

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 izdelava razmeroma drago orodje za izdelavo razmeroma cenjenih 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.

© 2005 Strojniški vestnik. Vse pravice pridržane.

(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 product.

© 2005 Journal of Mechanical Engineering. All rights reserved.

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

0 UVOD

Le okoli dvajset izmed nekaj sto zamisli izdelkov je temeljito preišljenih [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 dosegajo 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 freziranje z velikimi hitrostmi pri izdelavi orodij, podajata 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 razpozna 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 konstruiranje 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 prioriternih 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 izvornost 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 izvornost 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, plastenik 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.

Elektroerozijska 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 K^* in izdelavo orodja s T , potem zapišemo:

$$T=F(K^*) \tag{1}$$

kjer sta K^* in T vektorja prilastkov, ki popisujeta konstrukcijske oz. tehnološke lastnosti: $K^*=(k_1^*,k_2^*,\dots,k_p^*,\dots,k_p^*)$, $T=(t_1,t_2,\dots,t_q,\dots,t_Q)$. Tudi F je množica funkcij, ki popisuje razmerja med posameznimi prilastki k_p^* in t_q . Prilagajanje konstrukcije izdelka, popisane z vektorjem K^* , izdelavi orodja, popisani z vektorjem T , pomeni reševanje enačbe:

where K^* and T are vectors of the attributes that are describing the design and manufacturing properties respectively: $K^*=(k_1^*,k_2^*,\dots,k_p^*,\dots,k_p^*)$ and $T=(t_1,t_2,\dots,t_q,\dots,t_Q)$. Function F embraces several functions, which are describing the relations between the attributes k_p^* and t_q . The adaptation problem deals with the inverse problem to derive design vector D^* from the manufacturing vector T :

$$K=F^{-1}(T) \tag{2}$$

Tako je treba za vsak tehnološki prilastek m_q definirati preslikave f_r med preostalimi tehnološkimi prilastki m_q in konstrukcijskimi prilastki k_p :

For each manufacturing attribute m_q it is necessary to define all the mapping functions f_r with other manufacturing attributes m_q and design attributes d_p :

$$t_q=f_r(k_p,t_q): p \in \{1,2,\dots,P\}; q,q' \in \{1,2,\dots,Q\}, q \neq q'; r \in \{1,2,\dots,R\} \tag{3}$$

Preslikave iz konstrukcijske na tehnološko raven so bolj 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.

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.

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 poglobljena zamisel sistema v določitvi kritičnih mest konstrukcije

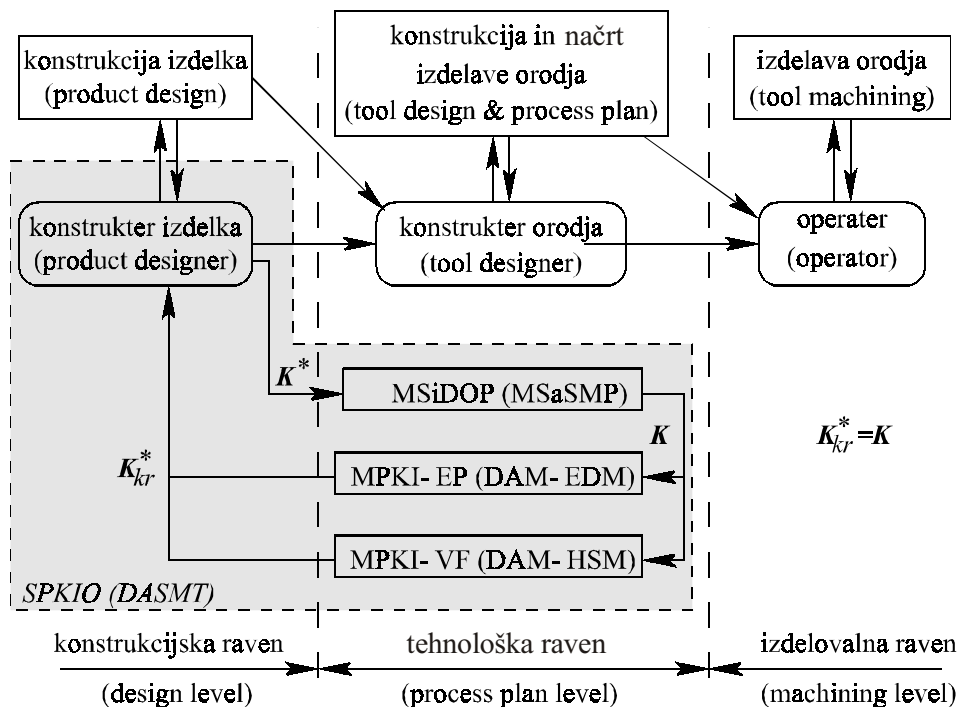
The expert systems included into the DASMT manage manufacturing knowledge to provide the designer with only the critical information on the product (critical from the manufacturing point of view). The decision about the design adaptation is only up to the designer, by considering the demands for the 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. Prilaganje 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 prilaganje konstrukcije izdelavi z elektroerozijskim postopkom (MPKI-EP) in modul za prilaganje konstrukcije izdelavi s frezanjem z velikimi hitrostmi (MPKI-VF).

