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Novi dosežki v tehniki odrezovanja
New Achievements in Cutting Technique

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Zahteve svetovnega trga: kratek čas obdelave in nizka proizvodna cena narekujeta uvajanje sodobnih dosežkov v tehniki odrezovanja tudi slovenskim proizvajalcem.

Prispevek zajema visokohitrostno odrezovanje (VHO), ki ga omogočajo sodobna rezalna orodja in zmogljivi odrezovalni stroji. Predstavljeno je »suho« odrezovanje, kjer z minimalno uporabo hladilno-mazalnih tekočin prispevamo k varovanju okolja. Z več tehniško-tehnološkimi primeri so ponazorjene različne zahtevne obdelave.

Ključne besede: tehnika odrezovanja, odrezovanje visokohitrostno, materiali rezalni, obdelave suhe, frezanje stružilno

World market requirements, short production time and low price dictate a need for introducing new achievements into cutting techniques by Slovenian producers.
This paper contains some information about HSC - high speed cutting technology which can be achieved only with modern cutting materials /tools and modern machine tools. Here »dry« cutting is introduced as an alternative for better environmental protection. Some technical/technological examples are illustrated for hard cutting.

Keywords: cutting technique, high speed cutting, cutting materials, dry cutting, turn milling

0 UVOD

Tehnika odrezovanja že dalj časa doživlja hude napade in potiskanje v kot od drugih postopkov izdelave. Zaradi doseganja vedno večjih natančnosti se močno uveljavlja hladno preoblikovanje; izpopolnili so se postopki alternativnih obdelav - laser, vodni curek z abrazivi, elektroerozija itn. Novi materiali, iz katerih so izdelki, so na osnovi plastike, polimerov, polnil, kompozitov in dosegajo lastnosti jekel in litin. Vse to na nek način kaže na odstotno zmanjšanje zastopanosti tehnike odrezovanja med izdelovalnimi postopki.

Znan je tudi podatek o zvečanju proizvodnje in glede na to širitev finančnega deleža, ki ga zasedajo postopki odrezovanja. Širijo se tudi nove tehnologije, ki so interdisciplinarne, npr. NNS (near - net shape), ki združuje področje preoblikovanja in odrezovanja. Natančnost pri odrezovanju je še vedno tolikšna, da lahko dopolnjuje vse druge procese (preoblikovanje, tlačno litje, brizganje plastike) glede okroglosti, ravnosti oziroma dopolni zahtevne oblike, kakor so vrezovanje navojev, povrtavanje lukenj, zarezovanje sedežev za vskočnike in tesnilke itn.

V zadnjem času je na ameriškem in zahodnoevropskem proizvodnem področju prišlo do okrepljenega uvajanja hitrega odrezovanja in nadomeščanja elektroerozije s tako imenovanimi postopki hitrega odrezovanja (VHO) v trdo.

Rezalni materiali so dosegli tak napredek, da je postala obdelava trdih materialov neproblematična; ob tem pa se dosegajo številne prednosti: krajši časi izdelave gravure, nižja cena izdelka, toplotno nepoškodovana površinska plast orodja itn.

0 INTRODUCTION

For a long time cutting technique has been losing an advantage over other manufacturing techniques. In cold forming we can find a greater precision rate. Alternative technique are stronger - laser, jet abrasive cutting, EDM, etc. New workpiece materials like plastics, polymers and composites have reached the stage of steel and casts. All this has yielded a percentage drop in cutting techniques versus other approaches.

With the world production growing, the economical aspect of cutting techniques is also growing in importance but it is only one of the reasons for a decline in cutting technique.New interdisciplinary approches are spreading, e. g. NNS (near -net shape) technology which combines the fields of forming and cutting techniques. Precision in cutting is still the highest one and that why it is still supports supported by many other processes like cold forming, high pressure cast production, plastic injection moulding etc. Fine machining is still used in cases of ovalness, parallelity, roughness and to make complex shapes like threads, reaming of holes, cutting of seats into sealings etc.

In the American and European production of the last few years we can note an intensive introduction of HSC - high speed cutting into car production and into tool - die productions.

New cutting materials offer the possibility of hard cutting, with some important advantages like shorter time of production, lower price, no thermal damage of the upper layer of the die - tools contour, etc.

Vendar tega postopka ni povzela samo industrija za izdelavo orodij - gravur, pač pa se je hitro uveljavil v večjih tovarnah avtomobilov, kjer z mehansko obdelavo po postopku VHO dosegajo velike prihranke.

