grafičnega uporabniškega vmesnika (GUV) v Matlabu, toda med vajami jih ne uporabljamo zaradi pomanjkanja časa in poznavanja programskega jezika.

Matlab in njegove uporabe so pripravljeni v angleškem jeziku. Za inženirje je neizogibno, da uporabljajo angleščino, toda uporaba tujega jezika lahko povzroči dodatne probleme pri posameznih študentih zaradi napačnega razumevanja slovnice ali pomoči. Zelo pomembno je tudi, da dajemo karseda veliko informacij v maternem jeziku. Največ kar lahko pri tem naredimo je, da izdelamo uporabniški vmesnik v slovenščini. Tako omogočimo študentom natančnejše učenje, ki je zaradi tega tudi veliko lažje.

3 UČENJE Z UPORABO RAČUNALNIKA IN ORODJE ZA TEORIJO LINEARNIH SISTEMOV

Sodobne učne metode izpostavljajo pomembnost posameznega študija, ki mora biti kolikor je mogoče avtonomno, dejavno in prilagojeno posameznikom. Da bi lahko ponudili tak študij, moramo ponuditi poleg knjig še veliko različnih virov. V zadnjem desetletju je bilo veliko novih zamisli in metod predstavljenih v okviru študija na daljavo. Elektronski viri, na primer skripta v elektronski obliki ali uporabe z računalniško podporo lahko naredijo študij zanimivejši, toda veliko bolj pomembno je uporabljati nove tehnologije in neprestano prilagajati znane metode. Tako je predstavljeno orodje pripravljeno za študente dodiplomskih programov tehničnih smeri. Orodje povezuje dvoje skript v elektronski obliki in veliko število primerov, izdelanih v Matlabu in Simulinku prek grafičnega uporabniškega vmesnika.

Slika 1 prikazuje prehod med tradicionalnim učenjem na računalniško podprtim učenjem, ko nekatere vire uporabimo v elektronski obliki. Povezavo med knjigami pripravljenimi v elektronski obliki, in računalniškimi vajami udejanimo z uporabniškim vmesnikom, ki hkrati omogoča uporabo mnogih drugih uporab, npr. pomoč, vizualizacijo in dodatne opise snovi. Predlagamo, da predavanja še vedno obdržijo glavno vlogo pri izobraževanju.

2 A PROGRAMMING TOOL AND TECHNICAL COMPUTING LANGUAGE

Computer simulations, symbolic computations and visualization can be done in Matlab. These interactive programming languages allow for easy debugging and their toolboxes give a lot of support for engineering. The students prepare simulations or find solutions for different tasks using Matlab with the support of the teacher and a demonstrator. Students find this approach quite acceptable, although they need to acquaint themselves with new syntax and many new functions and principles. However, there are some limitations in their use because the students need to have access to Matlab software. This can be arranged by educational institutions.

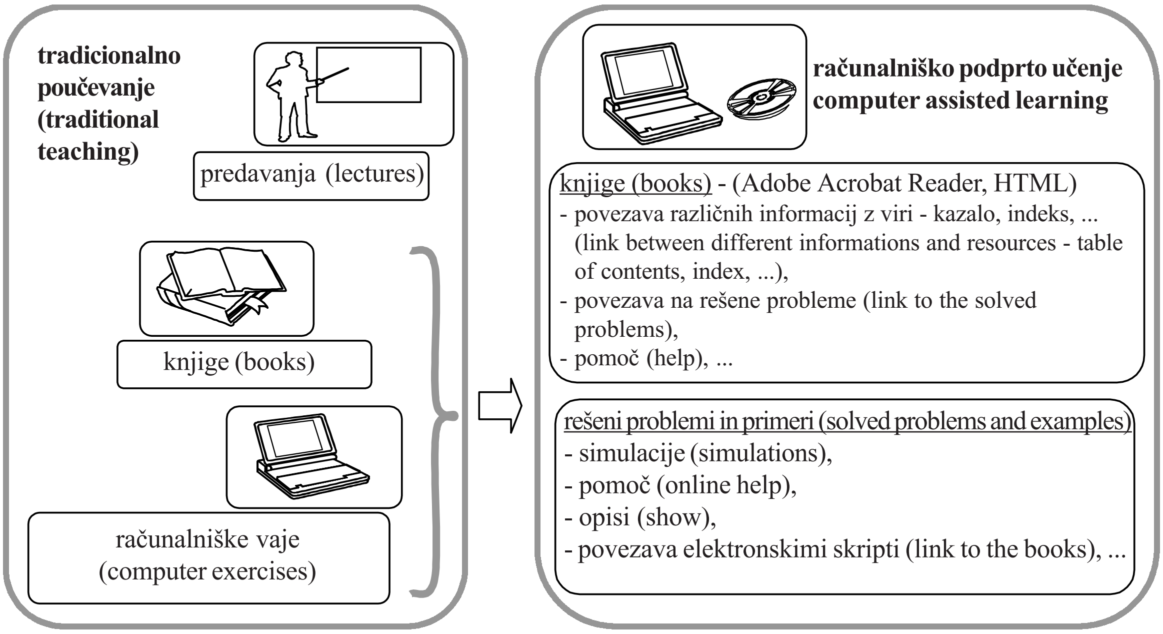
Advanced users can build their own interfaces, tools and visual presentations using the GUI in Matlab, but the GUI normally remains unused during the courses because of a lack of time and a lack of programming-language knowledge.

Matlab and all its applications use English. Therefore, it is necessary for the engineers to use English, and this can cause other problems for some students who misunderstand the grammar or the help. For this reason it is very important to provide as much information as possible in the students' native language. What we can do is to build a user interface in Slovene. This gives the students the possibility to learn more exactly and much more easily.

3 COMPUTER-ASSISTED LEARNING WITH THE LINEAR SYSTEMS THEORY EDUCATION TOOL

Contemporary teaching methods emphasize the importance of individual studies, which should be as much as possible autonomous, active and adapted to the individual. To provide such studies, many different sources, in addition to the books, should be available. In the last decade, distance learning has provided many new ideas and methods. Electronic sources, such as electronic manuscripts and computer-assisted applications, can make studies more interesting, but it is very important to use new technologies and adopt modern methods. The Linear Systems Theory Education Tool is designed for undergraduate engineering students. This tool connects electronic manuscripts and many examples in Matlab and Simulink through a GUI.

Figure 1 presents the transition from traditional to contemporary computer-assisted learning, where some media can be organized in electronic form. The connection between books prepared in electronic form and computer exercises can be realized through a user interface, which also provides the use of many other applications, such as help, visualization and additional descriptions. We expect that lectures will keep their main role in education.



Sl. 1. *Tradicionalno učenje in računalniško podprto učenja: razvoj s pomočjo uporabniškega vmesnika*
Fig. 1. *Traditional learning and computer-assisted learning: the further development provided by a user interface*

Grafični uporabniški vmesnik, izdelan v Matlabu. smo prvotno izdelali le z namenom, da bi povezali primere v celoto. Zatem smo sledili zamislim o študiju na daljavo in glede na to je nastalo orodje za učenje teorije linearnih sistemov.

4 GRAFIČNI UPORABNIŠKI VMESNIK

Predstavljeno grafično orodje za učenje teorije linearnih sistemov je sestavljeno iz glavnega navigacijskega izbora in štirih glavnih grafičnih enot: podizborov za navigacijo po poglavjih, pomoč, predstavitev (tutoriali) in grafično okno. Dodatno smo pripravili še pomoč v pisno-povezovalnem jeziku (PPJ) HTML (Hyper Text Markup Language) in povezavo s skripti, spremenjenimi v elektronsko obliko. To grafično okolje daje predstavitev in pomoč v Matlabovih standardnih oblikah, ki so le malenkostno prilagojene (npr. navigacija in vznikajoči izbori so dodani v slovenščini). Na sliki 2 vidimo glavne strukture predstavljenega grafičnega vmesnika (GUV).

GUV je zgrajen tako, da je mogoča sprememba v druge jezike v glavnem le s preprostim prevodom komentarjev. Orodje je mogoče poljubno razširiti na dodatna poglavja in primere, pri čemer nas omejujejo le možnosti izvedbe znotraj Matlaba in zmogljivost računalnika. Učinkovitost grafičnega vmesnika je povečana z uporabo Matlabove kode p, kakor tudi z uporabo večmedijskih in drugih pripomočkov učenja na daljavo prek medmrežja. Vse našteto omogoča prihodnje dograjevanje.

Dokumentacija za PPJ HTML (pomoč) in skripta so v elektronski splošni prikazovalni obliki (SPO) PDF (Portable Document Format) kot samostojni uporabi. Vse skupaj je povezano v enotno uporabo (sl. 3).

