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Spremljanje obrabe rezalnega orodja z uporabo signalov krmilnega sistema

Monitoring Cutting-Tool Wear Using Signals from the Control System

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Varnost in zanesljivost delovanja industrijskih obdelovalnih postopkov je pomemben pogoj za gospodarsko donosnost. Motnje v postopku, kakor so kolizija, preobremenitev, izpad in obraba orodja, niso popolnoma razumljive in povzročajo napake proizvodnega sistema. Da bi preprečili vpliv različnih motenj obdelovalnega postopka, npr. obrabo in lom orodja, posvečajo moderni tehnološki sistemi posebno pozornost napovedovanju stanja rezalnega orodja. Številne teorije o spremljanju skušajo klasificirati in pojasniti obrabo orodja, vendar še nobena ni dala zadovoljivih rezultatov, ki bi hkrati zagotovila prilagodljivo in preprosto obvladovanje postopka za sprejemljivo ceno. Brezzančna struktura modernega ali digitalnega krmiljenja odpira nove možnosti in perspektive v tem pogledu. V mnogih primerih kombinacija signalov digitalne opreme in internih podatkov krmilnega sistema stroja, skupaj z izpolnjenimi metodami analize signalov, lahko nadomesti zunanje sisteme za spremljanje. Vgradnje programskega modula za nadzor postopka v krmilni sistem stroja omogoča hitre reakcije, če se pojavijo motnje postopka, in sicer brez dodatnega povečanja računalniške opreme.Ta prispevek preučuje občutljivost signalov v nadzornem sistemu na postopke obrabe rezalnega orodja pri čelnem struženju.

(Ključne besede: nadzor stanj, sistemi krmilni, občutljivost signalov, struženje, obraba orodij)

The safety and reliability of operation of industrial manufacturing processes is a very important prerequisite for economic production. Process disturbances such as collision, overload, breakdown and tool wear are not yet fully understood, and cause production-system failures. In order to prevent the effects of excess wear or eventual tool breakdown, modern technological systems pay particular attention to predicting the condition of tool. Numerous theories of monitoring have tried to classify and explain tool wear, but none have given completely satisfactory results as yet, while at the same time ensuring flexible, simple and cost-effective process control. The open structure of modern digital control opens up new possibilities: in many cases the combination of digital plant signals and the internal data of the machine control system, along with advanced methods of signal analysis, can replace external control systems. The integration of a process-control software module into the machine control system allows fast reactions, should there be any process disturbances, without any additional hardware expansion. This paper studies the sensitivity of signals contained in the control system to the cutting-tool wear processes in face turning.

(Keywords: condition monitoring, control systems, sensitivity analysis, turning, tool wear)

0 UVOD

Obdelovalni stroji in proizvodni sistemi so nosila razvoja nove proizvodne opreme, to pomeni, da je stroj tehnična struktura, vsota mnogih tehnologij in je konstruiran z namenom, da preoblikuje material v funkcionalne izdelke, koristne za ljudi. V zadnjih letih so obdelovalni stroji in proizvodni sistemi doživeli velike spremembe, v največji meri zaradi razvoja informatike in prilagodljive avtomatizacije. Premik od klasičnih v smeri izpopolnjenih, hitrih,

0 INTRODUCTION

Machine tools and production systems are the generators of new production equipment, i.e., the machine is the technical structure, a collection of many technologies, designed with the aim of reshaping raw materials into functional units that are useful to people. Over recent years, machine tools and production systems have gone through dramatic changes caused, to a large extent, by the development of information technology and flexible automation.

prilagodljivih in zelo učinkovitih obdelovalnih celic je očiten. Na področju odrezovanja je v zadnjih letih obdelava z velikimi hitrostmi postala standard. Spremenila je odnos do strojne obdelave, rezalnih orodij in obdelovalnih strojev. Da bi dosegli velike hitrosti strojne obdelave, je potreben razvoj dinamičnih strojev lahke zgradbe in majhne mase, zgoščene izvedbe in velike togosti. V takih okoliščinah je namestitev motornega vretena obdelovalnega stroja z visokimi frekvencami vrtenja, hlajenjem s tekočino, z avtomatskim sistemom vpenjanja orodja (HSK - gnezdenje), podajalnimi zobniki z digitalnimi pogonskimi sistemi in hitrimi vodili postala standardna.

Krmiljenje obdelovalnih strojev z velikimi hitrostmi je zelo zahtevna naloga, ki terja močne in učinkovite sisteme za spremljanje in diagnosticiranje postopkov obdelave. Glavna pogoja za dobro izvajanje spremljanja postopka obdelave sta poznavanje postopka in izvajanje ustreznih ukrepov. Ker je postopek obdelave brezzančni sistem in ni popolnoma definiran, lahko pride do motenj v postopku, ki niso povsem razumljive in jih ni mogoče napovedati. Glavni parameter, ki povzroča nepričakovane motnje v sistemu obdelave in med samo obdelavo, je obraba rezalnega orodja [1], ki ga povzroča interakcija med orodjem, obdelovancem in obdelovalnimi razmerami. Raznolikost vhodnih parametrov, nenehni razvoj novih materialov, geometrijska oblika in novi materiali orodja pa tudi večja hitrost obdelave [2], s hkratnim uvajanjem vedno strožjih standardov glede varnosti, zapletejo spremljanje krmilnega postopka [3], tako da je spremljanje postopka obdelave ena najzahtevnejših nalog pri nadaljnjem razvoju obdelovalnih sistemov.

1 SISTEMI ZA SPREMLJANJE OBDELOVALNEGA POSTOPKA

Pri postopkih obdelave z odvzemanjem materiala se uporabljajo različne metode za spremljanje in nadzorovanje postopkov, vendar je glavni vir za spremljanje postopka signal zaznavala. Zaznavalo pretvori eno fizikalno vrednost v drugo (sila, akustična emisija, vibracije in električni signal) [4]. Vgrajena zaznavala morajo biti podprta z dodatno programsko opremo za analizo in sprejemanje signalov z ustreznim sistemom za ovrednotenje podatkov. Dodatna oprema mora biti prilagojena posameznemu stroju in obdelovalnim opravilom. S tehničnega vidika [5] je povezava zunanjih sistemov in krmilnega sistema stroja vedno povezana z določenimi težavami, tako da je mogoče pri uporabi klasičnih sistemov za spremljanje poudariti nekaj slabih strani:

- potrebne so dodatne naprave in zaznavala, ki morajo biti prilagojeni stroju,
- zunanji sistemi dajejo dobre rezultate šele po dobri pripravi,

The shift from classical towards sophisticated, fast, flexible and high-efficiency machining cells is obvious. In the field of material removal, over recent years, high-speed machining has become a standard process. It has changed attitudes towards machining, cutting tools and machine tools. In order to achieve high-speed machining, the development of dynamic machines with a light structure and low mass, a compact construction and high rigidity is required. As a result the installation of motor spindles with high rotation frequencies, liquid-cooled, with an automatic tool clamping system (HSK – nesting), feed gears equipped with digital drive systems and fast guides have become standard practise.