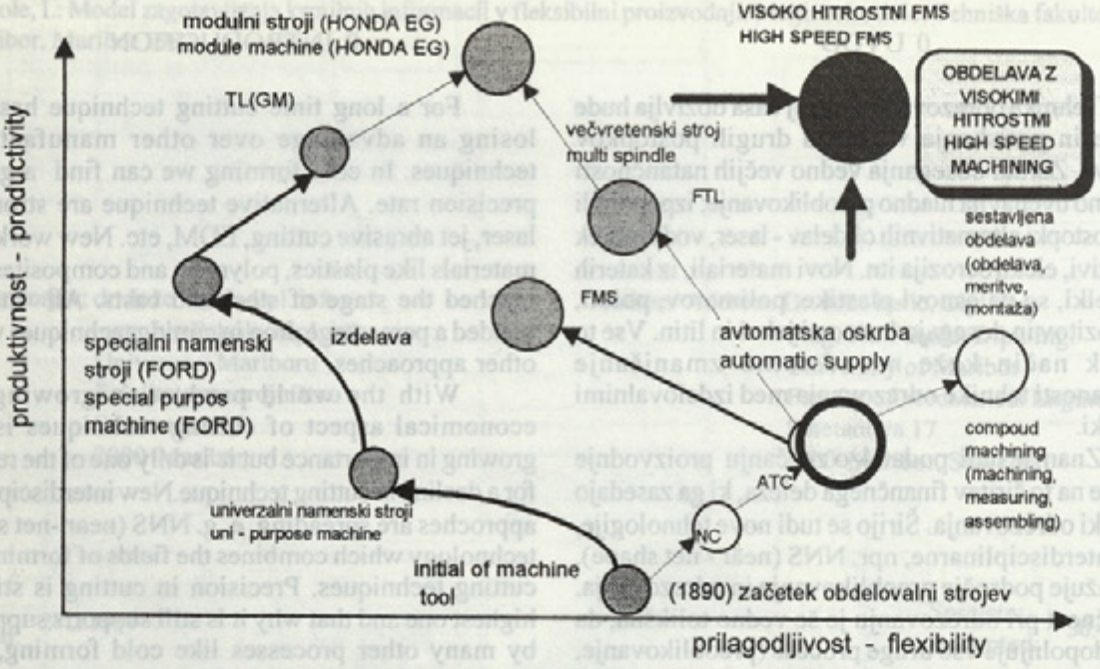
1 SEDANJI IN PRIHODNJI OBDELOVALNI SISTEMI

Poznan je razpon med produktivnostjo in prilagodljivostjo. Zelo produktivni stroji niso bili prilagodljivi, prilagodljivi pa niso omogočali velike produktivnosti. Pri iskanju kompromisa ob uvajanju novih rezalnih orodij in tehnologij so končno našli optimalno rešitev, to so visoko hitrostni prilagodljivi obdelovalni sistemi VH FMS, ki slonijo na visoko hitrostnem odrezovanju VHO. Slika 1 prikazuje zgodovinski potek razvoja obdelovalnih sistemov. Trenutni končni dosežek omogoča obdelavo v velikoserijski proizvodnji, kakor tudi v namenski, npr. v orodjarstvu [1].

As mentioned, not only tool - dieworkshops but also large car factories are using HSC in order to achieve better profits.

1 PRESENT AND FUTURE MACHINING SYSTEMS

It is well-known that there is a great discrepancy between productivity and flexibility of machining systems. Machine tools with high production are not very flexible too, but machine tools which are highly flexible do not have a higher production level. To find a compromise between both of them by the support of new and special cutting material tools an optimal solution should be looked for HS - FSM - high speed flexible manufacturing system, the basis of which is high speed cutting - HSC. In Figure 1 is shown a short historical review of development of machining systems [1]. Today machining is possible on a high economical level in mass production or in special purpose machining too.



Sl. 1. *Sedanji in prihodnji obdelovalni sistemi*
Fig.1. *Present and future machining system*

2 SODOBNI REZALNI MATERIALI IN ORODJA

Sodobna rezalna orodja omogočajo hitro in natančno obdelavo pri običajnih rezalnih hitrostih, kakor tudi obdelavo pri velikih hitrostih.

Tipična VH orodja so orodja, pri katerih je polikristalni diamant ali kubični borov nitrid (kot rezalni rob) čvrsto prilotan na osnovno orodje. Za večje notranje premere je VH krožno frezanje lahko alternativa VH natančnemu povrtavanju. Polikristalna

2 HIGH TECH CUTTING MATERIALS AND TOOLS

High tech tools which, due to their complexity, can machine a workpiece rapidly and exactly at conventional cutting speeds and feeds, also belong to the topic Precise Machining at High Speeds.

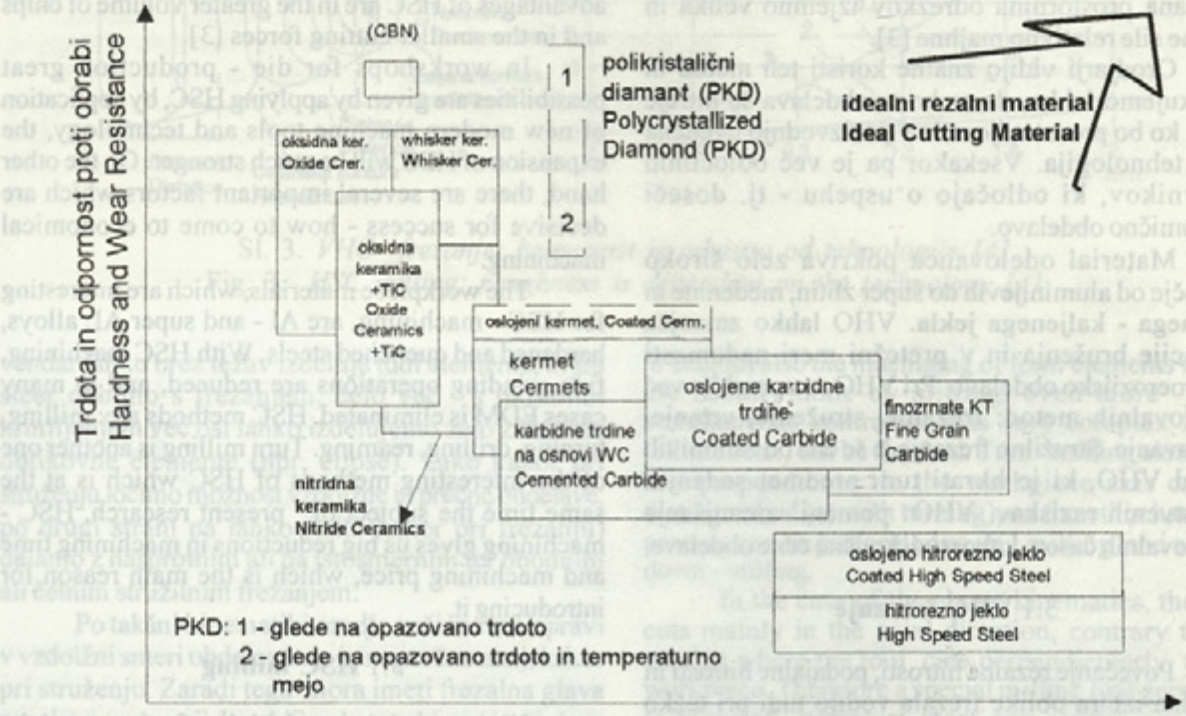
Typical HSC tools are tools in which polycrystalline diamond (CD) or cubic boron nitride (BN) cutting edges are firmly brazed to the basic body. For larger inner diameters HSC circular milling can be an alternative to HSC precision boring. PCD

diamantna orodja (PKD) so idealna za obdelavo aluminija; omogočajo obdelavo od desettisoč do sto tisoč kosov in pri tem dosegajo veliko kakovost obdelane površine in mersko natančnost izdelka.

