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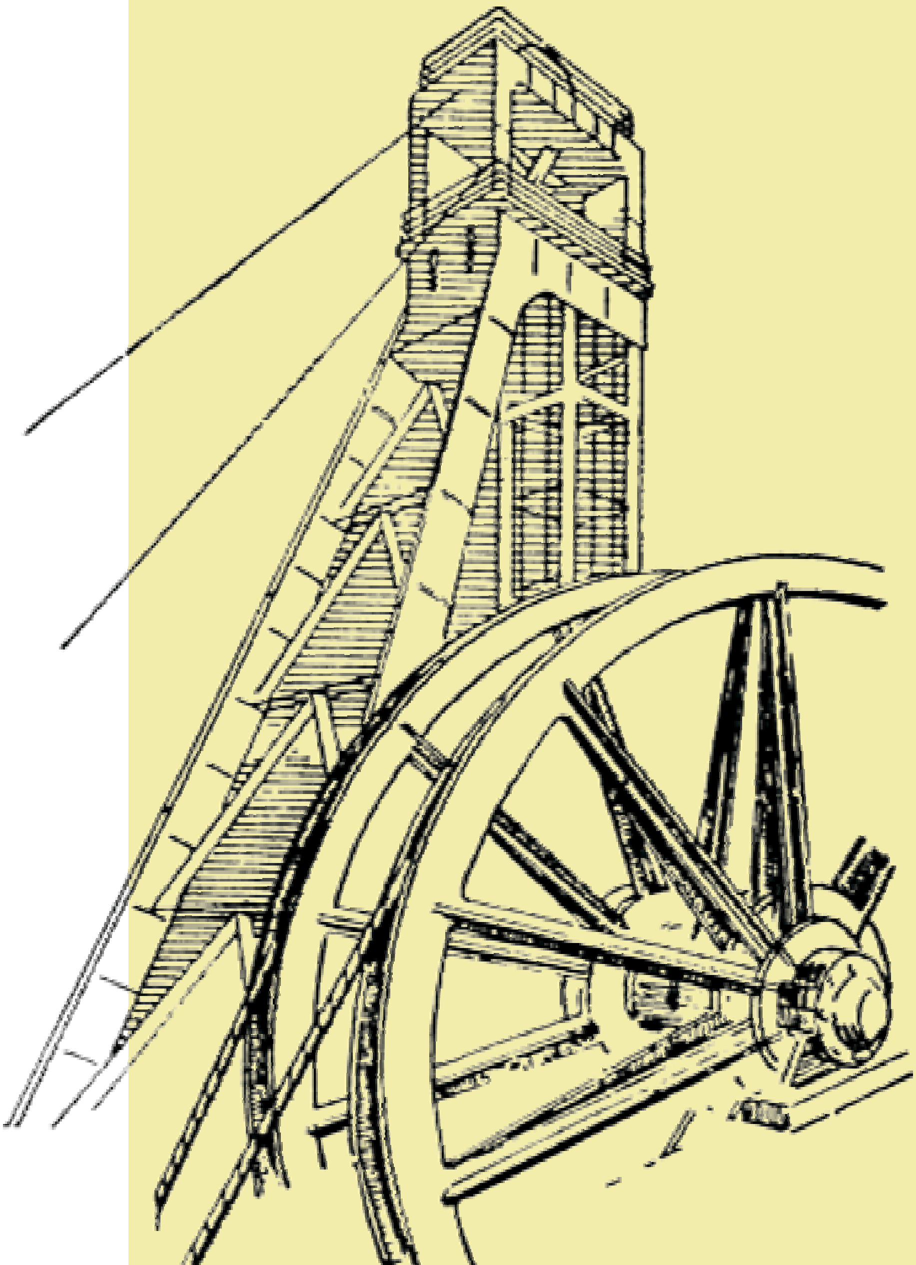



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# Nov način predstavitve tehnološkega znanja na konstrukterski ravni v orodjarstvu

## A Novel Approach to Presenting Manufacturing Knowledge on the Design Level in Toolmaking

Joško Valentinčič - Daniel Brissaud - Mihael Junkar

*V pričujočem prispevku predstavljamo nov način premostitve razkoraka med konstrukcijo izdelka in tehnologijo izdelave. Poglavitni namen je izdelava odločitvenega sistema v obliki računalniškega programa, katerega jedro je tehnološki izvedeniški sistem, ki ga uporablja konstrukter izdelka. Sistem odkriva kritična mesta novo konstruiranega izdelka z vidika tehnologije izdelave in nanje opozori konstrukterja izdelka. Glede na to se konstrukter odloči za morebitne spremembe konstrukcije – on je namreč odgovoren za spremembe konstrukcije izdelka. Sistem, ki ga predstavljamo, je namenjen orodjarstvu, kjer se izdela razmeroma drago orodje za izdelavo razmeroma cenenih izdelkov. Ker je oblika orodja negativna oblika izdelka, že majhne spremembe v konstrukciji izdelka lahko zmanjšajo ceno izdelave orodja. Sistem za prilagajanje konstrukcije izdelavi v orodjarstvu (SPKIO) odkriva kritična mesta konstrukcije izdelka, predlaga odločitve o spremembi konstrukcije, končno presojo pa prepušča konstrukterju izdelka.*

**(Ključne besede: konstruiranje za izdelavo, obdelave elektroerozijske, orodjarstvo)**

*A novel approach to avoiding the knowledge gap between design and manufacture is presented in this paper. The main idea is to build the system in the form of a computer program, the core of which is the manufacturing expert system, to be used by the product designer. The system reveals critical features of the newly designed product from the manufacturing point of view and points them out to the product designer. Based on the critical features of the product design, the product designer can decide whether to change the critical part of the product or not. The designer is the only one who can make changes to the design of the product. The system presented in this paper is prepared for the toolmaking industry, where a lot of relatively cheap products are made by one relatively expensive tool. Since the shape of the cavity in the tool is the negative of the product's shape, small changes in the product design can significantly reduce the manufacturing costs of the tool. A design adaptation system for machining in toolmaking (DASMT) reveals features that are critical for machining and makes suggestions to the product designer about how to alter the features while keeping the overall functionality of the produc*t.

**(Keywords: design for manufacture (DFM), electrical discharge machining, toolmaking)**

## 0 UVOD

Le okoli dvajset izmed nekaj sto zamisli izdelkov je temeljito premišljenih [1]. Razloga sta predvsem dva: površno preiskovanje vseh možnih zamisli izdelka in neučinkovito povezovanje konstrukcijske in izdelovalne ravni z ocenjevalnimi kriteriji, to so primernost za izdelavo in proizvodni stroški [2].

## 0 INTRODUCTION

From hundreds of product concepts, only five to twenty will merit serious consideration [1]. This is due either to an inadequate exploration of all the feasible alternative concepts or to an ineffective integration of the product design concepts with evaluation criteria such as ease of manufacture and cost of production [2].

Sprotnost konstruiranja in načrtovanja izdelave izdelka za dosego najboljših rezultatov in posledično optimalnih skupnih stroškov je karakteristika t.i. konstruiranja za izdelavo. Stopnjo povezanosti med izdelkom in izdelovalnim postopkom meri *izdelovalnost*; izdelovalnost pomeni lažjo proizvodnjo in je ocenjena z zmožnostjo doseči želeno kakovost in produktivnost z optimalnimi stroški.

Veliko dela je bilo narejenega v zadnjih desetih letih na področju konstruiranja izdelka z upoštevanjem zakonitosti izdelave orodij. Izvedba konstruiranja za izdelavo zahteva veliko *izvedeniškega znanja o obdelovalnih postopkih*. Na primer, obrabo elektrode pri izdelavi orodij opisujejo Mohri in sod. [3], sistem za načrtovanje izdelave po elektroerozijskem postopku podajata Lauwers in Kruth [4] in primerjavo in izbiro dopolnilnih postopkov, kakor sta elektroerozijska obdelava in frezanje z velikimi hitrostmi pri izdelavi orodij, podajajo Alam in sod. [5]. Le-ti v drugem delu obravnavajo osnovne tehnike konstruiranja za izdelavo, kakor so: pravila svetovanja konstrukterju, napotki, ki mu pomagajo pri metodologiji, simulacijska programska oprema, ki razpoznava problematične dele oblike, kakovost ali produktivnosti in programska oprema za kalkulacijo izdelovalnih stroškov. Pregled tega področja podajata tudi Boothroyd in Dewhurst ([6] in [7]); podan je tudi v [8].

Za izvedbo sprotnega konstruiranja izdelka in orodja predlagajo Lee in sod. ([9] in [10]) *racionalizacijo postopka konstrukcije*. Chin in Wong [11] sta podala racionalizacijo konstrukcijskega postopka za konstruiranje orodji za injekcijsko brizganje plastike, Ding in sod. [12] pa za postopek konstruiranja elektrode.

Najpomembnejša naloga sistema za kostruiranje za izdelavo je *vodenje celotnega znanja in podatkov*. Chen in Hsiao [13] predlagata sistem za povezovalno vodenje podatkov. Young in sod [14] predlagajo sistem, ki temelji na najbolj kakovostni informaciji, na podlagi katere konstrukter sprotno utemeljuje svoje odločitve. Največ avtorjev predlaga združitev informacij v bazo podatkov in izvedeniške sisteme ([10] in [11]).

Zadnji del znanja, potrebnega za konstruiranje za izdelavo, je povezan z *metodologijo konstruiranja*. Literatura predlaga klasično metodologijo, ki je podana v sedmih korakih ([8] in [15]): (1) analiza izdelka z zbiranjem in prečiščevanjem podatkov, (2) analiza izdelovalnega postopka z

The design-for-manufacture (DFM) philosophy is characterized by the simultaneous design of a product and its manufacturing process in order to achieve the best outcome and, consequently, optimise the overall costs. The degree of integration between the product and the process is measured by the *manufacturability*; manufacturability implies easy production and can be approximated by the capacity to achieve the desired quality and productivity while optimising costs.

A lot of work has been done over the past ten years in the field of design, this has been driven by the manufacturing issues of tools. DFM needs a lot of *expert knowledge of the manufacturing process itself*. For example, knowledge of the wear process of the electrode machining of a tool is proposed in Mohri et al. [3], a process planning system for EDM operations is proposed by Lauwers and Kruth [4] and knowledge about the comparison and selection of competitive technologies, such as sinking electrical discharge machining (EDM) and high-speed milling (HSM) in tool manufacturing is the topic of Alam et al.'s article [5]. The second part of this last work deals with the basic DFM techniques, such as the rules advising the designer, the guidelines assisting the designer throughout the methodology, simulation software to detect problems in shape, quality or productivity, and cost-calculation software to control manufacturing costs. An overview of this field is given in Boothroyd and Dewhurst ([6] and [7]) and in [8].

For DFM implementation Lee et al. ([9] and [10]) suggest the *rationalization of the design process*. Chin and Wong [11] propose a system for rationalization of the design process of tools for plastic injection, and Ding et al. [12] for the EDM electrode design process.

What becomes the most significant topic in the DFM system is *the management of the whole body of knowledge and data*. Chen and Hsiao [13] proposed a collaborative data management system. Young et al. [14] proposed a system providing high-quality information on which designers can base their decisions online. Most authors proposed embodying information into knowledge bases and expert systems ([10] and [11]).

The last portion of the knowledge needed in a DFM system is related to the *design methodology*. Literature proposes classical methodology based on seven steps ([8] and [15]): (1) product analysis to collect and clarify zbiranjem, obdelavo in poročanjem o podatkih, specifičnih za obdelovalni postopek in ustrezne vire, (3) merjenje interakcij med izdelkom in obdelovalnim postopkom v smislu pomembnih kazalcev učinkovitosti, (4) poudarjanje problemov, (5) diagnoza vzrokov in posledic, (6) nasveti za rekonstrukcijo in (7) podajanje prioritetnih sprememb pri postopku konstruiranja, če je to potrebno.

V pričujočem prispevku predlagamo *integracijski sistem za sprotno konstruiranje izdelka in njegovo prilagajanje orodju*. Sistem je namenjen predvsem konstrukterjem izdelka. Glede na glavna načela konstruiranja za izdelavo je njegova izvirnost v metodologiji prilagajanja konstrukcije in uvedbi izvedeniškega znanja. Sistem za prilagajanje konstrukcije izdelavi v orodjarstvu (SPKIO) zajema celotno in podrobno konstrukcijo izdelka, kakor tudi zamisel konstrukcije orodja v zgodnji fazi, ko je še vedno čas za večje spremembe v konstrukciji. Metodologija je zelo uporabna, saj omogoča vrednotenje in optimizacijo konstrukcije z vidika izdelave in zmanjšuje časovno potratne ponovitve med konstrukterjem in tehnologom.

Pričujoč prispevek je razdeljen v naslednja poglavja. V prvem poglavju bomo predstavili problematiko konstruiranja za izdelavo. V drugem poglavju podajamo pregled stanja v slovenskih orodjarnah z vidika konstruiranja za izdelavo. V tretjem poglavju predstavljamo izvirnost naše metodologije prilagajanja konstrukcije izdelka izdelavi orodja, kjer je tudi podrobneje predstavljen izvedeniški sistem za prilagajanje konstrukcije orodja izdelavi z elektroerozijskim postopkom. V četrtem poglavju bodo podani sklepi.

## 1 PREGLED STANJA V ORODJARSTVU Z VIDIKA KONSTRUIRANJA ZA IZDELAVO

Povezava med konstrukcijo in izdelavo izdelkov, ki se izdelujejo v masovni proizvodnji, je še posebej zapletena, saj je za izdelavo takšnih izdelkov potrebno izdelati orodje. Takšna orodja izdelujejo orodjarne in so vmesni izdelek, ki omogoča hitro izdelavo končnih izdelkov, npr. okrovov, plastenk ipd. Orodje je v splošnem sestavljeno iz ene ali več vdolbin. Oblika vdolbine je odvisna od oblike izdelka, ki jo predpiše konstrukter izdelka in je običajno precej zapletena. Zato je treba razdeliti orodje na posamezne t.i. *elemente* glede na zahtevano obliko, tolerance in hrapavost površine vdolbin.

information, (2) manufacturing-process analysis concerned with the collection, processing and reporting of process-specific and resource-specific data, (3) measurement of the interactions between product and process information in terms of the relevant performance indicators, (4) highlighting of problems, (5) diagnosis for effects and causes, (6) advice on redesign, and (7) prioritising changes in the design procedure, if necessary.

In this paper, an integrating system for the design of the product and its simultaneous adaptation to tool manufacturing is proposed. The system is to be used by product designers. Based on the main principles of DFM techniques, its originality comes from both the adaptation methodology and the implementation of professional knowledge. The design adaptation system for machining in toolmaking (DASMT) aims to address the embodiment and detail design phases of the product definition, as well as the conceptual design phase of the die definition at an early stage, when there is still time to make significant changes. This methodology is extremely useful, as it enables the evaluation and optimisation of the design and avoids the designer's time-consuming iterations.

The paper is organised as follows: The design for manufacturing was introduced in the first section. In the second section, an overview of the Slovenian toolmaking industry from the DFM point of view is given. In the third section, the originality of our method is presented, and a detailed description of the expert system for tool-design adaptation to machining by EDM is given. Finally, the conclusions are drawn in the fourth section.

## 1 AN OVERVIEW OF THE SLOVENIAN TOOLMAKING INDUSTRY FROM THE DFM POINT OF VIEW

The relation between the design and the manufacturing of the products made in mass production is complex since the tool for mass production of the product has to be made. The tools are made in toolmaking, and they are intermediary products from which the basic products or their components are produced, such as casings, plastic bottles, etc. In general, a tool consists of one or more cavities. The shape of the cavity depends on the product design, and is usually extremely complex. Therefore, it is important to decompose it to individual *features* in terms of the requested shape, tolerance and surface roughness of the cavity.

Elektroerozjiska obdelava in frezanje z velikimi hitrostmi sta najbolj pogosto uporabljena obdelovalna postopka za izdelavo orodij. V večini primerov se za izdelavo enega orodja uporabljata oba postopka. V primeru elektroerozijske obdelave je potrebno izdelati tudi elektrodo, katere oblika se preslika v obdelovanec, orodje. Tako celoten postopek konstruiranja sestoji iz naslednjih faz: konstruiranje izdelka, konstruiranje orodja in konstruiranje elektrod. Orodje mora biti konstruirano glede na konstrukcijo izdelka z upoštevanjem tako karakteristik izdelovalnega postopka izdelka (kovanja, tlačnega litja itn.) kakor tudi uporabljenih obdelovalnih postopkov za izdelavo orodja (elektroerozija, frezanje z velikimi hitrostmi). Izdelava elektrode je odvisna od oblike elementa v orodju in običajno izdelana z žično elektroerozijo ali frezanjem. Celoten proizvodni postopek tako sestoji iz konstruiranja izdelka, orodja, elektrod in določitve pripadajočih izdelovalnih postopkov. Vse te dejavnosti naj bi se dogajale sočasno, kar pa v praksi žal še ni mogoče.

Izdelava orodij poteka v orodjarnah, ki niso nujno del podjetja, kjer konstruirajo izdelek. Zaradi tega je konstruiranje za izdelavo še bolj zapleteno in uspešnost izdelave je odvisna od sporazumevanja med konstrukterjem izdelka in konstrukterjem orodja – tehnologom. Običajno je konstrukcija izdelka predana izdelovalcu orodja, ki mora določiti ustrezno konstrukcijo orodja za izdelavo danega izdelka in določiti primerne obdelovalne postopke za izdelavo orodja. Ker so konstrukterji izdelkov za masovno proizvodnjo po izobrazbi večinoma oblikovalci, je njihovo znanje o obdelovanih postopkih v orodjarstvu zelo skromno. Zato se pri konstruiranju takšnih izdelkov ne upošteva problematike izdelave orodja. Narejen je bil pregled devetih slovenskih orodjarn [16], da bi ugotovili povezanost med konstrukcijo izdelka in izdelavo orodja. Rezultati kažejo, da je pogosto treba konstrukcijo izdelka prilagoditi izdelavi orodja zaradi lažje in cenejše izdelave. V nekaterih primerih je celo nemogoče izdelati orodje za predpisan izdelek. Zato industrija potrebuje zunanjo pomoč pri prilagajanju konstrukcije izdelka izdelavi orodja.

## 2 METODOLOGIJA SISTEMA ZA PRILAGAJANJE KONSTRUKCIJE IZDELAVI V ORODJARSTVU

SPKIO je, kakor smo zapisali že v uvodu, namenjen prilagajanju konstrukcije izdelka, ki bo

Electrical discharge machining (EDM) and high-speed milling (HSM) are the two processes generally applied for the machining of tool features. In most cases, both processes are applied sequentially for the production of a given tool. When EDM has been selected the electrode has to be made, the shape of which is transferred to the workpiece, i.e., the tool. The entire design process consists of the design of the product, the tool and the electrode. The tool has to be designed according to the product design by taking into account all the properties of the manufacturing process of the product (forging, moulding, etc.) and the manufacturing processes of the tool (EDM, HSM). The electrode itself is defined by the tool features and is generally machined by either wire-EDM or a milling process. Consequently, the entire production process includes the simultaneous design of the product, the tool(s), the electrode(s) and the associated manufacturing processes. All these activities should be done simultaneously, but, unfortunately, in practice this is still impossible.

The production of dies is often outsourced and carried out by specialised toolmakers. The design task becomes more complex and the efficiency of the production becomes increasingly dependent on the communication between the product designer and the tool designer. At the moment, the product design is normally passed to the tool manufacturer. The latter has to find an effective tool-design solution for manufacturing the product and the appropriate machining processes for manufacturing the tool. Since the product designers' knowledge about the machining processes in toolmaking is rather poor, the tool manufacturing is not considered at the design level. A survey has been made in nine Slovenian toolmaking companies [16] to find the relation between the product design and the tool manufacturing. Results show that product design often has to be adapted to the manufacture of the tool to produce easier and cheaper machining. In some cases it is even necessary to change the product design altogether, in order to make the manufacturing possible. The conclusion is that industry needs to adapt the product design to the tool-manufacturing processes.

## 2 METHODOLOGY OF THE DESIGN ADAPTATION SYSTEM FOR MACHINING IN TOOLMAKING

As mentioned before, the DASMT's aim is to adapt the product design, which will be made in narejen v masovni proizvodnji, za lažjo in cenejšo izdelavo orodja, ki omogoča tako proizvodnjo. Z integracijo znanja in rezultatov iz literature smo zasnovali sistem, ki obvladuje orodjarsko znanje in ga predstavlja na konstrukcijski ravni. Če označimo lastnosti oz. zahteve za izdelek s $\boldsymbol{K}^*$ in izdelavo orodja s $\boldsymbol{T}$, potem zapišemo:

mass production, to tool manufacturing. The system, which presents the toolmaking knowledge on the design level, was developed by the integration of results from the literature and our knowledge. If the properties or demands for the product are denoted as $\boldsymbol{K}^*$, and the properties or demands for the tool manufacturing are denoted as $\boldsymbol{T}$, then:

$$\boldsymbol{T}=F(\boldsymbol{K}^*) \quad (1),$$

kjer sta $\boldsymbol{K}^*$ in $\boldsymbol{T}$ vektorja prilastkov, ki popisujeta konstrukcijske oz. tehnološke lastnosti: $\boldsymbol{K}^*=(\boldsymbol{k}_1^*,\boldsymbol{k}_2^*,..,\boldsymbol{k}_p^*,..\boldsymbol{k}_P^*)$, $\boldsymbol{T}=(\boldsymbol{t}_1,\boldsymbol{t}_2,..,\boldsymbol{t}_q,..\boldsymbol{t}_Q)$. Tudi $F$ je množica funkcij, ki popisuje razmerja med posameznimi prilastki $\boldsymbol{k}_p^*$ in $\boldsymbol{t}_q$. Prilagajanje konstrukcije izdelka, popisane z vektorjem $\boldsymbol{K}^*$, izdelavi orodja, popisani z vektorjem $\boldsymbol{T}$, pomeni reševanje enačbe:

where $\boldsymbol{K}^*$ and $\boldsymbol{T}$ are vectors of the attributes that are describing the design and manufacturing properties respectively: $\boldsymbol{K}^*=(\boldsymbol{k}_1^*,\boldsymbol{k}_2^*,..,\boldsymbol{k}_p^*,..\boldsymbol{k}_P^*)$ and $\boldsymbol{T}=(\boldsymbol{t}_1,\boldsymbol{t}_2,..,\boldsymbol{t}_q,..\boldsymbol{t}_Q)$. Function $F$ embraces several functions, which are describing the relations between the attributes $\boldsymbol{k}_p^*$ and $\boldsymbol{t}_q$. The adaptation problem deals with the inverse problem to derive design vector $\boldsymbol{D}^*$ from the manufacturing vector $\boldsymbol{T}$:

$$\boldsymbol{K}=F^{-1}(\boldsymbol{T}) \quad (2).$$

Tako je treba za vsak tehnološki prilastek $\boldsymbol{m}_q$ definirati preslikave $f_r$ med preostalimi tehnološkimi prilastki $\boldsymbol{m}_{q'}$ in konstrukcijskimi prilastki $\boldsymbol{k}_p$:

For each manufacturing attribute $\boldsymbol{m}_q$ it is necessary to define all the mapping functions $f_r$ with other manufacturing attributes $\boldsymbol{m}_{q'}$ and design attributes $\boldsymbol{d}_p$:

$$\boldsymbol{t}_q=f_r(\boldsymbol{k}_p,\boldsymbol{t}_{q'}):\ p\in\{1,2,..,P\};\ q,q'\{1,2,..,Q\},\ q\neq q';\ r\in\{1,2,..,R\} \quad (3).$$

Preslikave iz konstrukcijske na tehnološko raven so bolje poznane kakor povezave iz tehnološke na konstruktersko raven. Zato je funkcijo $F$ veliko preprosteje zapisati kakor pa njeno obratno funkcijo $F^{-1}$, ki jo je treba poznati za prilagajanje konstrukcije izdelka izdelavi orodja. Funkcijo $F$ zapišemo v obliki algoritmov, ki so združeni v tri izvedeniške podsisteme (module) za posamezno področje. Obratno funkcijo $F^{-1}$ dosežemo z vključitvijo konstrukterja izdelka v interakcijo z izvedeniškimi sistemi. Takšen sistem, ki vključuje tudi konstrukterja, smo označili s SPKIO.