2.1 Delovanje SPKIO

Konstruktorski prilastki 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 konstruktorskih prilastkov orodja 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 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 obdelava z vidika obdelovalnosti z danim postopkom. V tem postopku se določijo tisti konstruktorski prilastki, ki so najbolj neugodni z vidika obdelave. Poimenovali smo jih kritični konstruktorski prilastki orodja in jih označili s K_{kr} . Le-ti so identični kritičnim konstruktorskim prilastkom izdelka 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 konstruktorskih prilastkov se takoj kaže na sporočanju novih kritičnih konstruktorskih 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 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 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 built 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 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 K_{kr} and they are identical to the critical product-design attributes 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 konstrukcijskim zahtevam orodja oziroma izdelka. Takrat je tudi izdelava orodja najcenejša.

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.

Zamiseln 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

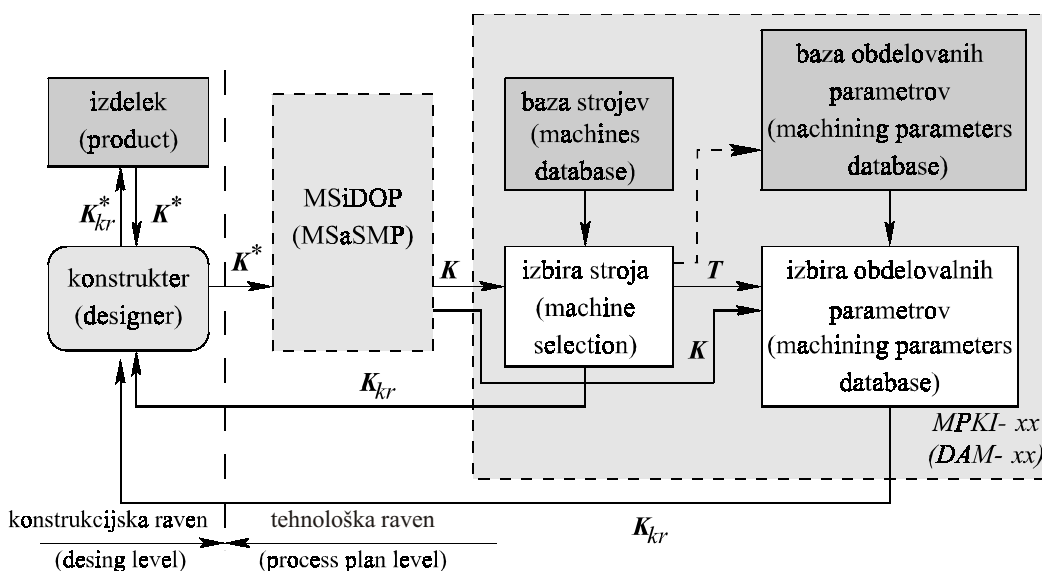
situation is that all the parts of the product are critical. In such a case, the selected machining parameters hardly achieve the demands for the product and tool design—the machining of the tool is the cheapest and the fastest.