V splošnem se vsi, tudi rezalni materiali, kakor so definirani po DIN/ISO 513, kar pomeni karbidni keramični diamant (DP) in borov nitrid (BN), uporabljajo pri VHO. DP je najbolj primeren za obdelavo aluminija, BN pa za obdelavo sive litine in jekla. Za diamantno prevlečena orodja se napoveduje uporaba v prihodnosti. Lastnosti in uporabnost rezalnega materiala so odvisni od žilavosti in upogibne trdnosti pa tudi od obrabne trdnosti in trdote. Razvrstitev različnih skupin rezalnih materialov glede na te značilnosti prikazuje slika 2.

tools are ideal for machining aluminium, and tool lives from ten thousand up to one hundred thousand pieces are achieved with the highest surface quality and accuracy.

In general, all hard cutting materials as defined by DIN/ISO513, which means carbide - ceramic-diamond (DP) and boron nitride (BN), are used for HSC applications. However, DP is primarily suited for aluminium and BN for gray cast iron and steel. Diamond - coated tools are expected to be used more often in the future. The properties and usefulness of cutting materials depend on wear resistance and hardness. Classification of different kinds of cutting material versus the mentioned characteristics is shown in figure 2.



Sl. 2. *Mehanske lastnosti različnih rezalnih materialov [2]*
Fig. 2. *Mehanical properties of different cutting materials [2]*

Težke razmere pri obdelavi titanovih in nikljevih zlitin so zelo zahtevne glede na dane značilnosti in usmeritev k popolnemu rezalnemu materialu. Uporabna so celo sintrana hitrorezna jekla, ki morajo biti oplaščena (HSS+TiN+TiC), neoplaščene karbidne trdine različnih uporabnih skupin, oplaščene karbidne trdine in kermet. Od keramičnih rezalnih materialov prihajajo oksidna keramika (Al_2O_3), mešana keramika (Al_2O_3+TiC) ter nitridna keramika (Si_3N_4) pa tudi polikristalni diamant (PKD) ter kubični borov nitrid (CBN). Povečana rezalna hitrost, posebno pri teh težko obdelovanih materialih, pomeni močno povečano obrabo zaradi vse večje toplotne obremenitve. Zato je potreben prehod na najbolj kakovostna orodja (PKD, CBN); razmere so tu popolnoma drugačne, kajti obraba na orodju se zmanjša na minimum, ob tem pa so cene orodij že sprejemljive.

Hard machining of Ti and Ni Alloys request the way in goal of ideal cutting material. On other hand sintered high speed steels are useful in HS cutting if they are coated (HSS+TiN+TiC); cemented carbide, cermet and coated cemented carbide too. From cutting ceramics we can find oxide ceramic (Al_2O_3), mixed ceramic (Al_2O_3+TiC) and nitride ceramic (Si_3N_4), polycrystal diamond PCD and cubic boron nitride (CBN). Higher cutting speeds, especially in hard machining, cause greater wear on the cutting edge because the thermal effect is much higher. For this reason a transition to using high quality tools (PCD, CBN) is necessary; the relationships by tool wear on this cutting material are totally different; tool life is extremely long but the prices are quite normal.

3 VISOKOHITROSTNA OBDELAVA (VHO)

Kaj razumemo pod imenom VHO? VHO nima točne definicije, je široko ime za različne oblike uporabe. Preprosta definicija je lahko ta, da je VHO obdelava, pri kateri se vreteno vrti zelo hitro. V praksi pa pomeni postopek z znatno večjimi hitrostmi - posebno na področju obdelave trdih materialov. Tako je npr. za obdelavo trdega jekla, kjer smo do sedaj uporabljali hitrost 100 m/min nova hitrost 300 m/min že VHO.

VHO vsebuje obdelavo, ki uporablja znatno višje rezalne hitrosti in podajanja, kakor se uporabljajo pri običajni obdelavi. Globine rezanja so navadno manjše, toda prednosti so še vedno vidne v tem, da je odrezana prostornina odrezkov izjemno velika in rezalne sile relativno majhne [3].

Orodjarji vidijo znatne koristi teh metod in pričakujemo lahko, da se bo ta obdelava še hitreje širila, ko bo predstavljena in v proizvodnjo uvedena nova tehnologija. Vsekakor pa je več odločilnih dejavnikov, ki odločajo o uspehu - tj. doseči ekonomično obdelavo.

Material odelovanca pokriva zelo široko področje od aluminijevih do super zlitin, medenine in utrjenega - kaljenega jekla. VHO lahko zmanjša operacije brušenja in v pretežni meri nadomesti elektroerozijsko obdelavo. Pri VHO se uporablja več obdelovalnih metod: frezanje, struženje, vrtanje, povrtavanje. Stružilno frezanje je še ena od zanimivih metod VHO, ki je hkrati tudi predmet sedanjih znanstvenih raziskav. VHO pomeni zmanjšanje obdelovalnih časov, kakor tudi končne cene obdelave.

3.1 **VHO frezanje**

Povečanje rezalne hitrosti, podajalne hitrosti in pravilna izbira oblike frezala vodijo tudi pri težko obdelovalnih zlitinah k bistvenemu zmanjšanju hrapavosti površine. Še posebej v orodjarnah pri izdelavi tridimenzionalnih obrisov je pomembna prava izbira tehnologije, da so vrhovi površine po prehodu frezala čim manjši, s tem bistveno znižamo stroške fine končne obdelave (sl. 3).

3.2 **Stružilno frezanje**

Stružilno frezanje kot dokaj nov postopek je namenjen predvsem za obdelavo rotacijskih obdelovancev in združuje posamezne parametre obeh postopkov, kar se kaže v podobnostih obdelave.

Glavno rezalno gibanje je rotacijsko in ga opravlja orodje; podajalno gibanje je sestavljeno iz glavnega podajalnega gibanja, ki je rotacijsko in ga opravlja obdelovanec, in iz vzdolžnega podajalnega gibanja, ki je premočrtno in ga običajno opravlja obdelovanec (v tem primeru je togost orodja večja). Postopek je namenjen predvsem obdelavi rotacijskih površin,

3 HIGH SPEED CUTTING (HSC)

What do we understand under the name HSC? HSC has no exact definition, it is a name with a great spectrum of usage. A simple definition is, that this is cutting in which the main spindle is turning very fast. In practice it means that we use a significantly higher cutting speed than before - especially in hard machining. For example machining hard steel where we had previonsly used a cutting speed of 100 m/min, and we are non using 300 m/min is in every case HSC.