Izvedeniški sistemi, vključeni v SPKIO, obvladajo tehnologijo izdelave orodja in sporočajo konstrukterju le kritične informacije o konstrukciji izdelka (kritičnih z vidika izdelave orodja). S tem se prepušča konstrukterju odločitev o spremembi konstrukcije izdelka. Le-ta se mora sam odločiti o spremembi konstrukcije, pri čemer mora upoštevati zahteve za izdelek, ki jih pozna, in zahteve za orodje, ki so mu preprosto podane le kot kritična mesta konstrukcije izdelka. Torej je poglavitna zamisel sistema v določitvi kritičnih mest konstrukcije

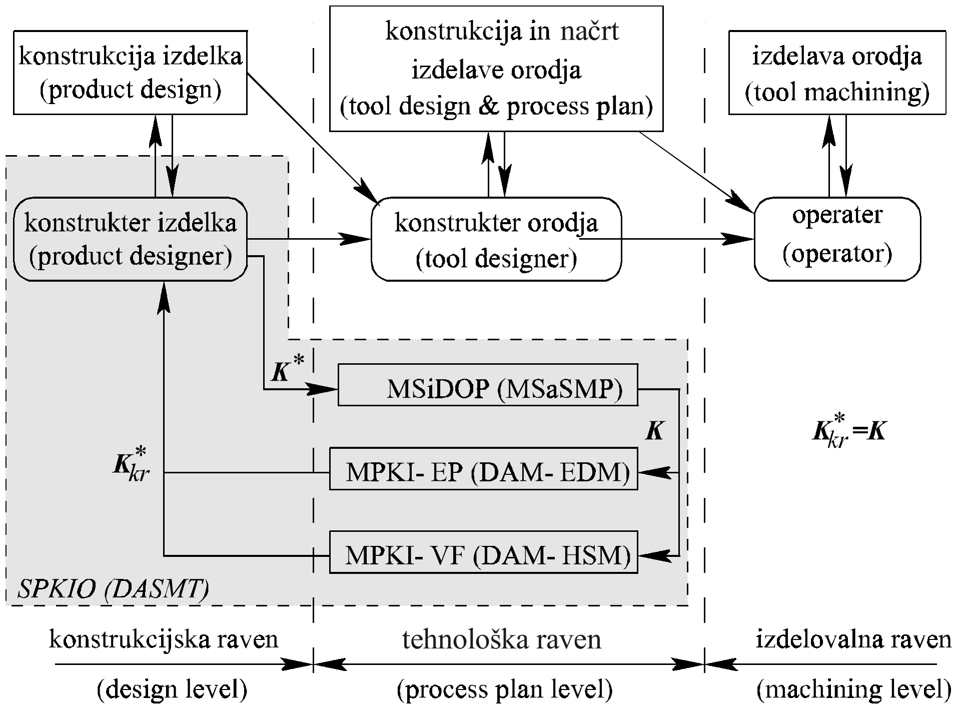
The mappings from the design to the process-planning level are better defined than the mappings from the process-planning to the design level. Thus, function $F$ is easier to describe than the inverse function $F^{-1}$, which is needed for design adaptation of the product to the tool manufacturing. Function $F$ is represented in the form of computer algorithms, which are assembled into three expert subsystems (modules) for each field. The inverse function $F^{-1}$ is obtained by including the product designer into the interaction between the three expert systems. Such a system was named DASMT.

The expert systems included into the DASMT manage manufacturing knowledge to provide the designer with only the critical information on the product (critical from the manufacturing point of view). The decision about the design adaptation is only up to the designer, by considering the demands for the product and the demands for the tool. The latter are presented to the designer by DASMT as critical parts of the product design from the tool-manufacturing point of view. Thus, the basic idea of the system is to determine the critical design izdelka; določitev kritičnih mest sloni na mreži odvisnosti med konstrukcijskimi in izdelovalnimi prilastki. Izdelovalne prilastke orodja smo določili na podlagi podanih konstrukcijskih prilastkov izdelka. Pri tem smo upoštevali inženirske izkušnje, izvedeniško in znanstveno vedenje o obdelovalnih postopkih in študije na primerih.

SPKIO določi delilno ravnino orodja in razbije obe polovici orodja na elemente glede na množico konstrukcijskih podatkov o izdelku. Nadalje določi primeren obdelovalni postopek za vsak element posebej in predlaga izboljšanje izdelka z vidika izdelave orodja. Če zahteve za izdelek dopuščajo spremembe v konstrukciji, potem konstrukter na teh mestih konstrukcijo prilagodi lažji izdelavi orodja. Ko konstrukter spremeni konstrukcijo izdelka, SPKIO ustrezno spremeni tudi konstrukcijo orodja in prilagodi obdelovalne postopke in obdelovalne parametre novi, spremenjeni konstrukciji. Spremembe izvaja konstrukter izdelka v smislu boljše definicije izdelka in orodja, manjšanja celotnih proizvodnih stroškov in povečanja produktivnosti. Lažja izdelava orodja se dosega že z majhnimi spremembami v konstrukciji

attributes; the determination is based on the network of the dependencies between the design and the manufacturing attributes. The manufacturing attributes of the tool were established according to the given product-design attributes by considering engineers' knowledge, expert and scientific knowledge about the machining processes and case studies.

First, the dividing plane of the tool is defined by the DASMT, and both parts of the tool are segmented into several features according to the design data of the product. Later, the appropriate machining process is defined for every feature, and critical parts of the features are revealed. If the demands for the product enable the adaptation of the critical parts, the designer adapts those parts to the ease of tool manufacturing. Once the designer changes the design configurations and the attributes, the DASMT makes changes to the tool design and adapts the machining processes and its machining parameters to the new design. Adaptations are driven by improvements of the product and tool definitions, minimising the overall production costs and maximising productivity. Substantial increases in ease of tool production can be achieved by slight alterations of critical product design attributes, which should, however, not deteriorate its functionality.




Sl. 1. *Shema SPKIO*
Fig. 1. *DASMT scheme*

izdelka, ki seveda ne smejo poslabšati njegove funkcionalnosti in estetike. Prilagajanje se izvaja v več ponovitvah in tako se izdatno zmanjša število ponavljanj med konstrukterjem izdelka in tehnologom v orodjarni.

Shema SPKIO je prikazana na sliki 1, kjer zgornji del prikazuje informacijski tok med konstrukterjem izdelka, tehnologom v orodjarni in operaterji za stroji, ki dejansko izdelajo orodje. Spodnji del prikazuje tok informacij med konstrukterjem in moduli v SPKIO. To so: modul za segmentacijo orodja in določitev obdelovalnega postopka (MSiDOP), modul za prilagajanje konstrukcije izdelavi z elektroerozijskim postopkom (MPKI-EP) in modul za prilagajanje konstrukcije izdelavi s frezanjem z velikimi hitrostmi (MPKI-VF).

## 2.1 Delovanje SPKIO

Konstrukcijski prilastki $\boldsymbol{K}^*$, ki jih poda konstrukter, najprej vstopajo v MSiDOP, kakor je prikazano na sliki 1. Modul določi delilno ravnino orodja, nato pa razdeli orodje na posamezne elemente, za katere predpiše ustrezne obdelovalne postopke. Generira se set konstrukcijskih prilastkov orodja $\boldsymbol{K}$. Preslikava je razmeroma preprosta, saj je oblika orodja le negativna slika izdelka z upoštevanjem skrčkov zaradi temperaturne razteznosti. Ta modul je razvil Nardin [17] in trenutno deluje kot samostojni sistem.

Obdelovalni postopek je izbran za vsak element na orodju, ki je popisan s $\boldsymbol{K}$: izbira se med elektroerozijo in frezanjem z velikimi hitrostmi. Glede na to izbiro se vsak od elementov predstavi v ustreznem modulu: MPK-EP ali MPK-VF, kjer se ga obdela z vidika obdelovalnosti z danim postopkom. V tem postopku se določijo tisti konstrukcijski prilastki, ki so najbolj neugodni z vidika obdelave. Poimenovali smo jih kritični konstrukcijski prilastki orodja in jih označili s $\boldsymbol{K}_{kr}$. Le-ti so identični kritičnim konstrukcijskim prilastkom izdelka $\boldsymbol{K}_{kr}$*, ki so predstavljeni konstrukterju izdelka. Tako je konstrukter seznanjen s kritičnimi mesti izdelka z vidika izdelave orodja, na podlagi česar se odloči o morebitni spremembi konstrukcije. Komunikacija je interaktivna: vsaka vnesena sprememba konstrukcijskih prilastkov se takoj kaže na sporočanju novih kritičnih konstrukcijskih prilastkov, ki opisujejo posamezna mesta konstrukcije. Seveda se kritičnih prilastkov ne da odpraviti. Vedno bo vsaj eden, zaradi katerega bo treba izbrati npr. večje število elektrod ali manjše podajanje frezala.

The designer tunes the critical attributes of the product to the process attributes of the selected machining process of the die throughout the iterative process. Thus, the number of iterations between the designer and the die engineer is significantly reduced.

The general concept of DASMT is presented in Fig. 1. The upper part of the figure presents the information flow between the product designer, the tool engineer and the operator of the machine, who actually makes the tool. The lower part of the figure shows the information flow between the designer and the modules of DASMT. These are as follows: the system for die segmentation and the determination of the machining process (MSaSMP), the design adaptation module for EDM (DAM-EDM) and the design adaptation module for HSM (DAM-HSM).

## 2.1 Functioning of the DASMT

The product design attributes $\boldsymbol{K}^*$ are introduced to the MSaSMP as shown in Fig. 1. The module defines the dividing plane and segments each part of the tool into several features, and for each feature it determines the appropriate machining process. Later, a set of tool design attributes $\boldsymbol{K}$ is generated. The mapping is relatively simple, since the tool has the negative shape of the product. The product dimensions differ from the tool dimensions for the contraction of the product material due to the temperature dilatation. The MSaSMP module was build by Nardin [17], and so far it works as an autonomous system.

The machining process is selected for each feature described by the tool-design attributes $\boldsymbol{K}$: the selection is made between EDM and HSM. According to this selection, each tool feature is presented to the appropriate design adaptation module, DAS-EDM or DAS-HSM, to be examined from the manufacturing point of view. In this process, the design attributes that are the most problematic from the manufacturing point of view are established. They are named the critical design attributes, denoted as $\boldsymbol{K}_{kr}$ and they are identical to the critical product-design attributes $\boldsymbol{K}_{kr}$*, that are introduced to the designer. The designer then tries to adapt the design, focusing on the given critical product-design attributes. The system is interactive: every product-design adaptation reflects in the establishing of new critical product design attributes that are describing certain product parts. Of course, the critical design parts cannot be avoided. The most convenient

Pravzaprav je najbolje, če so vsa mesta na izdelku kritična. Takrat so vsi obdelovalni parametri izbranih obdelovalnih postopkov izbrani tako, da ravno še zadostijo konstrukcijkim zahtevam orodja oziroma izdelka. Takrat je tudi izdelava orodja najcenejša.

situation is that all the parts of the product are critical. In such a case, the selected machining parameters hardly achieve the demands for the product and tool design—the machining of the tool is the cheapest and the fastest.

### 2.2 Delovanje posameznih modulov

Na sliki 1 je prikazan celoten SPKIO, ki je sestavljen iz treh modulov. MSiDOP je predstavil Nardin [17] in ga zato na tem mestu ne bomo podrobno opisovali. Oba preostala modula, MPKI-EP in MPKI-VF, še nista bila predstavljena v literaturi, zato ju podajamo na tem mestu.

MPKI-EP in MPKI-VF lahko delujeta tudi kot samostojna sistema, ki rešujeta specifične probleme, kakor je prilagajanje konstrukcije orodja obdelovalnemu postopku, ki je že vnaprej določen. Takšen samostojni sistem je namenjen konstrukterju orodja, ki določi konstrukcijo orodja za dani izdelek ter nato preverja in optimira obliko posameznih elementov na orodju glede na izdelovalni postopek orodja. Seveda konstrukter orodja ne pozna zahtev za izdelek, za katerega konstruira orodje, zato takšna optimizacija zahteva tudi navzočnost konstrukterja izdelka.

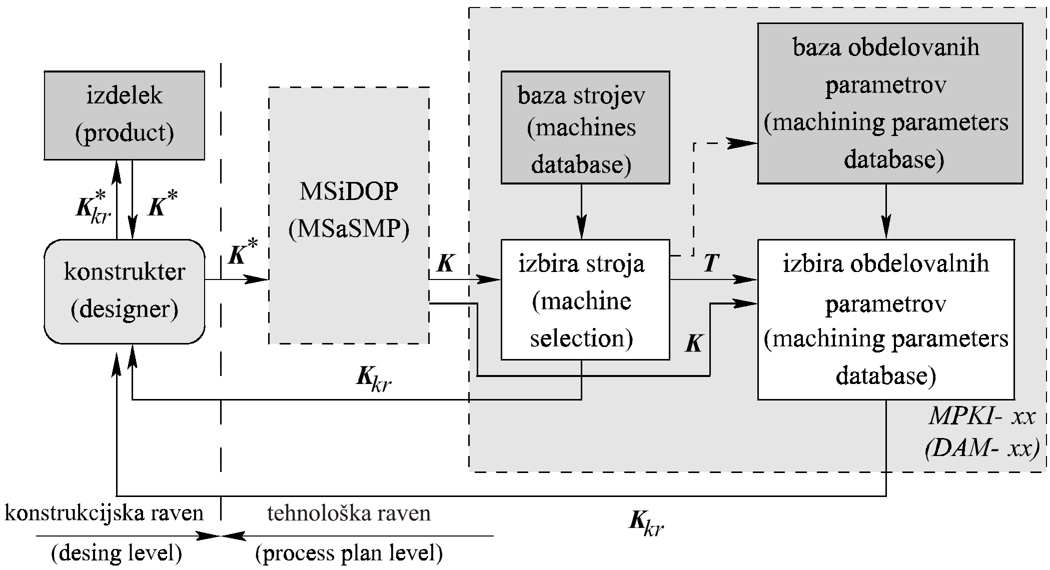
Zamiselna shema je enaka za oba obravnavana modula in je prikazana na sliki 2. Konstrukcijske prilastke orodja določi MSiDOP, ki izbere tudi primeren obdelovalni postopek za vsak

### 2.2 Functioning of the modules

The whole DASMT, which consists of three modules, is presented in Fig. 1. Nardin presented MSaSMP in [17] and thus it will not be presented in detail here. Since both other modules, namely DAM-EDM and DAM-HSM, have not been presented in the literature yet, they are presented here.

DAM-EDM and DAM-HSM can also work as an autonomous system, which solves specific problems such as tool-design adaptation to the specific machining process that is determined in advance. Such an autonomous system is to be used by the tool designer who makes the tool design for the given product and checks and optimizes the shape of tool features according to the selected machining process of the given feature. Since the tool designer is not familiar with the demands of the product, such optimization also requires the presence of the product designer.

The conceptual scheme is equal for both modules and is shown in Fig. 2. The design attributes of the tool are established by MSaSMP, where also the most appropriate machining process is selected




Sl. 2. *Zamiselna shema, po kateri delujeta MPKI-EP in MPK-VF.*
Fig. 2. *Conceptual scheme of DAM-EDM and DAM-HSM.*

element orodja posebej in ustrezne konstrukcijske prilastke sporoča ustreznemu modulu; če je za obravnavan element določena elektroerozijska obdelava, potem pošlje konstrukcijske prilastke elementa v MPKI-EP, v nasprotnem primeru je za obravnavani element določeno frezanje z velikimi hitrostmi in konstrukcijske prilastke elementa pošlje v MPKI-VF.

Jedro vsakega od obeh modulov je izvedeniški sistem, ki izbere primeren obdelovalni stroj za izdelavo danega elementa orodja. Vsebina podatkovne baze strojev je odvisna od orodjarne, kjer se bo izdelovalo orodje. Vsak stroj ima svojo bazo obdelovalnih parametrov. Različni stroji za elektroerozijsko obdelavo imajo priporočene različne vrednosti obdelovalnih parametrov za dosego enakih rezultatov obdelave. Tudi vsi stroji za frezanje z velikimi hitrostmi niso enako zmogljivi in nimajo enakih frezal, ki so na voljo v dani orodjarni. Tako prekinjana črta na sliki 2 označuje odvisnost baze obdelovalnih parametrov od izbranega stroja. Algoritma izbire stroja in izbire obdelovalnih parametrov sta seveda močno odvisna od obdelovalnega postopka. V nadaljevanju bomo podrobneje predstavili delovanje MPKI-EP.

### 2.3 Podrobnejši vpogled v MPKI-EP

#### *2.3.1 Konstrukcijski prilastki orodja*

Popis konstrukcije orodja je formaliziran v konstrukcijske prilastke orodja $\boldsymbol{K}$, ki skupaj ustrezno popisujejo orodje za določitev njegove izdelave. Glede na literaturo, izkušnje iz industrije in naše izkušnje smo določili deset konstrukcijskih prilastkov, ki zadostujejo za določitev tehnoloških prilastkov in s tem za definiranje izdelave orodja. Konstrukcijski prilastki so v splošnem vektorji in jih označujemo s $\boldsymbol{k}_i$. Dva prilastka se nanašata na celotno orodje: $\boldsymbol{k}_1$ pomeni zunanje mere orodja ($x$, $y$, $z$) in $\boldsymbol{k}_4$ popisuje materal orodja. Vsak element na orodju je popisan s sedmimi prilastki; glavni je prilastek $\boldsymbol{k}_2$, ki popisuje obliko elementa. Drugi prilastki so: $\boldsymbol{k}_5$ erodirna površina, $\boldsymbol{k}_6$ globina obdelave, $\boldsymbol{k}_7$ hrapavost površine, $\boldsymbol{k}_8$ globina toplotno prizadete cone, $\boldsymbol{k}_9$ zaokrožitev robov in $\boldsymbol{k}_{10}$ nagib stranskih ploskev. Prilastek $\boldsymbol{k}_3$ vsebuje izmerne, oblikovne in položajne tolerance.

Večina naštetih konstrukcijskih prilastkov je dovolj dobro opisanih že z imenom in imajo številčno zalogo vrednosti, zato podrobnejši opis ni potreben za razumevanje delovanja SPKIO.

for each feature of the tool, and the attributes are sent to the corresponding module; if a feature is machined by EDM process, the design attributes of the feature will be sent to the DAM-EDM, in the case that the HSM process is determined to machine the given feature, the design attributes will be sent to the DAM-HSM.

The kernel of each module is an expert system that chooses an appropriate machine for the given feature machining. The content of the machine's database depends on the toolmaking company where the tool will be manufactured. Each machine has its own machining parameters' database. The EDM machines use different machining parameters to achieve the same machining results. Not all of the HSM machines have the same performances and the same tools available in the given toolmaking company. Thus, the dashed line in Fig. 2 indicates that the machining parameters' database depends on the selected machine. Algorithms of the machine selection and the machining parameters selection strongly depend on the selected machining process. Later, the functioning of the DAM-EDM will be described.

### 2.3 Detailed insight into the DAM-EDM

#### *2.3.1 Design attributes of the tool*

The description of the tool design has been formalised into design attributes, which all together describe the tool to determine its manufacturing. According to the literature, industrial experience and our own experience, ten tool-design attributes have been selected to determine the EDM manufacturing attributes and thus to define the tool manufacturing. The design attributes are, in general, vectors and noted as $\boldsymbol{k}_i$. Two attributes characterise the whole tool: $\boldsymbol{k}_1$ represents the maximum dimensions of the tool (x, y, z), and $\boldsymbol{k}_4$ represents the tool material. Each tool feature is characterised by seven attributes; the main one is the attribute $\boldsymbol{k}_2$ characterising the shape of the feature. The remaining attributes are: $\boldsymbol{k}_5$ surface area, $\boldsymbol{k}_6$ machining depth, $\boldsymbol{k}_7$ surface roughness, $\boldsymbol{k}_8$ heat-affected zone, $\boldsymbol{k}_9$ roundness of edge, and $\boldsymbol{k}_{10}$ slope of flank surface. The attribute $\boldsymbol{k}_3$ is a global attribute characterising the tolerances of the dimensions, the shapes and the positions.

Most of the presented design attributes are well defined by their name, and their values are numbers. Thus, a detailed description is not required. However, attribute $\boldsymbol{k}_2$ describes the shape of the

Prilastek $\boldsymbol{k}_2$, ki popisuje obliko elementa, pa zahteva podrobnejšo razlago.

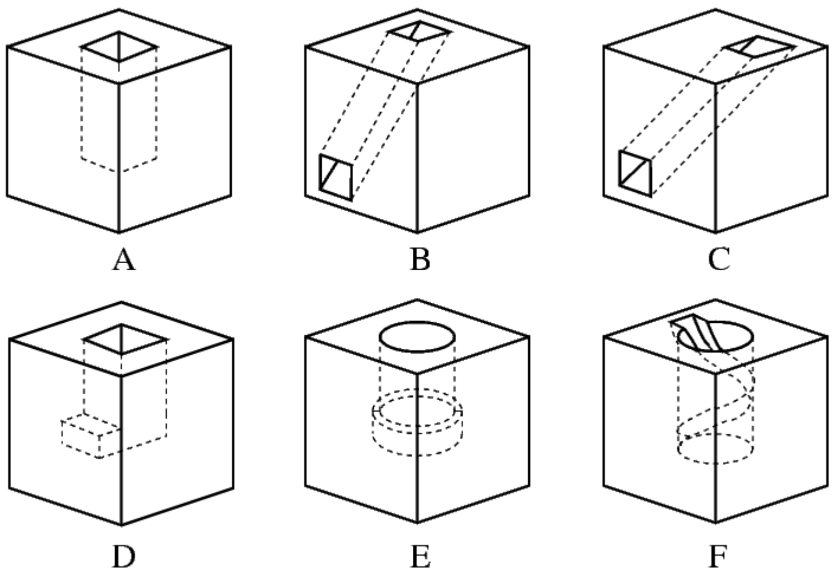
Izdelovalni element je definiran kot geometrijska oblika, ki določa tehnološke lastnosti in glede na katero je določen obdelovalni postopek. *V primeru elektroerozijske obdelave je element del orodja, ki ga je mogoče izdelati z eno elektrodo ali skupkom elektrod za grobo in fino obdelavo na danem obdelovalnem stroju*. Elementi so karakterizirani z dvema lastnostima: s potrebnimi smermi pomikanja elektrode in z dostopnostjo elementa. Pomikanje elektrode poteka v eni smeri (1D), dveh kombiniranih smereh (2D), v treh kombiniranih smereh (3D) in v treh kombiniranih smereh z dodano zavrtitvijo elektrode okoli svoje osi (4D). Glede na dostopnost elementa ločimo odprte elemente, ki jih dosežemo v celoti s pomikom elektrode v eni smeri iz vrha orodja. V nasprotnem primeru je element zaprt. Preglednica 1 zajema zgoraj povedano in podaja šest prototipnih oblik elementov, označenih od A do F, ki zajemajo vse

feature and it requires a detailed description. In general there are many features on a tool, thus there is more than one instance of attribute $\boldsymbol{k}_2$ for each tool.

A manufacturing feature can be defined as a geometrical form of the workpiece to which manufacturing properties are associated and for which a manufacturing process is known. *In the case of the EDM process, a feature is a part of the tool that can be machined by an electrode or a set of electrodes for rough and fine machining on a given EDM machine.* The features are characterised by two properties: the tool movement direction and its accessibility to the feature. The movement of the electrode could be in one linear direction (1D), it could be in two combined directions (2D), in the combination of the three possible directions (3D) and the rotation of the electrode could be added to the three linear directions (4D). According to the accessibility of the electrode to the feature, the feature is called open when the feature can be reached from the top of the tool. It is closed when features cannot be reached directly from the top of the tool and extra actions are needed. Table 1 summarises these classifications and suggests six

Preglednica 1. *Karakteristike prototipnih oblik*
Table1. *Characteristics of the feature prototypes*

| | | Pomik elektrode (Electrode movement) | | | |
|---|---|---|---|---|---|
| | | 1D | 2D | 3D | 4D |
| Dostopnost elementa (Feature access) | odprt (open) | A | B | C | F |
| | zaprt (closed) | - | D | E | - |




Sl. 3. *Prototipne oblike elementov*
Fig. 3. *Prototypes of feature shapes*

oblike elementov, izdelane z elektroerozijo. Prototipne oblike so podane na sliki 3.

*2.3.2 Tehnološki prilastki za izdelavo orodja*

Da bi zajeli značilnosti elektroerozijskih strojev in karakteristike obdelovalnih parametrov, je treba zgraditi dve podatkovni bazi. Prva baza vsebuje podatke o elektroerozijskih strojih, ki so na voljo v dani orodjarni. Pomembni podatki so: velikost delovnega prostora $\boldsymbol{m}_1$, število interpoliranih osi $\boldsymbol{m}_2$ in natančnost obdelave v vsaki izmed interpoliranih osi $\boldsymbol{m}_3$.

Druga baza vsebuje obdelovalne režime in njihove karakteristike. Obdelovalni režim $\boldsymbol{m}_5$ je popisan s tremi glavnimi obdelovalnimi parametri: vžigno napetostjo, tokovno amplitudo in časom trajanja razelektritve. Vsak obdelovalni režim je navzdol omejen z najmanjšo obdelovalno površino, ki je še primerna za obdelavo z danim režimom. Poleg tega so za vsak obdelovalni režim značilne še: relativna obraba robu elektrode, dosežena hrapavost površine, globina toplotno prizadete plasti in zahtevan dodatek za nadaljnjo obdelavo, ki ga je treba upoštevati tudi pri spremembi iz enega obdelovalnega režima v drugega. Ta baza je neposredna kopija tehnoloških preglednic, ki jih podaja izdelovalec stroja za pomoč operaterju pri stroju.