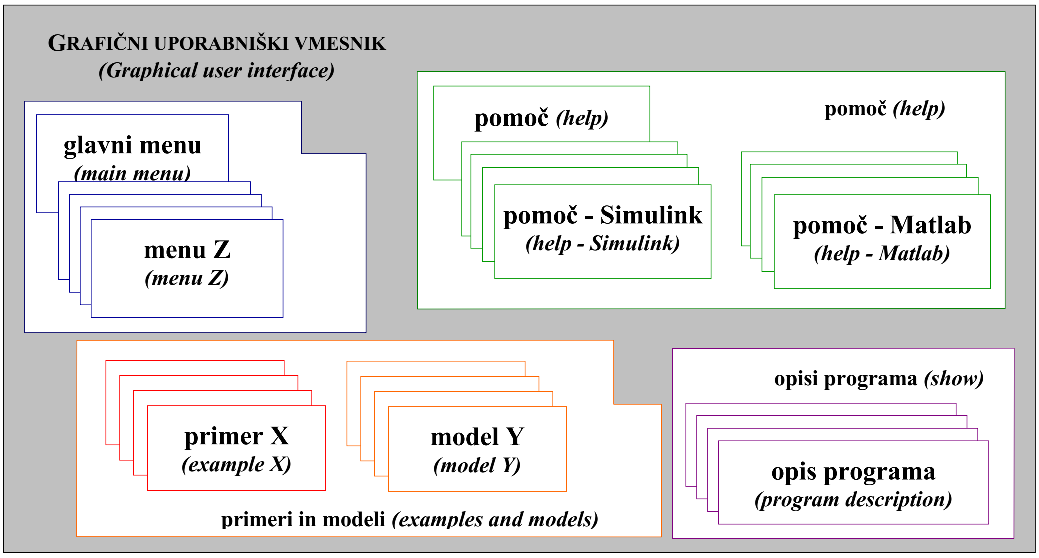
A GUI was prepared in Matlab. First, it was only designed to provide a connection between computation examples and simulations. Following the new ideas from distance learning a more comprehensive Linear Systems Theory Education Tool was developed later.

4 GRAPHICAL USER INTERFACE

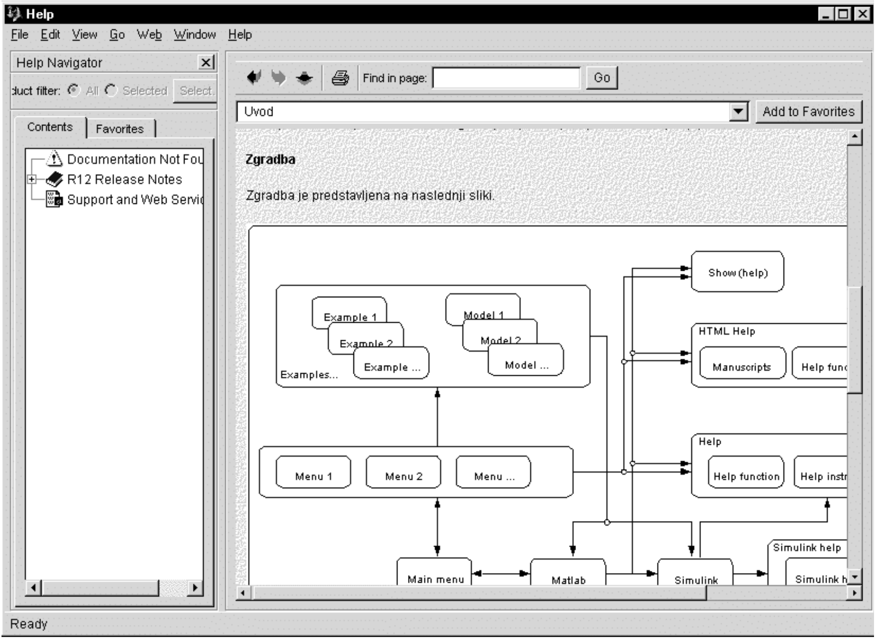
The Linear Systems Theory Education Tool consists of a main navigation menu and four main graphic units: submenus for navigation through chapters, help, show (tutorials) and a graphic presentation window. Additionally, HTML-help and connections to electronic manuscripts are prepared. This graphical environment provides show and help in Matlab standard forms, they have only been changed in some details (e.g. navigation controls and pop-up menus are supplemented in Slovene). Figure 2 presents the main structures of the presented GUI.

The GUI was built in such a way that changing to another language only requires a simple translation of the comments. This tool is also easy to expand to an arbitrary number of topics and examples, and is only limited with the realization possibilities in Matlab and the computer's capacity. The effectiveness of the user interface is improved by the use of Matlab's p-code as well as multimedia and distance-learning capabilities from the during World Wide Web, for future developments.

HTML documentation (Help) and electronic manuscripts in PDF are self-dependent applications. However, they are connected through a GUI with Matlab help (Figure 3).



Sl. 2. *Grafični uporabniški vmesnik – osnovne strukture*
Fig. 2. *Graphical user interface – four main structures*



Sl. 3. *Dokumentacijav PPJ HTML (v Matlabovem oknu za pomoč)*
Fig. 3. *HTML documentation (browsed in the Matlab Help-window)*

5 STRUKTURA UPORABNIŠKEGA VMESNIKA

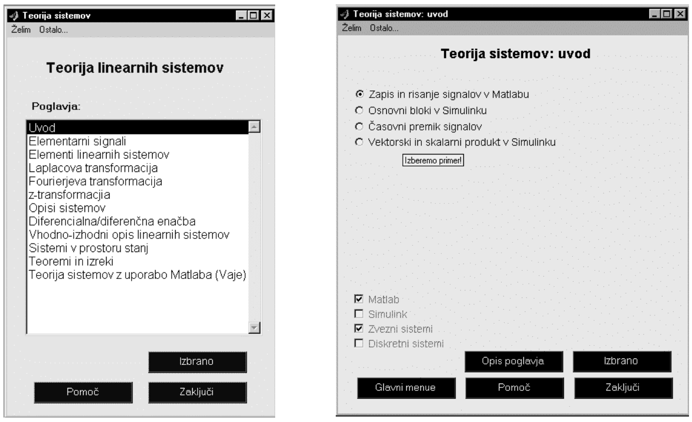
Osnovni izbor omogoča preprosto navigacijo skozi poglavja. Vsako poglavje je samostojna neodvisna enota v lastnem standardiziranem oknu, ki uporablja skupno masko, toda z različnimi lastnostmi (sl. 4).

Iz vsakega okna je mogoč preprost dostop do Matlabove pomoči s kazalom na vsebino teorije linearnih sistemov. Kolikor je le mogoče, so vse operacije standardizirane – tako npr. prikazovanje signalov (sl. 5), pomoč in opisi poglavij – tako imenovani prikaz (sl. 6).

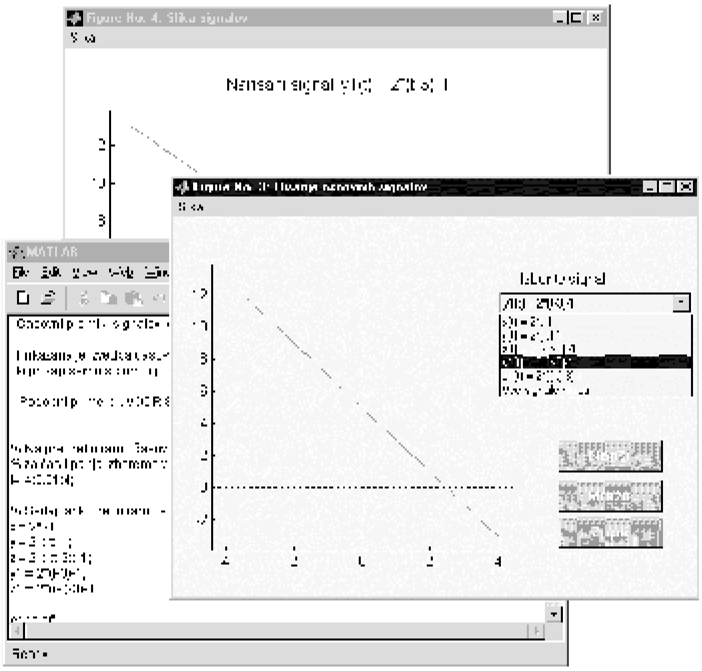
5 USER INTERFACE STRUCTURE

The main menu allows for simple navigation through the chapters. Each chapter is an independent unit with its own standardized window, using the same mask but different properties (Figure 4).

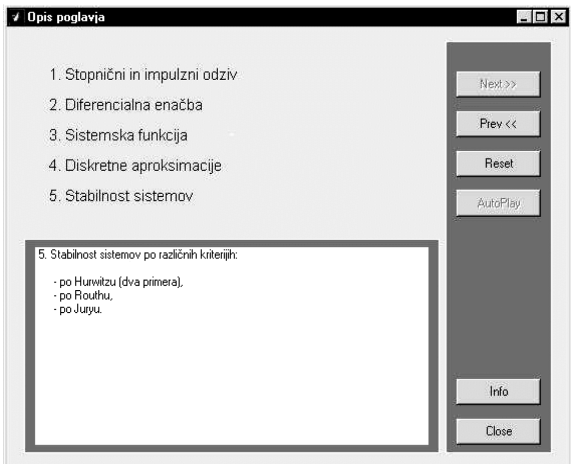
From each window, easy access to the Matlab help with a table of contents of Linear Systems Theory is possible. The tasks are also standardized as much as possible, these tasks include signals visualization (Figure 5), help and chapter descriptions, see (Figure 6).