The control of high-speed machines is a very demanding task that requires powerful and efficient systems of process monitoring and diagnostics. The basic conditions for good management of machining monitoring include knowledge about the process state and the undertaking of adequate actions. Since the machining process is an open system and is not fully defined, process disturbances that are not completely understandable or predictable might be encountered. The main parameter generating unexpected disturbances in a machining system during machining is the process of cutting-tool wear [1], which is caused by the interaction between the tool, the work piece and the machining conditions. The diversity of input parameters, the constant development of new materials, new geometries and new tool materials, as well as higher machining speeds [2], with the simultaneous setting of increasingly strict standards regarding safety, complicate control process monitoring [3], so that process monitoring remains one of the most demanding tasks in further development of machining systems.

1 MACHINING-PROCESS MONITORING SYSTEMS

In material-removal processes different methods for monitoring and controlling processes are applied, but the main monitoring source is the signal obtained from the sensor. The sensor converts one physical value into another (force, sound emission, vibrations into electrical signal) [4]. Built-in sensors have to be supported by additional equipment for analysis and the reception of signals with an appropriate assessment system. Additional equipment needs to be adapted to the particular machine and the machining operations. From the technical point of view [5], the linking of external systems and the machine control system is always related to certain difficulties, so that some of the disadvantages can be highlighted when using conventional monitoring systems:

- additional devices and sensors are necessary, and they need to be adapted to the machine,
- external systems provide good exploitation results only after good preparation,

- ne uporabljajo se razpoložljivi podatki, ki jih vsebuje krmilje,
- vzdrževanje sistema za spremljanje in definiranje parametrov je pogosto zahtevno in zapleteno.

Ugotoviti je mogoče stanje sistema kadar se v merilnem signalu pojavi napaka. Vpliv na merilni signal naj ne bi bil samo teoretičen, ampak bi moral delovati na tok signalov z možnostjo ponovitve (obraba - sile, vibracije, zvočna emisija itn.). Žal ni vedno (če sploh kdaj) mogoče ugotoviti preproste povezave med stanjem sistema in signalom, toda iz različnih razlogov lahko pride do sprememb signala, tako da razlaga napak znatno vpliva na učinkovitost in zanesljivost sistema za spremljanje. Razvoj metod in sistemov zaznaval se nagiba k temu, da zagotovi največjo zanesljivost v večini pogojev obdelave in izboljšanje občutljivosti na opazovani pojav [6]. Glede zahtevane zanesljivosti sistema za spremljanje morajo zaznavala izpolniti različne potrebe glede zaznavanja stanja. Po eni strani je treba napake zaznati zelo hitro, po drugi strani pa morajo biti odločitve zelo zanesljive, da se popravijo izgube zaradi lažnih opozoril. Problemi analiz ropota in pogosto nasprotujoče si informacije o zaznavah pri analizi signalov so središče raziskav, kajti tudi najuspešnejša strategija odločanja je omejena, če vhodni podatki niso zadosti obsežni in zanesljivi.

Po prejšnjih izkušnjah se zdi, da metode analiziranja posameznih signalov ne morejo zagotoviti večjih izboljšav v sistemih za spremljanje postopkov, tako da so najnovejše raziskave usmerjene v razvoj večzaznavalnih sistemov z namenom, da bi dobili boljše, bolj zanesljive in varnejše podatke o stanju nadzorovanega postopka ali sistema. Uporaba izpopolnjenih tehnologij sprejemanja in analiziranja signalov, kakršni so ocenitev parametrov, nevronska mreža [8], prepoznavanje vzorcev, mehka logika pomenijo mogoče možne pripomočke, kadar je treba obdelovati dvoumne signale in šume. Torej tudi moderni brezzančni računalniški numerični krmilni sistem (RNK) ponuja nekaj možnosti za vzpostavitev preprostih in poceni sistemov za spremljanje, s katerimi ni težko ravnati.

2 ZGRADBA BREZZANČNIH KRMILNIH SISTEMOV

Nadzorna naprava znatno vpliva na zmogljivost obdelovalnih sistemov. Težnje pri razvijanju nadzornih sistemov so usmerjene k vzpostavitvi inteligentnega sistema z vgrajenimi moduli za prilagoditev dinamičnim spremembam okolja, možnostim vključitve novih uporabniških uporab in motnostim učenja iz postopka. Definicija brezzančnega RNK sistema je lahko raznolika, odvisno od izdelovalcev opreme in uporabnikov RNK obdelovalnih strojev. Tipični brezzančni RNK sistem

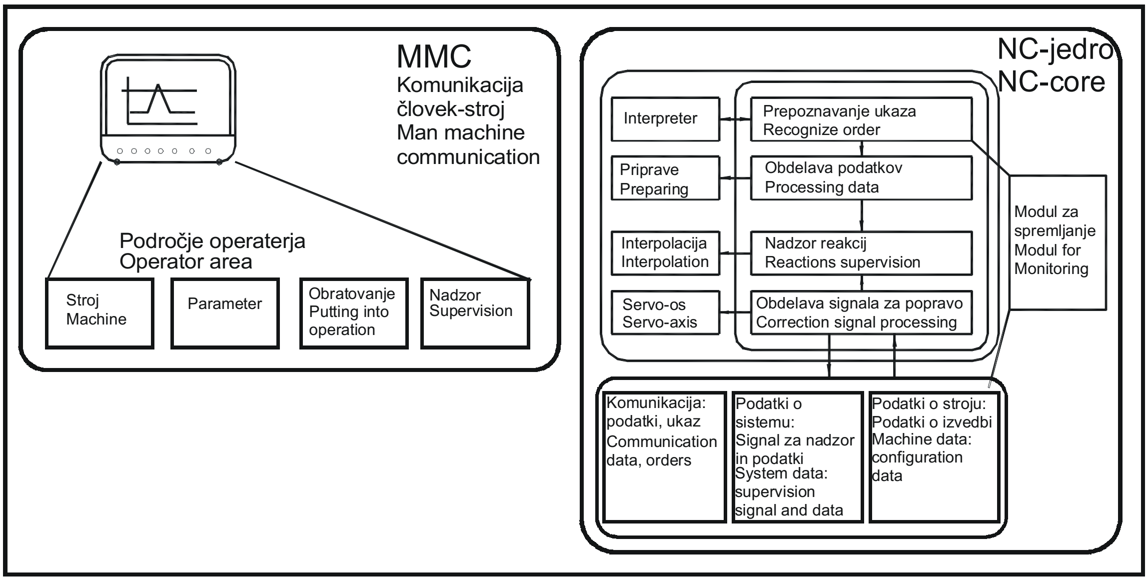
- available information contained in the control is not used,
- maintaining the monitoring system and defining the parameters is often demanding and complicated.