Da bo predstavitev tehnoloških prilastkov popolna, podajmo na tem mestu še material elektrode $\boldsymbol{m}_4$ in potrebno število elektrod za izdelavo danega elementa na orodju $\boldsymbol{m}_6$. Ta dva prilastka sta enoznačno določena s predpisanimi konstrukcijskimi zahtevami za orodje in jih MPKI-EP določi glede na preslikave konstrukcijskih v tehnološke prilastke. Shema povezav je podana na sliki 4.

Prikazani so vsi konstrukcijski prilastki, ki so pomembni za določitev tehnoloških prilastkov za izdelavo orodja. Nekatere izmed preslikav iz konstrukcijskih prilastkov v tehnoške so zelo preproste: npr. velikost delovnega prostora stroja, ki ga MPKI-EP določi za izdelavo orodja, mora biti večji od zunanjih mer orodja. Drugi, najbolj zapleten problem je določitev obdelovalnih parametrov. Rešljiv je s sintezo računalniškega algoritma, ki upošteva izbrani stroj (s tem je določena podatkovna baza obdelovalnih režimov in njihovih karakteristik – preslikava $f_7$) in konstrukcijske

prototypes, marked from A to F, which well describe all the feature shapes machined by EDM. The prototypes of feature shapes are given in Fig. 3.

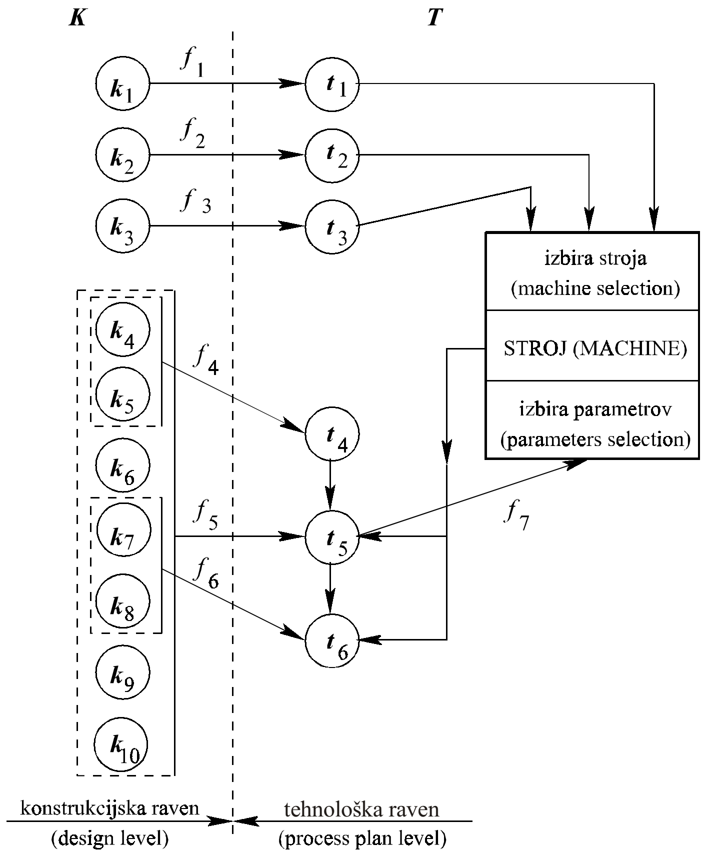
*2.3.2 Manufacturing attributes of the tool*

To describe the characteristics of EDM machines and the performance of the machines when certain machining parameters are used, two databases were built. The first database consists of the EDM machines data, which are available in the described toolmaking. The important data are the working area size in the $x, y, z$ axes $\boldsymbol{m}_1$, the list of axes that can operate on the particular machine $\boldsymbol{m}_2$, and the precision of the machine in each axis $\boldsymbol{m}_3$.

The second database consists of machining parameters and their performance. A group of set-up parameters, denoted as $\boldsymbol{m}_5$, includes free voltage, electric current amplitude and pulse-on time. Each group of parameters is limited by the smallest eroding surface size that can be machined by the given values of the set-up parameters. For each group of set-up parameters, the following performance is given: the relative corner wear of the electrode, the achieved surface roughness, the achieved depth of the heat-affected zone and the requested machining allowance, which should be taken into account also when changing from rough set-up to fine set-up. This database is a direct copy of the technological tables, given by the machine manufacturer as an assistance to the machine operator.

In order to present all the manufacturing attributes, it is necessary to describe the electrode material $\boldsymbol{m}_4$ and the required number of electrodes for machining of the given feature of the tool $\boldsymbol{m}_6$. These attributes are directly determined in MPKI-EP by the design demands for the tool, and they are established according to the mappings of the design to the manufacturing attributes.

Mappings from design to the manufacturing level are presented in Fig. 4, where are the design attributes that are required to establish the manufacturing attributes for tool machining. Some of the mappings are very simple, e.g., the machine working area size, which DAM-EDM selects for the machining of the given tool, must be larger than the size of the tool. A more complex problem is to determine the suitable machining parameters. This can be solved with a computer algorithm, which takes into account the selected EDM machine (the database of the machining parameters and process performances is




Sl. 4. *Preslikava konstrukcijskih prilastkov orodja v tehnološke prilastke za izdelavo orodja. Oznake konstrukcijskih prilastkov:* $\boldsymbol{k}_1$ *zunanje mere orodja,* $\boldsymbol{k}_2$ *oblike elementov,* $\boldsymbol{k}_3$ *predpisane tolerance,* $\boldsymbol{k}_4$ *material orodja,* $\boldsymbol{k}_5$ *velikost erodirne površine elementa,* $\boldsymbol{k}_6$ *globina elementa,* $\boldsymbol{k}_7$ *hrapavost elementa,* $\boldsymbol{k}_8$ *dovoljena globina toplotno prizadete cone elementa,* $\boldsymbol{k}_9$ *zaokrožitve robov,* $\boldsymbol{k}_{10}$ *nagib površin. Oznake tehnoloških prilastkov:* $\boldsymbol{t}_1$ *velikost delovnega prostora stroja,* $\boldsymbol{t}_2$ *število interpoliranih osi stroja,* $\boldsymbol{t}_3$ *natančnost posameznih osi stroja,* $\boldsymbol{t}_4$ *material elektrode,* $\boldsymbol{t}_5$ *obdelovalni parametri za obravnavan element,* $\boldsymbol{t}_6$ *število elektrod za izdelavo obravnavanega elementa.*

Fig. 4. *Mappings of the design attributes of the tool to the manufacturing attributes for tool manufacturing. Denotations of the design attributes:* $\boldsymbol{k}_1$ *size of the tool,* $\boldsymbol{k}_2$ *shape of the feature,* $\boldsymbol{k}_3$ *given tolerances,* $\boldsymbol{k}_4$ *tool material,* $\boldsymbol{k}_5$ *eroding surface size,* $\boldsymbol{k}_6$ *feature depth,* $\boldsymbol{k}_7$ *surface roughness of the element,* $\boldsymbol{k}_8$ *allowed heat-affected zone,* $\boldsymbol{k}_9$ *edge roundings,* $\boldsymbol{k}_{10}$ *slope of the flak surface. Denotations of the manufacturing attributes:* $\boldsymbol{t}_1$ *working area size of the machine,* $\boldsymbol{t}_2$ *number of axes,* $\boldsymbol{t}_3$ *precision of each axis,* $\boldsymbol{t}_4$ *electrode material,* $\boldsymbol{t}_5$ *set-up parameters,* $\boldsymbol{t}_6$ *number of electrodes required to machine a given feature.*

prilastke obravnavanega elementa – preslikavo $f_5$. Pri izbiri podatkovne baze obdelovalnih režimov je pomemben tudi material elektrode, ki je določen z materialom orodja in velikostjo erodirne površine elementa (preslikava $f_4$).

Ker je naš namen idejno predstaviti delovanje SPKIO, ne bomo na tem mestu predstavljali posameznih algoritmov, ki preslikujejo konstrukcijske in tehnološke prilastke in so predstavljeni v [16]. S slike 4 je razvidno, da gre za

known – mapping $f_7$) and the design attributes of the given feature – mapping $f_5$. When a database of the process parameters is selected, the electrode material, which is defined by the tool material and the eroding surface size, plays an important role (mapping $f_4$).

Since the purpose of this paper is to present a novel approach to manufacturing knowledge presentation on the design level, the algorithms for mapping from design to manufacturing level will not be presented here. They are presented in [16]. From Fig.

preslikavo iz konstrukcijskih v tehnološke prilastke, torej za funkcijo $F$. Obratna funkcija $F^{-1}$ je izvedena preko uporabnika SPKIO, torej konstrukterja izdelka (sl. 1).

## 3 SKLEP

V pričujočem prispevku predstavljamo SPKIO, ki spada v skupino sistemov za prilagajanje konstrukcije izdelavi. Glavna razlika med SPKIO in podobnimi sistemi je v tem, da prepušča odločitve o najboljši konstrukciji konstrukterju samem, ki najbolje pozna zahteve za izdelek. Prav tako pozna tudi zakonitosti estetike, ergonomičnosti ipd. Na takšen način konstrukterjeva ustvarjalnost ni omejena: namesto da se konstrukterja vodi skozi vnaprej določen protokol konstruiranja, ga SPKIO le opozarja na kritična mesta konstrukcije z vidika izdelave orodja in prepušča konstrukterju popolno svobodo glede spreminjanja konstrukcije. Kritična mesta odkrijeta izvedeniška sistema MPKI-EP in MPKI-VF.

Konstruiranje za lažjo izdelavo je zapletena naloga, še posebno v orodjarstvu, kjer je treba koordinirati veliko delnih rešitev. Zato je primerna modulna gradnja sistema. Posamezni moduli so uporabni tudi kot samostojni sistemi, vendar do prave veljave pridejo šele, ko so vsi združeni v skupen sistem. Do sedaj sta bila razvita dva izvedeniška sistema, ki delujeta samostojno. MSiDOP je predstavljen drugje [17], MPKI-EP pa smo v grobem predstavili v pričujočem prispevku. V prihodnje bomo razvili še MPKI-VF, ki bo pokrival frezanje z velikimi hitrostmi in vse tri module vključili v skupen sistem, ki je idejno predstavljen v pričujočem prispevku.

4 one can see that the mappings are made from the design to the manufacturing level, i.e., following the function $F$. The inverse function $F^{-1}$ is obtained through the use of DASMT, i.e., the product designer.

## 3 CONCLUSIONS

In this paper the DASMT system has been described. It belongs to the group of DFM systems, but it differs from other DFM systems as it leaves the best design solutions to the designer, who has the best knowledge about the demands on the product characteristics. The designer's knowledge also incorporates knowledge about the aesthetics, the ergonomics, etc. In this way the designer's creativity is fully supported: instead of leading the designer through the process of design, the DASMT system only points out the weak parts of the product design from the manufacturing point of view and leaves full freedom to the designer to adapt the design. The weak points of the design are revealed by the expert systems DAM-EDM and DAM-HSM.

Design adaptation for the ease of manufacture is a complex task, particularly in the toolmaking industry, where plenty of decisions have to be coordinated. Thus, the modular approach to system building is very suitable. Up to now two problem solvers of the DASMT system have been developed separately, and each of the problem solvers works autonomously. The MSaSMP was presented in [17] and DAM-EDM is briefly presented in this paper. Future work will be focused on the development of the DAM-HSM for adapting features that will be machined by HSM. The DAM-HSM will follow the same philosophy as the DAM-EDM. Later, all three modules will be included into a general system—DASMT—the functionality of which is described in this paper.

## 4 LITERATURA
## 4 REFERENCES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# Mikro nepravilnosti kovinskih površin

## Micro-Irregularities of Metal Surfaces

Edward Miko

*V prispevku ugotovljamo, da parametri obdelave, kot so: podajanje na zob, vrtilna frekvenca, interval poti orodja in nastavni kot orodja,vplivajo na hrapavost površine pri frezanju s krogelnim frezalom. Za ugotavljanje in analizo morfologije tako obdelane površine smo uporabili vrstični elektronski mikroskop (VEM - SEM). V prispevku smo prikazali in obravnavali fotografije z VEM površine z vzdolžnim in prečnim profilom. Prav tako smo ocenili vpliv faktorjev obdelave na geometrijsko mikrostrukturo površine. Predstavili smo tudi frekvenčno analizo profila obdelane površine s krogelnim frezalom. Raziskave kažejo, da ima interval poti orodja znaten vpliv na hrapavost površine, obdelovane s frezanjem.*

**(Ključne besede: frezanje oblikovno, obdelave površin, nastavljanje frezal, morfologija površin)**

*It has been established that machining parameters such as feed per tooth, rotational speed, tool path interval and cutter setting angle can influence the surface roughness during ball-end milling. A scanning electron microscope (SEM) was used to register and analyze the morphology of milled surfaces. SEM photographs of the surfaces with longitudinal and lateral profiles are included and discussed. The influence of the machining factors on the geometrical microstructure of the surface is also evaluated. A frequency analysis of the profiles of surfaces milled with a ball-end cutter is presented. The investigations show that the tool path interval has a considerable effect on the roughness of the milled surfaces.*

**(Keywords: ball-end mill, surface finish, cutters, setting, surface morphology)**

## 0 INTRODUCTION

Machining is a basic manufacturing technique used in mechanical engineering, and it is predicted that in the future its importance will not change. The amount of machining might even increase, as is in the case of precision machining [1].

Because of strong national and international economic competition, manufacturers are forced to introduce automation and flexible manufacturing, which increase the efficiency and the quality of products. The state of the superficial layer is one of the most important features of a product's quality. For this reason it is essential to be aware of the quality of the surface and attempt to improve it.

The improving accuracy of metal cutting, especially by turning and milling, means that machined surfaces often do not require any further finishing, which indirectly affects the operating properties of a product. Recently, a number of producers have replaced the polishing of certain elements with an initial casting or forging process followed by turning or milling to obtain the final dimensions and surface finish by means of tools with ceramic and CBN wedges [2]. The constitution of the geometrical structure and the properties of the superficial layer generated by chip milling are important problems and, therefore, require further theoretical and experimental investigations. An important feature of the superficial layer quality is its roughness ([3] and [4]).

High-speed tracer milling (HSM) and contour milling performed by means of numerically controlled (CNC) milling machines are commonly used in the manufacturing of elements with complex shapes, such as casting and injection moulds, matrixes, blanking and press-forming dies, turbine blades, screw propellers and others ([5] and [6]). One of the most popular methods of milling is machining with a ball-end cutter, which enables, for example, full form contouring on a CNC or tracer machine. No replacement of the tool is necessary, so the set-up and the machining time are much shorter. In the case of a 3-axis milling machine, it is desirable to use ball-end cutters that permit a quite different tool orientation in relation to the workpiece and, accordingly, machining a surface with complex 3D shapes [7]. Moreover, it would be essential to plan an optimum tool path for cutting, especially during the 3-axis milling of a 3D curvilinear surface. Milling with a ball-end cutter makes it possible to obtain a high, geometrical surface quality. Also, this type of milling can be applied to tasks once performed by EDMs (the milling of hardened materials or indenting). Therefore, machining with ball-end cutters has become interesting to many researchers and production engineers ([8] to [11]). A ball-end cutter is indispensable when it comes to the machining of surfaces inclined at a large angle [12].

Today, it is increasingly important that the form and the dimensional accuracy should be higher and the surface roughness should be lower. Therefore, face milling is being more and more frequently applied as a final treatment ([1] and [4]). Milling with a ball-end cutter can be used in the finishing of machine parts, if the requirements relating to surface quality are lower. However, the geometrical structure and the size of irregularities when a machined surface is subjected to further treatment are also of significance. The above factors will affect the machining time and related costs. In order to reduce the high labor consumption of finishing (usually manual polishing) [5], it is advisable to reduce as much as possible the surface irregularities after milling.

For these reasons, investigations have often focused on the evaluation of the influence of machining factors on the roughness of surfaces machined with a ball-end cutter. Due to the fact that the surface's geometrical structure obtained after machining was non-homogeneous, the surfaces had to be evaluated using a scanning electron microscope. Measurements of the longitudinal and lateral roughness were also useful. In addition, the frequency of the longitudinal and lateral profiles of the milled surfaces were analyzed.

## 1 THEORETICAL SURFACE ROUGHNESS AFTER MILLING WITH A BALL-END CUTTER

The cutting edges of the cutter rotating around its own axis determine the axial-symmetrical area of the cutter's interaction. The machined surface is an envelope of the feed motion in the cutter interaction area. In the case of a ball-end cutter, the interaction area can have different shapes depending on the setting of the cutting part in relation to the workpiece. The cutter interaction area is also affected by the value of the depth of cut, $a_p$.

During ball-end milling, the tool touches the stock. The characteristic repeatable structure of the machined surface results from the path interval, $a_e$ (i.e., the distances between particular paths). The structure reflects the height of surface irregularities (Fig. 1).

The height of the roughness, *Rt*, resulting from the path interval is the maximum roughness measured in the direction lateral to the milling direction and depends on the cutter diameter, the corner radius and the tool's cutting-edge angle (Fig. 1).

For a given path interval and tool diameter, the theoretical roughness height can be determined from the dependence:

$$Rt = \frac{D_c}{2} - \sqrt{\frac{D_c^2 - f_w^2}{4}} \quad (1),$$

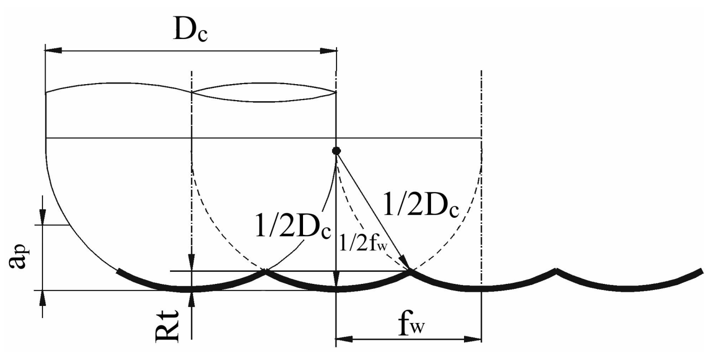



Fig. 1. *Auxiliary diagram for determining the surface roughness parameters*

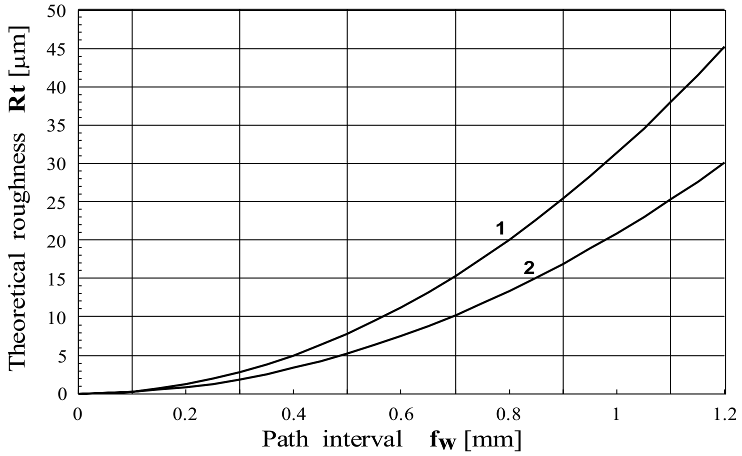



Fig. 2. *Theoretical height of the surface roughness, Rt , in relation to the tool path interval,* $f_w$*, for a tool diameter of: 1,* $D_c$ *= 8 mm, and 2,* $D_c$ *= 12 mm*

where $D_c$ is the tool diameter, and $f_w$ is the path interval.

The dependence of the height of the roughness, *Rt*, on the path interval, $f_w$ , for diameters of ball-end cutter equal to $D_c$ = 8 mm and $D_c$ = 12 mm is presented in Fig. 2

The value of the mean arithmetic profile deviation from the mean line Ra can be defined from the relationship:

$$Ra = \frac{f_w^{\,2}}{9\sqrt{3}\cdot D_c} \qquad (2).$$

The interdependence of the roughness, Ra, and the tool path interval, $f_w$ , for cutters with diameters of $D_c$ = 8mm and $D_c$ = 12mm is presented in Fig. 3.

During ball-end milling, the cutting speed changes depending on the depth of cut, $a_p$. The depth of cut is connected with the term of the effective diameter, $D_{ef}$. The value of this diameter affects the cutting speed, $v_c$. For a given depth of cut it is the maximum cutting speed. If the depth of cut, $a_p$, is smaller than the radius R = $D_c$/2 of the ball-ended tip, then the real diameter of the cutting tool, $D_{ef}$, can be calculated from:

$$D_{ef} = 2\sqrt{a_p(D_c - a_p)} \qquad (3).$$

Figure 4 shows the dependencies of the effective diameter, $D_{ef}$, on the depth of cut, $a_p$, for a ball-end cutter with diameters of $D_{c1}$ = 12 mm and $D_{c2}$ = 8 mm.

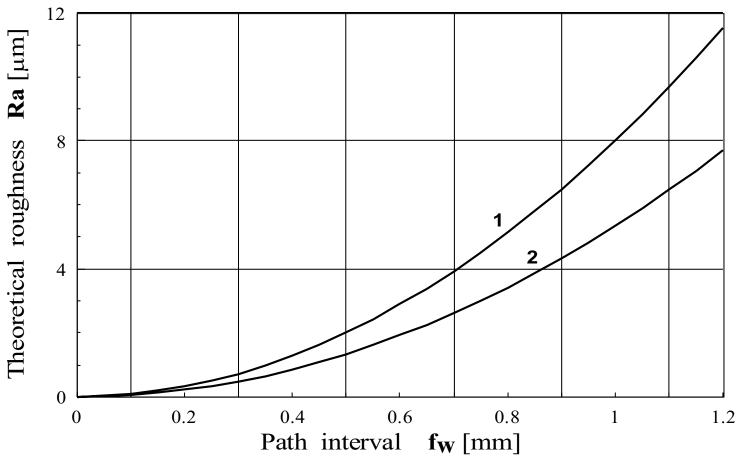



Fig. 3. *Mean arithmetic profile deviation, Ra, in relation to the tool path interval,* $f_w$*, for a tool diameter of: 1,* $D_c$ *= 8 mm, and 2,* $D_c$ *= 12 mm*

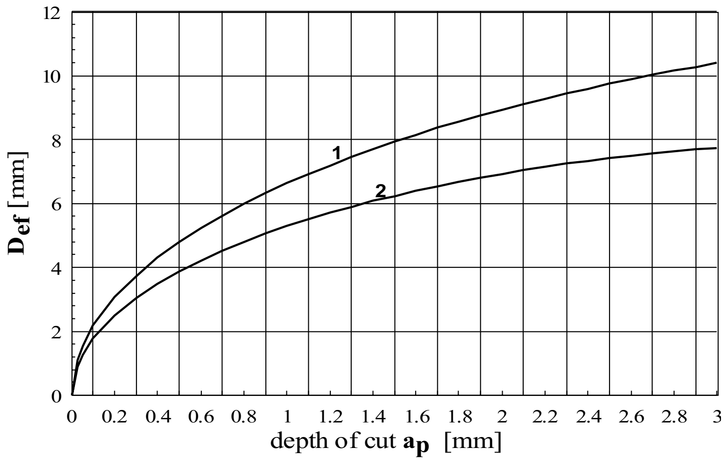



Fig. 4. *Effective diameter of the cutting in relation to the depth of cut with a ball-end cutter with a diameter of : 1, $D_{c1}$ = 12 mm, and 2, $D_{c2}$ = 8 mm*

Table 1. *Cutting conditions for the studied samples*

| Cutting conditions | Tool - *Heliball* ball-end cutter made by ISCAR<br>*CM D12*<br>*CR D120–QF–(IC328)* insert | |
|---|---|---|
| Sample setting angle | 0° | 60° |
| Feed per tooth $f_z$ [mm/tooth] | 0.04; 0.08; 0.12; 0.16; 0.20; 0.24 | 0.02; 0.04; 0.08; 0.12; 0.16; 0.20 |
| Types of milling | In-cut, out-cut | In-cut, out-cut |
| Workpiece material | 45 carbon steel, MO58 brass | |
| Tool rotational speed *n* [rpm] | 500; 1000; 1750; 2500; 3750; 4000 | |
| Tool path interval $f_w$ [mm] | 0.1; 0.3; 0.5; 0.7; 0.9; 1.1 | |

## 2 THE RESEARCH SUBJECT, RANGE AND METHODOLOGY

The aim of the research is to analyze the influence of selected machining factors on the roughness of surfaces milled with ball-end cutters on a CNC milling machine.

The samples were machined by applying the parameters given in Table 1. The machining was performed by changing one of the milling conditions, i.e., feed, $f_z$, tool path interval, $f_w$, or the rotational speed, *n*, and, accordingly, the cutting speed, $v_c$, and by milling with an appropriate part of the curvilinear edge of the insert.

The samples used in the experiments were made of 45 carbon steel (in accordance with the Polish standard No. - 93/H - 84019) and MO58 brass (in accordance with the Polish Standard No. 77/H - 87025). Their construction allowed a measurement of the longitudinal and lateral roughness.

Figure 5 shows the milling process and the method of sample fitting.