Sl. 4. *Glavni izbor in izbor za poglavje Uvod*
Fig. 4. *Main menu and menu for chapter Introduction*



Sl. 5. *Grafični prikaz rezultatov je mogoče prenesti v standardno grafično okno (za primer v delovnem oknu)*
Fig. 5. *Graphic window could be exported to the standard graphic windov (for example in main window)*



Sl. 6. *Pomoč v Matlabovem prikazu*
Fig. 6. *Help provided by Matlab show*

6 DOKUMENTACIJA IN SKRIPTA V ELEKTRONSKI OBLIKI

Običajno uporabljamo pomoč v Matlabu s klicem pomoči v Matlabovem delovnem prostoru: *help ime_funkcije*. Ta oblika je skromna, zaradi tega sta mogoči še dve dodatni obliki pomoči: pomoč in prikaz (razširitev demonstracijskega dela Matlaba). Matlabova pomoč omogoča interaktivne povezave, prikaz pa je razširjen tudi še z vizualizacijo. Študentom smo omogočili uporabo obeh oblik.

Dodatno smo dve knjigi – teorijo in vaje – deloma prevedli v PPJ HTML, v celoti pa v SPO vrste PDF. Dodali smo nekatere dodatne operacije: povezave na poglavja, slike, pomembnejše ključne besede in slike. S tem smo uredili skripta v primernejšo obliko, primernejšo tudi za študij na daljavo.

7 PRIMER

V tem poglavju bomo prikazali uporabo orodja za teorijo linearnih sistemov skupaj z dokumentacijo pri določanju stabilnosti sistema po Routhovem kriteriju.

Izberemo poglavje: Matematični modeli in zatem Routhov kriterij. Že iz izborov je razvidno, da lahko izbiramo med primeroma za zvezne in diskretne sisteme, vendar le v Matlabu (ostala dva gumba: Matlab in Simulink ostaneta siva). Ko zaženemo program s funkcijo Routh (ki smo jo sami dodali) z gumbom Izbrano, dobimo naslednji izpis v glavnem oknu.

```
% Stabilnost po Routhovem kriteriju (VhodIzhodRouth)
% Opis funkcije in delovanje ...
% Dodatni primeri: ROUTH, VHODIZHODROUTHD
% Zvezni sistem s karakteristično enačbo:
KE = [1 4 5 2];
CharactEqn = poly2sym(KE,’x’)
CharactEqn =
x^3+4*x^2+5*x+2
%  Funkcija Routh daje naslednji rezultat:
R = Routh(KE)
Routh =
  [   1,   5]
  [   4,   2]
  [ 9/2,   0]
  [   2,   0]
Sistem je stabilen!
Polynom =
  x^3+4*x^2+5*x+2
RouthTable =
  1.0000    5.0000
  4.0000    2.0000
  4.5000         0
  2.0000         0
```

6 DOCUMENTATION AND ELECTRONIC MANUSCRIPTS

Usually, Matlab help is retrieved from the workspace by typing the *help function_name*. This form is very poor, thus, two additional help applications can also be used: Matlab-help and Matlab-show (enhancement of Matlab-demo). Matlab-help provides interactive help with links and Matlab show also provides enhanced visualization. We give the students both possibilities: we have prepared help using both applications.

Additionally, two Systems Theory books, theory and exercises, have been rewritten and transferred into HTML and PDF formats. Some additional operations have been supplemented, such as links to some important keywords (from Index), chapters or pictures. This makes those electronic manuscripts to be prepared also for the distance learning.

7 STABILITY CRITERION – AN EXAMPLE

In this section we demonstrate the use of the Linear Systems Theory Education Tool together with the electronic manuscripts for determing stability according to the Routh criterion.

We chose Mathematical models from the main menu chapter and then we chose the Routh criterion. We can find out from the chapter graphical menu that the examples are available for continuous and discrete systems, but only for Matlab. The other two check buttons (Matlab and Simulink) are gray and not available. The Selected button starts the program (with function Routh, not included in Matlab) in the main Matlab window, with the following result.

```
% Stability according Routh criterion (VhodIzhodRouth)
% About Routh criterion ...
% See also: ROUTH, VHODIZHODROUTHD
% Continuous system with characteristic equation:
KE = [1 4 5 2];
CharactEqn = poly2sym(KE,’x’)
CharactEqn =
x^3+4*x^2+5*x+2
%  Function Routh gives the following result:
R = Routh(KE)
Routh =
  [   1,   5]
  [   4,   2]
  [ 9/2,   0]
  [   2,   0]
System is stable!
Polynom =
  x^3+4*x^2+5*x+2
RouthTable =
  1.0000    5.0000
  4.0000    2.0000
  4.5000         0
  2.0000         0
```

Izbrani primer prikazuje sintakso funkcije Routh in njeno uporabo za izbrani primer. Pomoč je organizirana na način, kot je to običajno v Matlabu. Uporabimo jo lahko v Matlabovem delovnem oknu ali pa s pritiskom na gumb Pomoč v enem izmed izborov. Dokumentacijo v PPJ HTML je mogoče priklicati iz Matlabovega okna 'Pomoč' ali pa podobno kakor prej s pritiskom na gumb 'pomoč HTML'.

Vsako poglavje ima svoj lasten opis, ki je grafično bolj obsežen in za katerega smo uporabili Matlabov prikaz (sl. 6).

Primer kratko prikazuje principe grafičnega uporabniškega vmesnika in njegovo uporabo. Vključili smo mnogo drugih primerov in pri tem skušali uporabiti čimveč različnih metod. Vgradili smo na primer tudi grafično orodje RLTOOL, v katerem smo spremenili le pomoč v slovenščino.

This example shows the syntax of the Routh function and how it is used for a specific problem. Help is organized in the same way, as is usual in Matlab. We can use it from the Matlab main window or it starts after clicking on the "Help" button in chapter or main menu. The HTML documentation can be browsed from the Matlab help window (relative to the chosen example) or with a click on the 'HTML Help' button.

Each chapter also has its own description, which is graphically more comprehensive and is based on Matlab Show (Figure 6).

This example briefly presents the principles of this GUI and its usefulness. Many other interesting examples using different techniques provided in Matlab are also included. For example, a graphic tool RLTOOL is incorporated, in which the ToolTips are rewritten in Slovene.

8 PRIMERJAVA DVEH RAZLIČNIH RAČUNALNIŠKO PODPRTIH METOD UČENJA

Končno smo povabili študente k izpolnjevanju vprašalnika o dveh različnih računalniško podprtih učnih metodah:

- računalniške vaje z video predstavitev ob stalni pomoči učitelja,
- individualno reševanje problemov z uporabo predstavljenega orodja in učbenikov.

Zajeli smo dve različni populaciji: v prvi skupini so bili študentje, ki so se praviloma prvikrat srečali z Matlabom, v drugi skupini pa študentje, ki so se z orodjem že srečali. Postavili smo jim podobna – primerljiva vprašanja in odgovori so bili presenetljivo podobni. Bistvene ugotovitve je mogoče videti v analizi odgovorov (sl. 7).

Iz odgovorov je mogoče zbrati najpomembnejše sklepe: s predlaganim orodjem prispevamo k preglednosti, povečamo količino informacij, povečamo stopnjo samostojnega dela in prispevamo z znanjem k drugim predmetom.

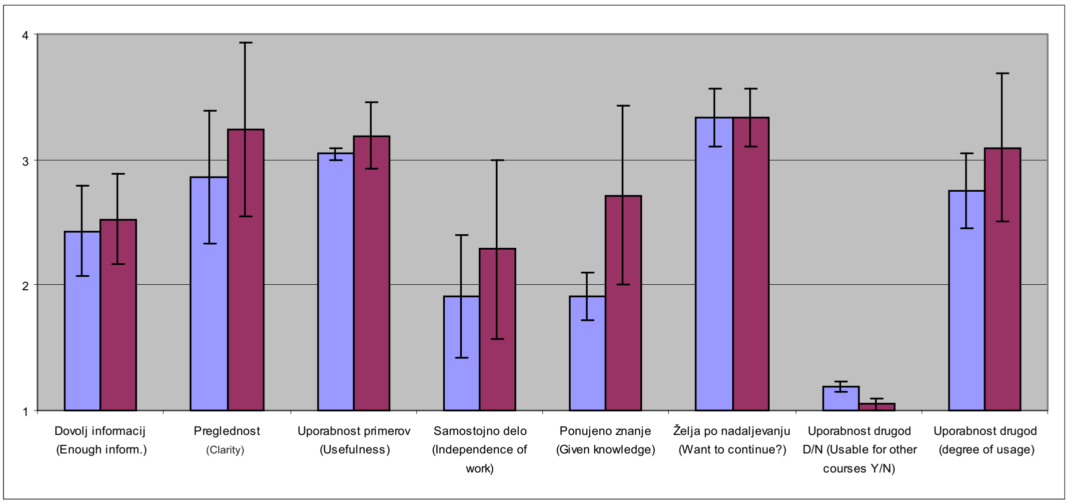
8 COMPARISON OF DIFFERENT COMPUTER-ASSISTED LEARNING METHODS

Finally, we invited students to answer questions about two different computer-assisted learning methods:

- video presentation with exercises in a computer room and the assistance of a teacher,
- individual problem-solving using the presented tool and manuscripts.