It is possible to identify the system condition when failure shows in the measuring signal. The influence of failure on the measuring signal should not only be theoretical, but should act on the signal flow with the possibility of reproduction (wear forces, vibrations, sound emission, etc.). Unfortunately, it is not always (if ever) possible to establish a simple link between the condition of the system and the signal, but signal changes can result due to various causes, so that the interpretation of failures significantly influences the efficiency and reliability of the monitoring system. The development of sensory methods and systems is led by the tendency to realize the maximum reliability in most machining conditions, and the improvement of sensitivity on the observed phenomenon [6]. Regarding the required reliability of the monitoring system, sensors have to satisfy various needs with regard to detection of the condition. On the one hand, failures need to be detected very quickly, and on the other hand, the decisions have to be trustworthy, so as to eliminate losses due to false alarms. The problems of noise analyses, and the often contradictory information of senses in signal analysis, represent the focus of research, since even the most successful strategy of decision-making is limited if the input information is not sufficiently extensive and reliable.

Based on previous experiences, it seems that the methods of analyzing particular signals cannot provide any major improvements to the monitoring system, so that the latest research is directed to the development of multi-sensory systems with the aim of obtaining better, more reliable and safer information on the condition of the monitored process or system. The application of advanced technologies of reception and analysis of signals, such as the assessment of parameters, neural networks [8], pattern recognition, fuzzy logic, represent possible tools regarding the need to process ambiguous signals and noises. This also means that a modern, open CNC control system offers some possibilities for establishing simple, inexpensive and easy-to-manage monitoring systems.

2 THE STRUCTURE OF OPEN CONTROL SYSTEMS

The controller significantly affects the capabilities of machining systems. The trends in developing control systems are directed towards establishing an intelligent system with integrated modules for adaptation to the dynamic environmental changes, the possibilities of integration of new users' applications, and the learning possibilities from the process. The definition of an open CNC system can vary, depending on the equipment manufacturers and the CNC machine tools' users. A typical CNC open



Sl. 1. *Zgradba brezzančnega nadzornega sistema (3)*
Fig. 1. *Structure of the open control system (3)*

ima standardne funkcije, ki se na splošno uporabljajo za vse obdelovalne stroje (sl. 1).

Odvisno od kinematike stroja in njegovih specifičnih karakteristik imajo lahko nekatere lastnosti različne opravilne algoritme, čeprav je splošna zgradba RNK ista. RNK sistem se dobi tako, da izberemo programske module iz standardne knjižnice in jih avtomatsko povežemo. Obstaja možnost, da razvijemo manjkajoče funkcije in jih dodamo standardni knjižnici. Tako je mogoče standardno knjižnico funkcij dopolniti s specifičnimi moduli za spremljanje orodja, da bi uporabnikom zagotovili nove možnosti na področju sprotnega spremljanja postopka obdelave glede na preprečitev kolizije, loma orodja, preobremenitve ter spremljanja obrabe orodja [7]. Programski modul, nameščen v krmilnem sistemu, zagotavlja tudi najhitrejšo reakcijo v primeru že znane motnje v postopku. Vendar je treba za vsak določen primer nadzirati občutljivost in uporabnost takih sistemov v različnih razmerah obravnave in temu ustrezno prilagoditi strategijo nadzora.

3 OPIS NAČRTOVANJA PREIZKUSOV

Cilj preizkusa je določiti občutljivost parametrov pogonskega sistema na obrabo proste ploskve orodja pri postopku finega struženja. Postopek določitve občutljivosti krmilnih signalov na obrabo orodja je razdeljen na dva dela:

- določitev stopnje obrabe proste ploskve orodja [9] in
- zbiranje podatkov med postopkom obdelave in njihovo nadaljnje analiziranje.

Občutljivost nadzornega signala na obrabo proste ploskve orodja je bila preizkušena na NK stružilni enoti, izvedeni za obdelavo vztrajnika. Glavni

system has standard functions that are used generally for all the machine tools, Figure 1.

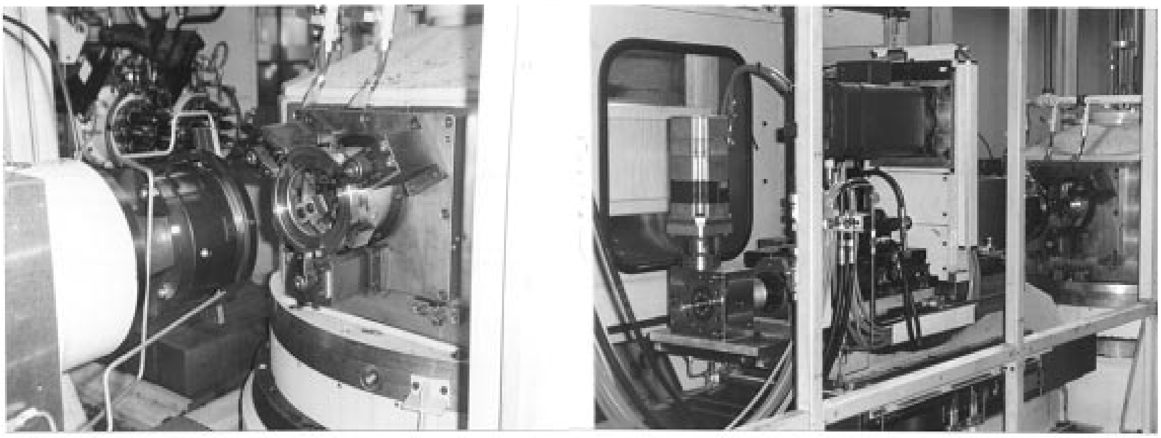
Depending on the machine kinematics and its specific characteristics, some properties can have different operation algorithms, although the general CNC structure is the same. The CNC system is formed by selecting the software modules from the standard library and their automatic linking. There is the possibility of developing the missing functions and their being added to the standard library. Thus, a standard-functions library can be supplemented by specific modules for tool monitoring in order to provide the users with new possibilities in the field of online process monitoring with regard to avoiding collisions, breakdowns, overloads and the monitoring of tool wear [7]. The software module installed in the control system also provides the fastest reaction in the case of a known process disturbance. However, for every concrete case the sensitivity and applicability of such systems in various processing conditions need to be checked, and the supervision strategies need to be adapted accordingly.