As soon as the cutting tests were completed and the specimens removed from the machine tool, longitudinal and lateral profiles of the roughness of the machined surface were registered and analyzed. In-cut and out-cut milling was performed on a CNC TRIAC 200 milling machine using Castrol syntilo RHS coolant. The applied CNC TRIAC 200 milling machine made by DENFORD was equipped with a 3-axis HEIDENHAIN 360 controller. The machining programs were generated with the MASTERCAM MILL system. Since the machine tool head cannot be turned, the samples were fitted in a specially designed machining holder. This enabled surfacing at 0° and 60° angles, which corresponded to the application of two different parts of the curvilinear edge of the cutter. A Heliball CM D120 ball-end cutter with a CR D12–QF–(IC328) double-edged insert 12 mm in diameter made by ISCAR was used for the machining.

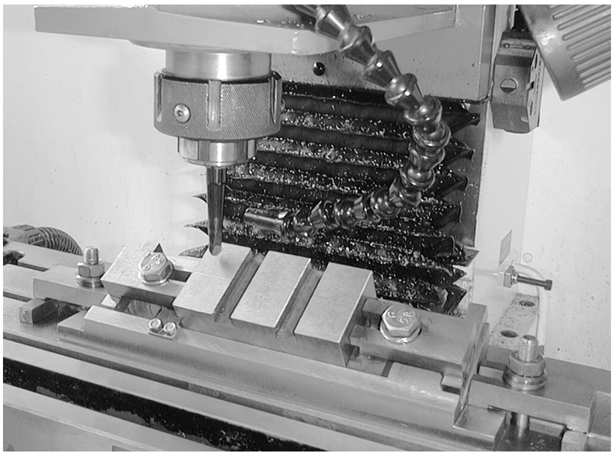


Fig. 5. *View of milling of a specimen mounted in a machining holder at an angle of 60° using a CNC TRIAC 200 milling machine*

The complex analysis of the geometrical surface structure ([4] and [10]) involved registration and study of the morphology of samples by means of a JEM-540 scanning electron microscope made by the Japanese company JEOL.

The research, divided into four stages, was conducted at the laboratories of the University of Technology in Kielce and the Institute of Metal Cutting in Cracow.

- The first part of investigations concerning machining was carried out at the Laboratory of Numerically Controlled Machine Tools, where by means of the MASTERCAM program the geometries of the specimens were prepared and CNC machining programs were developed. The programs were transmitted to a CNC TRIAC 200 milling machine, on which most tests, i.e., machining, were performed (Fig. 5). Two materials, 45 steel and MO58 brass, were used for machining and other tests.
- The next step was to measure the roughness, *Ra*, using a PM-03 profilometer in a room that satisfied the requirements given in the specifications of the device. The values of the lateral (perpendicular to the feed direction) and longitudinal (parallel to the feed direction) roughness were measured.
- At the third stage, the obtained surfaces were observed, evaluated and analyzed with respect to the microstereometry achieved by means of an scanning electron microscope. The observed surfaces of the brass and steel specimens were registered in a graphical file format that was attached to the investigation results.
- Finally, a PM-03 profilographometer was used to register and measure the lateral and longitudinal profiles. The POM–16 software was applied to determine the standardized unilateral functions of the spectral power density (FSPD) of these profiles.

The laboratory investigations were carried out at special stands, which enabled machining and measurement of the specimens and registration of the measuring results.

The test stand for machining the specimens consists of:

- a computer with the MASTERCAM MILL software,
- a CNC TRIAC 200 milling machine (Fig. 5),
- a workpiece.

The test stand for measuring the surface roughness includes:

- a tested-machined workpiece,
- a PM–03 profilometer for contact measurement of the roughness *Ra.*

The test stand for observing the surface morphology consists of:

- a JEM 5400 scanning electron microscope made by the Japanese company JEOL,
- a computer set and software for registering photographs.

The test stand for registering profiles and determining the FSPD consists of:

- a tested-machined workpiece,
- a PM–03 profilometer for contact measurement of the roughness *Ra*,
- a computer set and the POM–16 software.

## 3 ANALYSIS OF THE RESULTS

Figures 6–9 show the influence of the studied factors on the lateral and longitudinal roughness, *Ra,* of 45 carbon-steel samples after machining with a ball-end cutter with a diameter of $D_c$ = 12 mm.

An increase in the tool path interval, $f_w$, causes an increase in the lateral roughness, *Ra* (Fig. 6). This figure shows the theoretical values of the parameter *Rao* determined from Eq. (2). One can see that the values measured on the surfaces machined at 0° and 60° angles are greater than the theoretical

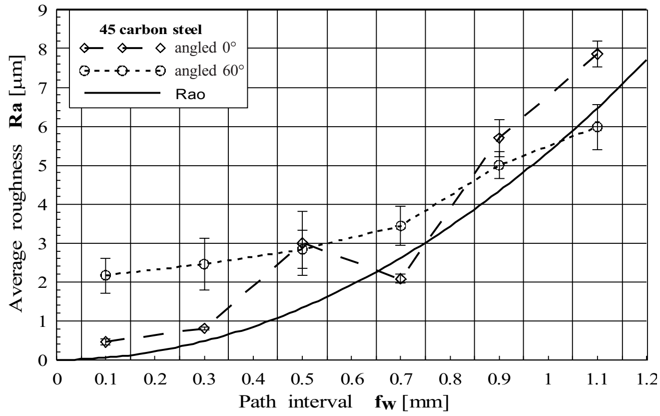



Fig. 6. *Influence of the tool path interval, $f_w$, on the lateral surface roughness, Ra. The cutting conditions used were: $a_p$ = 0.25 mm, n = 2500 rpm, $f_z$ = 0.08 mm/tooth, $D_c$ = 12 mm, in-cut milling*

a)

b)

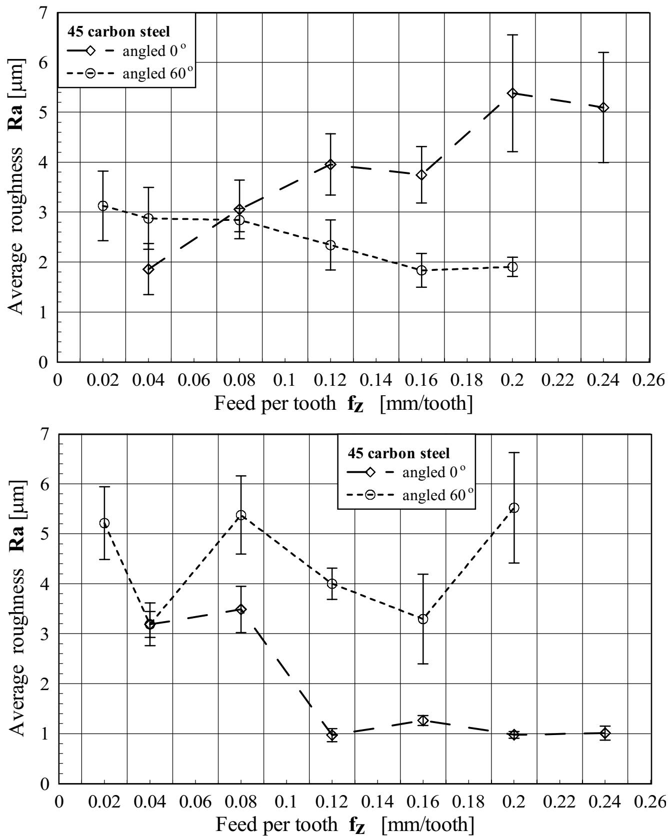



Fig. 7. *Influence of the feed, $f_z$ , on the lateral surface roughness, Ra. The cutting conditions used were: $f_w$ = 0.5 mm, $a_p$ = 0.25 mm, n = 2500 rpm, $D_c$ = 12 mm; a) in-cut milling b) out-cut milling*

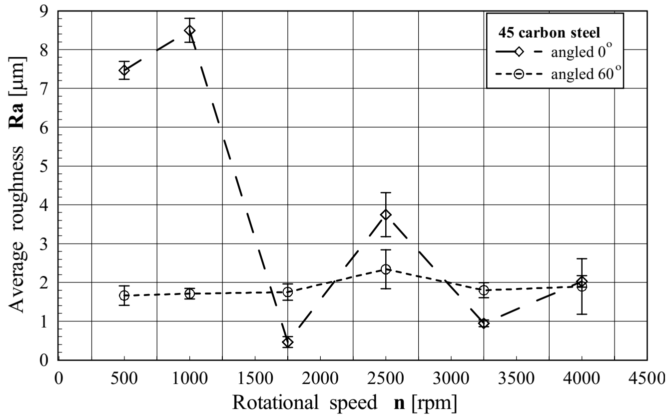



Fig. 8. *Influence of the rotational speed, n , on the lateral surface roughness, Ra. The cutting conditions used were:* $f_w$ *= 0.5 mm,* $a_p$ *= 0.25 mm,* $f_z$ *= 0.08 mm/tooth,* $D_c$ *= 12 mm, in-cut milling*

ones. Particularly large discrepancies occur for small tool path intervals, $f_w$. This confirms that other factors, forepart from the cutter-wedge representation, have considerable influence on the roughness of a machined surface. The factors include relative vibrations of the tool and the workpiece, the run-out of the cutter wedge and the plastic strain of the material.

During the in-cut milling of 45 steel, an increase in $f_z$ causes an increase in the lateral roughness, *Ra*, when the sample is set at an 0° angle and its decrease at 60° (Fig. 7a). During out-cut milling, an increase in $f_z$ results in a decrease in the value of the parameter *Ra* at 0° angle; yet no clear influence of $f_z$ is observed at the 60° angle (Fig. 7b).

The cutter rotational speed, *n,* has no particular effect on the value of the parameter *Ra* when the angle of the setting is 60°. However, the influence is not clear at the downward trend and 0° angle (Fig. 8).

The effect of the feed, $f_z$, on the longitudinal roughness, *Ra,* is not clear during in-cut or out-cut milling (Fig. 9). In most cases, the roughness, *Ra,* was smaller after milling at a 0° angle than after milling at a 60°angle. A completely different situation was observed during milling with a single-wedge cutter with a diameter of $D_c$ = 8 mm [13]. During milling at 0° angle with a double-wedge cutter 12 mm in diameter for a given depth $a_p$ = 0.25 mm, only one wedge was used. At a 60° angle, however, two wedges were used. We can speculate that the increase in the roughness, *Ra,* was caused by the run-out of the cutter wedges. Despite the fact that at a 0° angle we have the effect of the small cutting speed and its unfavorable influence on the roughness, confirmed during machining with a cutter 8 mm in diameter [13], the increase in roughness was smaller than when machining with a cutter 12 mm in diameter. The roughness was greater only when the 45 steel was milled at small values of rotational speed, n = 500 and n = 1000 rpm (Fig. 8), and great feeds at 0° angle rather than at 60° (Fig. 7b). This was probably due to a build-up edge, which is observed at the small cutting speed, and as such occurred for those revolutions and the 0° setting angle.

Figure 10 shows a photograph of surface morphology of a 45 carbon steel specimen machined with a ball-end cutter with a diameter of $D_c$ = 12 mm. The lateral and longitudinal profiles of the surface roughness can be seen on the left-hand side and at the top, respectively.

The presented out-cut milled surface has clear marks resulting from tool paths.

In a lateral profilogram the predominant frequency results from the tool path interval, $f_w$. The value of the roughness for this profile is Ra = 3.19 ± 0.26 µm (Fig. 7b). The tool paths and the tool marks are also seen, and the intervals between them are equal to $f_z$. In a longitudinal profilogram the predominant frequency corresponds to the feed per tooth, $f_z$. The value of the parameter *Ra* for this profile is Ra = 2.42 ± 0.30 µm (Fig. 9b). The frequency analysis of these profiles is shown in Figs. 12 and 13. Figure 11a is a photograph of a surface with tool marks magnified 90 times. Also, in Fig. 11b, where a magnification of 300 was applied, there are tool marks and boundaries of the material flow. Cracks and tears of the workpiece material are also observed.

The registered longitudinal and lateral profiles of the micro-roughness of the surfaces milled

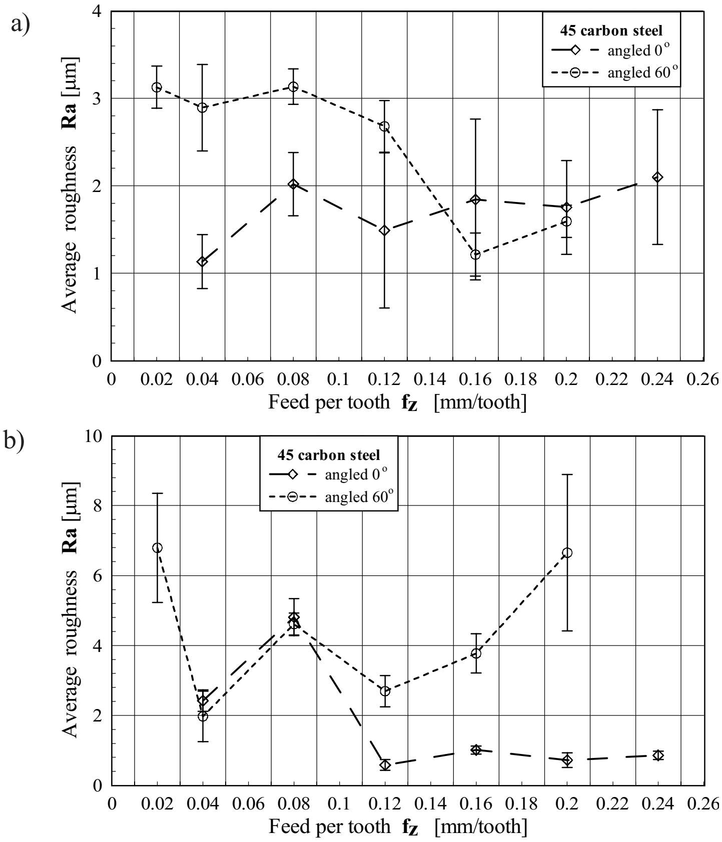



Fig. 9. *Influence of the feed, $f_z$, on the longitudinal surface roughness, Ra. The cutting conditions used were: $f_w$ = 0.5 mm, $a_p$ = 0.25 mm, n = 2500 rpm, $D_c$ = 12 mm; a) in-cut milling b) out-cut milling*

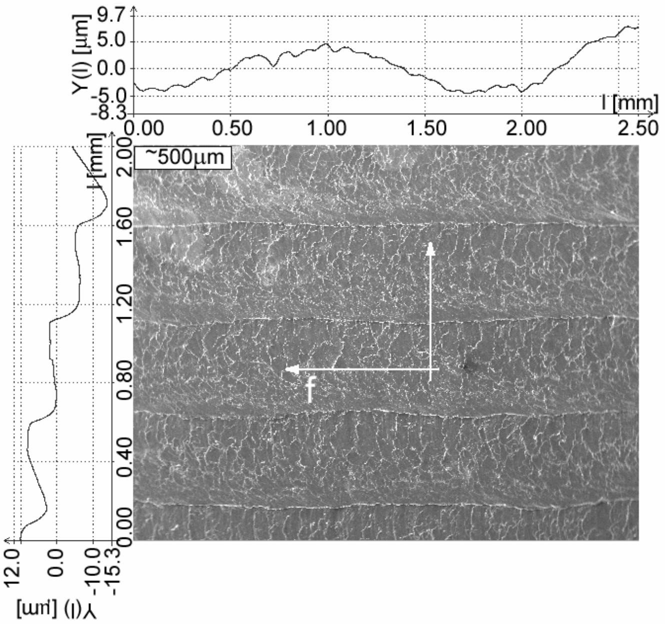
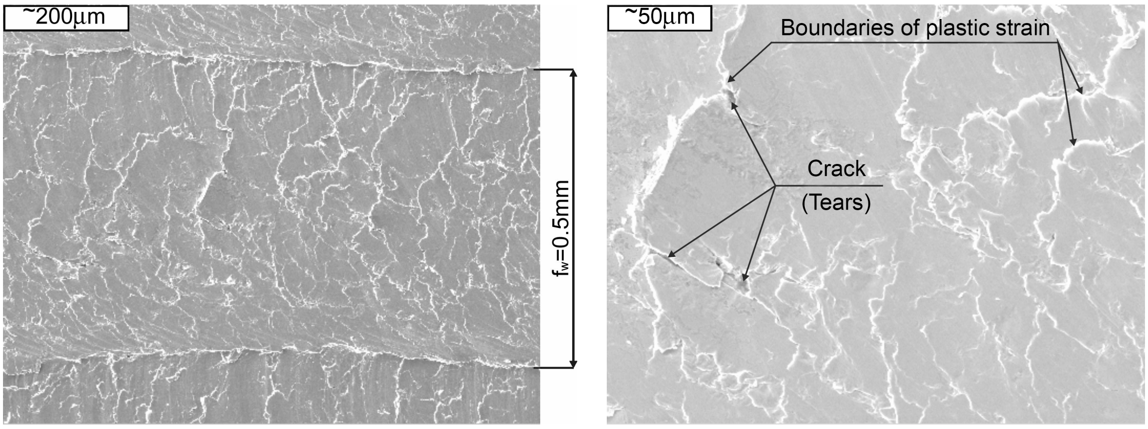



Fig. 10. *Morphology and longitudinal and lateral profilograms of a surface machined with a ball-end cutter. The cutting conditions used were: $f_z$ = 0.04 mm/tooth, $a_p$ = 0.25 mm, $f_w$ = 0.5 mm, $D_c$ = 12 mm, n = 2500 rpm, 45 steel workpiece material, $0^o$ angle, out-cut milling. Magnification of 50*




a) b)

Fig. 11. *Surface morphology. The cutting conditions used were: $f_z$ = 0.2 mm/ tooth, $a_p$ = 0.25 mm, $f_w$ = 0.5 mm, $D_c$ = 12 mm, n = 2500 rpm, 45 steel workpiece material, 0º angle, out-cut milling; a) magnification of 90; b) magnification of 300.*

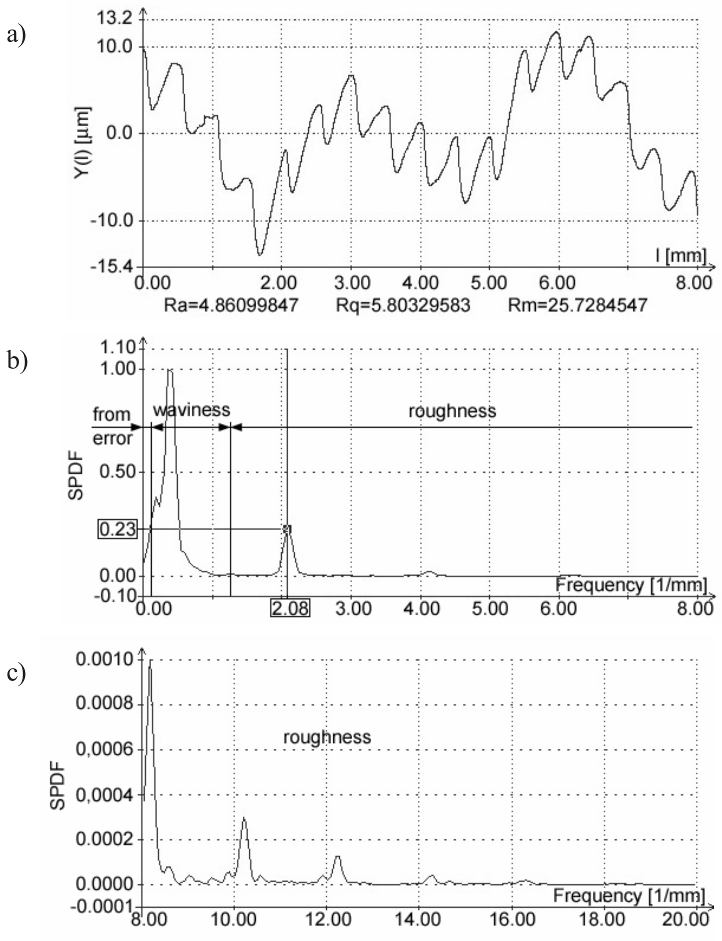



Fig. 12. *Lateral profilogram (a) and the corresponding diagram of a standardized unilateral function of spectral power density of a profile (b, c). The cutting conditions used were: $f_z$ = 0.04 mm/tooth, $a_p$ = 0.25 mm, $f_w$ = 0.5 mm, $D_c$ = 12 mm, n = 2500 rpm, 45 steel workpiece material, 0º angle, out-cut milling*

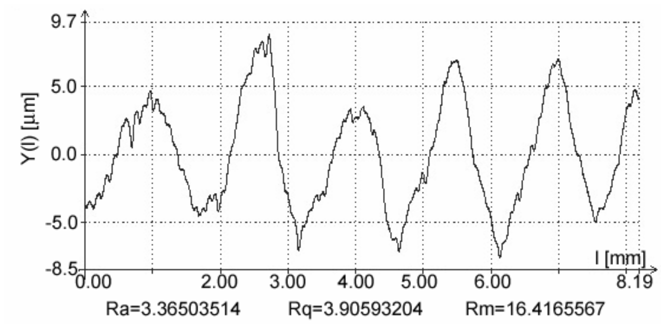
according to the sampling plan (Table 1) were analyzed by determining a standardized unilateral function of the spectral power density (FSPD). The investigation results are presented in the form of profilograms and the corresponding FSPDs (periodograms), which define the profile frequency structure. In addition, in the FSPD diagrams, the ranges corresponding to the form and surface waviness and roughness errors are marked.

Bands corresponding to the tool path interval, $f_w$, were identified in the analyzed lateral periodograms, whereas the bands corresponding to the feed per tooth, $f_z$, were identified in the longitudinal ones.

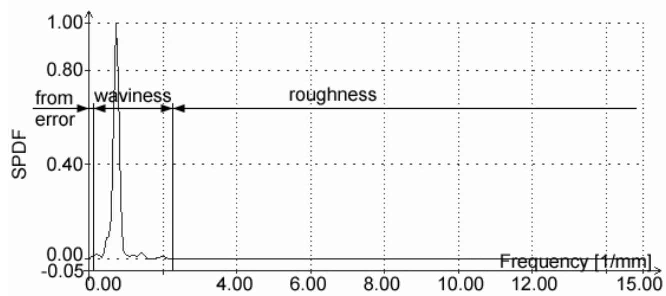
Selected investigation results are presented in Figs. 12 and 13. Figure 12 shows a band with a frequency of 2.08 1/mm corresponding to $f_w$ = 0.5 mm, which is within the range of roughness. This means that, for the cutting conditions given in Fig. 12, this value of $f_w$ will cause irregularities that are roughness. In Figs. 12 b and c subsequent harmonics of this band are seen. The influence of the tool path interval is predominant here.

Figure 13 presents a longitudinal profilogram and its frequency analysis. In Fig. 13b a band with a frequency of 0.8 1/mm situated within the range of waviness can be seen. The surface roughness, as the band indicates, is probably a result of errors of the machine tool table shift caused by the waviness of the shears of a Triac 200 milling machine. In Fig. 13c a band with a frequency of 24.29 1/mm was identified, which corresponds to a feed per tooth of $f_z$ = 0.04 mm/tooth. This figure shows a random character of the spectrum.

a)




b)




c)

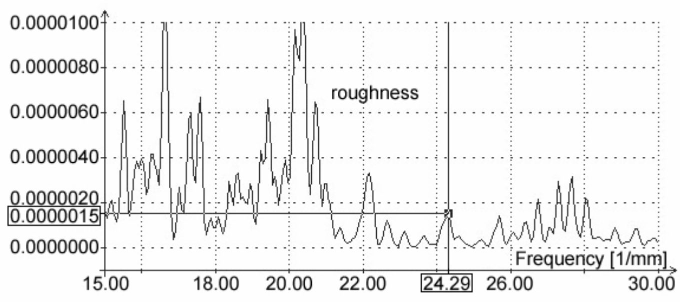



Fig. 13. *Longitudinal profilogram (a) and the corresponding diagram of a standardized unilateral function of spectral power density of a profile (b, c). The cutting conditions used were:* $f_z$ *= 0.04 mm/ tooth,* $a_p$ *= 0.25 mm,* $f_w$ *= 0.5 mm,* $D_c$ *= 12 mm, n = 2500 rpm, 45 steel workpiece material,* $0^o$ *angle, out-cut milling*

## 4 CONCLUSIONS

The comparative studies of the in-cut and out-cut ball-end milling using a cutter with a diameter of $D_c$ = 12 mm revealed that surface irregularities were smaller after in-cut milling.

Actually, when the diameter of the cutter is $D_c$ = 12 mm, smaller irregularities *Ra* are observed at a 0° angle (milling with the cutter tip) than at a 60° angle (milling with the cutter sides). We can speculate that the increase in roughness during milling with the cutter sides is probably caused by the run-out of the cutter wedges, which does not occur during milling with the cutter tip because, for such a setting and depth of cut $a_p$ = 0.5 mm, only one wedge is used. During milling with the cutter tip the effect of the low cutting speed is observed. It has an unfavorable influence on the surface roughness. In most cases, the effect of the run-out of the cutter wedges predominated over the effect of the low cutting speed, hence the irregularities of the surfaces milled with the cutter sides were usually greater than those milled with the cutter tip.