This means that in HSC the cutting speeds and feed rates are essentially higher than in conventional machining. The depth of cut is smaller, but the advantages of HSC are in the greater volume of chips and in the smaller cutting forces [3].

In workshops for die - production great possibilities are given by applying HSC, by application of new modern machine tools and technology, the expansion of HSC will be much stronger. On the other hand, there are several important factors which are decisive for success - how to come to economical machining.

The workpiece materials, which are interesting for HSC - machining, are Al - and super AL alloys, hardened and quenched steels. With HSC machining, fine grinding operations are reduced, and in many cases EDM is eliminated. HSC methods are: milling, turning, drilling, reaming. Turn milling is another one of the interesting methods of HSC which is at the same time the subject of present research. HSC - machining gives us big reductions in machining time and machining price, which is the main reason for introducing it.

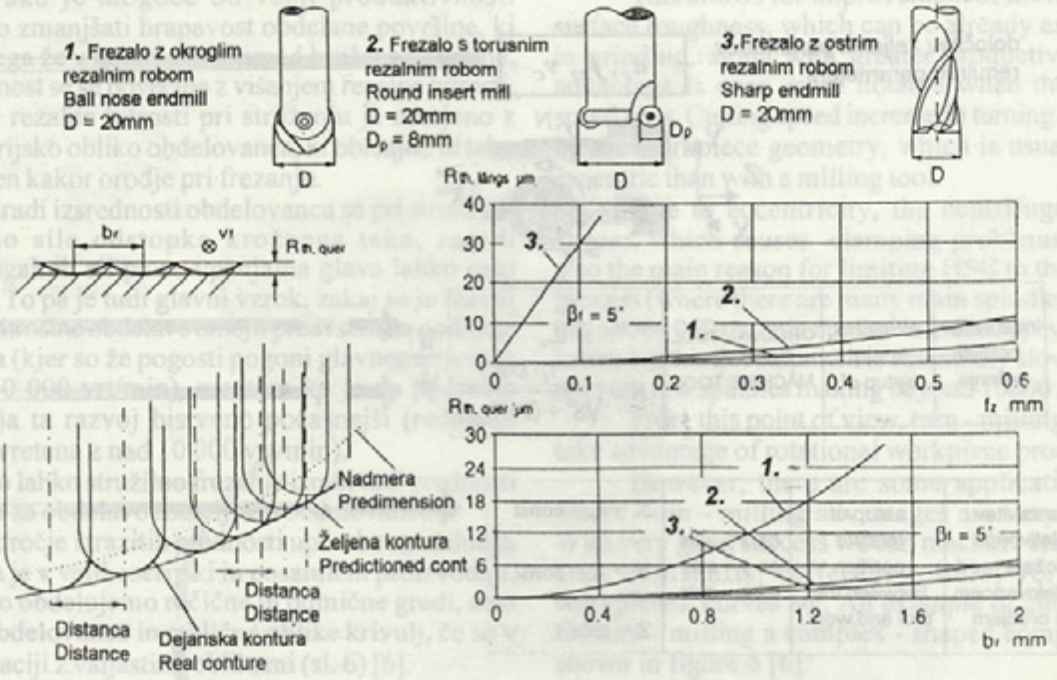
3.1 **HSC milling**

Higher cutting speed, higher feed rate and the right choice of mill by hard milling help us to get smaller roughness of die - surfaces. In die - workshops, for the machining of 3D - contours it is important to choose the right technology, which gives us low tops after milling. In this way we reduce the cost of finishing (Fig. 3).

3.2 **Turn - milling - HSC**

Turn - milling is quite a new cutting process designed especially for machining of rotational parts combined from turning and milling process properties, as is also evident from the kinematic similarities.

The main motion is rotational and is performed by the tool, the feed rate is combined from the main feed rate, which is achieved by the workpiece rotation, and from the feed rate alongside the workpiece, which is usually done by the workpiece (in that case the over stiffness can be greater). Although the process is created for the machining of rotational parts,



Sl. 3. *VHO frezanje; hrapavost je odvisna od tehnologije [4]*
Fig. 3. *HSC milling; roughness is dependent on the technology [4]*

vendar lahko brez težav izdeluje tudi elemente, ki jih sicer dobimo s frezanjem, celo več - s hkratnim krmiljenjem več osi lahko izdelujemo zelo zahtevne oblikovne elemente (npr. elipse). Tako kakor pri struženju ločimo možnost vzdolžne in prečne obdelave, po drugi strani pa lahko (tako kakor pri frezanju) delamo z nasprotnim ali pa istosmernim ter obodnim ali čelnim stružilnim frezanjem.

