CHOSEN ASPECTS OF MICRO MILLING MACHINE DIAGNOSTICS

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Summary

The paper deals with the one of the designed diagnostic issue for micro milling machine. The short description of designed and set in motion micro machine for milling is presented. Geometrical construction is deliberated as well as a drive and measurement systems are depicted. Moreover capabilities of the machine are compared to conventional ones and advantages of presented machine are listed. The machine supervisory control system, which base on artificial intelligence diagnostic system is described. Conducted in design process deliberations about types and structures of the net and form and source of the signals are presented. The last part of the paper includes conclusions and final remarks.

Keywords: micro cutting machine, diagnostics, artificial intelligence.

WYBRANE ASPEKTY DIAGNOSTYKI MIKROFREZARKI

Streszczenie

W artykule przedstawia się jedno z zagadnień diagnostycznych związanych z mikrofrezarką. Zaprezentowany został także krótki opis zaprojektowanej i uruchomionej maszyny do mikro frezowania. Rozważona została konstrukcja geometryczna maszyny oraz przedstawione zostały systemy pomiarowe i napędowe. Ponadto porównuje się właściwości tej maszyny z rozwiązaniami konwencjonalnymi i wymienia się jej wady i zalety. Opisano bazujący na sztucznej inteligencji system diagnostyczny oraz system nadzoru maszyny. Prezentuje się rozważania przeprowadzone w procesie projektowania sieci dotyczące typu i struktury sieci oraz formy i źródła sygnałów. Ostatnia część artykułu zawiera wnioski.

Słowa kluczowe: maszyna do mikro obróbki, diagnostyka, sztuczna inteligencja.

1. INTRODUCTION

The production of the precise miniature component is stimulated by increasing requests from e.g. aircraft industry, electronic industry or biomedicines [1], [10], [11]. Moreover global tendency to devices miniaturization and very fast development of mechatronics cause increase importance of the micro machining processes; in particular large interest of the Micro Electro - Mechanical Systems (MEMS) that contain precise mechanic components with high shape ratio, sizes of a few micrometers to a few millimeters and very often characterize by lack of the axial symmetry [11]. Moreover mechanic components of such systems have to be made of the difficulty machined materials such as high alloy steel, ceramic or titanium compounds. Obtaining required precision of manufacturing such elements is impossible using classical technology as: molding, pressing, hammering, electro or chemical erosion and even laser tooling, but only using micro cutting [11]. That is why, among many technique of micro components production there is observed the growing interest of micro cutting, which arises with large potential of that method in the zone of the realization of the geometrically complex elements. Especially high rate of adoption such machines takes place in case of tooling "micro shapes" in the area of micro element.

The micro cutting technique, in case of unitary production, allows for projection of the 3D free face with relatively little costs effort. It all causes a large applicability of micro cutting, for instance in case of micro mold manufacturing [2]. Another advantage of such tooling technique is relatively high efficiency, low harmfulness for environment, relatively low cost of devices and their exploitation.

Nowadays the operations of micro cutting are leaded on high precision machines characterized by the high efficient of stiffness with systems for temperature control [3], [4], [5]. Mainly from cost reduction point of view the strong tendency is actually observed due to build tooling machines characterized by small dimensions and possibility to move it easily [6], [7], [8], [9]. Unfortunately such construction are incomparable worst in contrast with conventional precision tooling machine from stiffness, precision and vibration moving by basis damping point of view. For that reason the development of new construction of micro machines for tooling is very important and actual topic. The researches on the micro cutting subject, both in Poland and all over the world, are still pioneering kind [12]. However, there are brands offering specified commercial solutions of micro cutting machines, which are quite expensive and have rather only individual character.

The rest of the paper is organized as follows. In section 2 a micro milling machine is presented. The machine diagnostic system is described in section 3. Supervisory system and its hardware solution are presented in section 4. Brief conclusions are drawn in section 5.