2.2 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 doseg enakovrednih 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 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 k_i . Dva prilastka se nanašata na celotno orodje: k_1 pomeni zunanje mere orodja (x, y, z) in k_4 popisuje material orodja. Vsak element na orodju je popisani s sedmimi prilastki; glavni je prilastek k_2 , ki popisuje obliko elementa. Drugi prilastki so: k_3 erodirna površina, k_6 globina obdelave, k_7 hrapavost površine, k_8 globina toplotno prizadete cone, k_9 zaokrožitev robov in k_{10} nagib stranskih ploskev. Prilastek 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 k_i . Two attributes characterise the whole tool: k_1 represents the maximum dimensions of the tool (x, y, z), and k_4 represents the tool material. Each tool feature is characterised by seven attributes; the main one is the attribute k_2 characterising the shape of the feature. The remaining attributes are: k_3 surface area, k_6 machining depth, k_7 surface roughness, k_8 heat-affected zone, k_9 roundness of edge, and k_{10} slope of flank surface. The attribute 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 k_2 describes the shape of the

Prilastek k_2 , ki popisuje obliko elementa, pa zahteva podrobnejšo razlago.

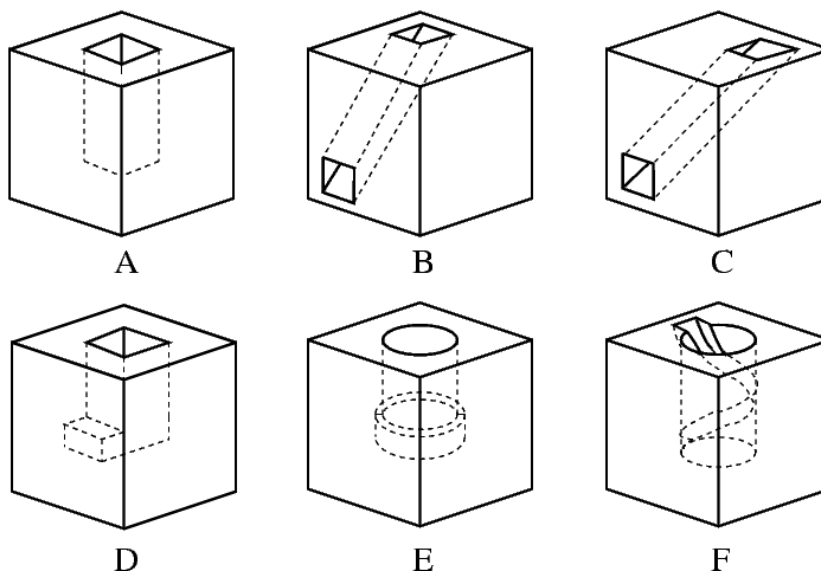
Izdelovalni element je definiran kot geometrijska oblika, ki določa tehnološke lastnosti in glede na katero je določen obdelovalni postopek. V primeru elektroerozijske obdelave je element del orodja, ki ga je mogoče izdelati z eno elektrodo ali skupkom elektrod za grobo in fino obdelavo na danem obdelovalnem 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 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
Table 1. Characteristics of the feature prototypes

Dostopnost elementa (Feature access)	odprt (open) zaprt (closed)	Pomik elektrode (Electrode movement)			
		1D	2D	3D	4D
	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 m_1 , število interpoliranih osi m_2 , in natančnost obdelave v vsaki izmed interpoliranih osi m_3 .

Druga baza vsebuje obdelovalne režime in njihove karakteristike. Obdelovalni režim m_5 je opisan 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 m_4 in potrebno število elektrod za izdelavo danega elementa na orodju 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 tehnološke 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_1) 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.