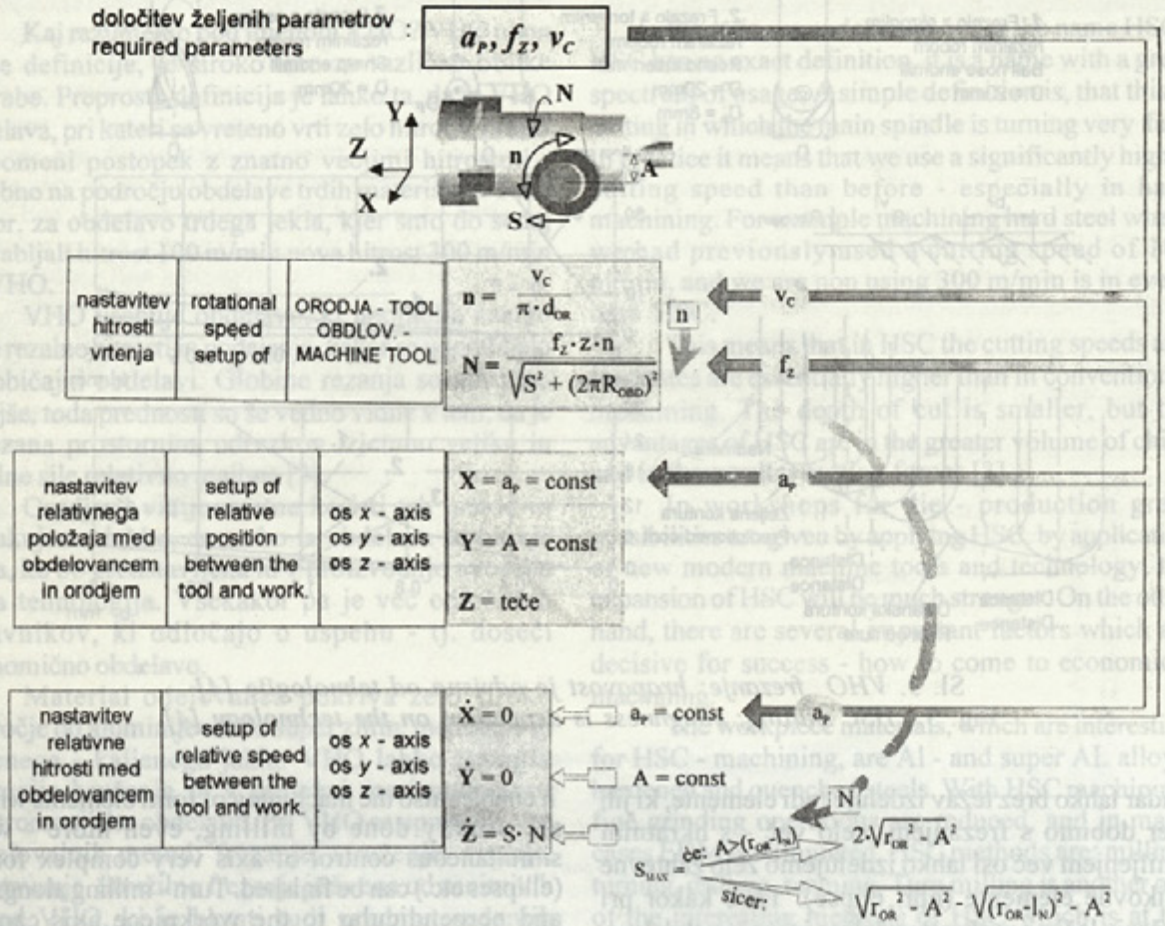
Po takšni kinematiki orodje večino reza opravi v vzdolžni smeri obdelovanca in ne prečno nanj, kakor pri struženju. Zaradi tega mora imeti frezalna glava posebno geometrijsko obliko, katere bistvo je to, da je najmanj ena rezalna ploščica namenjena za gladilno obdelavo. V nasprotnem primeru se ne bo izdeloval valj, ampak vijak.

Pri stružilnem frezanju je bistveno bolj zapletena kinematika, kakor npr. pri struženju. Obstaja nekaj glavnih parametrov, ki so bistveni za določitev postopka. Najprej določimo glavne tri veličine, ki so običajne pri postopkih odrezovanja. To so globina rezanja a_p, podajanje na rezilo f_z in rezalna hitrost v_c. Ekscentričnost bo nekoliko večja od vrednosti, ki jo dobimo če polmeru orodja odštejemo širino rezalnega robu ($A = r - l_N$). Rezalna hitrost določa število vrtljajev obdelovanca n. Velikost vzdolžnega podajanja na vrtljaj obdelovanca (S ali f) pa naj bo 75% največjega mogočega. Pri teh razmerah je postopek pokazal najboljše rezultate, predvsem glede na dinamične razmere. Dinamika stružilnega frezanja je namreč močno odvisna od vstopno-izstopnih razmer rezila v obdelovanec in iz njega (sl. 4) [5].

it enables also the machining of form elements which are usually done by milling, even more - with simultaneous control of axis very complex forms (ellipses etc.) can be finished. Turn - milling alongside and perpendicular to the workpiece axis can be distinguished (as with turning), on the other hand the process can be performed as up - milling and also as down - milling.

In the case of the above kinematics, the tool cuts mainly in the axial direction, contrary to the turning where the tool cuts perpendicularly to the workpiece. Therefore a special milling tool geometry is required, where at least one cutting insert is designed for polishing. In other cases instead of the cylinder the screw - form will be machined.

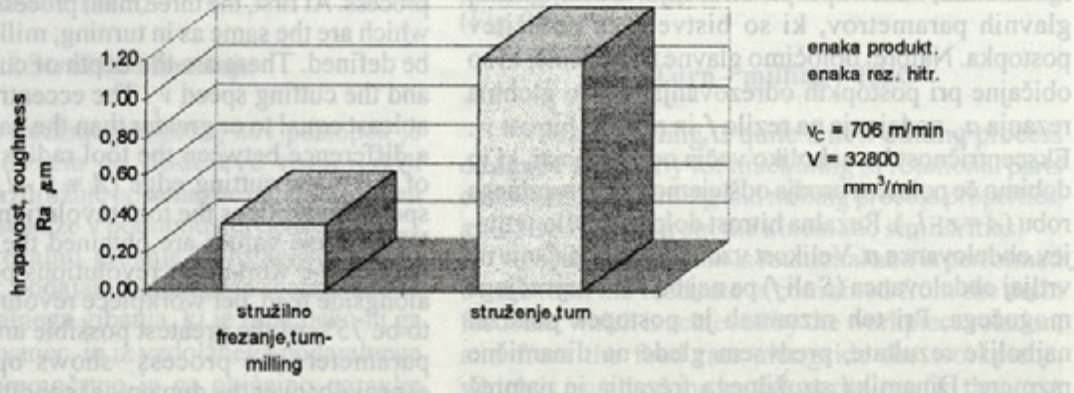
In turn - milling, the kinematics is essentially more complex than turning kinematics. However, there is a set of main parameters which define the process. At first, the three main process characteristics which are the same as in turning, milling etc. have to be defined. These are the depth of cut a_p, the feed f_z, and the cutting speed v_c. The eccentricity should be at least equal to or greater than the value obtained as a difference between the tool radius and the length of the plane cutting edge ($A = r - l_N$). The cutting speed determines the tool revolutions per minute n. When these values are obtained the feed per tooth defines the workpiece revolutions per minute. The alongside feed per workpiece revolution (S or f) has to be 75% of the greatest possible amount. At these parameters the process shows optimal results, especially over the dynamical conditions. The turn - milling dynamics depends very much on the entry - exit circumstances of the cutting inserts, (Fig. 4) [5].