3 DESCRIPTION OF THE PLANNING OF THE EXPERIMENT

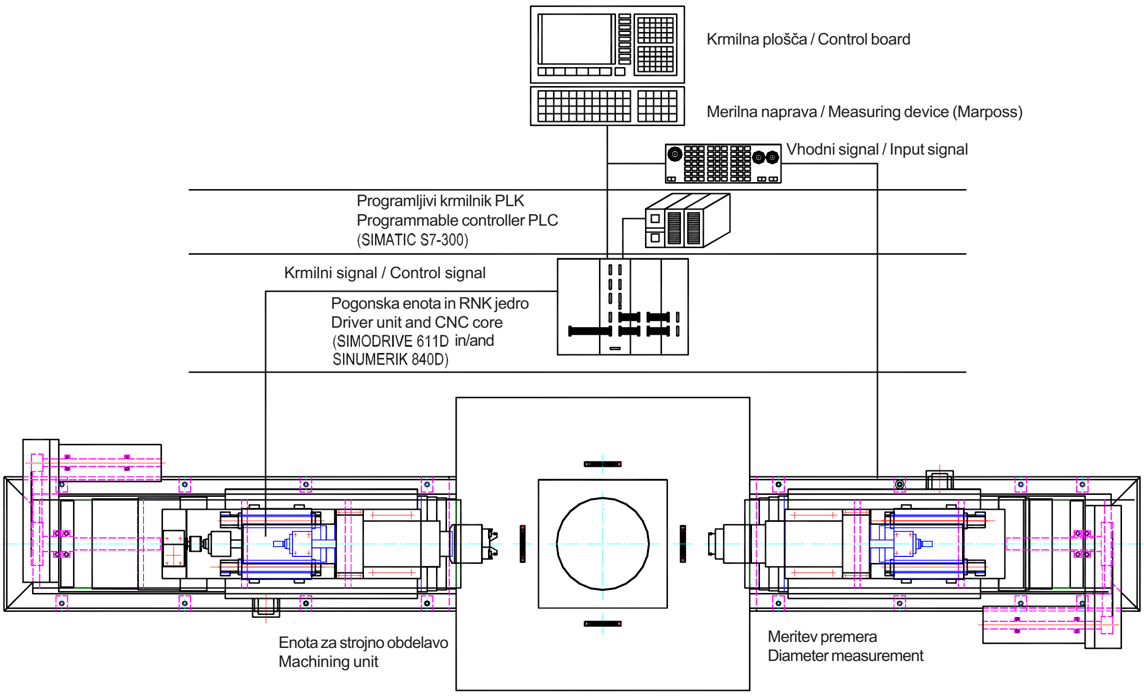
The aim of the experiment was to determine the sensitivity of the drive-system parameters to tool-flank wear in the process of fine turning. The procedure for determining the sensitivity of control signals to tool wears is divided into two parts:

- determining the level of tool-flank wear [9],
- gathering the data during the machining process and its subsequent analysis.

The sensitivity of the control signal to tool-flank wear was tested on an NC turning unit, designed for flywheel machining. The main and feed drive



Sl. 2. *Enota za fino stru□enje (SAS-Zadar)*
Fig. 2. *Unit for fine turning (SAS-Zadar)*



Sl. 3. *Specialni stroj za obdelavo vztrajnika (SAS - Zadar)*
Fig. 3. *Special machine for flywheel machining (SAS - Zadar)*

pogonski motorji in motorji za podajanje so bili digitalni, ponovljivost lege je bila v območju ±2µm.

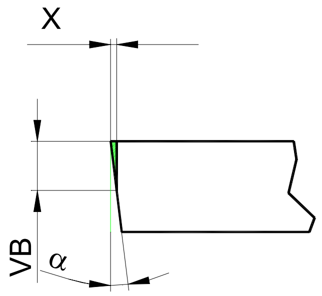
Stružilna enota je bila nameščena v sklopu specialnega stroja, krmiljena s Siemensovim digitalnim krmilnim sistemom, Sinumerik 840D (sl. 3). Specialni stroj je obsegal štiri postaje, od katerih je bila ena opremljena z merilnim sistemom Marposs za merjenje poprej strojno obdelanega premera. Izmerjena vrednost je bila osnova za popravo geometrijskih parametrov rezalnih orodij. Na podlagi znanega razmerja med obrabo orodja in spremembo struženega premera [10] so bile hkrati shranjene popravne vrednosti, uporabljene za oceno obrabe proste ploskve orodja (sl. 4).

Preizkusni parametri so podani v preglednici 1. Rezalni parametri so bili definirani v skladu s podatki,

motors were digital, and the position repeatability was in the range of ±2µm.

The turning unit was fitted within the unit of special machine controlled by a Siemens digital control system, Sinumerik 840D, Figure 3. The special machine consisted of four stations, one of which was fitted with a Marposs measuring system for measuring the previously machined diameter. The measured value was the basis for the correction of the geometric parameters of cutting tools. At the same time, based on the known relation between the tool wear and the change of the turned diameter [10], stored correction values were used for an estimation of the tool-flank wear, Figure 4.

The experimental conditions are presented in Table 1. The cutting parameters were defined in



$$VB = X / tg\alpha$$

Sl. 4. *Geometrijska oblika rezalnega roba*
Fig. 4. *Geometry of cutting edge*

Preglednica 1. *Parametri struženja*
Table 1. *Turning conditions*

material obdelovanca workpiece material	16MnCr5
začetni premer d_0 mm start diameter d_0 [mm]	ϕ 115H8
končni premer d_1 mm final diameter d_1 [mm]	ϕ 115,7H6
vrtilna frekvenca n min^{-1} number of revolutions n [min^{-1}]	600
rezalna hitrost v_c m/min cutting speed v_c [m/min]	218
podajanje f mm feedrate f [mm]	0,15
dolžina rezanja l mm cutting length l [mm]	10
čas rezanja t s cutting time t [s]	7,2
hladilno sredstvo coolant	suha obdelava dry machining
rezalna ploščica (Sumitomo) insert type (Sumitomo)	SCMT 09T3 04N FP-T 110A

ki jih je priporočil proizvajalec, vendar je nesprejemljiva oblika odrezkov (neprekinjen odrezek) zahtevala spremembo rezalnih parametrov. Da bi dobili sprejemljivo obliko odrezka, smo povečali globino reza in uporabili suho obdelavo.