In the diagrams of the function of the spectral power density of the lateral profiles there are bands with a frequency corresponding to the value of the tool path interval and their subsequent harmonics. In the diagrams of the function of the spectral power density of longitudinal profiles there are bands with a frequency corresponding to the value of feed per tooth. In the diagrams we can also see a spectrum of a random character representing the influence of other factors of the machining system and the tool. The photographs of the machined surface present results of morphological investigations, i.e., the influence of a change of particular parameters ($f_z$, $f_w$, $n$) on the character of the machined surface.

The photographs, where the feed was the key parameter, include, except for the evaluated surface, longitudinal and lateral profiles, testifying to difficult cutting conditions. In the photographs showing milling with the cutter tip (0° angle) there are clear grooves, i.e., tool marks with unremoved material fragments and tears along the edges. This is caused by unfavorable cutting conditions near the tip, where the cutting speed is close to zero.

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# Model stenskega uparjanja za popis podhlajenega vrenja toka pri nizkih tlakih

## Wall-Evaporation Model for a Description of Sub-Cooled Flow Boiling under Low-Pressure Conditions

Boštjan Končar - Borut Mavko - Ivo Kljenak

*V prispevku je predstavljen model stenskega uparjanja za popis podhlajenega vrenja pri nizkih tlakih. Model temelji na lokalnih mehanizmih nukleacije mehurčkov in obsega vpliv debelitve toplotne mejne plasti ob greti steni. Model smo vključili v enorazsežni termo-hidravlični program RELAP5. Spremenjeni program smo testirali na številnih nizkotlačnih preizkusih podhlajenega vrenja iz literature ([1] do [4]). V nasprotju s sedanjim programom smo dosegli zelo dobro ujemanje izračunov z meritvami.*

**(Ključne besede: uparjanje stensko, vrenje toka podhlajeno, programi termohidravlični, RELAP5)**

*In this paper we propose a wall-evaporation model for sub-cooled flow boiling under low pressures. The model is based on local mechanisms of bubble nucleation and captures the effect of the developing thermal boundary layer near the heated wall. The model was incorporated into the one-dimensional thermal-hydraulic code RELAP5. The modified code was validated against a number of published low-pressure sub-cooled boiling experiments ([1] to [4]), and in contrast to the existing code it shows good agreement with the experimental data.*

**(Keywords: hot wall evaporation, sub-cooled flow boiling, thermal-hydraulic code, RELAP5)**

### 0 UVOD

Podhlajeno vrenje toka se pojavi, ko ob greti steni kanala nastaja para, kljub temu da je povprečna temperatura toka kapljevine po prerezu toka nižja od temperature vrelišča. Pojav je posebej pomemben v jedrskih reaktorjih hlajenih z vodo, pri katerih parni mehurčki v sredici vplivajo na obnašanje reaktorskega sistema, tako med normalnim obratovanjem kot tudi v primeru nezgodnih scenarijev.

Za celovite analize prehodnih pojavov v hladilnih sistemih jedrskih reaktorjev se večinoma uporabljajo enorazsežni termohidravlični programi (RELAP5, TRAC, CATHARE, ATHLET). V zadnjih letih se je zaradi potreb po varnostnih analizah raziskovalnih jedrskih reaktorjev, ki obratujejo pri nizkih tlakih, in zaradi raziskav koncepta hlajenja zbiralnika zadrževalnega hrama prihodnjih

### 0 INTRODUCTION

Sub-cooled flow boiling occurs when vapour is produced as a cold liquid flows along a heated channel, even though the average liquid temperature over the channel cross-section is lower than the liquid saturation temperature. The phenomenon is especially important in water-cooled nuclear power reactors, where the presence of vapour bubbles in the core influences the behaviour of the reactor system, either during normal operation or in the case of accident scenarios.

To perform integral simulations of the transient phenomena in nuclear-reactor coolant systems one-dimensional thermal-hydraulic codes (such as RELAP5, TRAC, CATHARE and ATHLET) are widely used. In recent years, the interest in numerically simulating sub-cooled flow boiling at low pressures (1 to 3 bar) has increased, driven by the need to perform lahkovodnih reaktorjev (PLVR - ALWR) povečalo zanimanje za numerične simulacije podhlajenega vrenja toka pri nizkih tlakih (1 do 3 bar). Vendar je večina konstitucijskih modelov v današnjih termohidravličnih programih razvita in preverjena pri visokih tlakih (zaradi uporabnosti v jedrskih elektrarnah), zato jih ne moremo brez sprememb uporabiti za preračune nizkotlačnih sistemov. Eden od glavnih ciljev razvijalcev programov je razširitev uporabnosti celovitih programov tudi v območje nizkih tlakov.

V zadnjem času je bilo z različnimi termohidravličnimi programi izvedenih več simulacij podhlajenega vrenja pri nizkih tlakih. Rezultati analiz modelov podhlajenega vrenja ([5] do [8]), ki se uporabljajo v sedanjih termohidravličnih programih, so pokazali, da je izračunani delež parne faze pri nizkih tlakih mnogo nižji kakor tisti v preizkusih. Pri nizkih tlakih je razlika med gostotama kapljevine in pare bistveno večja kakor pri visokih tlakih (1:1590 pri 1 bar, 1:6.2 pri 150 bar), zato enaka količina nastale pare zavzame bistveno večjo prostornino. Pri visokih tlakih so parni mehurčki razmeroma majhni, medtem ko so pri nizkih tlakih le-ti bistveno večji. Večanje deleža parne faze vzdolž toka je tako močno odvisno od spremembe velikosti mehurčkov. V splošnem na količino proizvedene pare med pojavom podhlajenega vrenja vplivajo različni fizikalni mehanizmi, kakor so stensko uparjanje, kondenzacija parnih mehurčkov v podhlajeni kapljevini, koncentracija medfazne površine (določena z velikostjo mehurčkov) in medfazno trenje. V tem prispevku smo posebej obravnavali modeliranje stenskega uparjanja. Predlagali smo novi posplošeni model stenskega uparjanja za uporabo v termohidravličnih programih in ga vključili v program RELAP5.

## 1 MODEL STENSKEGA UPARJANJA

Model stenskega uparjanja popisuje hitrost generacije parnih mehurčkov na greti površini stene. Predstavljen je enorazsežni model stenskega uparjanja za uporabo v termohidravličnih programih. Pri razvoju modela smo upoštevali naslednje predpostavke:

1. V razmerah nasičenja, v katerih sta kapljevina in para v toplotnem ravnovesju ($T_l=T_g=T_{sat}$), se celotni dovedeni toplotni tok porabi samo za generacijo pare.
2. Model uparjanja mora temeljiti na osnovnih

safety analyses of research nuclear reactors operating at low pressures and to investigate the sump-cooling concept for advanced light-water reactors (ALWR). However, as most of the constitutive models in present-day thermal-hydraulic codes have been developed and validated for high-pressure conditions (due to the relevance for nuclear power plants), they cannot be straightforwardly applied for calculations involving low-pressure systems. One of the main goals of code developers is to extend the applicability of current integral codes to the low-pressure region.

Recently, several simulations of sub-cooled boiling under low-pressure conditions using different thermal-hydraulic codes have been performed. The results of analyses of the sub-cooled boiling models ([5] to [8]) used in the current thermal-hydraulic codes have shown that, at low pressures, the calculated void fraction is significantly lower than in experiments. At low pressures, the difference between the liquid and vapour densities is much higher than at high pressures (1:1590 at 1 bar, 1:6.2 at 150 bar); therefore, the same amount of generated vapour occupies a significantly larger volume. The vapour bubbles are relatively small at high pressures, whereas they are much larger at low pressures. The increasing of the void fraction along the flow therefore strongly depends on the change of bubble size. In general, the amount of vapour produced during the sub-cooled flow boiling process is governed by different physical mechanisms, such as wall evaporation, the condensation of vapour bubbles in a sub-cooled liquid, the interfacial area concentration (determined by the bubble size) and the interfacial drag between the phases. In this paper we focus on the modelling of wall evaporation. A new generic wall-evaporation model for application in thermal-hydraulic codes is proposed and incorporated into the RELAP5 code.

## 1 THE WALL-EVAPORATION MODEL

The wall-evaporation model describes the generation rate of vapour bubbles on a heated wall surface. A one-dimensional wall evaporation model for implementation in thermal-hydraulic codes is presented. When developing the model, the following assumptions were taken into account:

1. Under saturation conditions, where the liquid and vapour are in thermal equilibrium ($T_l=T_g=T_{sat}$), the entire wall heat flux has to be used for vapour generation.
2. The model of wall evaporation has to be based on the basic parameters that describe bubble nucleation:

parametrih, ki opisujejo mehurčkasto vrenje: velikost mehurčka, gostota nukleacijskih jeder $N_a$ in frekvenca nukleacije mehurčkov $f$.

3. Pri nizkih tlakih mora biti delež toplotnega toka za uparjanje bistveno večji kakor v modelih stenskega uparjanja, ki se uporabljajo v sedanjih termohidravličnih programih. Kakor je navedeno v literaturi, termohidravlična programa RELAP5 ([7] in [8]) in ATHLET [5] napovesta prenizko hitrost stenskega uparjanja.

Hitrost stenskega uparjanja lahko določimo z uporabo t.i. modela razdelitve toplotnega toka, ki predpostavlja, da se celotni dovedeni toplotni tok porabi delno za uparjanje pregrete kapljevine v mejni plasti tik ob greti površini in delno za segrevanje podhlajene kapljevine v jedru toka. Za osnovo pri razvoju modela stenskega uparjanja smo uporabili model razdelitve dovedenega toplotnega toka Kurula in Podowskega [9]. Po njunem modelu je vsaka enota grete površine razdeljena na dva dela: prvi del obsega vplivno območje nukleacije mehurčkov $A_{bub}$, medtem ko na preostalem delu grete površine $A_{1\phi}$ poteka konvektivni prenos toplote s stene na kapljevino. $A_{bub}$ in $A_{1\phi}$ v brezrazsežni obliki pomenita deleže celotne grete površine:

bubble size, the number of active nucleation sites per unit surface and the nucleation frequency of the bubbles.

3. Under low-pressure conditions, the fraction of wall heat flux used for wall evaporation must be significantly higher than in the wall-evaporation models used in the existing thermal-hydraulic codes. According to the literature, the thermal-hydraulic codes RELAP5 ([7] and [8]) and ATHLET [5] predict a wall-evaporation rate that is too low.

The wall-evaporation rate can be determined from the so-called heat-flux partitioning model, which assumes that the total applied heat flux is consumed partially for the evaporation of the superheated liquid in the boundary layer adjacent to the heated surface and partially for the heating of the sub-cooled liquid in the core flow. As a basis for the development of the wall-evaporation model, the heat-flux partitioning model of Kurul and Podowski [9] was used. According to their model, each unit of the heated surface consists of two parts: the first part of the heated area occupies the influence area of bubble nucleation, $A_{bub}$, whereas single-phase convection from the wall to the liquid takes place on the remaining part of the heated area, $A_{1\phi}$. In non-dimensional form, $A_{bub}$ and $A_{1\phi}$ represent the fractions of the total heated area:

$$A_{bub} + A_{1\phi} = 1 \qquad (1).$$

Celotni dovedeni toplotni tok iz stene na dvofazni vrelni tok sestoji iz treh različnih komponent (sl. 1):

The total heat flux transferred from the wall to the two-phase boiling flow consists of three different components (Figure 1):

$$q_w = q_{1\phi} + q_Q + q_e \qquad (2),$$

kjer:

- $q_{1\phi}$ označuje toplotni tok zaradi enofazne konvekcije, ki se vrši zunaj vplivnega območja nukleacije mehurčkov;
- $q_Q$ označuje toplotni tok zaradi površinskega hlajenja znotraj vplivnega območja mehurčkov $A_{bub}$ (to je prenos toplote s stene na podhlajeno kapljevino, ki periodično zapolnjuje izpraznjen prostor mehurčkov, ki se trgajo s stene med nukleacijskim krogom);
- $q_e$ označuje uparjalni toplotni tok, ki se porablja za neposredno generacijo parnih mehurčkov.

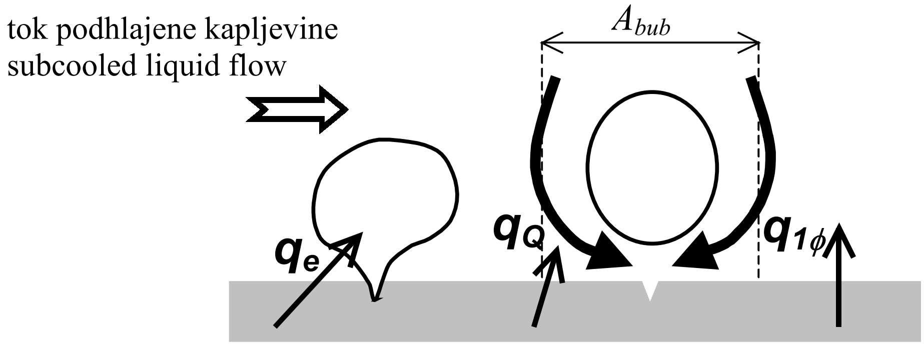
Vplivna površina mehurčkov na enoto površine stene $A_{bub}$ je definirana kot:

where:

- $q_{1\phi}$ denotes the single-phase convection heat flux that takes place outside the influence area of the bubble nucleation,
- $q_Q$ denotes the surface-quenching heat flux within the bubble influence area, $A_{bub}$ (i.e., the heat transferred from the wall to the sub-cooled bulk liquid that periodically fills the volume vacated by the departing bubbles during the bubble nucleation cycle),
- $q_e$ denotes the wall-evaporation heat flux that is used for the direct generation of vapour bubbles.

The bubble influence area per unit wall area, $A_{bub}$, is determined as:

$$A_{bub} = \min\left[1, N_a K\left(\frac{\pi d_{bw}^2}{4}\right)\right] \qquad (3),$$




Sl. 1. *Porazdelitev toplotnega toka na steni*
Fig. 1. *Heat-flux partitioning at the wall*

kjer sta $N_a$ gostota aktivnih nukleacijskih jeder in $d_{bw}$ premer mehurčkov, nastalih na greti steni. Premer $d_{bw}$ je izračunan z uporabo Unalove korelacije [10], ki upošteva vpliv tlaka, podhladitve kapljevine, dovedenega toplotnega toka in hitrosti toka na velikost mehurčka. Parameter $K$ določa velikost vplivnega območja mehurčka v okolici nukleacijskega jedra. Navadno se vzame nespremenljiva vrednost parametra $K = 4$ [11]. Pri največji gostoti aktivnih nukleacijskih jeder $N_a$ vplivno območje mehurčkov pokriva celotno greto površino ($A_{bub}$= 1). Pri vrednosti $K$= 4 vplivna površina mehurčkov postane enaka celotni greti površini, kadar povprečni razmik med dvema sosednjima nukleacijskima jedroma doseže velikost dveh premerov mehurčka (2 $d_{bw}$).

Osnovni model Kurula in Podowskega [9] smo prilagodili za uporabo v enorazsežnih termohidravličnih programih, ki uporabljajo spremenljivke povprečene po prečnem prerezu kanala. Uparjalni toplotni tok je sorazmeren gostoti aktivnih nukleacijskih jeder $N_a$, frekvenci nukleacije mehurčkov $f$, masi mehurčka in uparjalni toploti $h_{lg}$:

where $N_a$ is the density of active nucleation sites and $d_{bw}$ is the diameter of the bubbles generated on the heated wall. The diameter $d_{bw}$ is calculated from the Unal correlation [10], which takes into account the effects of pressure, liquid sub-cooling, heat flux and liquid flow velocity on the bubble size. The parameter $K$ determines the size of the bubble influence area around the nucleation site. A constant value of $K = 4$ is assumed [11]. At the maximum density of nucleation sites, $N_a$, the bubble influence area covers the entire heating surface ($A_{bub}$= 1). At the value of $K$= 4, the bubble influence area becomes equal to the total heating surface if the average spacing between two neighbouring nucleation sites reaches the size of two bubble diameters (2 $d_{bw}$).

The basic model of Kurul and Podowski [9] has been adapted for application in one-dimensional thermal-hydraulic codes, which use variables averaged over the channel cross-section. The evaporation heat flux is proportional to the density of nucleation sites, $N_a$, the mass of a single bubble, the bubble nucleation frequency, $f$ , and the latent heat, $h_{lg}$:

$$q_e = N_a f\left(\frac{\pi}{6} d_{bw}^3\right)\rho_g h_{\mathrm{lg}} \qquad (4).$$

Frekvenca nukleacije mehurčkov je definirana po Coleu (1960, citirano v Ivey [12]):

The bubble nucleation frequency is defined by Cole (1960, cited by Ivey [12]):

$$f = \sqrt{\frac{4}{3}\frac{g(\rho_l - \rho_g)}{d_{bw}\rho_l}} \qquad (5),$$

kjer je $f$ odvisen samo od premera mehurčka $d_{bw}$ in od gostot faz $\rho_l$ in $\rho_g$. Toplotni tok zaradi površinskega hlajenja izračunamo kot:

where $f$ is affected only by the bubble diameter, $d_{bw}$, and by the phase densities $\rho_l$ and $\rho_g$. The quenching heat flux is calculated as:

$$q_Q = h_Q A_{bub}\left(T_w - T_l\right)\cdot\xi \qquad (6),$$

kjer so $h_Q$ toplotna prestopnost, $T_w$ temperatura stene in $T_l$ povprečna temperatura kapljevine. Koeficient $h_Q$ izračunamo tako, da upoštevamo časovno odvisen prevod toplote s stene na polneskončno kapljevino [11]:

where $h_Q$ is the heat-transfer coefficient, $T_w$ is the wall temperature, and $T_l$ is the average liquid temperature. The coefficient $h_Q$ is calculated by considering transient conduction from the wall to a semi-infinite liquid [11]:

$$h_Q = \frac{1,6f}{\sqrt{\pi}}\sqrt{k_l \rho_l c_{pl}} \tag{7}$$

Komponenta toplotnega toka enofazne konvekcije zunaj vplivnega območja mehurčkov je izračunana takole:

The single-phase convection heat-flux component outside the bubble influence area is calculated in the following way:

$$q_{1\phi} = h_{1\phi}\cdot(1-A_{bub})\cdot(T_w - T_l)\cdot\xi \tag{8}$$

kjer je toplotna prestopnost $h_{1\phi}$ za enofazni turbulentni konvektivni tok, izračunana po Kurulu in Podowskem [9]:

where the heat-transfer coefficient $h_{1\phi}$ for the single-phase turbulent convective flow is calculated according to Kurul and Podowski [9]:

$$h_{1\phi} = St\cdot\rho_l\cdot c_{pl}\cdot u_l \tag{9}$$

kjer je $St$ Stantonovo število. Faktor $\xi$ smo vključili v en. (6) in (8) za segrevanje kapljevine, da bi zadostili pogoju, da se pri nasičenju celotni dovedeni toplotni tok porabi za generacijo pare:

where $St$ is the Stanton number. The inhibiting factor $\xi$ was introduced in Eqs. (6) and (8) for the liquid-heating components to satisfy the condition that at saturation, the entire wall heat flux is consumed for vapour generation:

$$\xi = \frac{2\cdot(h_{lsat}-h_l)/(h_{lsat}-h_{lcr})}{1+(h_{lsat}-h_l)/(h_{lsat}-h_{lcr})} \tag{10}$$

Faktor $\xi$ je padajoča funkcija podhladitve kapljevine in popisuje dvorazsežno naravo razvijajoče se toplotne mejne plasti ob steni, kjer so temperaturni gradienti največji. Z debelitvijo plasti vzdolž kanala se vedno več kapljevine uparja, medtem ko je vedno manj toplote na voljo za segrevanje kapljevine. Kritična entalpija $h_{lcr}$, ki je izračunana po korelaciji Saha-Zuber [13], označuje mesto, kjer postane vpliv toplotne mejne plasti pomemben.

Temperaturo stene $T_w$ in temperaturo kapljevine $T_l$ v en. (6) in (8) izračunamo z implicitno sklopitvijo energijske enačbe in enačbe za prevod toplote v steni [14], tako da je gostota nukleacijskih jeder $N_a$ edina preostala neznana veličina. Iz vsote komponent dovedenega toplotnega toka lahko izračunamo neznano vrednost $N_a$:

The factor $\xi$ is a decreasing function of the liquid sub-cooling and captures the two-dimensional nature of the developing thermal boundary layer near the heated wall, where the liquid temperature gradient is significant. As the layer gets thicker along the channel, more vapour is being generated, thus less heat is transferred to the liquid. The critical enthalpy, $h_{lcr}$, calculated from the Saha-Zuber correlation [13], defines the location where the effect of the thermal boundary layer becomes significant.

The wall temperature, $T_w$, and average liquid temperature, $T_l$, in Eqs. (6) and (8) are calculated by the implicit coupling of the energy equation and the equation for the heat-transfer conduction through the wall [14], so that $N_a$ remains the only unknown variable. The unknown value of $N_a$ can be calculated from the sum of the heat-flux components:

$$N_a = \frac{q_w - h_{1\phi}(T_w - T_l)\cdot\xi}{\pi\cdot d_{bw}^2\left[f\frac{1}{6}d_{bw}\cdot h_{fg}\cdot\rho_g(1+\varepsilon)-\left(\frac{K}{4}\right)h_{1\phi}(T_w-T_l)\cdot\xi\right]} \tag{11}$$

kjer je ε faktor površinskega hlajenja, ki je definiran kot razmerje med toplotnima tokovoma $q_Q$ in $q_e$:

where ε is the quenching factor, defined as the ratio between heat fluxes $q_Q$ and $q_e$:

$$\varepsilon = \frac{q_Q}{q_e} = \left(\frac{3}{2}K\right)\frac{h_Q\cdot\tau_q(T_w-T_l)}{d_{bw}\cdot\rho_g\cdot h_{lg}}\cdot\xi \tag{12}$$

Ko poznamo vrednosti komponent dovedenega toplotnega toka, lahko iz uparjalnega toplotnega toka $q_e$ izračunamo hitrost stenskega uparjanja. Hitrost stenskega uparjanja $\Gamma_w$ je definirana kot količina pare na enoto časa in prostornine, ki nastaja v pregreti toplotni mejni plasti kapljevine ob steni:

Knowing the values of the heat-flux components, the wall-evaporation rate can be calculated from the evaporation heat flux, $q_e$. The wall-evaporation rate, $\Gamma_w$, is defined as the amount of steam per unit time and unit volume generated in the superheated liquid thermal boundary layer near the wall:

$$\Gamma_w = \frac{q_e \cdot A_w}{V \cdot h_{lg}} \qquad (13),$$

kjer sta $A_w$ in $V$ greta površina in prostornina računske celice.

where $A_w$ and $V$ are the heated area and the volume of the computational cell.

## 2 VKLJUČITEV MODELA V PROGRAM RELAP5

## 2 INCLUSION OF THE MODEL IN THE RELAP5 CODE

Termohidravlični program RELAP5 se zelo pogosto uporablja za izvajanje varnostnih analiz v jedrskih reaktorjih. Sedanji program RELAP5 uporablja Laheyev model [15] za izračun stenskega uparjanja. Naše predhodne analize [7] so pokazale, da Laheyev model izračuna prenizke hitrosti uparjanja pri preizkusnih podhlajenega vrenja, izvedenih pri tlakih pod 3 bar. Model ne upošteva eksplicitno premera mehurčka, ki pri nizkih tlakih bistveno vpliva na hitrost stenskega uparjanja in posledično na količino pare v vrelnem kanalu. Zato smo v zadnjo razpoložljivo verzijo programa RELAP5/MOD3.2.2 Gamma vključili novi model stenskega uparjanja. Program temelji na dvofluidnem sistemu neravnotežnih enorazsežnih transportnih enačb [14] za prenos:
mase:

The thermal-hydraulic code RELAP5 is frequently used to perform safety analyses of nuclear reactors. The existing code RELAP5 uses Lahey's model [15] to calculate wall evaporation. Our previous analyses [7] have shown that Lahey's model calculates evaporation rates that are too low, for sub-cooled boiling experiments performed at pressures below 3 bar. The model does not explicitly take into account the bubble size, which significantly affects the wall-evaporation rate at low pressures, and consequently the amount of vapour in the boiling channel. Thus, the new wall-evaporation model was included in the latest available code version RELAP5/MOD3.2.2. Gamma. The code is based on the two-fluid system of non-equilibrium one-dimensional transport equations [14] for
mass

$$\frac{\partial}{\partial t}\left(\alpha_k \rho_k\right) + \frac{1}{A}\frac{\partial}{\partial x}\left(\alpha_k \rho_k v_k A\right) = \Gamma_k \qquad (14),$$

gibalne količine:

momentum

$$\alpha_k \rho_k \frac{\partial}{\partial t} v_k + \frac{1}{2}\alpha_k \rho_k \frac{\partial}{\partial x} v_k^2 = -\alpha_k \frac{\partial}{\partial x} p + \alpha_k \rho_k g + WFR_k + \Gamma_k\left(v_{ik} - v_k\right) - C_i \left|v_r\right| v_r - C_{VM} a_{VM} \qquad (15),$$

in notranje energije:

and internal energy

$$\frac{\partial}{\partial t}\left(\alpha_k \rho_k e_k\right) + \frac{1}{A}\frac{\partial}{\partial x}\left(\alpha_k \rho_k e_k v_k A\right) = -p\frac{\partial}{\partial t}\alpha_k - \frac{p}{A}\frac{\partial}{\partial x}\left(\alpha_k v_k A\right) + Q_{wk} + Q_{ik} + \Gamma_k h_k + DISS_k \qquad (16),$$

kjer se spodnji indeks $k$ nanaša bodisi na kapljevito fazo ($k=l$) bodisi na plinasto fazo ($k=g$). Členi na levi strani enačb (14) do (16) opisujejo spremembo fizikalnih veličin po času in kraju. Člen izmenjave mase na desni strani en. (14) lahko razdelimo na prenos mase na medfaznem stiku pare in kapljevine $\Gamma_{ik}$ (kondenzacija) in na prenos mase zaradi

where the subscript $k$ refers either to the liquid phase ($k=l$) or to the gas phase ($k=g$). The terms on the left-hand side of Eqs. (14–16) describe the variation of physical variables in time and space. The mass-exchange term on the right-hand side of Eq. (14) can be divided into the mass-transfer term at the vapour-liquid interface, $\Gamma_{ik}$ (e.g., condensation) and the mass-uparjanja v toplotni mejni plasti ob steni $\Gamma_w$ (stensko uparjanje):

$$\Gamma_k = \Gamma_{ik} + \Gamma_w \quad (17).$$

Členi na desni strani gibalne en. (15) po vrsti pomenijo: silo tlaka, silo teže, trenje ob steni, prenos gibalne količine zaradi izmenjave mase med fazama, medfazno trenje in silo navidezne mase. Prva dva člena na desni strani energijske en. (16) pomenita delo tlaka, tretji člen toplotni tok, ki prehaja s stene na fazo $k$, četrti člen medfazni prenos toplote, peti člen prenos notranje energije zaradi izmenjave mase med fazama in zadnji člen disipacijo notranje energije zaradi stenskega trenja.