Sl. 4. *Določitev lege in hitrosti osi stroja, na katerem se izvaja stružilno frezanje*
Fig. 4. *Definition of position and velocity of turn - milling machine*

Zaradi drugačne kinematike se obdelovanec vrti zelo počasi, medtem ko se orodje vrti z bistveno večjim številom vrtljajev (nekakšno povprečno razmerje bi bilo 1:1000). To pomeni, da lahko, ne glede na obliko obdelovanca, vedno obdelujemo z optimalno rezalno hitrostjo, pri čemer je hrapavost obdelane površine bistveno boljša od tiste pri struženju (sl. 5).

Due to different kinematics the workpiece rotates very slowly, meanwhile the tool is rotating with an essentially greater number of revolutions (the average could be stated as 1:1000). This also means that optimal cutting speed can always be achieved; even more, the machined surface roughness is essentially better than in turning (Fig. 5).



Sl.5. *Primerjava hrapavosti s struženjem*
Fig. 5. *Roughness comparisson with turning*

Tako je mogoče ob večji produktivnosti bistveno zmanjšati hrapavost obdelane površine, ki lahko sega že v kakovostni razred brušene površine. Ta prednost se še povečuje z višanjem rezalne hitrosti. Višanje rezalne hitrosti pri struženju je omejeno z geometrijsko obliko obdelovanca, ki običajno ni tako središčen kakor orodje pri frezanju.

Zaradi izsrednosti obdelovanca se pri struženju pojavijo sile odstopka krožnega teka, zaradi centrifugalnih sil pa se vpenjalna glava lahko celo razpne. To pa je tudi glavni vzrok, zakaj se je razvoj visokohitrostne obdelave omejil predvsem na področje frezanja (kjer so že pogosti pogoni glavnega vretena z nad 50 000 vrt/min), medtem ko je na področju struženja ta razvoj bistveno počasnejši (redka so glavna vretena z nad 10 000 vrt/min).

Tako lahko stružilno frezanje izrabi tudi prednosti frezanja za obdelavo rotacijskih obdelovancev.

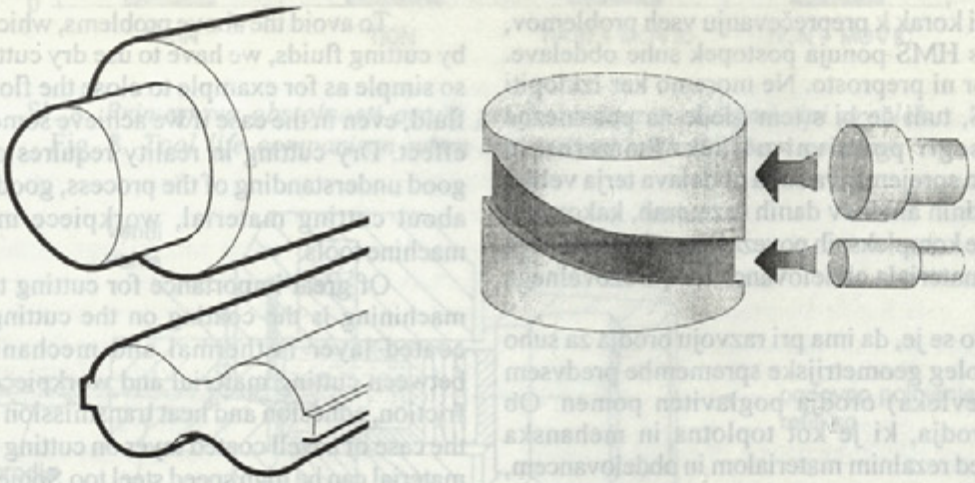
Področje izrazitih prednosti uporabe stružilnega frezanja je v velikoserijski in posamični proizvodnji. Uspešno obdelujemo ročične in odmične gredi, zelo težko obdelovance in različne oblike krivulj, če so v kombinaciji z valjastimi oblikami (sl. 6) [6].

This allows for improvement of the machined surface roughness, which can be already as good as in grinding, along with greater productivity. This advantage is even more notable when the cutting speed rises. Cutting speed increase in turning is limited by the workpiece geometry, which is usually more eccentric than with a milling tool.

Due to eccentricity, the centrifugal forces appear, which causes clamping problems. This is also the main reason for limiting HSC to the milling process (where there are many main spindles making beyond 50 000 rev/min applied in industry) by contrast, in turning this development is essentially slower (there are very few spindles making beyond 10000 rev/min).

From this point of view, turn - milling can also take advantage of rotational workpiece production.

However, there are some application areas where turn - milling advantages are very marked. With very good success we can machine crankshafts and camshafts, different rollers, very heavy workpieces, curves etc. An example of cutting data for turn - milling a complex - shaped component is shown in figure 6 [6].



Sl. 6. *Primeri različnih krivulj, izdelanih s postopkom stružilnega frezanja*
Fig. 6. *Some of examples of different curves, machined with turn - milling application*

4 SUHA OBDELAVA

Razprave o postopku suhe obdelave so pri mnogih uporabnikih hladilno-mazalnih sredstev vzbudile zavest o njihovih stroških ter odlaganju. Stroški hladilno-mazalnih sredstev (sistemov) so v veliko primerih večji od stroškov orodij ter zavzemajo vedno večji delež skupnih stroškov.

Zakaj postopek suhe obdelave? V Nemčiji se letno porabi okroglih 850 000 ton emulzije (sl. 7).