2. MACHINE DESCRIPTION

Described prototype of machine for micro tooling was built as an effect of realization of the grant partly supported by the Grant No N R03 0050 06/2009 "Construction of a prototype system for testing micromachining – researches and modeling of process" financed by the Polish Ministry of Science and Higher Education. The basis of the machine composes of specially produced stabile granite corps (Absolute Black Granite) on which the electro-spindle with controlled rotary velocity (100.000 RPM) and precise system of liner motion are mounted. What is more, the machine is equipped with condition system stabilizing temperature of the machine. That micro milling machine has three numerically controlled axes and is equipped in adequate measurement apparatus, among others: precocious multi axes dynamometer for measuring cutting forces, digital viewing microscope Keyence, model VHX-600ESO with high zoom and acoustic measurement system. The workspace such designed machine is limited to cuboid with size of 100x100x50 mm and the errors of positioning in near the value of 0.5 μm. The rest operation parameters are similar to other construction existing on the market, nevertheless expected price is many times lower, due to using ready-made modules with made by own control system and with individual construction of the corps. One of the most important properties of the constructed machine is monitoring system with diagnostic algorithms based on artificial intelligence. Generally in nowadays construction of such machines monitoring systems are quite rarely integrated in machine control system.

Design works on the machine were started from selection of kinematic structure, which has essential influence on technological precision possible to obtain by the machine; it is mean precision of relative tool and tooling object motion. For that reason two selected geometrical structures were taken into consideration.

Conducted simulation gave the possibility to compare the structure with vertical and horizontal spindle due to precision of projection the tool to tooling object. As a criterion for that comparison the lowest value and dispersion of volume error were chosen. Finally all conducted analysis lead to choosing the horizontal structure as better one especially in the view of precision of the projection of the tool and tooling object relative position. In the machine the spindle is horizontally moving along the Z axis and the tooling object could be moving on the surface Y-X. A computer comparative analysis of the machine construction with other ones known from literature shows that the chosen construction would meet with the highest ratio all requirements regarded: stiffness, dynamic and precision of tool position projection due to tooling object.

The constructions on each line moving axis were used commercial high precision drives of Aerotech brand from USA: "Y" axis working horizontally based on model ANT95-50-LV, "Z" axis based on model ANT95-50-L; "X" axis based on model ANT130-110-L. The drives working under control of the controller Epaq model EPAQ-S-FPB-XX-/1-MP10MI-MP10M-MP10M-MP10.

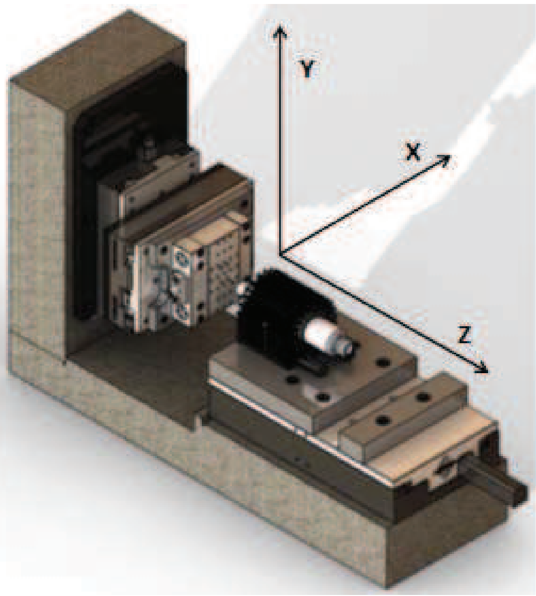

Fig. 1. Project of the milling micro machine with pointed out axes

The main driven system consist of commercial electro spindle type 4015 DC, which was made by SycoTec brand from Germany, controlled by controller and supplier e@syDrive 4425. Moreover, that system requires supplying of compressed (0.5-0.8 bar) air of adequate clarity due to protect ceramic bearing from pollutants. Additionally servo drive of vertical axes is using pneumatic cylinder actuator for supporting the operations of electrical linear motor. For that reason there were designed pneumatic installation for the machine. The main component of that installation is rotary vane compressor for continuous work, model Gast 74R130-P114H201X, moreover there are air filters, valves and pressure reducers.

One of the most important parameter of correct leading process of micro milling is supporting constant temperature of machine and tooling object.

Due to these requirements the machine is installed in closed cover, inside which the temperature and humidity are stabilized by maintained-free air conditioner made by Schroff brand. The machine is presented in the figure number 2.