Prenos mase, energije in gibalne količine med fazama in med dvofaznim tokom in steno je popisan z dodatnimi zapiralnimi enačbami [14]. V primeru podhlajenega vrenja v toku, se medfazna kondenzacija ($\Gamma_{ik} < 0$) in stensko uparjanje ($\Gamma_w \geq 0$) pojavljata sočasno. Hitrost stenskega uparjanja $\Gamma_w$ je definirana z en. (13).

## 3 REZULTATI IN RAZPRAVA

Pri podhlajenem vrenju toka je neto količina pare v kanalu odvisna od interakcije med stenskim uparjanjem, kondenzacijo in relativno hitrostjo mehurčkov glede na kapljevino. Ker je glavni namen prispevka modeliranje stenskega uparjanja, podrobnosti modeliranja preostalih mehanizmov niso obravnavane (najdemo jih lahko v [16]). Nabor zapiralnih enačb za stensko uparjanje, kondenzacijo in relativno hitrost med fazama (model gonilnega toka) smo z uporabo lastnih FORTRAN-skih podprogramov [17] vključili v sedanji program RELAP5/MOD3.2.2 Gamma.

Izračune s spremenjenim programom (označenim z RELAP5_new) smo primerjali z izračuni s sedanjim programom (označenim z RELAP5_old) in z nizkotlačnimi preizkusi podhlajenega vrenja iz literature ([1] do [4]). Obratovalne razmere obravnavanih preizkusov so podane v preglednici 1. Preizkusi Zeitouna in Shoukrija ([1] in [2]) ter Donevskega in Shoukrija [3] so bili izvedeni v 306 mm dolgi greti cevi kolobarjastega prečnega prereza z notranjim premerom 13 mm in zunanjim premerom 25 mm. Testna sekcija Dimmicka in Selanderja [4] je bila 308 mm dolga cev z greto steno notranjega premera 12,3 mm. Za vsak preizkus smo razvili vhodni

transfer due to evaporation in the wall's thermal boundary layer, $\Gamma_w$ (wall evaporation):

The terms on the right-hand side of the momentum Eq. (15) represent, respectively, the pressure gradient, the body force, the wall friction, the momentum transfer due to mass exchange, the interfacial drag force and the virtual mass force. The first two terms on the right-hand side of Eq. (16) represent the pressure work, the third term represents the heat flux from the wall to phase $k$, the fourth term describes the interfacial heat transfer, the fifth term describes the internal energy transport due to mass exchange and the last term represents the energy dissipation due to wall friction.

The transfer of mass, energy and momentum between the phases and between the two-phase flow and the wall is described by additional closure equations [14]. In the case of sub-cooled boiling flow, interfacial condensation ($\Gamma_{ik} < 0$) and wall evaporation ($\Gamma_w \geq 0$) occur simultaneously. The wall-evaporation rate, $\Gamma_w$, is defined by Eq. (13).

## 3 RESULTS AND DISCUSSION

The net amount of vapour in the channel during sub-cooled flow boiling depends on the interaction between the wall evaporation, the condensation and the relative velocity of the bubbles with regard to the liquid. As this paper focuses on wall-evaporation modelling, the details about the modelling of other mechanisms are not provided; however, they can be found in [16]. The set of closure relations for the wall evaporation, the condensation and the relative velocity between phases (drift-flux model) was incorporated into the current code RELAP5/MOD3.2.2 Gamma via our own FORTRAN subroutines [17].

The calculations with the modified code (denoted as RELAP5_new) were compared with the existing code calculations (denoted as RELAP5_old) and against low-pressure sub-cooled boiling experiments from the literature ([1] to [4]). The operating conditions of the experiments are given in Table 1. The experiments of Zeitoun and Shoukri ([1] and [2]) and Donevski and Shoukri [3] were performed in a 306-mm-long heated annulus with inner and outer diameters of 13 mm and 25 mm, respectively. The test section of Dimmick and Selander [4] was a 308-mm-long cylindrical tube with a heated wall, having an inner diameter of 12.3 mm. An input model was developed for each

Preglednica 1. *Obratovalne razmere pri preizkusih*
Table 1. *Operating conditions of the experiments*

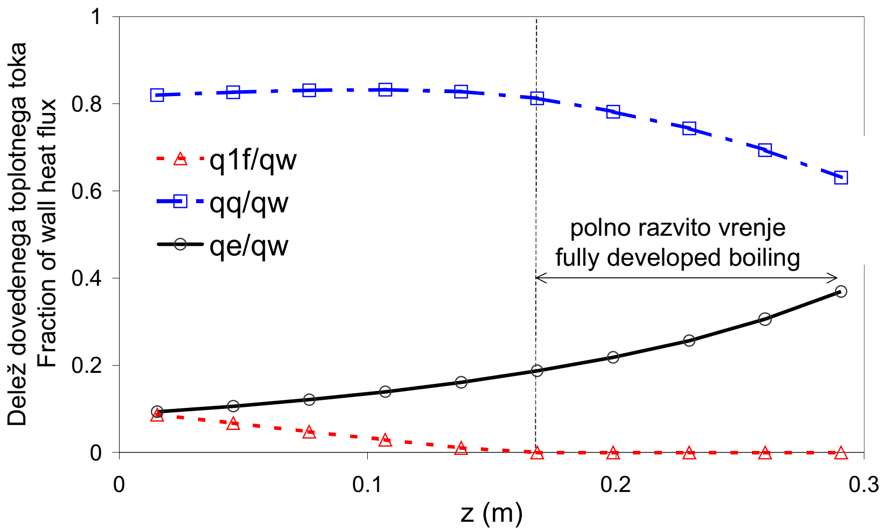
| Vir<br>Reference | Št. preiz.<br>Exp. No. | $q_w$<br>kW/m$^2$ | G<br>kg/m$^2$s | $p_{in}$<br>bar | $\Delta T_{sub,in}$<br>°C |
|---|---|---|---|---|---|
| [1] | 1 | 213,6 | 161,2 | 1,14 | 13,1 |
| | 2 | 480 | 208,1 | 1,14 | 20 |
| [2] | 3 | 508 | 264,1 | 1,5 | 16,8 |
| | 4 | 596 | 263,8 | 1,2 | 20,1 |
| [3] | 5 | 586,4 | 315,1 | 2,11 | 23,7 |
| | 6 | 481,4 | 392,1 | 1,54 | 18,5 |
| [4] | 7 | 805 | 620,2 | 1,65 | 44,3 |
| | 8 | 472 | 630,7 | 1,65 | 27,5 |

model, kjer smo definirali geometrijsko obliko testne sekcije, robne pogoje in diskretizacijo računskega območja [17].

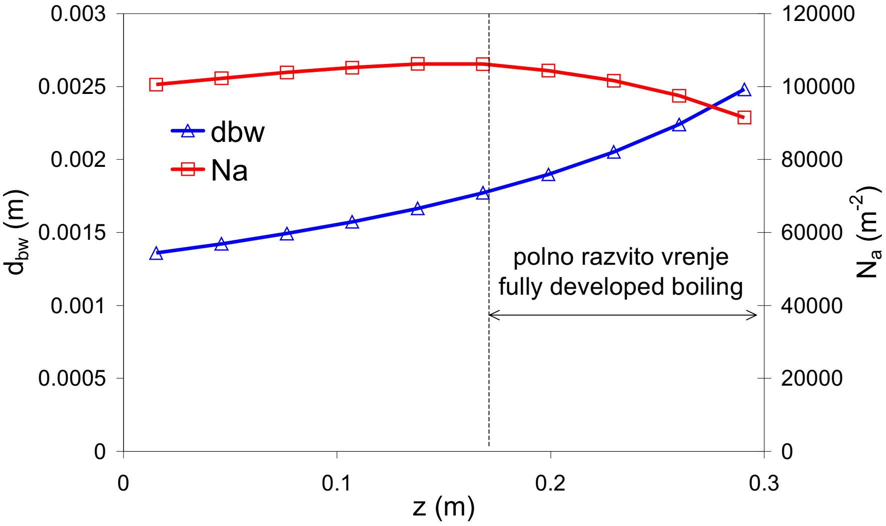
Na slikah 2 in 3 so predstavljeni značilni parametri novega modela stenskega uparjanja. S spremenjenim programom smo simulirali preizkus št.1 (preglednica 1). Na sliki 2 je predstavljena razdelitev dovedenega toplotnega toka vzdolž kanala. Vidimo lahko, da se enofazni konvekcijski toplotni tok $q_{1\phi}$ zmanjšuje, predvsem na račun večanja uparjalnega toplotnega toka $q_e$. Največji delež dovedenega toplotnega toka se prenaša na podhlajeno kapljevino zaradi površinskega hlajenja $q_Q$. Območje »*polno razvitega vrenja*«, kjer je $q_{1\phi}=0$, dosežemo približno na polovici gretega dela kanala. V tem območju vplivno območje mehurčkov pokriva celotno greto površino ($A_{bub}$ =1). Kakor je prikazano na sliki 3, se premer mehurčka $d_{bw}$ zvečuje vzdolž kanala, kar je v

experiment, where the test-section geometry, the boundary conditions and the discretization of the computational domain were defined [17].

Figs. 2 and 3 present the characteristic parameters of the new wall-evaporation model. Experiment No.1 (Table 1) was simulated with the modified code. Fig. 2 presents the partitioning of the wall heat flux along the heated channel. As can be seen, the single-phase convection heat flux, $q_{1\phi}$, decreases, mostly on account of the increasing of the evaporation heat-flux component, $q_e$. Most of the wall heat flux is transferred to the sub-cooled liquid as a result of quenching, $q_Q$. A "*fully developed boiling*" region, with $q_{1\phi}=0$, is reached approximately halfway along the heated channel. In this region, the bubble influence area covers the entire heated surface ($A_{bub}$ =1). As shown in Fig. 3, the bubble diameter, $d_{bw}$, increases along the channel, which is in accordance




Sl. 2. *Izračunana porazdelitev dovedenega toplotnega toka vzdolž kanala (primer 1, preglednica 1)*
Fig. 2. *Calculated partitioning of the wall heat flux along the channel (Case 1, Table 1)*




Sl. 3. *Izračunani razvoj premera mehurčka $d_{bw}$ in gostote aktivnih nukleacijskih jeder $N_a$ vzdolž kanala (primer 1, preglednica 1)*

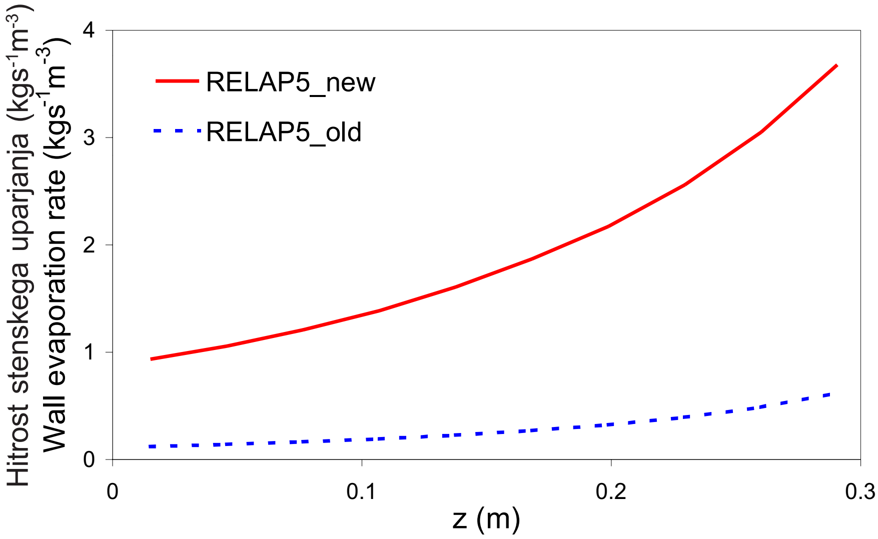
Fig. 3. *Calculated evolution of the bubble diameter, $d_{bw}$, and the density of the active nucleation sites, $N_a$, along the channel (Case 1, Table 1)*

skladu s preizkusnimi opažanji [2]. Gostota nukleacijskih jeder $N_a$ se počasi zvečuje v območju »*delno razvitega vrenja* « ($A_{bub}$<1), medtem ko se začne zmanjševati v območju *polno razvitega vrenja* zaradi nadaljnjega večanja premera mehurčka $d_{bw}$.

Na sliki 4 je za preizkusni primer 1 prikazana primerjava hitrosti stenskega uparjanja, izračunanih s spremenjenim (RELAP5_new) in sedanjim programom (RELAP5_old). Kakor vidimo, so hitrosti stenskega uparjanja bistveno višje v primeru spremenjenega programa.

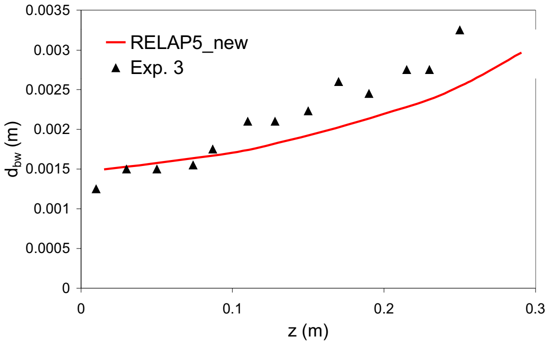
with experimental observations [2]. The nucleation site density, $N_a$, slowly increases in the "*partially developed boiling*" region ($A_{bub}$<1), whereas it starts decreasing in the *fully developed boiling region* due to a further increase in the bubble diameter, $d_{bw}$.

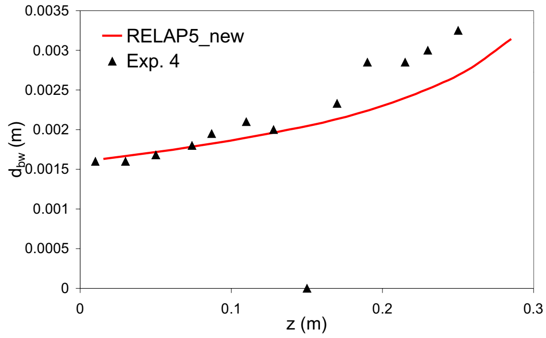
In Fig. 4, the wall-evaporation rates calculated by the modified (RELAP5_new) and the existing codes (RELAP5_old) are compared for the same experimental case 1. As can be seen, the wall-evaporation rates are significantly higher in the case of the modified code calculation.




Sl. 4. *Izračunane hitrosti stenskega uparjanja vzdolž kanala (primer 1, preglednica 1)*

Fig. 4. *Calculated wall-evaporation rates along the channel (case 1, Table 1)*




Sl. 5. *Izračunane in izmerjene [2] vrednosti premera mehurčka vzdolž kanala (primera 3 in 4, preglednica 1)*

Fig. 5. *Calculated and measured [2] values of the bubble diameter along the channel (cases 3 and 4, Table 1)*

Preglednica 2. *Izmerjene ([1] in [2]) in izračunane (RELAP5_new) vrednosti povprečne temperature stene*

Table 2. *Measured ([1] and [2]) and calculated (RELAP5_new) values of the average wall temperature*

| Št. preiz.<br>Exp. No. | $T_{w,exp}$<br>K | $T_{w,calc}$ (RELAP5_new)<br>K | $(T_{w,calc} - T_{w,exp})\times100/T_{w,exp}$<br>% |
|---|---|---|---|
| *1* | 393,0 | 391,8 | -0,3 |
| 2 | 400,0 | 400,1 | 0,025 |
| 3 | 410,5 | 410,0 | -0,12 |
| 4 | 406,3 | 407,0 | 0,17 |

Ker preizkusnih podatkov o gostoti aktivnih nukleacijskih jeder ni na voljo, smo izračun $N_a$ preverili posredno, s primerjavo izračunanih in izmerjenih vrednosti premera mehurčka in temperature stene. Po en. (11) je gostota aktivnih nukleacijskih jeder odvisna od premera mehurčka in temperature stene. Kakor je prikazano na sliki 5, izračun s spremenjenim programom RELAP5 razmeroma dobro napove izmerjene [2] vrednosti premera mehurčka (povprečene po prerezu kanala).

V preglednici 2 so za 4 preizkusne primere (preglednica 1) podane izmerjene in izračunane vrednosti temperature grete stene. Za vsak preizkusni primer je podana ena vrednost, ki pomeni temperaturo povprečeno po celotni notranji površini grete stene. Povprečenje je smiselno, saj so tako izmerjene kakor izračunane temperaturne porazdelitve vzdolž kanala skoraj nespremenjene. Kakor je prikazano v preglednici 2, je tudi ujemanje izmerjenih in izračunanih temperatur sten zelo dobro.

Celotni model podhlajenega vrenja sestoji iz posameznih podmodelov, ki vplivajo na izračun deleža pare v gretem kanalu. Poleg modela stenskega uparjanja sta najpomembnejša model kondenzacije in model gonilnega toka. Da bi zaupali izračunu hitrosti stenskega uparjanja, smo preverili

As the experimental data on the nucleation site density, $N_a$, are not available, the calculation of $N_a$ was validated indirectly, by comparing the calculated bubble diameter and the wall temperature with the experimental values. According to Eq. (11), the active nucleation site density depends on the bubble diameter size and on the wall temperature. As shown in Fig. 5, the measured [2] bubble diameter values (averaged over the channel cross-section) are reasonably well predicted by the modified RELAP5 calculation.

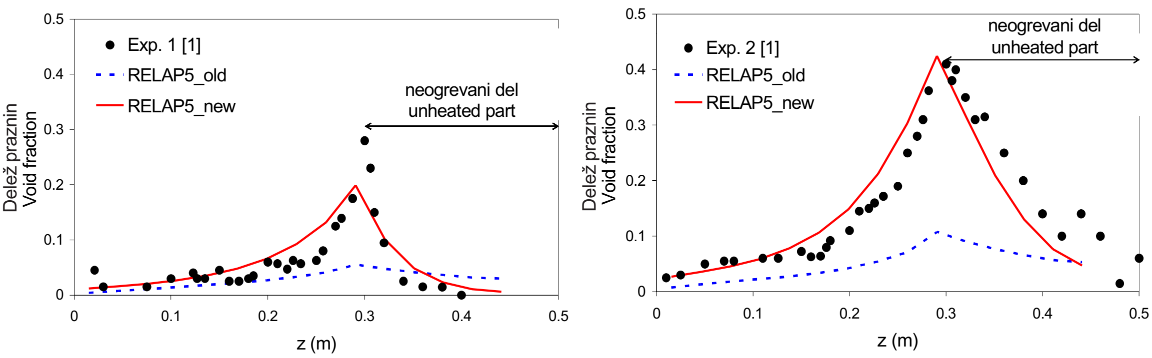
Table 2 provides measured and calculated values of the heated wall temperature for four experimental cases (Table 1). For each experimental case, one value is provided, representing the temperature averaged over the entire inner surface of the heated wall. The averaging is reasonable since both the measured and calculated temperature distributions along the channel are almost constant. As presented in Table 2, very good agreement between the measured and calculated wall temperatures is also obtained.

The overall sub-cooled boiling model consists of several sub-models that influence the calculation of the vapour content in the heated channel, [16]. Besides the wall-evaporation model, the condensation model and the drift-flux model are the most important. To have confidence in the wall-evaporation rate calculation, tudi ta dva modela. Na sliki 6 je prikazana primerjava izračunanih in izmerjenih [1] porazdelitev deleža parne faze v gretem in v neogrevanem delu navpičnega kanala. V gretem delu kanala na delež parne faze vplivata stensko uparjanje in kondenzacija, medtem ko v neogrevanem delu kanala poteka le kondenzacija parnih mehurčkov, zato se delež parne faze hitro zmanjšuje vzdolž kanala. Izračuni s spremenjenim programom (RELAP5_new) se dobro ujemajo z izmerjenim manjšanjem deleža parne faze in potrjujejo, da je bil uporabljen ustrezen model kondenzacije. V primeru izračunov s sedanjim programom (RELAP5_old) so vrednosti deleža parne faze bistveno nižje vzdolž celotne dolžine kanala, predvsem zaradi premajhne generacije pare ob steni. V neogrevanem delu kanala je nagib manjšanja deleža parne faze manj strm kakor v preizkusu, kar kaže na prenizko hitrost kondenzacije. Spremenjeni program RELAP5 (RELAP5_new) vključuje tudi novi model gonilnega toka [16], ki določa relativno hitrost med fazama. Primerjava izračunanih relativnih hitrosti z izmerjenimi vrednostmi je pokazala dobro ujemanje v primeru izračunov s spremenjenim programom, medtem ko je sedanji program (RELAP5_old) napovedal prevelike relativne hitrosti [16].

Na sliki 7 je prikazana primerjava izračunanih (RELAP5_old in RELAP5_new) in izmerjenih deležev parne faze vzdolž gretega kanala. Večja hitrost stenskega uparjanja v primeru izračuna RELAP5_new vpliva na večji delež pare v kanalu. Izračuni s sedanjim programom napovejo precej manjši delež parne faze od izmerjenega, medtem ko se izračuni s spremenjenim programom dobro ujemajo z izmerjenimi vrednostmi.