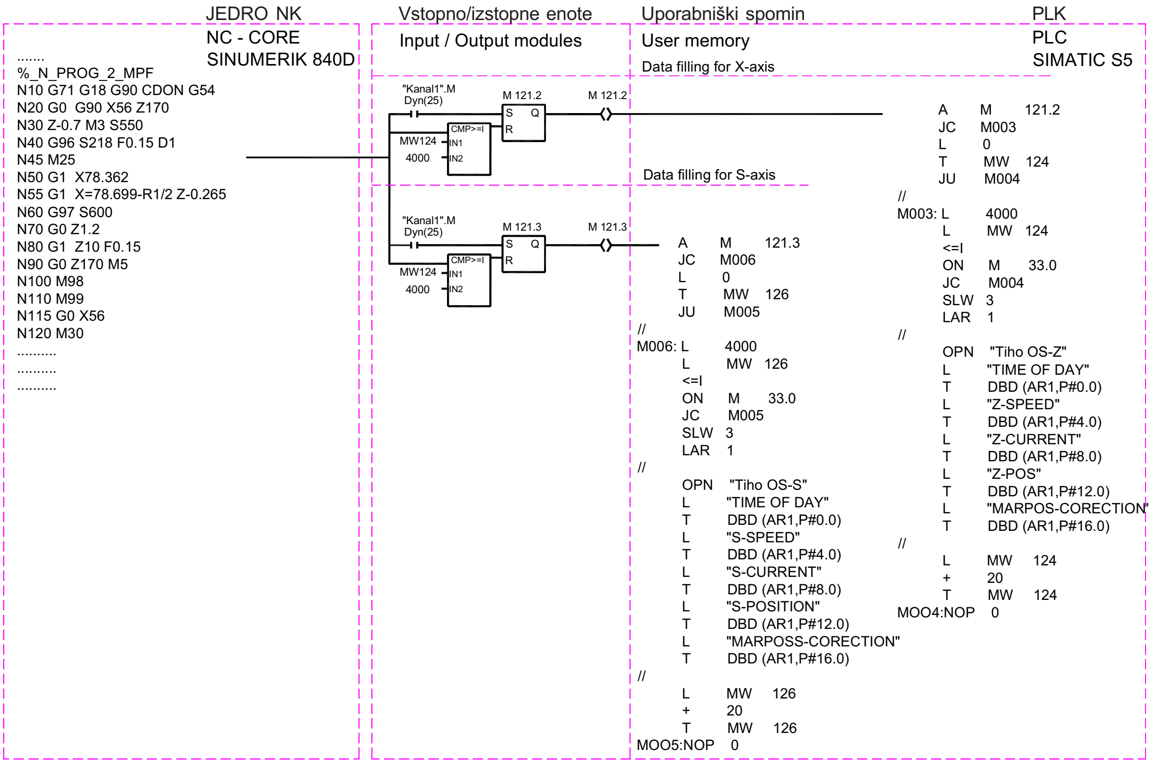
Med postopkom obdelave smo iz uporabniškega jedra NK zbrali podatke o toku, hitrosti in legi. Podatke smo zbrali s pomočjo PLK (Simatic 5). Podatke o krmilnem sistemu smo zbrali s programsko opremo, napisano v programskem jeziku Step5 (v PLK) (sl. 5). Podatke smo shranili v ustrezen podatkovni blok [11].

Začetek zapisovanja podatkov smo sprožili iz porabniškega programa NK z uporabo funkcije M(v tem preizkusu smo izbrali pomožno funkcijo M25). Podatki so bili zapisani prek vhodnih modulov v podatkovni blok v taktu PLK, in sicer hkrati za glavni in podajalni pogon. Tako je bilo mogoče podatke dalje analizirati, da bi našli popravo med obrabo orodja in ravnjo signala.

accordance with data recommended by the manufacturer, but an unacceptable chip form (continuous chip) demanded changes to the cutting data. In order to obtain an acceptable chip form the depth of cut was increased and dry machining was applied.

During the machining process, data on current, velocity and position were gathered from the NC users' core. The data were gathered by means of PLC (Simatic 5). The control system data were gathered by means of software written in the programming language Step5 (in PLC), Figure 5. The data were stored in the appropriate data block (DB) [11].

The start for data recording was activated from the users' NC program, using the M function (in this experiment the auxiliary function M25 was selected). The data were recorded through input modules into the data block (DB) in PLC tact, simultaneously for the main drive and the feed drive. Thus the recorded data could be subsequently analyzed to find a correlation between tool wear and signal level.



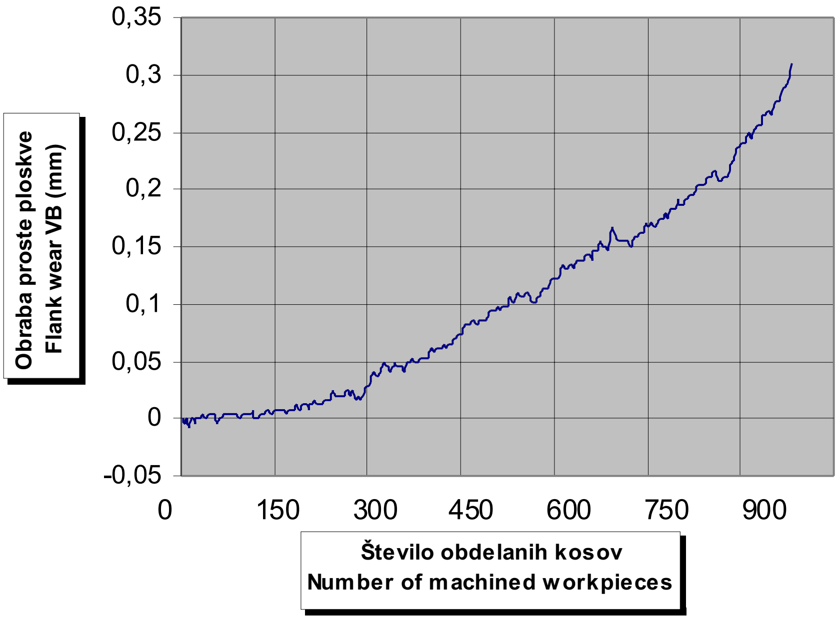
Sl. 5. *Zgradba toka signalov*
Fig. 5. *Structure of the signal flow*

4 REZULTATI ANALIZE

Podatki o popravah rezalnega orodja, ki so bile napravljene med delovanjem stroja brez strežbe (od začetka do takrat, ko je obraba orodja dosegla mejo) [12], smo shranili in omogočili še risanje krivulje, ki je prikazovala odvisnost obrabe proste ploskve od števila obdelanih kosov (sl. 6).