We invited two different groups to the comparison: the first group consisted of first-time users of Matlab and the second one of advanced users. Both groups received comparable questions and the results of the comparison were very similar. Some of the results are in Figure 7.

From the answers it is possible to conclude that this tool contributes to the clarity of the presented information and to the quantity of information, enlarges the amount of independent work and contributes knowledge to other courses.



Sl. 7. *Analiza odgovorov*
Fig. 7. *Analysis of answers*

9 RAZPRAVA

Računalniška in programska tehnologija lahko igrata pomembno vlogo pri prikazovanju rešitev za učenje na daljavo in za vseživljenjsko učenje. Mnogi tržni paketi, ki so dostopni na tržišču za tehnične predmete, so zelo zapleteni za uporabo ali pa ne dajejo dovolj funkcij, da bi lahko z njimi izvedli želene naloge. Matlab je interaktivni programski jezik, ki pripada prvi skupini zaradi velike količine funkcij. Predstavljeno orodje je močno grafično orodje, s katerim lahko izvajamo izobraževanje in je odprto za različne razširitve. Daje močno pomoč z uporabo mnogih orodij in funkcij znotraj Matlaba. Izdelano je bilo z namenom, da bi dali pomoč v maternem jeziku. Kljub vsemu povedanemu učenje iz rešenih problemov lahko uporabljamo le kot dodatno pomoč, ki ne more nadomestiti klasičnega izobraževanja.

9 DISCUSSION

Computer and software technology can play a significant role in solutions for distance and life-long learning. Many of the commercial packages available on the market for engineering courses are either very complex to use or do not provide all the necessary functions to achieve particular tasks. Matlab is an interactive programming language that belongs to the first group because of its large number of functions. The presented Linear Systems Theory Education Tool is a powerful graphical tool for carrying out engineering education and is suitable for improvements. It provides a lot of support using many of the available tools and functions in Matlab. This tool is designed to provide support in the students' native language. However, learning from solved problems is only intended to augment, not replace, classical education.

10 LITERATURA
10 REFERENCES

[1] Anand, P.G., A. Zaimi (2000) Computer-managed instruction: evaluation of alternative methods of technology integration in higher education, *Educat. Tech. & Soc*., 3 (1).

[2] Buckman, A.B. (1999) VI-based introductory electrical engineering laboratory course, *Int. J. Engng. Ed.*, 15 (5).

[3] Ertugrul, N. (1999) Towards virtual laboratories: a survey of LabVIEW-based teaching/learning tools and future trends, *Int. J. Engng. Ed*., 15 (5).

[4] Brooking, C.J., D.A. Smith (1999) Simulation and animation of kinematic and dynamic machinery systems with Matlab, *Comp. in Educ.* J., 9 (2), 2-3.

[5] Ghassemlooy, Z., R. Saatchi (1999) Software simulation techniques for teaching communication systems, 36 (4), 287-97.

[6] Chetty, M., Y.K. Tang (1999) A simple interface for running Matlab programs via Web, *Comp. in Educ. J.,* 9 (4), 29-33.

[7] Bradber, R. (1999) The effectivness of teaching introductory electronics in an integrated teaching studio environment, *Int. J. Engng. Ed.*, 15 (5), 344-52.

[8] Schmid, C. (1999) A remote laboratory using virtual reality on the Web, *Simulation*, 73 (1), 13-21.

[9] Adobe Acrobat 3.0, online guide, 1996.

[10] Matlab, User manuals, *Mathworks*, 1998.

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Rekonstrukcija odvaljnega bata zračne vzmeti

Reconstruction of an Air-Spring Piston

Tomaž Bešter

Odvaljni bat, ki ga izdeluje Goodyear EPE (Engineered Products Europe), prenese vse obremenitve, ki jih zahtevajo evropski tehnični standardi , v primeru, ko je podprt po celotni spodnji površini. Če je odvaljni bat podprt samo po delu površine, ne prenese vseh zahtevanih obremenitev. Za rešitev problema je bila najprej narejena trdnostna analiza odvaljnega bata, nato pa je bil bat spremenjen, tako da je zdržal vse zahtevane obremenive.

(Ključne besede: vzmeti zračne, bati odvaljni, analize trdnostne, modifikacije)

An air-spring piston, produced by Goodyear EPE (Engineered Products Europe), is able to withstand all the loads that are required by European Engineering Standards when it is supported on its entire lower surface. When the piston was only supported on a part of the lower surface it was not able to withstand all the loads. To solve this problem we made a strength analysis of the existing piston. The piston was then modified so that it was able to withstand all the required loads.

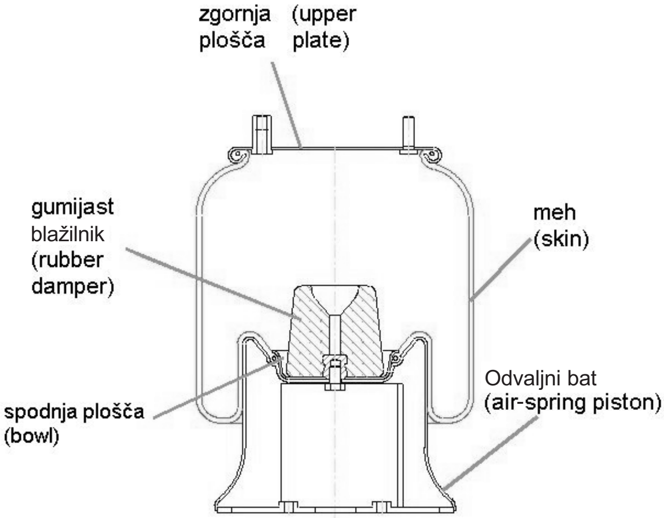
(Keywords: air springs, pistons, strength analysis, modifications)

0 OBREMENITVE ODVALJNEGA BATA

Zračna vzmet [7] je sestavljena iz odvaljnega bata, meha, blažilnika in zgornje plošče (sl. 1). Evropski tehnični standardi [6] za zračne vzmeti predpisujejo, da mora vzmet prestati dinamični preskus, preskus na utrujanje in preskus na razpočni tlak.

0 LOADS ON AN AIR-SPRING PISTON

An air-spring [7] is made of an air-spring piston, a skin, a rubber damper and an upper plate. According to European Engineering Standards [6] an air-spring piston has to pass a dynamic test, a static test and a pressure test (Fig. 1).



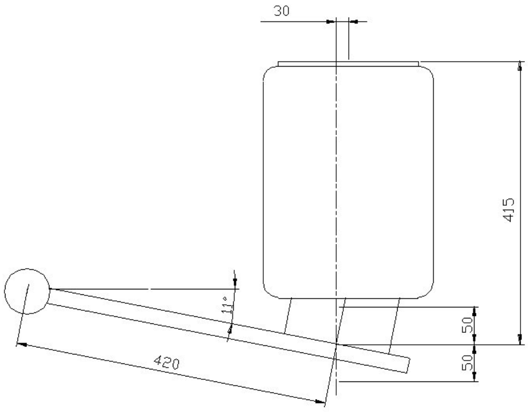
Sl. 1. *Odvaljni bat zračne vzmeti*
Fig. 1. *An air-spring piston*

Pri dinamičnem preskusu mora zračna vzmet prestati tri milijone ponovitev pri spremembi višine vzmeti 50 mm, tlaku v mehu 6 bar in frekvenci 1,25 Hz. Vpetje vzmeti je prikazano na sliki 2. Izkušnje kažejo, da v tem preskusu odvaljni bat običajno ni kritično obremenjen, ampak se poškodbe zaradi utrujanja navadno pojavijo na mehu, kjer pride do spuščanja zraka.

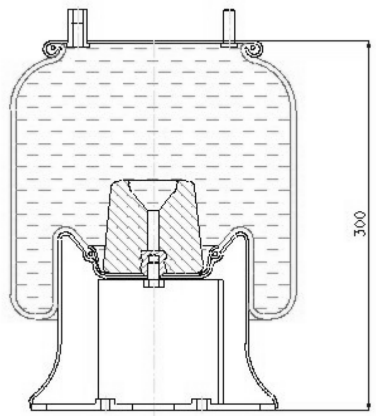
Preskus na razpočni tlak zahteva, da se meh zračne vzmeti pri višini vzmeti 300 mm napolni z vodo pod tlakom 18,2 bar. Pri tem tlaku ne sme priti do poškodbe meha ali odvaljnega bata.

During the dynamic test the air spring has to withstand three million cycles at an amplitude of 50mm, a pressure of 6 bar and a frequency of 1.25 Hz. The suspension of the spring is shown in Fig. 2. Our experiences show that in this case the piston is usually not critically loaded, while the damage usually occurs to the skin, which causes air to leak from the spring.

The pressure test (Fig. 3) requires that the air spring is filled with water at a pressure of 18.2 bar while the spring is 300mm high. This pressure must not cause any damage to the air spring.