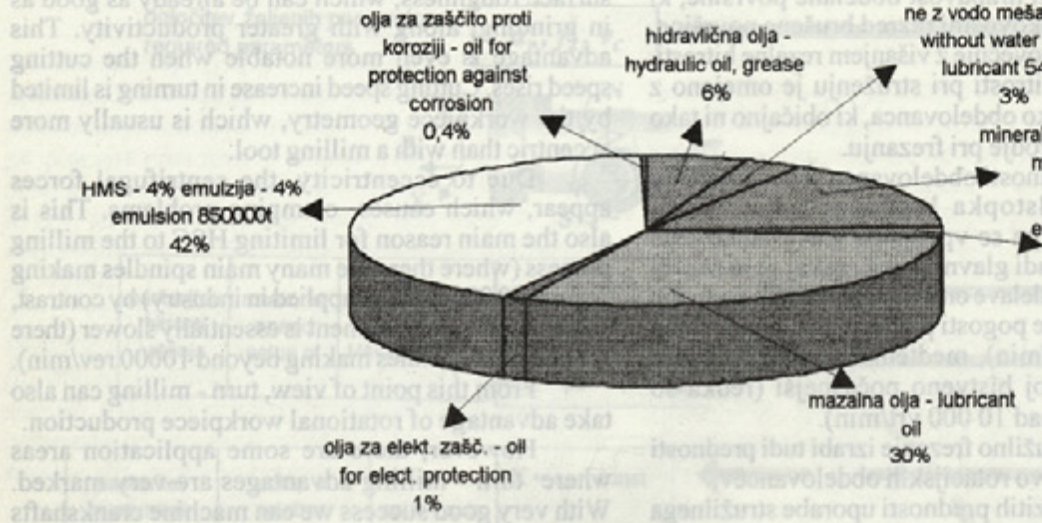
Izgube, voda za umivanje in nazadnje odlaganje izrabljenih hladilno-mazalnih sredstev ogrožajo tla, vodo in zrak. Sestavni deli HMS, reakcijski procesi nečistoče so lahko sprožilci različnih obolenj. Pri raziskavah poklicnih obolenj v kovinski dejavnosti se je izkazalo kar 30% znakov kožnih bolezni, njihov vzrok pa so HMS. Temu so izpostavljeni zlasti kovinarji - obdelovalci kovin.

4 DRY CUTTING

In discussing dry cutting, many users of cutting fluids have a positive attitude towards ecological problems, which are connected with costs. The costs of cutting fluids and cutting systems for recycling are almost greater than the costs which are connected with cutting tools.

Why dry cutting? For example, in Germany alone the use of cutting fluids is about 850 000 t per year (Fig. 7).

Losses, water for washing and deposit of used cutting fluids, are likely to - threaten the earth, water and air. The component parts of cutting fluids, some of the reaction processes and impurities, often cause illness among workers. About 30% workers who have contact with cutting fluids have skin disease.



Sl. 7. *Primer letne porabe hladilno-mazalnih sredstev (HMS) v Nemčiji [7]*
Fig. 7. *Example of used cutting fluids in Germany [7]*

Rešilni korak k preprečevanju vseh problemov, povezanih s HMS ponuja postopek suhe obdelave. To vsekakor ni preprosto. Ne moremo kar izklopiti dotok HMS, tudi če bi s tem glede na posamezne vidike dosegli pozitivni učinek. Primerna in ekonomično sprejemljiva suha obdelava terja veliko več predhodnih analiz v danih razmerah, kakor tudi razumevanje kompleksnih povezav procesa, rezalnega materiala, materiala obdelovanca ter odrezovalnega stroja.

Izkazalo se je, da ima pri razvoju orodja za suho obdelavo poleg geometrijske spremembe predvsem obloga (prevleka) orodja poglaviten pomen. Ob prevleki orodja, ki je kot toplotna in mehanska pregrada med rezalnim materialom in obdelovancem, se zmanjšajo trenje in adhezija, pa tudi toplotna obremenitev osnove rezalnega orodja, tako da je mogoča tudi uporaba prevlečenega rezalnega orodja iz HSS (hitroreznega jekla) [8]. Mehke prevleke MOVIC so namenjene integraciji maziva na orodju; močno se zmanjša trenje in izognemo se nalepku. Najboljše rezultate dosežemo v kombinaciji trda + mehka prevleka (sl. 8).

Pri suhi obdelavi ima tehnika zmanjšanja količine HMS velik pomen. S tokom stisnjenega zraka oskrbujemo orodje z malo hladilno mazalnega-medija. Na orodju dosegamo tako hladilni kakor mazalni učinek. Zmanjšana količina hladilno mazalnega sredstva je pri tem postopku obdelave alternativa mokre obdelave, pri kateri suha obdelava ni popolnoma uresničena.

Pri optimalno nastavljenem sistemu se porabi približno 10 do 20 ml/h HMS (sl. 9). Velike rezalne hitrosti zagotavljajo kratek čas dotika orodje - obdelovanec - odrezek.

To avoid the above problems, which are caused by cutting fluids, we have to use dry cutting. It is not so simple as for example to close the flow of cutting fluid, even in the case if we achieve some of positive effect. Dry cutting in reality requires of engineers good understanding of the process, good knowledge about cutting material, workpiece material and machine tools.

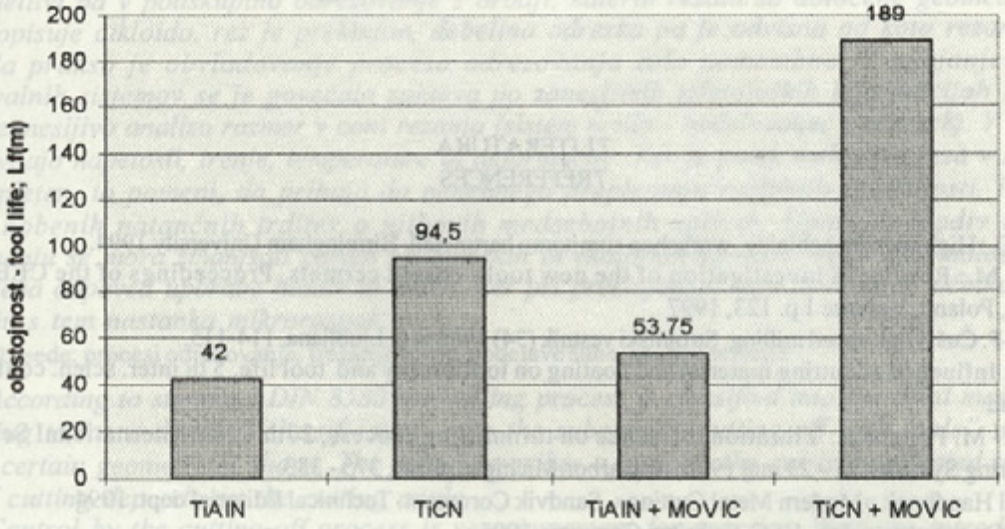
Of great importance for cutting tools for dry machining is the coating on the cutting edge. The coated layer is thermal and mechanical barrier between cutting material and workpiece. There the friction, adhesion and heat transmission decrease. In the case of a well coated layer on cutting tool, cutting material can be high speed steel too.Some soft coating layers like MOVIC are especially good, because they are self lubricating and have lower friction. In Figure 8 different coatings and results are shown versus tool life.