4 ANALYSIS OF THE RESULTS

The data on cutting-tool corrections that were applied during the unattended working of the machine (from the beginning, until the tool wear reached the limit) [12] were stored, and this allowed the drawing of a curve showing the dependence of flank wear on the number of machined workpieces, Figure 6.



Sl. 6. *Krivulja obrabe orodja*
Fig. 6. *Tool-wear curve*

Preglednica 2. *Izmerjene vrednosti obrabe proste ploskve orodja pri različnih časih obdelave*
Table 2. *Measured values of tool-flank wear for various machining times*

Meritev # Measurement #	1	2	3	4	5	6
obraba proste ploskve VB, *mm* tool flank wear VB, *mm*	0	0,012	0,215	0,252	0,289	0,309
število obdelanih kosov the number of machined workpieces	1	186	861	921	974	981
čas obdelave, *min* machining time, *min*	0,12	22,3	103,3	110,5	116,8	117,7

Oblika krivulje jasno prikazuje, da se intenzivnost obrabe povečuje, čim bolj se doba trajanja orodja bliža koncu, kar smo pričakovali. Nadaljnja obdelava z izrabljenim orodjem bi pripeljala do loma orodja in izpada sistema. Preglednica 2 prikazuje vrednosti obrabe orodja pri različnem številu obdelovancev in ustreznem času obdelave.

Slika 7 prikazuje odvisnost toka glavnega in podajalnega motorja pri različnih vrednostih obrabe rezalnega orodja.

Zlahka opazimo pojavljanje signala z visoko frekvenco, kar pomeni, da uporaba nefiltriranih signalov za nadziranje obrabe orodja ne bi bila primerna [13]. Ena od možnosti za filtriranje signala je, da uporabimo površino pod krivuljo signala toka. Preglednica 3 prikazuje vrednosti področja pod krivuljo toka pri različnih vrednostih obrabe.

Pokazali smo, da obraba orodja najbolj vpliva na glavno vreteno, to je glavni pogon. Signal toka glavnega pogona se je povečal za približno 23% med povečanjem obrabe orodja od VB1 do VB6 (od 0 do 0,309 mm). To je znatno povečanje in bi lahko rabilo za presojanje stanja orodja. Krivulja, ki kaže odvisnost moči glavnega vretena v razmerju do obrabe orodja, je skoraj linearno sorazmerna (sl. 8). Ujema se z nekaterimi prejšnjimi raziskavami zlasti z [10], ki prinaša enačbo (1) kot matematični model, ki opisuje razmerje med močjo glavnega vretena in obrabo orodja:

The curve shape clearly illustrates that wear intensity is increasing as the tool life approaches its end, as expected. Further machining with a worn tool would result in tool breakage and system breakdown. Table 2 shows the tool-wear values for a different number of workpieces and the corresponding cutting times.

Figure 7 shows the dependence of the main- and feed-motor currents for different values of cutting-tool wear.

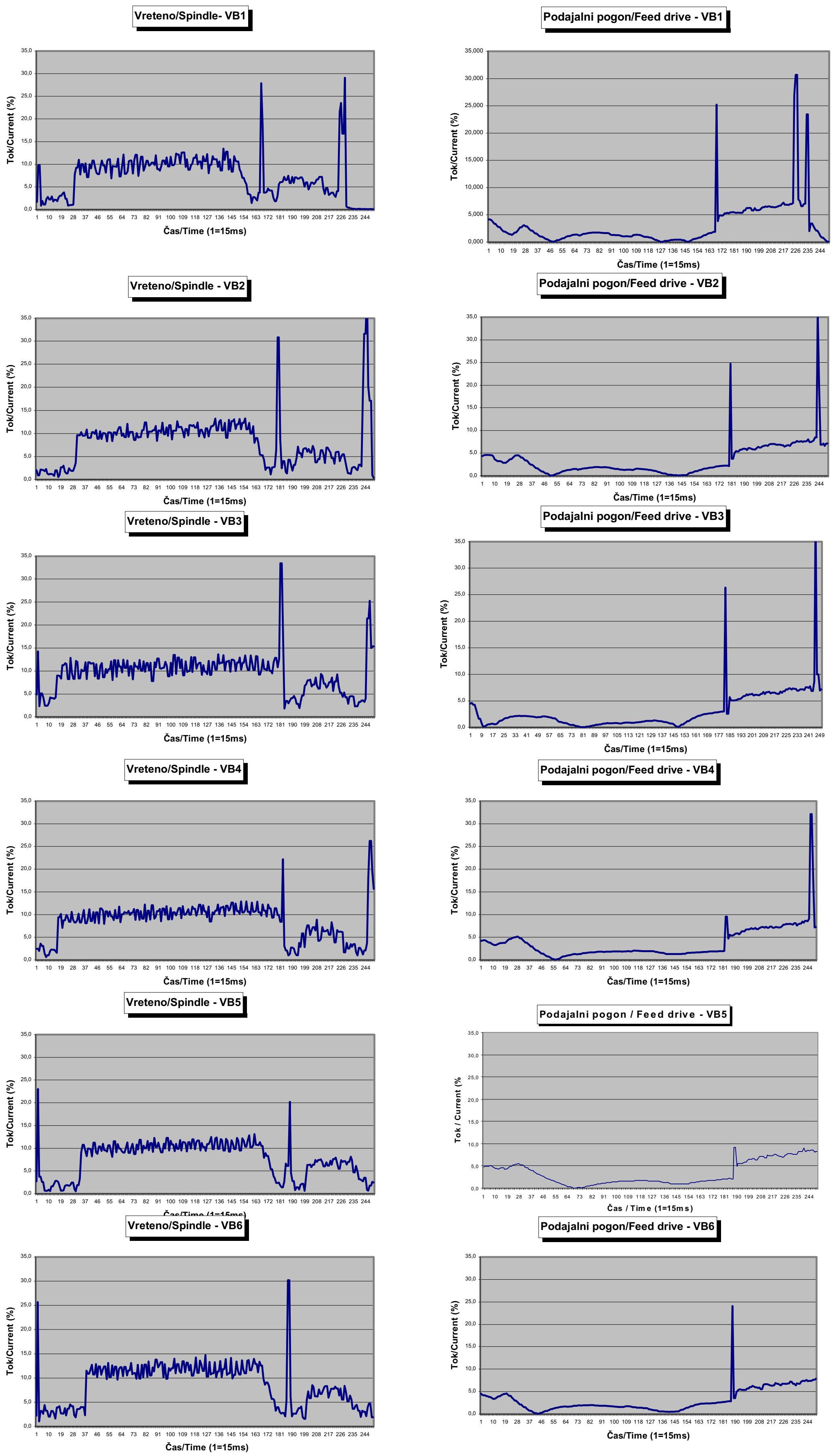
It is easy to observe the high-frequency signals, which implies that the use of unfiltered signals for tool-wear monitoring would not be appropriate [13]. One of the possibilities for signal filtering is to use the surface below the curve of the current signal. Table 3 shows the values of the area below the current curve for several tool-wear values.