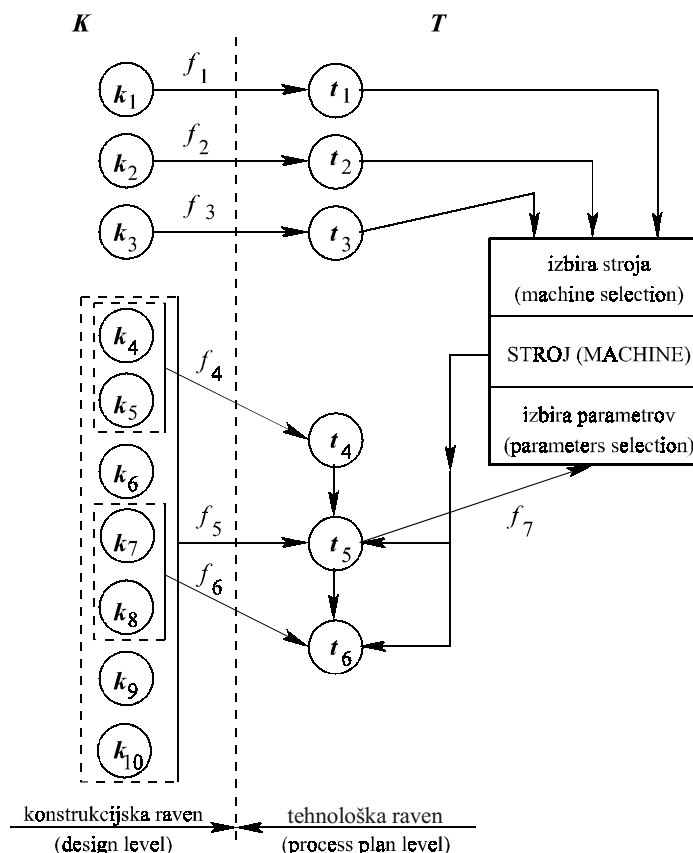
2.3.2 Manufacturing attributes of the tool

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 m_1 , the list of axes that can operate on the particular machine m_2 , and the precision of the machine in each axis m_3 .

The second database consists of machining parameters and their performance. A group of set-up parameters, denoted as 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 m_4 and the required number of electrodes for machining of the given feature of the tool 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: k_1 zunanje mere orodja, k_2 oblike elementov, k_3 predpisane tolerance, k_4 material orodja, k_5 velikost erodirne površine elementa, k_6 globina elementa, k_7 hrapavost elementa, k_8 dovoljena globina toplotno prizadete cone elementa, k_9 zaokrožitve robov, k_{10} nagib površin. Oznake tehnoloških prilastkov: t_1 velikost delovnega prostora stroja, t_2 število interpoliranih osi stroja, t_3 natančnost posameznih osi stroja, t_4 material elektrode, t_5 obdelovalni parametri za obravnavan element, 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: k_1 size of the tool, k_2 shape of the feature, k_3 given tolerances, k_4 tool material, k_5 eroding surface size, k_6 feature depth, k_7 surface roughness of the element, k_8 allowed heat-affected zone, k_9 edge roundings, k_{10} slope of the flank surface. Denotations of the manufacturing attributes: t_1 working area size of the machine, t_2 number of axes, t_3 precision of each axis, t_4 electrode material, t_5 set-up parameters, 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

- [1] Ulrich, K.T., S.D. Eppinger (1995) Product design and development, *McGraw-Hill*, New York.
- [2] Allada V., S. Anand (1995) Feature base modelling approaches for integrated manufacturing: state-of-the-art survey and future research directions, *International Journal of Computer Integrated Manufacturing*, 8/6(1995), pp. 411-441.
- [3] Mohri N., M. Suzuki, M. Furuya, N. Saito (1995) Electrode wear process in electrical discharge machining, *Annals of the CIRP*, 44(1995), pp. 165-168.
- [4] Lauwers B., J.P. Kruth (1994) Computer aided process planning for EDM operations, *Journal of Manufacturing Systems*, 13(1994), pp. 313-322.
- [5] Alam, M. R., K. S. Lee, M. Rahman, K. S. Sankaran (2002) Decision algorithm for selection of high-speed machining, EDM or a combination for the manufacture of injection moulds, *International Journal of Production Research*, 40/4(2002), pp. 845-872.