Sl. 2. *Dinamični preskus*
Fig. 2. *Dynamic test*



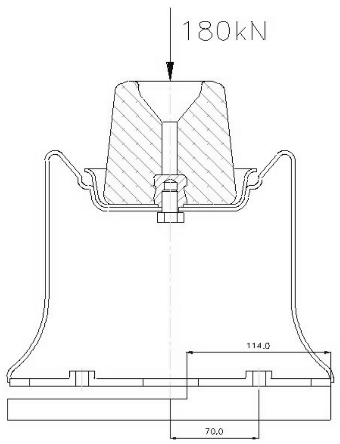
Sl. 3. *Preskus na razpočni tlak*
Fig. 3. *Pressure test*

Statični preskus zahteva, da morata odvaljni bat in blažilnik zdržati obremenitev s silo 180 kN. Pri tem preskusu se preskušata samo odvaljni bat in blažilnik vzmeti. Vpetje odvaljnega bata je odvisno od izdelovalca podvozja, tako je lahko podprt po celotni spodnji površini, ali pa je previsno podprt, kakor prikazuje slika 4.

Odvaljni bati, ki jih izdeluje Goodyear EPE, so izdelani iz umetnih mas ali jekla. Za plastične bate, ki jih izdeluje Goodyear EPE, se je pri preskusih izkazalo, da prenesejo vse obremenitve, ki jih terjajo evropski tehnični standardi, razen statičnega preskusa s

The static test requires that an air-spring piston and damper withstand a loading of 180 kN. In this way only the piston and damper are tested. The suspension of the piston depends on the undercarriage. The undercarriage manufacturers use two ways of supporting the piston, some support it on the whole lower surface, and others only on a part of the lower surface, as shown in Fig. 4.

The air-spring pistons manufactured by Goodyear EPE are made of plastic materials or steel. Tests of the plastic pistons have shown that they pass all the tests except the static ones, when only a



Sl. 4. *Statični preskus s previsnim vpetjem bata*
Fig. 4. *Static test*

previsnim vpetjem. Za rešitev problema je bila najprej narejena trdnostna analiza sedanje konstrukcije, pri obremenitvi, kakršno predpisuje statični preskus, in previsnem vpetju.

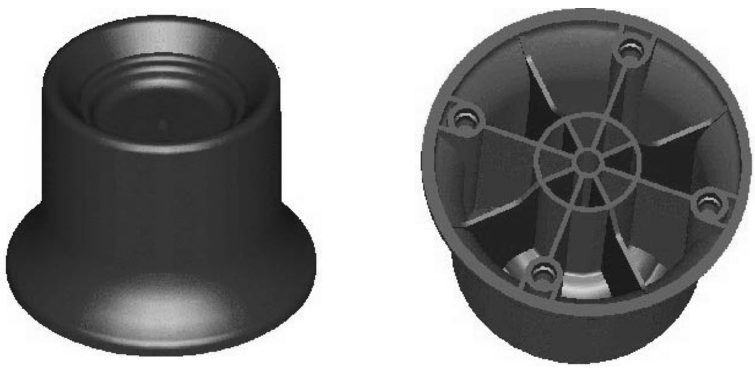
part of the lower surface is supported. To solve this problem a strength analysis of the existing piston for a static test was carried out for an overhanging support.

1 TRDNOSTNA ANALIZA SEDANJE KONSTRUKCIJE

Trdnostna analiza sedanje konstrukcije (sl. 5) je bila narejena z uporabo metode končnih elementov v programskem paketu Ideas [3]. V analizi se ni upoštevalo, da zaradi prevelike obremenitve pride do plastifikacije in porušitve, zato s to analizo nismo dobili natančnih napetosti na batu, ampak ta analiza razkrije mesta, na katerih se pojavijo največje napetosti, in da kriterij za primerjavo različnih variant. V modelu končnih elementov ([2] in [4]) so bili uporabljeni desetvozliščni piramidni elementi. Ker je odvaljni bat simetričen, je bilo mogoče modelirati samo polovico bata.

1 STRENGTH ANALYSIS OF THE EXISTING PISTON

A strength analysis of the existing piston (Fig. 5) was made using the finite-element method and the Ideas computer program [3]. The analysis did not consider that plastification and perhaps even destruction might occur due to overload; therefore, this analysis does not provide the exact stresses on the piston, but only the location of the maximum stress, and this gives the criterion for a comparison of the different designs. In the finite-element model, ten-node tetrahedron elements were used ([2] and [4]). Since the piston is symmetrical, we only need to model half of it.



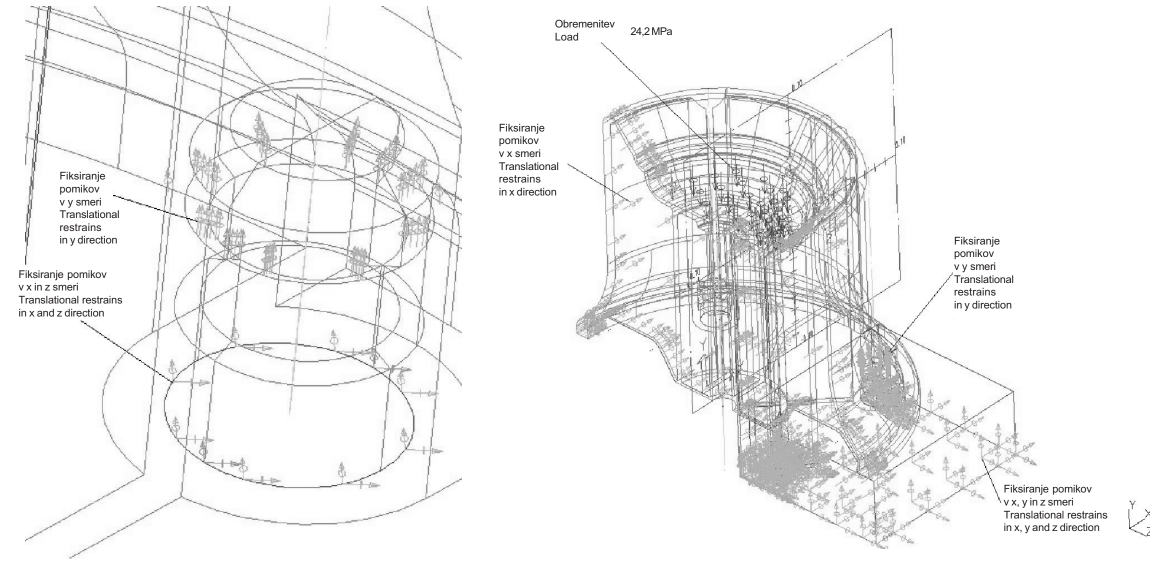
Sl. 5. *Sedanja konstrukcija*
Fig. 5. *Existing air-spring piston*

Bat je na obeso v primeru previsnega vpetja pritrjen samo z dvema vijakoma in na spodnji ploskvi podprt na manj ko polovici površine. Matica vijaka je jeklena in je vstavljena v bat med brizganjem umetne mase. Zaradi svoje oblike matica preprečuje pomikanje bata v navpični smeri na spodnjem robu matice, pa tudi v vodoravni smeri. Ker bi modeliranje matice terjalo lokalno zgostitev mreže in s tem povezano podaljšanje že tako dolgega računanja, v modelu končnih elementov ta matica ni bila modelirana, ampak so bile na površini, kjer matica preprečuje pomik v navpični smeri, postavljene podpore v tej smeri. Na sliki 6 so prikazane podpore na mestu, kjer je v bat iz umetne mase vstavljena matica (v smereh, kjer so omejitve pomika, so puščice). Takšen model ne upošteva elastičnosti vijaka in matice, vendar je modul elastičnosti vijaka in matice bistveno večji od modula elastičnosti umetne mase, ki obdaja matico, zato je takšna poenostavitev dovoljena.

Bat je podprt z jeklenim kvadrom na enako veliki površini kakor v primeru previsnega vpetja. Jeklen kvader je po vsej svoji spodnji površini podprt v navpični smeri. Takšno vpetje je zelo podobno

In the case of the overhanging support the piston is screwed down with only two bolts and supported on less than half the lower surface. The nut is made of steel and is inserted into the piston. Because of its shape the nut does not allow movements in the vertical and horizontal directions. Modelling of the nut would require condensation of the mesh around the nut; this would result in a considerable increase in the calculation time. Therefore, in the finite-element model the nut was not modelled; however, restraints were set in the vertical direction in the place where the nut restrains the piston. Fig. 6 illustrates this particular case (the arrows show the directions in which the displacements are restrained). Such a model does not consider the elasticity of the bolt and of the nut, but because the bolt and the nut have a much greater module of elasticity such a simplification is admissible.

The piston is supported with a steel block on the same surface as shown in Fig. 4. The steel block is supported in the vertical direction over its entire lower surface. Such a suspension is very similar to



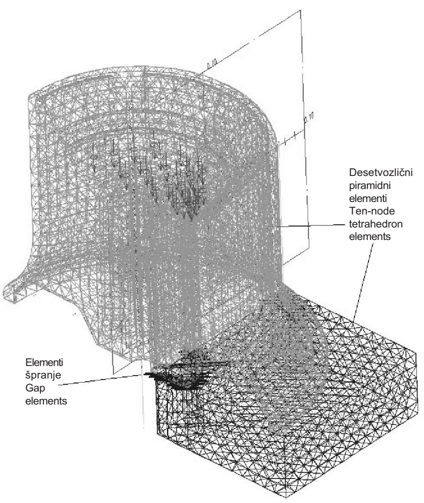
Sl. 6. *Podpore*
Fig. 6. *Restraints*

tistemu na preskuševališču za statični preskus. Poleg že prej opisanih podpor je treba, zaradi simetrije, namestiti podpore tudi pravokotno na ravnino prereza bata. Bat je od kvadra oddaljen za 1mm zato, da se lahko med kvader in bat postavijo tako imenovani elementi špranje, ki povezujejo vozlišča kvadra in bata. Elementi špranje prenašajo samo tlačne sile, ne pa tudi nateznih, tako da dovoljujejo povečevanje razmika med batom in kvadrom. Model končnih elementov je prikazan na sliki 7.