It has been shown that tool wear mostly influences the main spindle, i.e., the main drive. The current signal of the main drive increased by approximately 23% during the increase of tool wear from VB1 to VB6 (from 0–0.309 mm). It is a significant increase, and could be used for judging the tool's condition. The curve showing the dependence of the main spindle power in relation to tool wear is almost linear, Figure 8. This is in accordance with some previous studies, in particular [10], which introduces Equation 1 as the mathematical model describing the relation between the main spindle power and the tool wear:

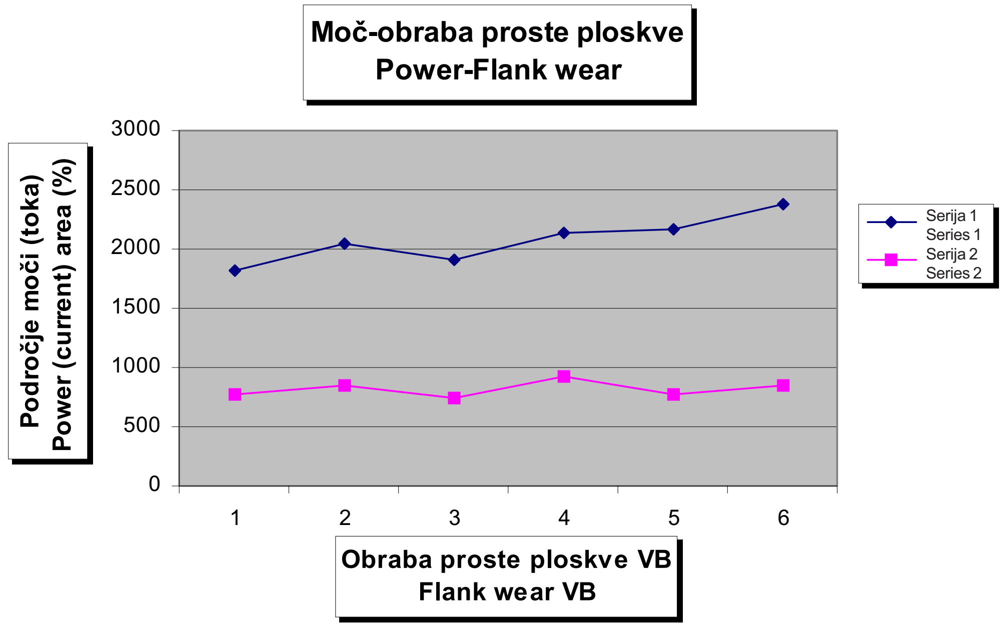
$$P = C \cdot VB + P_0 \qquad (1).$$

Preglednica 3. *Površine pod krivuljo toka v odvisnosti od velikosti obrabe rezalnega orodja*
Table 3. *Areas below the current curve depending on the level of cutting-tool wear*

Področje pod krivuljo toka Area bellow the current curve (%)	P-VB1	P-VB2	P-VB3	P-VB4	P-VB5	P-VB6
obraba proste ploskve Flank wear (mm)	0	0,012	0,215	0,252	0,289	0,309
vreteno S Spindle S	1823,61	2039,47	1914,77	2133,08	2169,7	2382,2
pogon osi X X axes drive	399,3	381,9	366,13	417,1	366,44	368,5



Sl. 7. *Krivulja signalov pogonov za glavno in podajalno os*
Fig. 7. *The curves of drive signals for the main and feed axes*



Sl. 8. *Odvisnost področja pod krivuljo toka glavnega motorja od obrabe orodja*
Fig. 8. *Dependence of the area below the main engine current curve on the flank wear*

Preizkusni rezultati potrjujejo, da signal motorja podajalnega gibanja ni primeren za določanje stanja orodja pri finem struženju. Ker je delež moči, potreben, da premaga trenje in mehanske izgube v podajalnem pogonu, zelo velik, ni mogoče izločiti spremembe moči v podajalnem pogonu, ki je posledica povečanja obrabe orodja. Potrebne so nadaljnje raziskave, da bi vzpostavili točno definirane meje za uporabo signala podajalnega pogona.

5 NADALJNJE RAZISKAVE IZBOLJŠANJA PODATKOVNE BAZE

Programski modul, vgrajen v nadzorno enoto, ponuja gospodarno rešitev v nasprotju z zunanjim zaznavnim sistemom. Pogonski sistem ne deluje neposredno na izvršilni del orodja, ampak je povezan s postopkom obdelave prek mehanskih komponent. Glavni vplivi motenj sistema prenosa so:
- trenje pri mirovanju in drsno trenje verige pogona, pri čemer je nelinearno obnašanje odvisno od hitrosti gibanja in stanja mirovanja,
- pospeševanje, ki pomeni obremenitev sistema,
- prazna razdalja, ki jo povzroči sprememba smeri verige pogona.