To make dry cutting a reality it is important to know, how to reduce the volume of cutting fluid. With assistance of compressed air we have to provide cutting tool with very small part of cutting - lubricant fluid. On the cutting tool we achieve cooling and lubricant effects. Smaller part of coolant - lubricant agents is only an alternative to normal »wet - cutting«, that is not the same like cutting without any cutting fluid.

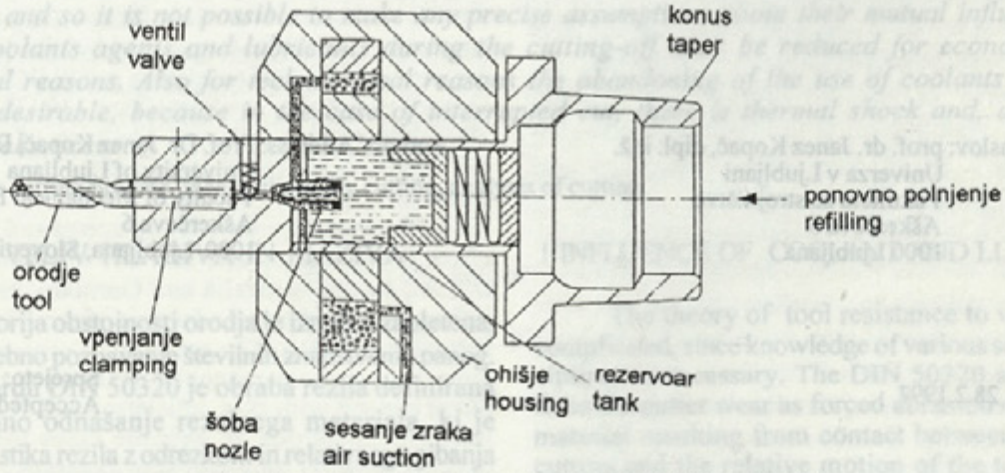
By good adjustment of nozzle, we need there approximately 10 to 20 ml/hr lubricant oil. In figure 9 is shown a system for cutting with min. cutting fluid. Another advantage is if we use HSC, the contact between cutting tool - workpiece - chip is very short, that's why dry cutting is more efficient.

Po možnosti naj bi bila obdelava izpeljana v enem rezu. To terja obdelovance z majhno odrezano prostornino in pravilnimi merami. Optimalno predpostavko ponuja postopek "Near-Net Shape", ki naredi končen obris pogosto samo z enim rezom.

Another advantage is if we use HSC, the contact between cutting tool / workpiece / chip is very short, that's why »dry cutting« is more efficient. We suggest machining with one cut in one layer with small volume of chips. It is new technology Near - Net - Shape, where small part of cutting is necessary after forming.



Sl. 8. *Primerjava obstojnosti orodij pri frezanju z različnimi tipi prevlek*
Fig. 8. *Tool life comparison when end milling with different coatings*



Sl. 9. *Tehnika dovajanja minimalne količine HMS*
Fig. 9. *Technics of supply of minimum cutting fluid on tool*

5 SKLEP

Več novih dosežkov v zadnjih letih, npr. novo razvita rezalna orodja za velike hitrosti; novi zmogljivi stroji, ki zagotavljajo visoke vrtljaje in veliko togost, omogočajo prehod na visokohitrostno obdelavo. Le ta je uporabna tako v orodjarstvu za izdelavo orodij - gravur, kakor v velikoserijski proizvodnji, saj je v končni fazi konkurenčna po kakovosti in ceni.

5 CONCLUSION

Development and Research in last years give to us new cutting materials/tools, new machine tools with high turning and stiffness. All of them ensure a soft way to HSC - high speed cutting technology, which is useful in die - tools productions for hard materials machining and in car production too. It is competitive on all three main areas: time of production, costs of machining and ecological approach.

Z ekološkega vidika je v veliki meri rešitev uvajanje »suhega« odrezovanja, kjer so uporabljene količine hladilno mazalnih sredstev minimalne.

Z uvajanjem novih dosežkov v slovensko industrijo bomo z novo tehniko odrezovanja zagotovili tudi svoj obstoj na svetovnem trgu, tako z vidika konkurenčnosti, kakor tudi glede na naše zmožnosti uvajanja vrhunske tehnologije.

Dry cutting will minimize quantity of used cutting fluid with the aim to reduce costs of production, to ensure workers and to help for better environment.

With introduction of new results in Slovenian production, we can with application of new cutting technique and technology ensure our position on world market place due to our capability to introduce "high tech" technology.

7 LITERATURA
7 REFERENCES

[1] Brauherr, G.: High speed machining, workshop sumitomo hartmetall. Birmingham University 1994.

[2] Soković, M.: Results of investigation of the new tool - coated cermets. Proceedings of the CEEPUS PL Workshop, Poland, Volume 1 p. 123, 1997

[3] Schulz, H.-F. Čuš: High speed milling. Strojniški vestnik (34) 1988/4-6, Ljubljana, 114-115.

[4] Kopač, J.: Influence of cutting material and coating on tool quality and tool life. 5 th inter. scien. conf. AMME 1996 Poland

[5] Kopač, J.- M. Pogačnik: Vibration influence on turnmilling process, 27th CIRP International Seminar on Manufacturing Systems, 21 - 23 maj 1995, Ann arbor,Michigan, USA, 375 - 383.

[6] A Practical Handbook »Modern Metal Cutting«, Sandvik Coromant. Technical Editorial dept. 1994.

[7] Cselle, T.: On the way to dry - HSC, Guhring, Germany, 1996.

[8] Dolinšek, S.- M. Soković: Influence of TiN (PVD) coating on the tool on the identification parameters in turning. 5th Inter. Scient. Conf. AMME 1996, Poland

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