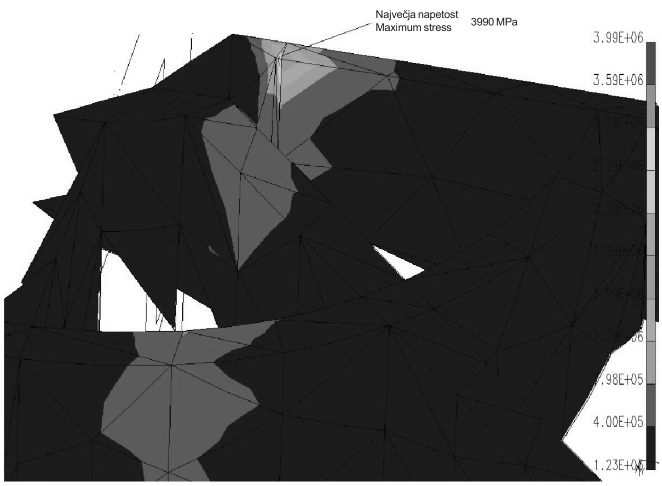
Pri dejanskem preskusu je odvaljni bat obremenjen s predpisano silo prek gumijastega blažilnika. Modeliranje tega blažilnika bi zopet močno povečalo število končnih elementov v modelu in s tem podaljšalo čas računanja. Poleg tega je blažilnik iz gume, ki je zelo deformljiva, kar pomeni, da ne bi več veljala predpostavka, da so na modelu samo majhni pomiki. Poleg tega ima guma nelinearno

the suspension with the static test. In addition to the previously mentioned restraints, it is necessary to set restraints perpendicular to the section plane of the piston. All the restraints are shown in Fig. 6. The piston is set 1 mm above the steel block, so that the gap elements can be placed between the piston and the block. The gap elements carry only the compressive forces and therefore allow stretching of the nodes on both surfaces in the contact. The finite-element model is shown in Fig. 7.

During the actual test the piston is loaded with the prescribed force on the rubber damper. Modelling of this damper would substantially increase the number of elements and thus prolong the already long calculation time. Furthermore, the damper is made of rubber, which is very deformable, and so the assumption about small displacements would no longer be true. The rubber also has a non-linear char-



Sl. 7. *Model končnih elementov*
Fig. 7. *Finite-element model*



Sl. 8. *Največja primerjalna napetost*
Fig. 8. *Maximum equivalent stress*

karakteristiko v diagramu σ–ε, kar bi zopet močno podaljšalo čas računanja. Modela končnih elementov, ki bi upošteval vse zgoraj naštete fizikalne pojave, računalnik, ki je bil na voljo, ni bil zmožen rešiti, zato je bil narejen poenostavljen model, na katerem se je sila enakomerno porazdelila po površini, na kateri blažilnik nalega na bat. Ker gre za razmeroma zgoščen vnos sile, ta poenostavitev ne vpliva bistveno na napetostno stanje.

Odvaljni bat je iz umetne mase AG3(H)(K), ki ji je dodano 30% steklenih vlaken, ta so enakomerno porazdeljena po celotni prostornini, zato lahko predpostavimo, da je material izotropen. Material izdeluje General Electric [1]. Materialne lastnosti so povzete po katalogu izdelovalca in Machinery's Handbook [5]:

Natezna trdnost:	σ_M = 170 MPa
Modul elastičnosti:	E = 9800 MPa
Gostota:	ρ = 1,36 g/cm^3
Poissonov količnik	ν = 0,3

Meja plastičnosti ni podana, vendar lahko rečemo, da je enaka natezni trdnosti, ker ima material skoraj povsem linearno karakteristiko v diagramu σ–ε.

Rezultati linearne analize z metodo končnih elementov so smiselni samo v primeru, da napetosti ne presežejo meje plastičnosti. V obravnavanem problemu so rezultati (sl. 8) analize močno presegli mejo plastičnosti, zato napetosti, ki so prikazane na slikah, niso stvarne, saj prej pride do plastifikacije in porušitve. Lahko pa iz teh slik ugotovimo, kje so mesta, kjer se pojavijo največje napetosti. Na sliki 8 se vidi, da se pojavi največja primerjalna napetost na robu površine, kjer je bat podprt s kvadrom, hkrati pa je to tudi mesto, kjer je rebro povezano z notranjim valjem.

2 SPREMINJANJE OBLIKE VALJA, DA BI ZADOSTILI ZAHTEVAM STANDARDA

Zunanja oblika valja se ne sme spreminjati, saj bi to pomenilo spremembo karakteristike vzmeti, zato lahko na batu spreminjamo samo lego in debelino reber. Prav tako ne smemo spreminjati lege pritrdilnih matic. Najprej se je spremenila lega reber, tako da so ležala pravokotno na previsni rob (sl. 9), da se je obremenitev porazdelila na več reber. Poleg geometrijske oblike so se na modelu končnih elementov spremenili tudi elementi v dotiku. Namesto tako imenovanih elementov špranje so se med obe dotikalni površini na mesta, kjer pričakujemo dotik med površinama, postavili togi elementi. Uporaba togih elementov bistveno skrajša čas računanja. Razlike v rezultatu med modelom s togimi elementi in modelom z elementi špranje so minimalne, če pravilno napovemo mesto, kjer pride do dotika površin. Zato so se v trdnostnih analizah vseh različic uporabljali

acteristic in the σ-ε diagram. Consideration of all these phenomena would require too much time for the computations, so a simplified model was made, where the prescribed force was uniformly distributed over the lower surface of the damper. Because we have a relatively concentrated transferance of the force, this simplification does not significantly influence the tensions in the piston.

The air-spring piston is made of a plastic material called AG3 (H)(K), which has 30% of glass fibres that are uniformly distributed over the entire volume, so that the material can be considered isotropic. The material is produced by General Electric, and its properties, reproduced from the General Electric [1] catalogue and Machinery's handbook, are as follows [5]:

Tensile strength:	σ_M = 170 MPa
Modulus of elasticity:	E = 9800 MPa
Density:	ρ = 1.36 g/cm^3
Poisson's ratio:	ν = 0.3

The yield stress is not given, but since the material has an almost linear characteristic we can assume that it equals the tensile strength.

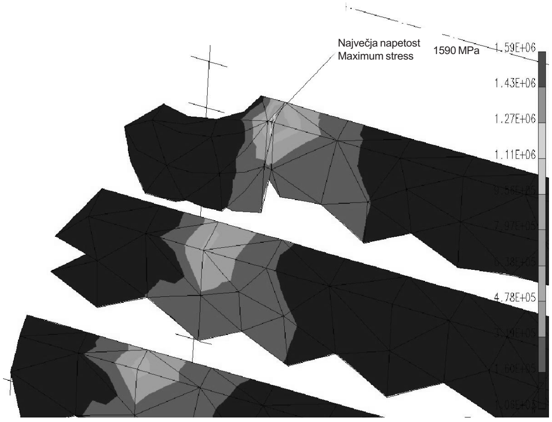
The linear finite-element method gives us reasonable results only when the tensions do not exceed the yield stress. In our case the yield stress was exceeded. Therefore the stresses that are shown in Fig. 8 are not the true ones – because destruction would occur first. However, we can locate the most critical places where the maximum stresses occur. We can see in Fig. 8 that the maximum equivalent stress occurs on the edge of the surface, where the piston is supported with a solid block. At the same time this is the place where the rib is connected to the inner cylinder.

2 MODIFYING THE SHAPE OF THE PISTON TO SATISFY THE NEEDS OF THE STANDARD

The external shape of the piston should not be changed, as this would change the characteristic of the air-spring piston; therefore, we can only change the position and thickness of the ribs. The position of the nuts should also not be changed. Firstly, the position of the ribs was changed so that they were perpendicular to the edge of the block. Secondly, the type of finite elements in the contact was changed. Instead of gap elements rigid elements were placed on the nodes where we anticipated contact between the surfaces. The use of rigid elements significantly reduced the computation time. The difference between the model with a gap and the model with rigid elements is minimal, that is if the nodes where the contact of the two surfaces occurs are correctly predicted. That is why in strength calculations of all the variants rigid elements were used, except for the last togi elementi, razen pri zadnji varianti, ki se je preverila tudi z modelom z elementi špranje. Rezultati trdnostne analize (sl. 10) kažejo, da so se napetosti bistveno zmanjšale, še vedno pa so večje od natezne trdnosti, zato bi se ta izvedba bata na preskusu porušila. Še vedno je najbolj problematična zgostitev napetosti na mestu, kjer je rebro povezano z notranjim valjem.

variant, which was checked with gap elements. The results of the strength analysis (Fig. 10) show that the stresses were substantially reduced, but they are still much greater than the tensile strength, so this variant would still break during the static test. The concentration of stress is still the most problematic area in connection with the ribs and the inner cylinder.