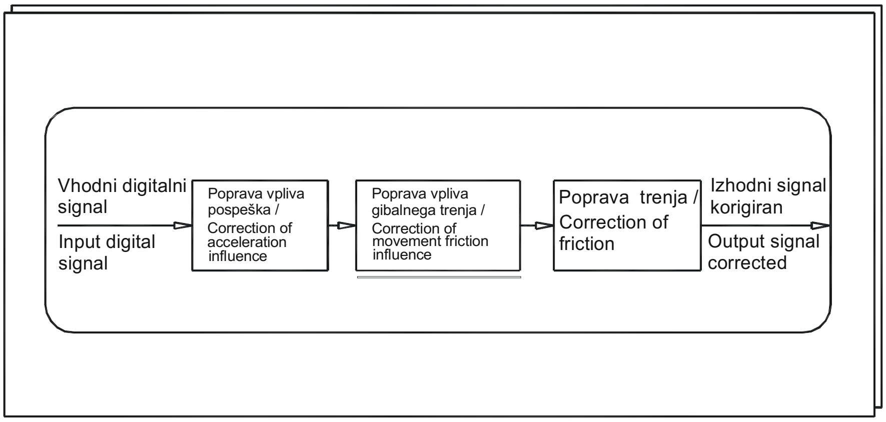
Kar se tiče vrednosti motenj, jih je lahko analizirati in ločiti od osnovnega signala med obdelavo signala, tako da ostanejo samo signali postopka. Upoštevati je treba naslednje vplive:
- vpliv pospeška zaradi vztrajnosti v postopku pospeševanja,
- vplivi trenja v premikajočih se oseh, vretenu, vodilih ali trenje zaradi vrtenja,
- vpliv drž anja pri mirovanju in prazna razdalja pri spremembi smeri.

The experimental results confirm that the feed drive signal is not suitable for judging the tool condition during fine turning. Because the share of power necessary to prevent friction and mechanical loses in the feed drive is very high, it is not possible to isolate the power changes in the feed drive that are the consequence of an increase in tool wear. Further investigations are necessary in order to establish closely defined limits for the application of the feed drive signal.

5 FURTHER RESEARCH ON IMPROVING THE INFORMATION BASE

A software module integrated into the control offers, in contrast to an external sensory system, an economical solution. The drive system does not act directly on the executive part of the tool, but is connected with the machining process through mechanical components. The main disturbance influences of the transmitting systems include:
- the resting and sliding friction of the drive chain, with non-linear behavior depending on the movement velocity, and the state of rest,
- acceleration that changes system load,
- the clearance caused by the change of direction in the drive chain.

Considering the values of disturbance, this needs to be analyzed and separated from the basic signal during signal processing, so that only the processing signals remain. The following effects have to be taken into account:
- the acceleration effect via inertia in the acceleration process,
- friction effects in moving axes, spindles, guides or rotation friction,
- holding effects in standstill and clearance in the change of direction.



Sl. 9. *Odvisnost toka glavnega motorja in raven obrabe*
Fig. 9. *Dependence of the main engine current and the level of wear*

Slika 9 podaja pregled popravnih veličin, ki se izločijo že v prototipu iz vpliva signalne motnje, kar naredi dober signal.

Nadaljnjo obdelavo tako dobljenih zelo dobrih signalov lahko opravimo z izpolnjenimi tehnologijami umetne inteligence, nevronskih mrež in prepoznavanjem vzorcev [14]. Ker za delovanje nevronskih mrež niso potrebni jasno definirani algoritmi niti teorija, ker imajo možnost pridobiti znanje prek niza primerov, so zelo primerni za delo s podatki o obrabi orodja [15] in napovedovanje preostale dobe trajanja orodja. Zmožnost nevronskih mrež, da ustvarijo zanesljive kazalnike obrabe orodja, je strogo odvisna od zgradbe mreže kakor tudi od pogojev možnosti učenja mreže.

6 SKLEP

Brzzančno krmiljenje z digitalnim sistemom pogona odpira nove možnosti in perspektive na področju sprotnega spremljanja obdelovalnih sistemov. V mnogih primerih lahko spremljanje orodij prek nadzornega sistema zamenja običajne zunanje sisteme spremljanja. S kombinacijo digitalnih sistemov pogona z dodatnimi podatki iz nadzornega sistema, z metodami izločevanja karakteristik iz signala in izpopolnjenimi tehnologijami obdelave podatkov dobimo veliko zanesljivost in varnost analize signala. Prav tako spremljanje obdelovalnega postopka prek programsko vgrajenih NK modulov jedru omogoča hitre reakcije na znane motnje postopka, in sicer brez dodatnih omejitev strojne opreme na sistemu. Tako je mogoče razviti praktične skupine postopkovnih modulov, ki so glede strojne opreme neodvisni in odprti, to je preobličljivi. Uporabnost teh sistemov je v glavnem omejena z občutljivostjo glede na opazovani pojav, ki mora biti vnaprej definirana. Raven nadzornega sistema z razvitim najmanjšim številom dodatnih funkcij spremljanja poenostavi povezavo med človekom in strojem, tako da postane

Figure 9 offers an overview of the corrective magnitudes that are already eliminated in the prototype from the disturbance signal influence, thus generating a good signal, Figure 9.

Further processing of the thus obtained valuable signals can be carried out by sophisticated technologies of artificial intelligence, neural networks, and pattern recognition [14]. Since no clearly defined algorithms or theory are necessary for the operation of neural networks, because they have the possibility to acquire knowledge through a series of examples, they are very suitable for working with data on tool wear [15] and predictions of the remaining tool life. The possibility of neural networks creating reliable indicators of tool wear depends strictly on the network structure, as well as on the conditions of the learning possibilities of the network

6 CONCLUSION

Open control with a digital drive system opens up new possibilities and prospects in online monitoring of machining systems. In many cases the monitoring of tools via a control system can replace conventional, external monitoring systems. By a combination of digital drive systems with additional information from the control system, methods of isolating the characteristic features from the signal and sophisticated data processing technologies, high reliability and the safety of signal analysis is achieved. Also, supervising the machining process through software-integrated modules in the NC core allows fast reactions to known processing disturbances, with no additional hardware restrictions on the system. In this way, practical sets of processing monitoring modules can be developed, hardware-independent and open, i.e., reconfigurative. The applicability of such systems is mainly limited by sensitivity in relation to the observed phenomenon, which has to be pre-defined. The control system platform with a developed minimum number of additional monitoring functions, simplifies the man-machine sprejemljiva za operaterja stroja. Nadaljnji razvoj teh sistemov in metoda izločevanja karakterističnih lastnosti s hkratno uporabo tehnologij umetne inteligence pomenijo znaten korak naprej k uresničitvi preprostega, zanesljivega, uporabniško prijaznega načina spremljanja rezalnih orodij in postopkov.

connection, and makes it acceptable to the operator. The further development of such systems, and the method of isolating characteristic features, at the same time applying the technologies of artificial intelligence, present a significant step towards realizing a simple, reliable, user-friendly way of monitoring cutting tools and processes.

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