- [6] Boothroyd G., P. Dewhurst (1994) Product design for manufacture and assembly, *Marcel Dekker Inc.*
- [7] Boothroyd Dewhurst Inc. (1998) BDI, software for world class product design, <http://www.dfma.com/software/index.html>
- [8] DFM Design for Manufacture (1994) Guide for improving the manufacturability of industrial products, *EUREKA publishers.*
- [9] Lee R.S., Y.M. Chen, C.Z Lee (1997) Development of a concurrent mold design system: a knowledge-based approach, *Computer Integrated Manufacturing Systems*, 10/4(1997), pp. 287-307.
- [10] Lee R.S., Y.M. Chen, Y.C. Hsin, M.D. Kuo (1998) A framework of a concurrent process planning system for mold manufacturing, *Computer Integrated Manufacturing Systems*, 11/3(1998), pp. 171-190.
- [11] Chin, K.S., T. N. Wong (1999) Integrated product concepts development and evaluation, *International Journal of Computer Integrated Manufacturing*, 12/2(1999), pp. 179-190.
- [12] Ding, X.M., J. Y.H. Fuh, K.S. Lee, Y.F. Zhang, A.Y.C. Nee (2000) A computer-aided EDM electrode design system for mold manufacturing, *International Journal of Production Research*, 38/13(2000), pp. 3079-3092.
- [13] Chen, Y.M., Y.T. Hsiao (1997) A collaborative data management framework for concurrent product and process development, *International Journal of Computer Integrated Manufacturing*, 10/6(1997), pp. 446-469.
- [14] Young, R.I., O. Canciglieri, C.A. Costa (1999) Manufacturing information interactions in data model driven design, *Journal of Engineering manufacture*, 213/5(1999), pp. 527-532.
- [15] Huang, G.Q., K.L. Mak (1998) The DFX shell: A generic applying 'Design for X' (DFX) framework for tools, *International Journal of Computer Integrated Manufacturing*, 11/6(1998), pp. 475-484.
- [16] Valentinčič, J. (2000) Adaptation of the product to electrical discharge machining in toolmaking, *Faculty of Mechanical Engineering*, Ljubljana, Master's thesis (selected chapters).
- [17] Nardin, B. (1999) Načrtovanje preoblikovalnih tehnologij in orodij v majhnih in srednje velikih podjetjih, *Faculty of Mechanical Engineering*, Ljubljana, Master's thesis.

Naslova avtorjev: dr. Joško Valentinčič
prof.dr. Mihael Junkar
Univerza v Ljubljani
Fakulteta za strojništvo
Aškerčeva 6
1000 Ljubljana
joze.valenticic@fs.uni-lj.si
mihael.junkar@fs.uni-lj.si

Daniel Brissaud
Institut National Polytechnique
de Grenoble
Laboratoire 3S, BP 53
38041 Grenoble cedex 9, France
daniel.brissaud@hmg.inpg.fr

Authors' Addresses: Dr. Joško Valentinčič
Prof.Dr. Mihael Junkar
Univerza v Ljubljani
Fakulteta za strojništvo
Aškerčeva 6
1000 Ljubljana, Slovenia
joze.valenticic@fs.uni-lj.si
mihael.junkar@fs.uni-lj.si

Daniel Brissaud
Institut National Polytechnique
de Grenoble
Laboratoire 3S, BP 53
38041 Grenoble cedex 9, France
daniel.brissaud@hmg.inpg.fr

Prejeto:
Received: 29.11.2004

Sprejeto:
Accepted: 29.6.2005

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