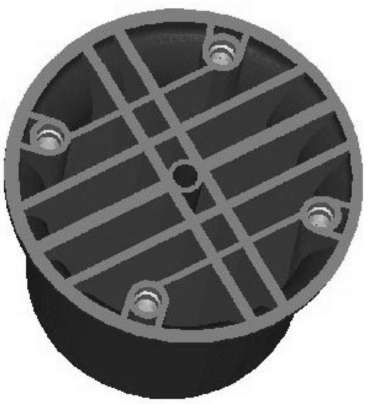
Sl. 9. *Varianta 1*
Fig. 9. *Variant 1*



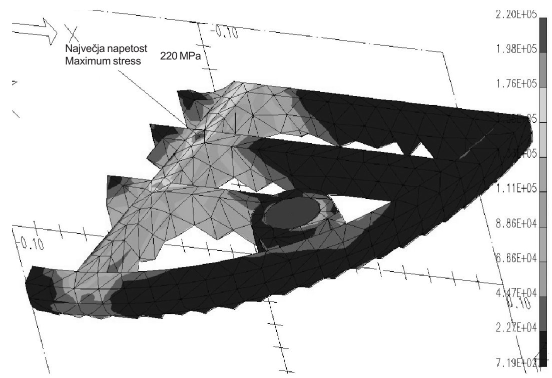
Sl. 10. *Največja primerjalna napetost*
Fig. 10. *Maximum equivalent stress*

V naslednji varianti sta bili rebrom iz prve variante simetrično dodani še dve, tako da eno od teh reber leži na robu podpornega kvadra (sl. 11). S tem se bistveno zmanjša površinski pritisk na robu kvadra. Rezultati analize (sl. 12) so pokazali, da so sedaj napetosti že blizu dovoljenim, zanimivo pa je tudi to, da največja napetost ni več na srednjem rebru, ampak na obeh rebrih ob njem.

In the next variant, two new ribs were symmetrically added to the existing ribs, so that one of these ribs lies on the edge of the steel block (Fig. 11). This significantly reduces the surface pressure near the edge of the block. The results of this analysis have shown that the stress is now near to the permitted stress. It is interesting that the maximum stress is no longer in the middle rib, but on the ribs beside it.



Sl. 11. *Varianta 2*
Fig. 11. *Variant 2*

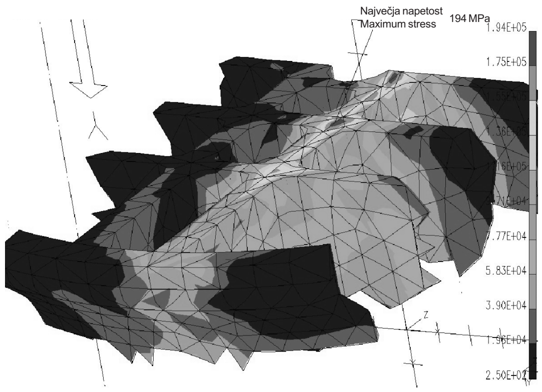


Sl. 12. *Največja primerjalna napetost*
Fig. 12. *Maximum equivalent stress*

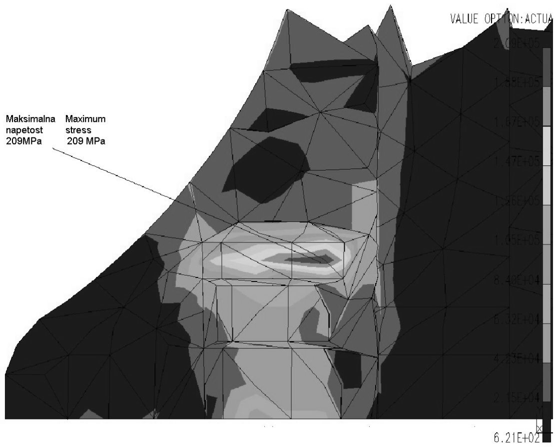
V tretji varianti so se zgolj dodale zaokrožitve s polmerom 5 mm na mesta, kjer se križajo rebra (sl. 13). Rezultati trdnostne analize so pokazali, da so se napetosti na previsnem robu zmanjšale, vendar še niso manjše od natezne trdnosti. Pokazalo se je tudi, da so napetosti na mestu, kjer je matica vstavljena v bat, sedaj večje od tistih na previsnem robu (sl. 14 in 15).

In the third variant, rounds with a radius of 5 mm were added to the rib joints (Fig. 13). The strength analysis results (Fig. 14 and Fig. 15) showed that the stress was reduced near the edge of the block, although it is still greater than the permitted stress. It was also shown that the stresses near the nut are now greater than the stresses near the edge of the block.

Sl. 13. *Varianta 3*
Fig. 13. *Variant 3*



Sl. 14. *Največja primerjalna napetost na dotiku*
Fig. 14. *Maximum equivalent stress in the contact*

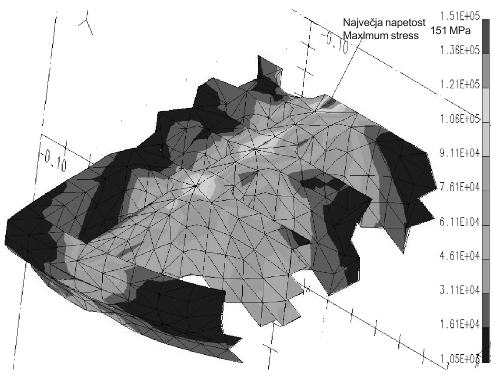


Sl. 15. *Največja primerjalna napetost*
Fig. 15. *Maximum equivalent stress*

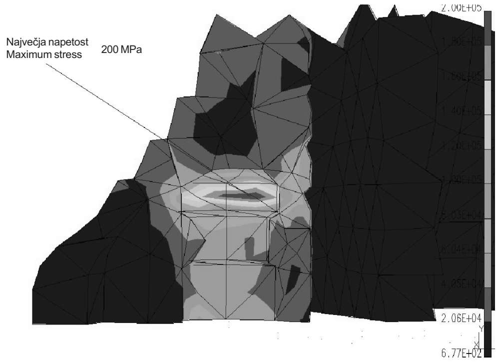
V četrti varianti (sl. 16) so bila vsa rebra nekoliko debelejša kakor v tretji varianti, medtem ko se matica vijaka ni spreminjala. Rezultati trdnostne analize (sl. 17 in 18) so pokazali, da so napetosti na previsnem robu manjše od natezne trdnosti, medtem ko so napetosti ob matici vijaka še vedno prevelike.

In the fourth variant, all the ribs were slightly thicker than in the third, while the nut was not changed. The results of the stress analysis showed that the stresses on the edge were now lower than the tensile strength while the stresses near the nut were still too high.

Sl. 16. *Varianta 4*
Fig. 16. *Variant 4*



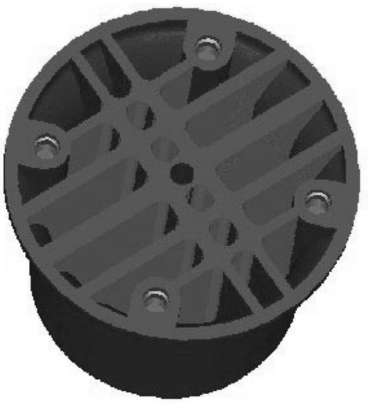
Sl. 17. *Največja napetost v dotiku*
Fig. 17. *Maximum equivalent stress in the contact*



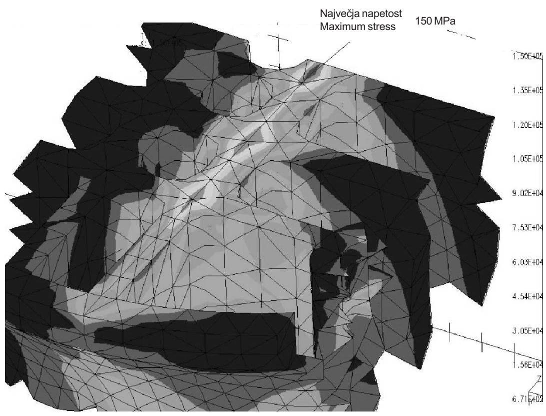
Sl. 18. *Največja napetost ob matici*
Fig. 18. *Maximum equivalent stress*

V peti varianti (sl. 19) se je znižala debelina matice vijaka zato, da je prišlo več materiala nad njo, poleg tega pa se je bat odebelil tudi ob straneh matice. V modelu končnih elementov so se med dotikalnima površinama zopet uporabili elementi špranje, da ne bi bilo nobenih dvomov o pravilnosti rezultata. Iz rezultatov (sl. 20, 21) je razvidno, da so napetosti v tej varianti povsod manjše od natezne trdnosti, tako da bi ta varianta zdržala obremenitve, ki jih zahtevajo evropski tehnični standardi.