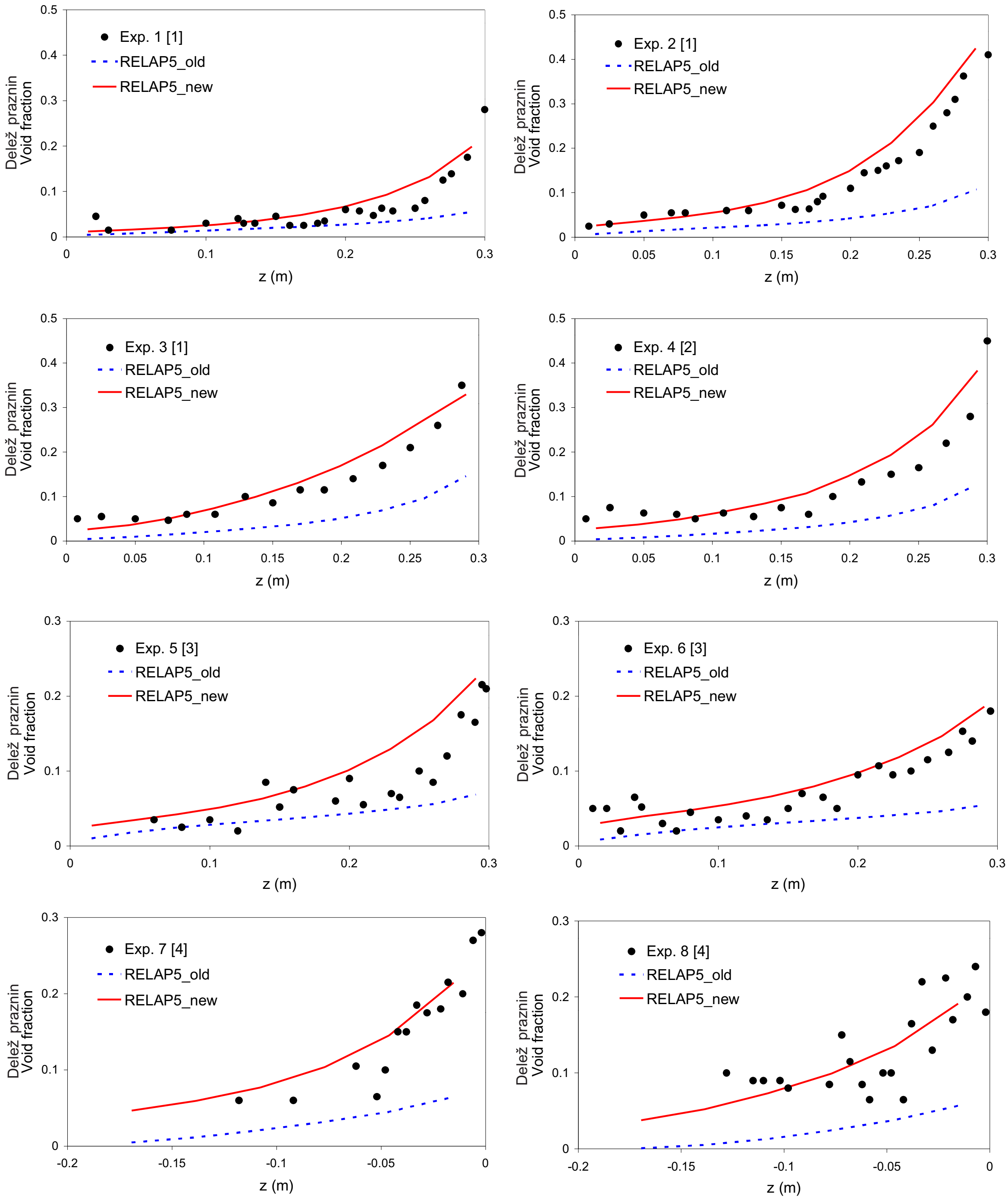
these two models were also validated. In Fig. 6. a comparison of the calculated and measured [1] void-fraction distributions in the heated and unheated parts of the vertical channel is presented. In the heated part of the channel both the wall evaporation and the condensation have an influence on the void fraction, whereas in the unheated part of the channel only the condensation of vapour bubbles is present, causing the void fraction to decrease rapidly along the channel. The modified code calculations (RELAP5_new) agree well with the measured void-fraction decrease and confirm that an appropriate condensation model was used. The void-fraction values along the entire length of the channel are significantly lower in the case of the existing code calculations (RELAP5_old), mostly due to the vapour generation near the wall being too low. The slope of the void-fraction decrease in the unheated part of the channel is less steep, as in the experiment, which indicates a condensation rate that is too low. The modified RELAP5 code (RELAP5_new) also includes a new drift-flux model [16], which determines the relative velocity between the phases. A comparison of the calculated and measured values shows good agreement in the case of modified code calculations, whereas the existing code (RELAP5_old) predicted relative velocities that were too high [16].

A comparison of the calculated (RELAP5_old and RELAP5_new) and the measured void fractions in the heated channels is presented in Fig. 7. A higher wall-evaporation rate in the case of the RELAP5_new calculations leads to higher vapour contents in the channel. The existing code calculations significantly under-predict the measured void fraction, whereas the calculations with the modified code show good agreement with the measured values.




Sl. 6. *Izračunane in izmerjene [1] porazdelitve deleža parne faze v gretem in neogrevanem delu kanala (primera 1 in 2, preglednica 1)*

Fig. 6. *Calculated and measured [1] void-fraction distributions in the heated and unheated parts of the channel (Cases 1 and 2, Table 1)*




Sl. 7. *Primerjava vzdolžnih porazdelitev deležev parne faze*
Fig. 7. *Comparison of the axial void-fraction distributions*

## 4 SKLEPI

Z namenom, da bi razširili uporabnost termohidravličnih programov v območje nizkotlačnega podhlajenega vrenja, smo razvili model

## 4 CONCLUSIONS

To extend the range of applicability of the thermal-hydraulic codes to low-pressure sub-cooled boiling, a wall-evaporation model consistent with stenskega uparjanja, ki je skladen z osnovnimi mehanizmi nukleacije mehurčkov na greti steni. Model upošteva delitev dovedenega toplotnega toka na delež, ki se porabi za generacijo pare in delež, ki se porabi za segrevanje kapljevine. Model je tudi zmožen napovedati prehod iz delno razvitega v polno razvito območje podhlajenega vrenja.

Novi model stenskega uparjanja smo vključili v program RELAP5. Spremenjeni program RELAP5 poleg novega modela stenskega uparjanja vključuje tudi nova modela kondenzacije in gonilnega toka, ki vsi skupaj vplivajo na delež parne faze pri podhlajenem vrenju toka. Spremenjeni program smo preverili na vrsti nizkotlačnih preizkusov podhlajenega vrenja. Dosegli smo zelo dobro ujemanje izračunanih in izmerjenih deležev parne faze vzdolž kanala. Nasprotno je sedanji program napovedal bistveno premajhen delež parne faze pri vseh obravnavanih preizkusih.

the basic physical mechanisms of bubble nucleation on a heated wall has been developed. The model considers the decomposition of the wall heat flux into vapour-generation and liquid-heating parts, and is able to predict the transition from the partially developed to the fully developed sub-cooled boiling region.

The new wall-evaporation model was incorporated into the RELAP5 code. Besides the new wall-evaporation model, the modified RELAP5 code also includes new models for condensation and drift-flux, which altogether influence on the void fraction during sub-cooled flow boiling. The modified code was verified against a series of low-pressure sub-cooled boiling experiments. Very good agreement between the calculated and measured void fractions along the channel was achieved. In contrast, the existing code significantly under-predicts the void-fraction data in all the experiments.

## 5 SPREMENLJIVKE
## 5 NOMENCLATURE

| | | | |
|---|---|---|---|
| pospešek navidezne mase | $a_{VM}$ | m/s$^2$ | acceleration due to virtual mass |
| prerez | $A$ | m$^2$ | cross-section |
| greta površina | $A_w$ | m$^2$ | heated area |
| specifična toplota kapljevine | $c_{pl}$ | J/kgK | liquid specific heat |
| koeficient medfaznega trenja | $C_i$ | | interfacial drag coefficient |
| koeficient navidezne mase | $C_{VM}$ | | virtual mass coefficient |
| premer mehurčka, ki nastane na steni | $d_{bw}$ | m | bubble diameter generated on the wall |
| hidravlični premer kanala | $D_e$ | m | channel equivalent diameter |
| specifična notranja energija | $e$ | J/kg | specific internal energy |
| težnostni pospešek | $g$ | m/s$^2$ | acceleration due to gravity |
| masni pretok | $G$ | kg/m$^2$s | mass flux |
| specifična entalpija | $h$ | J/kg | specific enthalpy |
| uparjalna toplota | $h_{lg}$ | J/kg | latent heat |
| toplotna prevodnost kapljevine | $k_l$ | W/mK | liquid thermal conductivity |
| Nusseltovo število = $q_w D_e/k_l$ | $Nu$ | | Nusselt number = $q_w D_e/k_l$ |
| tlak | $p$ | Pa, bar | pressure |
| Pecletovo število = $GD_e c_{p,l}/k_l$ | $Pe$ | | Peclet number = $GD_e c_{p,l}/k_l$ |
| Prandtlovo število kapljevine | $Pr_l$ | | liquid Prandtl number |
| površinski toplotni tok | $q$ | W/m$^2$ | surface heat flux |
| vir toplote na enoto prostornine | $Q$ | W/m$^3$ | heat source per unit volume |
| Reynoldsovo število toka = $GD_e/m$ | $Re$ | | Reynolds flow number = $GD_e/\mu$ |
| Stantonovo število = $Nu/RePr_l$ | $St$ | | Stanton number = $Nu/RePr_l$ |
| temperatura | $T$ | K | temperature |
| hitrost | $v$ | m/s | velocity |
| nadzorna prostornina | $V$ | m$^3$ | control volume |
| relativna hitrost med fazama | $v_r$ | m/s | relative velocity between phases |
| *Grške črke* | | | *Greek symbols* |
| prostorninski delež faze $k$ | $\alpha_k$ | | volume fraction of phase $k$ |

| | | | |
|---|---|---|---|
| hitrost prenosa mase | $\Gamma$ | kg/sm$^3$ | mass transfer rate |
| dinamična viskoznost kapljevine | $\mu_l$ | Pa s | liquid viscosity |
| gostota | $\rho$ | kg/m$^3$ | density |
| | | | |
| *Spodnji indeksi* | | | *Subscripts* |
| od meje faz proti fazi *k* | *ik* | | from interface to phase *k* |
| vstopni pogoji | *in* | | inlet conditions |
| kapljevina | *l* | | liquid |
| para | *g* | | vapour |
| faza *k* | *k* | | phase *k* |
| nasičenje | *sat* | | saturation |
| podhlajeno | *sub* | | sub-cooling |
| stena | *w* | | wall |
| od stene proti fazi *k* | *wk* | | from wall to phase *k* |

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# Namen in uporaba mednarodne baze podatkov o materialih v avtomobilski industriji

## The Aim and Use of the International Material Data System in the Automobile Industry

Marko Sečnjak - Bojan Ačko

*Prispevek opisuje mednarodno bazo podatkov o materialih (MBPM - IMDS), vgrajenih v osebna vozila, ki je nastala na pobudo združenja nemških proizvajalcev avtomobilov, z namenom obvladovanja zgradbe avtomobila z vidika okoljevarstvenih zahtev. Izhodišče zanjo so zakonska določila in prostovoljna odločitev avtomobilskih proizvajalcev, da bo mogoče čim večji delež avtomobilov reciklirati. V opisano bazo vnašajo proizvajalci surovin in sklopov podatke o kemični sestavi uporabljenih materialov, kar omogoča proizvajalcem avtomobilov učinkovito analizo njihove sestave. Ta analiza omogoča identifikacijo vgrajenih škodljivih snovi in njihov položaj v izdelkih, kar proizvajalcem olajša definiranje popravnih ukrepov za zmanjšanje deleža le-teh. Opisan je primer vnosa podatkov v sistem, trenutno stanje uporabnosti in predvidevanja o nadaljnjem razvoju sistema. Analiza sistema je bila narejena v podjetju SG Automotive d.o.o., ki dobavlja elektronske sklope avtomobilski industriji, na primeru dvesto štirinajstih vnosov, ki jih je to podjetje dobilo od svojih dobaviteljev, in dvesto devetindvajsetih vnosov, ki jih je isto podjetje poslalo svojim kupcem. Poleg omenjene analize je bilo izvedeno še izobraževanje v petintridesetih slovenskih, enem avstrijskem in enem nemškem podjetju, ki uporabljajo to bazo na zahtevo svojih kupcev. Izkušnje za analizo so bile pridobljene na delovnih seminarjih v skupini Schefenacker, ki ima 40-odstotni delež v svetovni proizvodnji zunanjih ogledal za avtomobile.*

**(Ključne besede: industrija avtomobilska, materiali, IMDS, varstvo okolja, reciklaža)**

*The subject of the presented work is the International Material Data System (IMDS), which is incorporated in automobiles and was developed for the German car manufacturers' association's initiative to use it for the management of car manufacture from an environmental viewpoint. The IMDS is based on legislative regulations and the car manufacturers' decision to recycle the largest possible number of cars. The database is used for manufacturers of raw materials and composites to input information on the chemical constitution of used materials, which enables car manufacturers to carry out an effective analysis of a car's composition. This analysis provides the means for car manufacturers to identify built-in dangerous materials and their location in a product, which makes it easier for manufacturers to define correction measures for the reduction of the amount of harmful substances. An example of data input, the current state of system applications and projections on further development of the system are described. The system analysis was carried out in the company SG Automative d.o.o., which supplies electronic composites to the automobile industry, on the basis of 214 inputs that this company received from its suppliers, and 229 inputs that were sent out by the company in question to its buyers. Besides execution of the analysis, an education course was presented in 35 Slovenian companies and in one Austrian and one German company; these companies are using IMDS because it is demanded by their buyers. The experiences necessary for conducting an analysis were gained by attending working seminars in the Schefenacker group, which owns a 40% share in the worldwide production of external rear-view car mirrors.*

**(Keywords: automobile industry, materials, IMDS, environmental engineering, recycling)**

## 0 UVOD

Proizvajalci avtomobilov se zavedajo odgovornosti, ki jo nosijo s svojo dejavnostjo na področju varstva okolja. Zavezali so se, da bodo upoštevali načela varstva okolja pri proizvajanju in recikliranju komponent, ki se vgrajujejo v avtomobile. Njihov cilj je upoštevati ekološke zahteve, ki se nanašajo na kemično sestavo uporabljenih materialov od razvoja izdelkov do njihovega recikliranja. S tem dosežejo, da se omejijo nezaželene oz. škodljive snovi v okolju in da se varujejo naravni viri čistega okolja. Avtomobili povzročajo onesnaževanje okolja:

· z uporabo škodljivih materialov pri postopku izdelave,
· z uporabo škodljivih materialov za izdelavo komponent avtomobila,
· s porabo virov (energija, materiali) in z nastajanjem odpadov (odlagališča starih avtomobilov).

Da bodo proizvajalci želene cilje dosegli, morajo poznati sestavo avtomobilov. Te podatke dobijo od svojih dobaviteljev pri vzorčenju izdelkov, vpisanih v MBPM, ki je na spletnih straneh [1].

## 1 ODOBRITEV POSTOPKA IN IZDELKOV PO VDA[1]

Način odobritve postopka in izdelkov preverja [2], če postopki in izdelki izpolnjujejo zahteve kupca. Postopek odobritve vključuje naslednji dejavnosti:

· raziskavo zmožnosti postopkov in/ali presojo postopkov in
· vzorčenje izdelkov.

Postopek naj bi pred začetkom serijske proizvodnje potrdil skladnost izdelkov s kakovostnimi in tehničnimi zahtevami kupca. Uporablja se za:

· serijske izdelke,
· rezervne dele,
· materiale in
· orodja.

Uporabljamo ga:

· za nove izdelke,
· za konstrukcijske in materialne spremembe,
· pri uporabi alternativnih materialov in konstrukcij,
· pri uporabi novih, spremenjenih ali nadomestnih orodij,
· po rekonstrukciji ali servisu orodij, če je primerno,
· če se spremenijo postopki,
· pri selitvi proizvodnje v drug prostor,
· pri uporabi nove opreme in pripomočkov,
· po zapori izdelkov zaradi neskladnosti izdelkov in
· če je oprema več ko 12 mesecev zunaj obratovanja (ne velja za rezervne dele).

### 1.1 Odobritev izdelkov

Postopek odobritve izdelkov po VDA poteka na podlagi vzorčenja. Vzorci so izdelki, pri katerih se preveri njihova skladnost z zahtevami kupcev. Ločimo dve vrsti vzorcev:

· **Prvi vzorci** so vzorci, ki so proizvedeni s serijskimi materiali pod serijskimi pogoji proizvodnje. Za postopek odobritve postopkov in izdelkov se uporabljajo vedno prvi vzorci. Njihovo število se uskladi med kupcem in dobaviteljem glede na njihovo zahtevnost.
· **Preostali vzorci** so tisti, ki niso bili izdelani pod serijskimi pogoji. **Ti se ne smejo uporabljati za odobritev postopkov in izdelkov.** Po navadi so namenjeni za funkcijska preizkušanja, vgradnjo, odobritev orodij.

Ločimo tri stopnje vzorčenj (pregl. 1), ti se razlikujejo med seboj glede na zahtevano dokumentacijo, ki jo je treba priložiti. 1. stopnja je najmanj zahtevna, uporablja se pri preprostih spremembah ali izdelkih. Če ni drugače dogovorjeno, se pošljejo kupcu vzorci in dokumentacija po 2. stopnji, ki zahteva nekoliko večji obseg dokumentacije (pregl. 1). V praksi se največkrat od dobaviteljev zahteva 3. stopnja (pregl. 1), ki terja največji obseg dokumentacije.

Stopnje se lahko določijo glede na naslednje kriterije:

**Stopnja 1**:

· dobavitelj poznan, do sedaj ni bilo problemov pri vzorčenju in serijski proizvodnji,
· preprosti izdelki, majhne spremembe in
· družine izdelkov, en izdelek vzorčimo po stopnji 2 ali 3, druge po stopnji 1.

**Stopnja 2**:

· nov dobavitelj,
· problemi s kakovostjo izdelkov pri znanem dobavitelju in
· novi izdelki ali postopki.

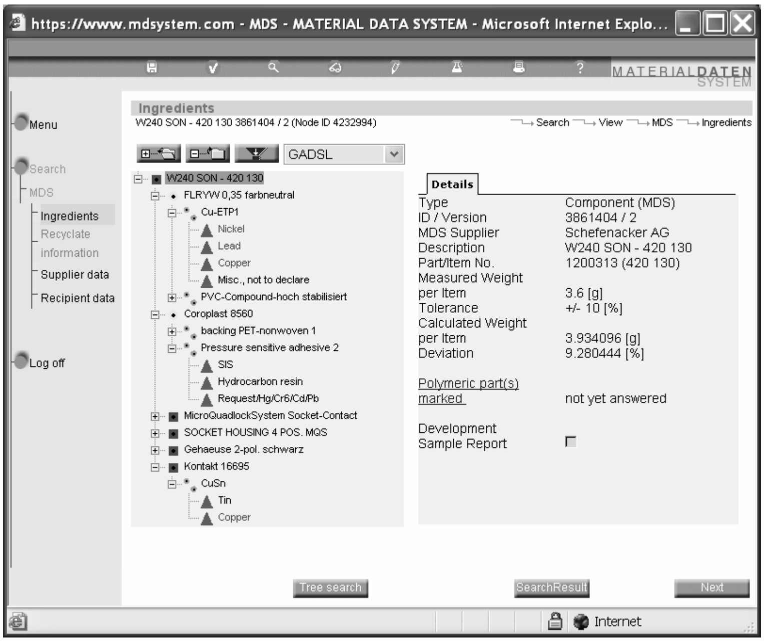
**Stopnja 3**:

· dobavitelj nima ustrezne merilne opreme,
· novi postopki,
· zapleteni postopki ali izdelki in
· izdelki, katerih dokumenti se morajo posebej arhivirati (to so lahko izdelki, ki posebej vplivajo na varnost, npr. zaznavalo za zračno vrečo).

[1] VDA-Verband der Automobilindustrie (združenje nemških proizvajalcev avtomobilov)

Preglednica 1. *Stopnje vzorčenj po VDA*

| | | Stopnja | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 1. | Krovni list MP | X | X | X |
| 2. | Rezultati preizkušanj (mere, material, funkcije, zanesljivost, hrup) | | V | V |
| 3. | Vzorci | A | A | A |
| 4. | Dokumenti (načrti kupca, RPK-podatki, norme ipd.) | | V | V |
| 5. | Razvojna odobritev in odobritev konstrukcije | | X | X |
| 6. | FMEA | | | E |
| 7. | Diagram poteka postopka | | X | X |
| 8. | Načrt nadzora | | | E |
| 9. | Seznam merilne opreme po izdelkih | | | X |
| 10. | Raziskava sposobnosti postopkov | | | V |
| 11 | Dokazila o upoštevanju zakonskih določil (varstvo okolja, recikliranje ipd.) | | X | X |

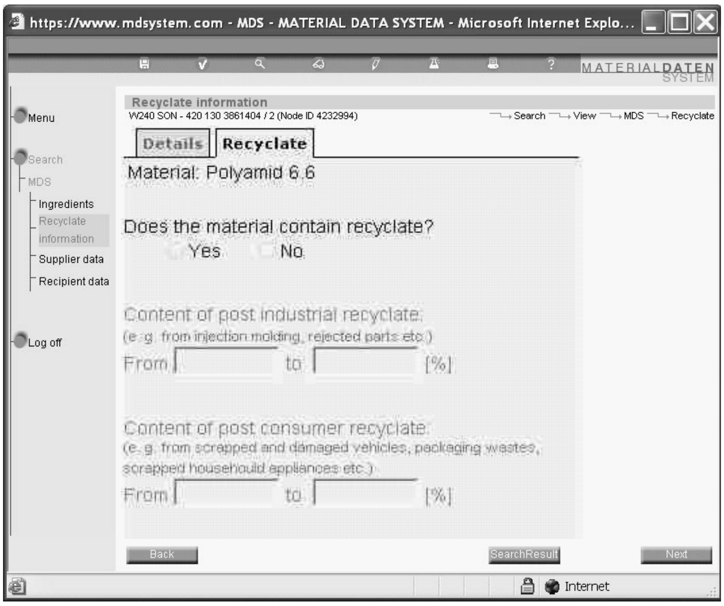



Sl. 1. *Strukturno drevo v MBPM*

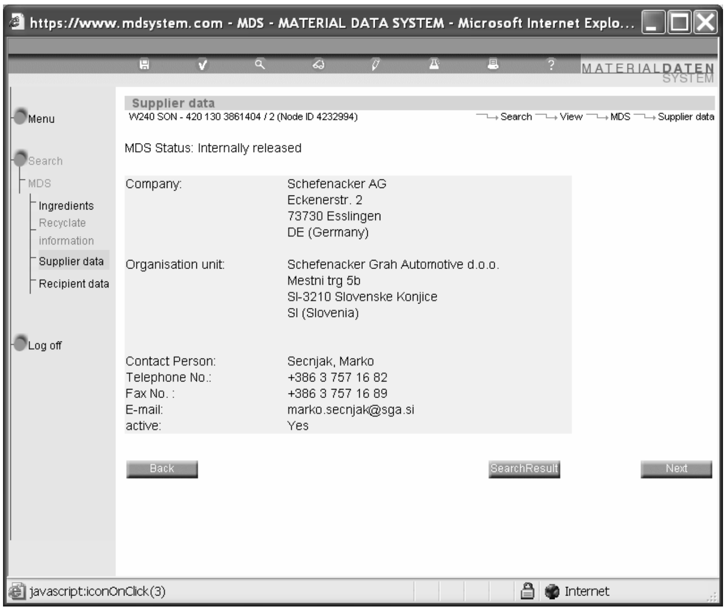
Merilni protokol (MP - EMPB), ki se priloži pri vzorčenju, ima predpisano obliko in vsebino. Prav tako ima predpisano obliko list, ki je dodatek k preizkusu materiala. Ta dodatek se imenuje materialni list. Še pred kratkim se je lahko vzorčenju priložil v papirni obliki, sedaj pa se mora vnesti v bazo podatkov (MBPM), ki je dosegljiva na spletnih straneh.

## 2 RAZVOJ MEDNARODNE BAZE PODATKOV O MATERIALIH

MBPM [1] je baza podatkov o materialih, ki se uporabljajo v avtomobilski industriji. Na temelju državnih in mednarodnih zakonov je dolžan vsak proizvajalec poznati vpliv svojih izdelkov na ekologijo. Da je mogoče upoštevati Smernico 2000/53/EG ([3] in [4]), je treba poznati sestavo posameznih izdelkov in v njih uporabljene materiale. Na podlagi tega so se pri VDA leta 1996 odločili, da bodo MP dopolnili z materialnim listom, ki vsebuje podatke o recikliranju, kemično sestavo in mase posameznih sestavnih delov. Upravni odbor VDA se je leta 1998 odločil, da bodo zgradili elektronski sistem za izdelavo materialnih listov. Materialni list v MBPM (sl. 1) vsebuje podatke o vrsti materiala, podatke o recikliranju (sl. 2), podatke o proizvajalcu (sl. 3) in podatke o prejemniku (sl. 4). Po tem so proizvajalci

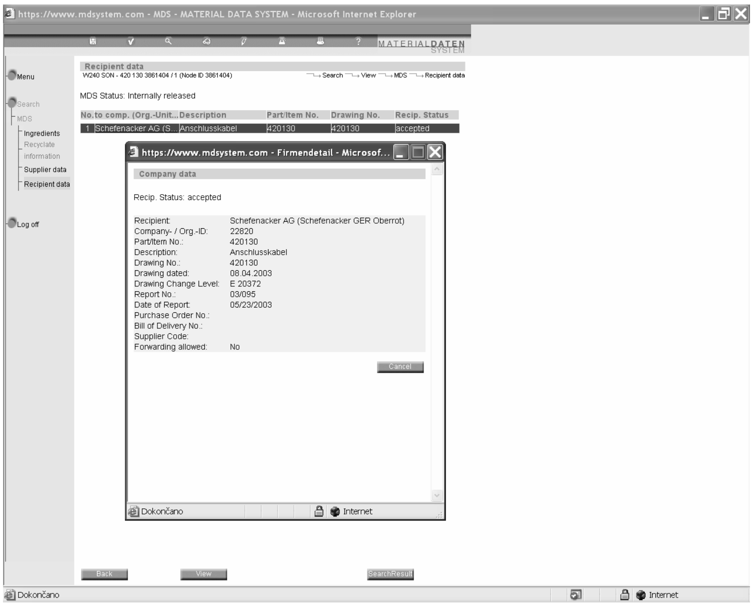



Sl. 2. *Recikliranje*




Sl. 3. *Proizvajalec*

avtomobilov sklenili pogodbo s podjetjem Electronic Data Systems Corporation [5] za izdelavo in upravljanje MBPM . Z uporabo MBPM se zahteve za materialne liste niso spremenile, spremenil se je le način izdelave materialnih listov, s čimer naj bi se povečala njihova dinamika. Vnos in obdelava podatkov se je spremenila iz papirne v elektronsko obliko na podlagi podatkovne baze. Takšna tehnična rešitev omogoča združevanje podatkov in njihovo uspešno uporabo. Vzrok za izgradnjo baze je bila prostovoljna odločitev proizvajalcev avtomobilov, da bo do leta 2006 mogoče reciklirati 85% mase avtomobila oz. 95% do leta 2015. Konec leta 1999 je potekalo poskusno trimesečno obratovanje 30 uporabnikov. Začetni problemi so bili odpravljeni na skupinskih delavnicah z dobavitelji polizdelkov. Začetek uporabe IMDS sega v junij 2000. Pokazalo se je tudi, da posamezni proizvajalci avtomobilov še




Sl. 4. *Prejemnik*

Preglednica 2. *Primer terminskega načrta*

| Rok | Oddelek | Aktivnost |
|---|---|---|
| 15. 03. 03 | nabava | Poslati dopise dobaviteljem. |
| 09. 03. 03 | QS | Priprava podatkov za spremembo kosovnic v sistemu. |
| 18. 04. 03 | informatika | Sprememba kosovnice v sistemu za potrebe MBPM |
| 10. 05. 03 | QS | Testiranje sprememb |
| 01. 06. 03 | informatika | Korekcija odkritih pomanjkljivosti pri testiranju |
| 01. 07. 03 | QS | Operativno izobraževanje |
| 01. 07. 03 | dobavitelji | Uporaba MBPM za dobavitelje |
| 15. 07. 03 | vsi | Uporaba MBPM za podjetje |

nimajo usklajenih predpisov z zahtevami, ki so potrebni za izdelavo materialnih listov. Baza je bila razvita po naročilu naslednjih podjetij:
- BMW,
- Daimler Chrysler,
- Porsche,
- Fiat,
- Ford Opel,
- General Motors,
- VW in
- Volvo.