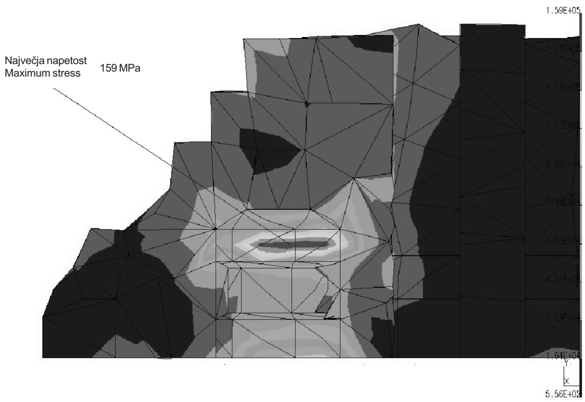
In the fifth variant, the thickness of the nut was lowered so that more plastic material was above it. In the finite-element model we used gap elements in order to avoid possible errors in the calculation. From the results (Fig. 20 and Fig. 21) it is clear that all the stresses in this variant are less than the tensile stress, which means that this variant would withstand the loads that are anticipated by European Engineering Standards.



Sl. 19. *Varianta 5*
Fig. 19. *Variant 5*



Sl. 20. *Največja primerjalna napetost v dotiku*
Fig. 20. *Maximum equivalent stress in the contact*



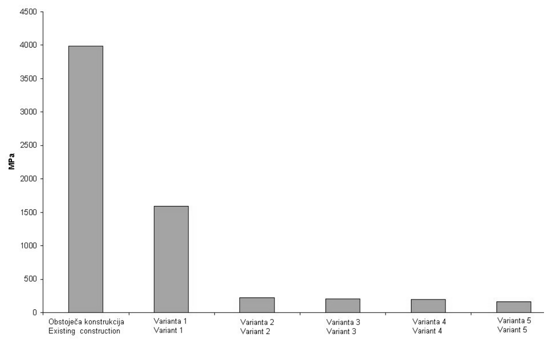
Sl. 21. *Največja primerjalna napetost*
Fig. 21. *Maximum equivalent stress*

3 SKLEP

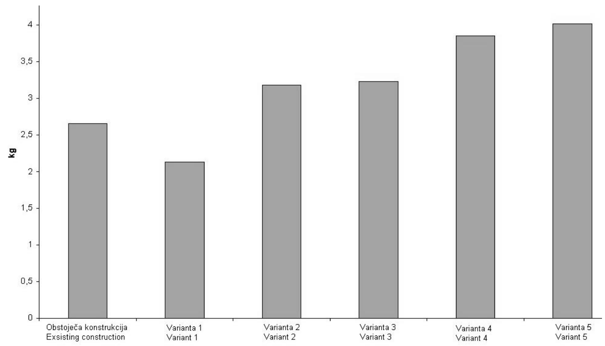
Če primerjamo mase in napetosti različnih variant odvaljnih batov (sl. 22 in 23), vidimo, da proti sedanjemu izdelku napetosti bistveno bolj padejo, kakor pa se poveča masa pri izboljšanih variantah, zato lahko rečemo, da zmanjšanje napetosti ni toliko posledica dodajanja materiala, kakor je posledica prilagoditve konstrukcije načinu vpetja. Analize so pokazale, da je mogoče izdelati odvaljni bat, ki bo prenesel obremenitve, kakršne terja statični preskus po evropski tehnični standardi, vendar bi tako oblikovan bat prenesel obremenitve samo, če je vpet natančno tako kakor načrtuje standard. Če bi bil rob podstavka postavljen drugje kakor pod rebrom bata, ta skoraj gotovo ne bi prenesel zahtevane obremenitve. Ker imajo nekateri izdelovalci podvozja nekoliko drugačna vpetja, ta bat zanje ne bi bil primeren. Druga težava je v tem, da mora biti bat pri montaži pravilno usmerjen, torej da rebro, za katero je načrtovano, da leži na previsnem robu, dejansko leži tam in ne pravokotno na rob.

3 CONCLUSION

If we compare the masses and stresses of different variants of air-spring pistons (Fig. 22 and Fig. 23), we see that the stresses drop much more than the mass is increased, which is why we can say that the reduction in the stresses is not the consequence of adding the material as much as it is the consequence of an adjustment of the design to the suspension. Our analyses showed that it is possible to produce a plastic air-spring piston that would withstand the loads that are anticipated by European Engineering Standards, but such a piston would withstand all the loads only if it were supported exactly as it is predicted in the standard. If the edge were to be placed anywhere else, for example, under the rib of the piston, this piston would almost certainly not withstand the required loads. Because some manufacturers have slightly different supports this piston would not be appropriate for them. The other problem is that during assembly the piston should be adequately oriented, so that the rib that is supposed to be on the edge of the block is really there and not perpendicular to it.



Sl. 22. *Primerjava največjih napetosti*
Fig. 22. *Comparison of maximum stresses*

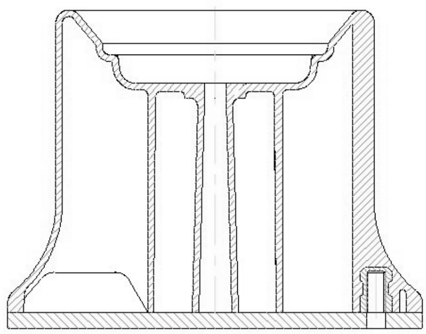


Sl. 23. *Primerjava teže*
Fig. 23. *Comparison of weights*

Analiza za primer vpetja po vsej spodnji površini za varianto 5 ni bila narejena. Ker je takšno vpetje bistveno bolj ugodno, bi peta varianta zanesljivo zdržala statični preskus tudi za tak način vpetja, vendar se pojavlja vprašanje, ali je primerno uporabljati peto varianto odvaljnega bata za vpetje po celotni spodnji površini bata, ker je težja od sedanjega izdelka in s tem tudi dražja. Po drugi strani je zopet vprašanje, ali je primerno izdelovati za različne izdelovalce podvozij različne odvaljne bate. Rešitev problema je, da se pod celotno spodnjo površino sedanjega odvaljnega bata postavi jeklena plošča (sl. 24), ki omili zgostitve napetosti ob previsnem robu. Tudi ta varianta ni idealna, saj smo dobili nov element v sestavi zračne vzmeti, vendar se je v praksi izkazala kot najcenejša rešitev. Analize takšnega načina vpetja niso bile narejene, ker je bilo bolj preprosto narediti preskus, ki ga je bat uspešno prestal. Z računalniki, ki so bili na voljo, bi ta način vpetja zelo težko trdnostno analizirali, saj je računanje že sedaj trajalo nekaj ur, če pa bi v model končnih

An analysis of the fifth variant for support on the whole lower surface of the piston was not made. Since such a support is much more favourable, the fifth variant would certainly withstand all the loads of the static test for that kind of support. However, there is a question: is it reasonable to use the fifth variant of the piston for the suspension on the whole lower surface, because this variant is heavier, and thus more expensive than the current product? A possible solution to this problem is to put a steel plate under the lower surface of the existing piston (Fig. 24). This plate would diminish the stress concentration near the edge of the block. This is also not an ideal solution, but it has been shown in practice that it is the cheapest solution so far. An analysis of such a support was not made because it was simpler to make a test, which the piston passed. To solve this problem with finite-element analysis would be very difficult, because computing time, which was several hours, would have had to be prolonged if we were to elementov dodali še eno dodatno ploščo pod valjem, bi s tem dobili še nekaj dodatnih elementov in še eno dodatno dotikalno površino, na kateri bi morali uporabiti elemente špranje. To bi vse skupaj bistveno podaljšalo čas računanja. Ker pa razvoj računalnikov zelo hitro napreduje, se bodo podobne analize v praksi vse bolj uveljavljale.

add the additional plate to the model because it would not only increase the number of elements, but it would also mean a new contact surface with gap elements. Since development in the computer industry is very rapid, this type of analysis will become increasingly common.



Sl. 24. *Drugačna rešitev*
Fig. 24. *Alternative solution*

4 LITERATURA
4 REFERENCES

[1] (1998) Catalog 1998, *General Electric*
[2] Spyrakos, C., Finite element modeling, *West Virginia University Press*
[3] Lawry, M.H., I – deas Master Series student guide, *Structural Dynamics Research Corporation*
[4] Zienkiewicz, O.C. (1991) The finite element method, *Mc Graw-Hill Publishing Company*, London.
[5] Oberg, E., Jones, F.D., Horton, H.L., Ryffel, H.H. (1996) Machinery's handbook, *Industrial Press Inc*., New York.
[6] Göbel, E. F. (1974) Rubber springs design, London.
[7] (1985) Procédure de réception de ressort à air, *European Engineering Standards 810*.

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Magisteriji, diplome

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Na Fakulteti za strojništvo Univerze v Mariboru so z uspehom zagovarjali svoja magistrska dela, in sicer:

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Besedilo naj bo pisano na listih formata A4, z dvojnim presledkom med vrstami in s 3 cm širokim robom, da je dovolj prostora za popravke lektorjev. Najbolje je, da pripravite besedilo v urejevalniku Microsoft Word. Hkrati dostavite odtis članka na papirju, vključno z vsemi slikami in preglednicami ter identično kopijo v elektronski obliki.

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

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