V bazo se arhivirajo materiali, ki se vgrajujejo v avtomobile. S to bazo podatkov naj bi proizvajalci avtomobilov povečali zmožnost izpolnjevanja zahtev državnih in mednarodnih standardov ter zakonov. Čim natančnejši bodo podatki v MBPM, natančnejše bo stanje na področju ekologije.

## 3 UPORABA IMDS

Da lahko proizvajalci avtomobilov upoštevajo Smernico 2000/53/EG, morajo poznati kemično sestavo posameznih sestavnih delov avtomobila. Proizvajalci te podatke pridobijo od dobaviteljev. Na podlagi teh podatkov je mogoče narediti analizo in podati mnenje o recikliranju ter vplivu posameznih avtomobilov na ekologijo in zdravje ljudi.

### 3.1 Model uvajanja MBPM v srednje veliko podjetje

Uvedba se začne s predstavitvijo, ki je namenjena širšemu krogu ljudi: nabava, tehnologija, razvoj, informatika, proizvodnja, vodstvo. Na predstavitvi, ki traja do pol ure, se predstavi uporaba, njen namen in dodatna dela v podjetju. Na podlagi predstavite se določi projektna skupina. Ta je odvisna od organizacije podjetja, sestavljati jo morajo ljudje iz različnih oddelkov; običajno iz nabave, zagotavljanja kakovosti, tehnologije, razvoja in informatike. Ta skupina se sestane 2 do 3-krat in določi potrebne dejavnosti, ki se dokumentirajo s terminskim planom (pregl. 2). Na koncu se izvede še operativno izobraževanje.

Pri uvedbi se največkrat pojavljajo naslednje težave:
- pomanjkanje interesa pri projektni skupini. Po navadi je vse delo opravljala ena oseba, največkrat predstavnik kakovosti;
- največje težave so bile z informatiki; po navadi so dali odgovor, da sprememb v sedanjem informacijskem sistemu ni mogoče narediti. Potrebno je bilo prepričevanje, da je informacijski sistem mogoče spremeniti, določiti je treba le stroške in čas, potreben za spremembo.

Pozitiven vidik je interes za operativno izobraževanje. Izobraževanje traja 5 ur, izvede se 3 do 5-krat (odvisno od sestave izdelkov). Za preproste izdelke, ki so sestavljeni samo iz enega materiala (izdelki iz plastičnih mas, odkovki, struženi deli itn.), je dovolj samo eno izobraževanje.

### 3.2 Pridobivanje podatkov od dobaviteljev

Dobavitelj se mora registrirati v MBPM, da lahko v sistem pošlje podatke svojemu kupcu. Na elektronski naslov prispe uporabniško ime in geslo. Ko dobi kupec od svojega dobavitelja podatke, jih mora pregledati ter odobriti ali zavrniti (sl. 5). Najpogostejša vzroka zavrnitev sta:
- nepopolni kupčevi podatki (naziv, številka načrta, številka izdelka itn.) in
- neupoštevanje smernic MBPM za vnos materialov.

### 3.3 Izdelava materialnega lista v MBPM za kabelski komplet

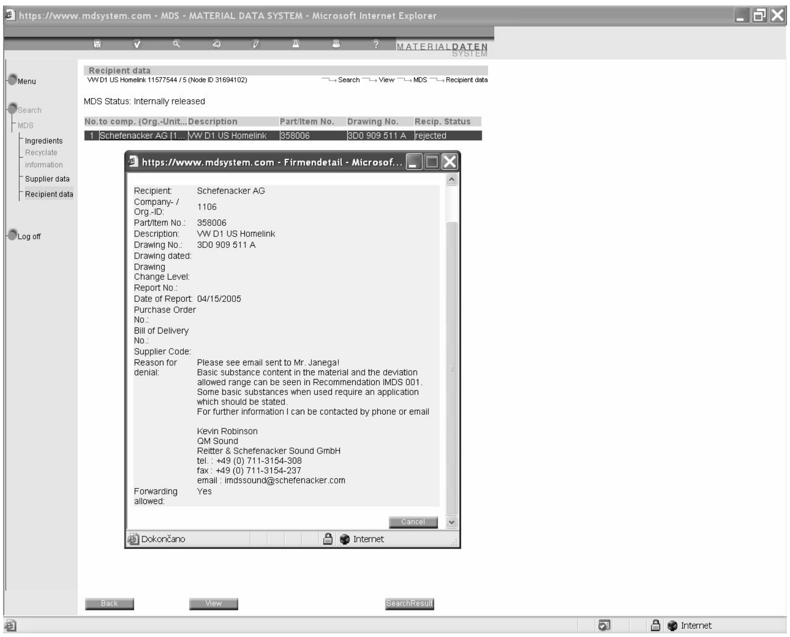
Materialni list imenujemo vse podatke, ki jih je treba vnesti v IMDS za posamezen izdelek. Na sliki 6 je prikazan postopek izdelave materialnega lista za kabelski komplet, ki je del elektroluminiscentne folije ambientne razsvetljave za avtomobile Maybach. Izdelek je sestavljen iz naslednjih komponent:

· žice,
· žičnih stikov,
· okrovov povezav ter
· tekstilnih trakov.

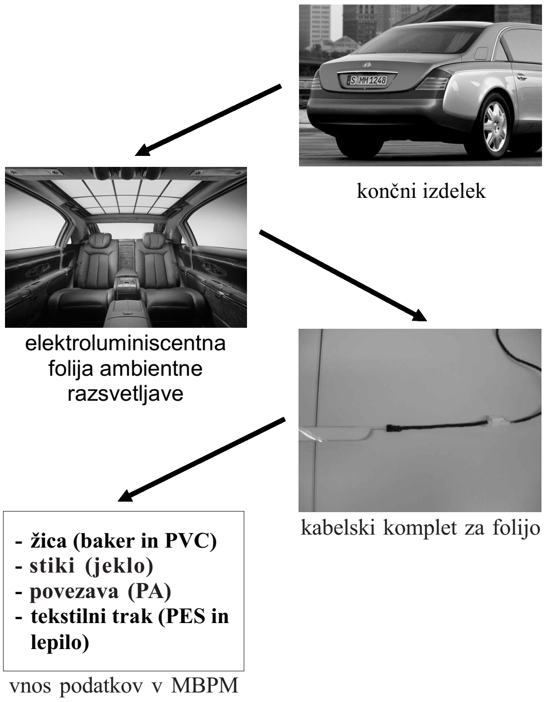
Preden začnemo uporabljati sistem, se moramo prijaviti. Vnesti je treba uporabniško ime in geslo (sl. 7).

Nato izpolnimo naslednje podatke o izdelku (sl. 1):

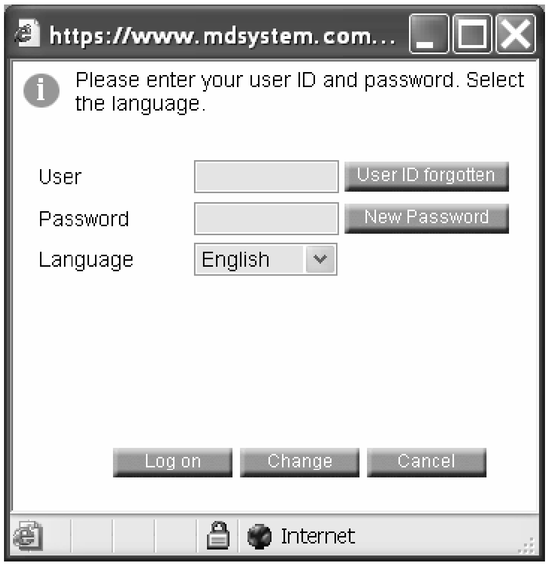
· ime,
· številko izdelka,
· maso izdelka in




Sl. 5. *Odgovor dobavitelju*




Sl. 6. *Namen MBPM*




Sl. 7. *Prijava v sistem*

· toleranco mase.

Materialni list je sestavljen iz štirih poglavij:

· uporabljeni materiali (sl. 1),
· recikliranje (sl. 2),
· proizvajalec (sl. 3) in
· prejemnik (sl. 4).

Izdelku je treba dodati vsebovane materiale, polizdelke in izdelke. Ko ponovimo postopek za vse izdelke, polizdelke in materiale, ki jih vsebuje kabelski komplet, dobimo strukturno drevo za celoten izdelek (sl. 1). Sledi izpolnitev preostalih treh poglavij. V drugem poglavju je mogoče vnesti podatke o recikliranju izdelka (sl. 2). Trenutno vnos teh podatkov ni obvezen. V poglavju "Proizvajalec" (sl. 3) je treba vnesti povezovalno osebo. Povezovalne osebe se določijo pri prijavi uporabnikov sistema. V poglavju "Prejemnik materialnega lista" (sl. 4) je treba izbrati kupce, ki jim pošiljamo materialni list. En materialni list je mogoče poslati večjemu številu kupcev. V tem primeru se lahko kupčevi podatki razlikujejo (npr. številka izdelka).

## 4 SKLEP

Vnos podatkov v MBPM ni odvisen samo od uporabnika, ampak tudi od njegovih dobaviteljev. Večina uporabnikov ima težave zaradi nepravočasnega prejema podatkov v MBPM od svojih dobaviteljev. Večina dobaviteljev v avtomobilski veji bazo na spletnih straneh pozna, potrebujejo pa več časa, da vnesejo posamezne materiale. Sistem je mlad in v fazi nenehnega izboljševanja. Posledica tega so večkratni vnosi za enak izdelek, kar je ekonomsko nepotrebno. Do sedaj se MBPM uporablja pretežno v Nemčiji. Preostala evropska (španska, angleška, francoska itn.), ameriška in japonska podjetja sistema še ne uporabljajo. V MBPM so registrirana tudi slovenska podjetja, ki so dobavitelji v avtomobilski industriji. Trenutno jih je registriranih okoli šestdeset. Uporaba sistema še ni optimalno zaživela. Sistem je tog, mogoč je še vnos nepopolnih podatkov. Opazne so tudi tehnične pomanjkljivosti. Menim, da bo sistem postal standard pri postopku vzorčenja izdelkov v dveh do štirih letih.

## 5 SIMBOLI

| | |
|---|---|
| X | zahteva |
| V | dogovor s kupcem v posameznih primerih |
| A | število vzorcev se dogovori s kupcem |
| E | vpogled |
| PVC | polivinilklorid |
| PA | poliamid |
| PES | poliester |
| VDA | Združenje nemških proizvajalcev avtomobilov |
| EMPB | poročilo o prvih vzorcih po VDA 2, točka 4 |
| IMDS | Mednarodna baza podatkov o materialih (MBPM) |

## 6 LITERATURA


[1] www.mdsystem.com
[2] VDA 2 zagotavljanje kakovosti dobav, tretja izdaja 1998.
[3] Smernica 2000/53/EG sveta evropskega parlamenta iz dne 18. 9. 2000 za stare avtomobile.
[4] Dodatek II k Smernici 2000/53/EG iz dne 27. 06. 2002.
[5] www.eds.com



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Osebne vesti - Personal Events

# Osebne vesti - Personal Events

## Prof. Boris Černigoj - 90 let - Prof. Boris Černigoj - 90 Years

Dne 2. oktobra 2005 praznuje svoj 90. rojstni dan prof. Boris Černigoj, dolgoletni profesor Fakultete za strojništvo Univerze v Ljubljani. Rodil se je v Innsbrucku, srednjo šolo z maturo je končal v Ljubljani, prva dva letnika univerzitetnega študija opravil v Ljubljani na tedanjem Elektrostrojnem oddelku Tehnične fakultete, nadaljeval študij na zagrebškem vseučilišču, kjer je ob izbruhu druge svetovne vojne diplomiral za strojnega inženirja. Kmalu po diplomi leta 1941 ga je za rednega asistenta nastavil prof. Feliks Lobe, predstojnik tedanjega Zavoda za strojništvo Tehnične fakultete Univerze v Ljubljani. S tem je bila začrtana slavljenčeva uspešna pot visokošolskega pedagoga in znanstvenika, ki ji je ostal zvest polnih 39 let do svoje upokojitve leta 1980. Ena od njegovih prvih nalog je bila, pomagati predstojniku prof. Lobetu novo zgrajeno in še ne povsem opremljeno stavbo zavoda čim bolj nepoškodovano spraviti skozi viharna leta druge svetovne vojne. Sodelovanje s prof. Lobetom je bilo plodno in stavba je predvsem po njuni zaslugi ostala skoraj nepoškodovana.

Prof. Černigoj je bil v letih 1941 do 1948 asistent, leta 1948 je postal docent, leta 1957 izredni in leta 1968 redni profesor na Fakulteti za strojništvo Univerze v Ljubljani. Bil je večkrat prodekan in v letih 1971 do 1973 tudi dekan fakultete. Od 1963 do 1982 je poučeval tudi na Višji pomorski šoli v Piranu, sedanji Fakulteti za pomorstvo in promet.

Prof. Boris Černigoj pripada pionirski generaciji slovenskih visokošolskih pedagogov, ki so vzgajali prve generacije diplomiranih strojnih inženirjev in jim jih je uspelo zelo dobro pripraviti za hiter razvoj slovenske termoenergetike po drugi svetovni vojni. Jubilant je nalogo izpolnil vzorno, znal je poklic visokošolskega učitelja v pravi meri povezati s svojim znanstvenim in svojim zelo kakovostnim strokovnim delom. Prof. Černigoj je v letih po končani svetovni vojni projektiral, konstruiral in dal v obratovanje več raznovrstnih strojev in naprav, vendar pa je njegovo zanimanje veljalo predvsem toplotnim pogonskim strojem: v prvih letih še aktualnim parnim batnim strojem, pozneje pa parnim in plinskim turbinam. Njegova ljubezen so bile plinske turbine in to že tedaj, ko so bile plinske elektrarne ne samo pri nas, ampak tudi v svetu še redek pojav. Upravičeno ga lahko imenujemo očeta naše plinske turbinske tehnologije. S svojim bogatim strokovnim znanjem je dejavno sodeloval pri postavitvi prvih plinskih postrojev v Sloveniji, tvorno pa je pomagal graditi skoraj vse slovenske termoelektrarne.

Kot visokošolski učitelj je napisal vrsto učbenikov in drugih strokovnih ter znanstvenih publikacij. Tu naj bo omenjena knjiga "Parne turbine", ki je izšla pred skoraj 50 leti pri Državni založbi Slovenije, članek o plinskih turbinah, ki je izšel leta 1958 v reviji Strojniški vestnik, in knjiga "Osnove plinskih turbin", tiskana je bila leta 1967 pri Univerzitetni založbi. Napisal je skupaj 25 pedagoških knjig, učbenikov in drugih učnih pripomočkov na več ko 3100 tiskanih straneh. To je dosežek, s katerim se tudi v današnjem času računalniške tehnike ni more pohvaliti veliko visokošolskih pedagogov.

Zelo dejavno je bilo tudi njegovo dolgoletno sodelovanje na področju slovenske strokovne terminologije pri Splošnem tehniškem slovarju in pri Slovarju slovenskega knjižnega jezika, predvsem pa pri reviji Strojniški vestnik, pri kateri je bil tudi član prvega uredniškega odbora.

Zveza strojnih in elektrotehničnih inženirjev in tehnikov tedanje Jugoslavije ga je leta 1956 imenovala za zaslužnega člana, Zveza inženirjev in tehnikov Slovenije pa leta 1972 za svojega častnega člana. Ob upokojitvi je za svoje delo prejel visoko jugoslovansko odličje "Red dela z zlatim vencem". Odlikovanje je prišlo v prave roke, za prof. Černigoja je mogoče zapisati, da ga je s svojim vzornim delom in s svojim osebnim zgledom vsekakor zaslužil. Uredništvo Strojniškega vestnika mu je letos ob 50-letnici izhajanja revije podelilo častno plaketo.

Prof. Boris Černigoj je ostal tudi po upokojitvi leta 1980 zvest svojim toplotnim strojem. Potem ko je užival zasluženi pokoj, se je seznanil z računalnikom in napisal nekaj nadaljnjih učbenikov s področja toplotnih pogonskih strojev, ki so še dandanes v uporabi med študenti na univerzi in med inženirji - energetiki v industriji. V zadnjih letih je v slovenščino prevedel najpomembnejše evropske standarde s področja parnih kotlov in parnih turbin. Sočasno je pripravljal in izdal nemško-slovenski in slovensko-nemški strojniški slovar, oba sta doživela več ponatisov. Ob njegovi 85-letnici je izšel na 190 straneh njegov zelo uporaben angleško-slovenski slovar za študente strojništva. S tem slovarjem šteje njegova bibliografja 51 tiskanih enot.

Prof. Černigoj je rojen pedagog širokih pogledov in bogatega strokovnega znanja, vsestransko razgledan strokovnjak, ki tekoče obvlada več svetovnih jezikov. Je tudi velik ljubitelj narave in navdušen gornik, ki pozna veliko lepih in skritih kotičkov ljubih mu slovenskih gora. Študentom je bil strog, vendar zelo pravičen učitelj, inženirjem v industriji pa vedno dobrodošel strokovni sogovornik in svetovalec. Jubilant je ostal kljub visokemu jubileju čil in prožen. Še vedno ga je mogoče tedensko srečati na daljših sprehodih po ljubljanskem Tivoliju. Še vedno prihaja na svojo “almo mater” na klepet ob kavi, ki se včasih spremeni v pravo strokovno debato.

Spoštovanemu visokošolskemu učitelju, priznanemu strokovnjaku in pionirju toplotnih turbinskih strojev čestitajo za visoki jubilej 90 let njegovi številni učenci iz slovenske industrije in z obeh slovenskih univerz.

*prof.dr. Matija Tuma*

## Diplome - Diploma Degrees

DIPLOMIRALI SO

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

dne *5. septembra 2005*: Jure BEZGOVŠEK, Klemen DOVRTEL, Boštjan PERDAN, Tadej PERHAVEC, Rok POTOČNIK;

dne *7. septembra 2005*: Gregor ALIČ, Anže JERIČ, Marko KEBER, Vanja PAHOR, Franci PUŠAVEC, Blaž SUHAČ, Matej TADINA, Matej VOLK, Marko VRH, Boštjan ZUPANC;

dne *27. septembra 2005*: Matjaž HAFNER, Mitja JERIČ, Marko PRAH, Gregor TROHA, Gregor ŽELEZNIK;

dne *28. septembra 2005*: Peter CASERMAN, Igor TURK, Gregor INGLIČ, Miha KUHAR, Aleksander ŠTRUKELJ;

dne *30. septembra 2005*: Primož BANTAN, Luka BOBIČ, Jože ČANDEK, Goran KOCJANČIČ, Tomaž KRIŽAN, Kristijan LAMOT, Vanja PAJIĆ, Andrej PUREBER, Borut STRAŽIŠAR, Midhat ŠEHOVIĆ.

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

dne *1. septembra 2005*: Klemen PLESTENJAK, Dejan ŠLEMER, Zdravko TIŠMA;

dne *15. septembra 2005*: Karl BENKIČ, Igor FRANKO, Jano MULEJ;

dne *29. septembra 2005*: Boštjan GREGORC, Jože IVANČIČ, Gregor RANC, Robert ZEMLJAK.

*

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

dne *15. septembra 2005*: Miha HOMAR, Rok HRAST, Zvezdan SELJAK, Mitja SEVER, Matjaž ŠTEFANIČ;

dne *16. septembra 2005*: Sandi AJSTER, Pavel CIGOJ, Janez GARVAS, Jaka JAKLIČ, Hrvoje LOZICA, Dragan LUZNAR, Mohor PREZELJ, Uroš REBOLJ, Jerneja SIMONČIČ, Valter TOMŠIČ, Tilen TRAMPUŽ;

dne *19. septembra 2005*: Tomaž LOVRENČIČ, Jernej MARKUN, Tomaž PELC, Jure RASPOTNIK, Miha ŠINK, Zdravko ŠPELIĆ, Boštjan URBANIJA, Vlado VLAŠIĆ;

dne *27. septembra 2005*: Primož DREŠAR, Andreas DULAR, Irena REMC, Aleš ŠINKOVEC, Danijel ŽMAUC.

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

dne *1. septembra 2005*: Franc HABIČ, Simon KRAJNIK, Branko LUKIĆ, Alen STOJANOVIĆ;

dne *15. septembra 2005*: Andrej KLEMENČIČ, Dušan KOCUVAN;

dne *22. septembra 2005*: Željko ŽMAUC;

dne *29. septembra 2005*: Matjaž AMON, Dejan OSTANEK, Aleš POKERŽNIK, Aleksander ŠKRLEC.

# Navodila avtorjem - Instructions for Authors

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

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

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

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

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

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

## VSEBINA ČLANKA

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

## THE FORMAT OF THE PAPER

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

## OBLIKA ČLANKA

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

Ne uporabljajte urejevalnika LaTeX, saj program, s katerim pripravljamo Strojniški vestnik, ne uporablja njegovega formata.

Enačbe naj bodo v besedilu postavljene v ločene vrstice in na desnem robu označene s tekočo številko v okroglih oklepajih

## THE LAYOUT OF THE TEXT

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

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

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

### Enote in okrajšave

V besedilu, preglednicah in slikah uporabljajte le standardne označbe in okrajšave SI. Simbole fizikalnih veličin v besedilu pišite poševno (kurzivno), (npr. *v, T, n* itn.). Simbole enot, ki sestojijo iz črk, pa pokončno (npr. $ms^{-1}$, K, min, mm itn.).

Vse okrajšave naj bodo, ko se prvič pojavijo, napisane v celoti v **slovenskem jeziku**, npr. časovno spremenljiva geometrija (ČSG).

### Slike

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

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

**Vse označbe na slikah morajo biti dvojezične**.

### Preglednice

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

**Vsi podnaslovi preglednic morajo biti dvojezični.**

### Seznam literature

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

[1] Tarng, Y.S., Y.S. Wang (1994) A new adaptive controller for constant turning force. *Int J Adv Manuf Technol* 9(1994) London, pp. 211-216.

[2] Čuš, F., J. Balič (1996) Rationale Gestaltung der organisatorischen Abläufe im Werkzeugwesen. *Proceedings of International Conference on Computer Integration Manufacturing,* Zakopane, 14.-17. maj 1996.

[3] Oertli, P.C. (1977) Praktische Wirtschaftskybernetik. *Carl Hanser Verlag,* München.

### Podatki o avtorjih

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

## SPREJEM ČLANKOV IN AVTORSKE PRAVICE

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

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

### Units and abbreviations

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

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

### Figures

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

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

**All figure captions must be bilingual**.

### Tables

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

**All table captions must be bilingual.**

### The list of references

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

[1] Tarng, Y.S., Y.S. Wang (1994) A new adaptive controller for constant turning force. *Int J Adv Manuf Technol* 9(1994) London, pp. 211-216.

[2] Čuš, F., J. Balič (1996) Rationale Gestaltung der organisatorischen Abläufe im Werkzeugwesen. *Proceedings of International Conference on Computer Integration Manufacturing,* Zakopane, 14.-17. maj 1996.

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### Author information

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

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