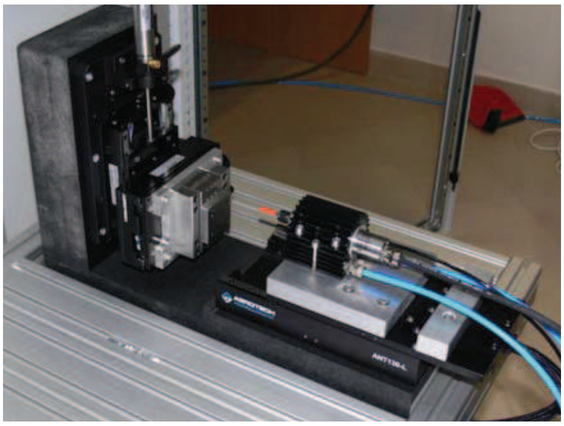

Fig. 2. The machine for micro milling

Summing up description of the micro machine for milling operation list of main features is depicted:

– small dimensions,
– very high precisions of tooling,
– very high stiffness and thermal stability,
– high rotary velocity of the tool – high coercion frequency during milling process.

For that machine the control and supervision system were designed and implemented. The scheme of the system is shown in the figure number 3.

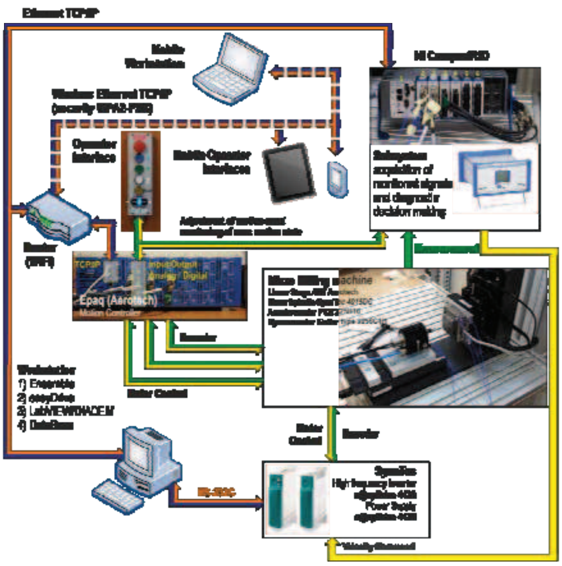

Fig. 3. Structure of the machine control and supervising system

The knowledge about course and character of the micro milling process, get on the way of experiment, were used to make conception of the intelligent diagnostic system. Seeing that micro milling process in comparison with classical tooling in macro scale is relatively poorly known, and what is more is characterized by many specific features only using recorded experimental data and its analysis could be the source of the diagnostic system concept.

3. DIAGNOSTIC SYSTEM FOR MICRO MACHINE FOR MILLING

One of the micro tools features is that they could be very easily destroyed, due to its small dimensions, e.g. 0.1 mm. Especially during installation in the spindle the tool could be damaged. For that reason it is very important to validate the state of micro tool (due to after mounting it in the grip of electro spindle, and of course before starting the tooling process.

The zoomed in edges of new (undamaged) and damage tools are presented in the figures number 4 and 5, respectively.

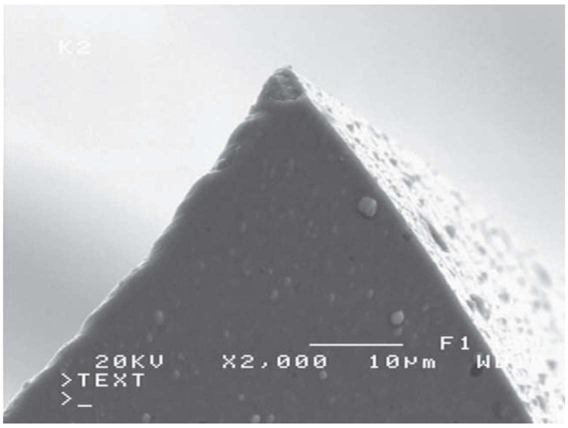

Fig. 4. Zoomed in edge of the new tool Kyocera 2FESM005-10-04

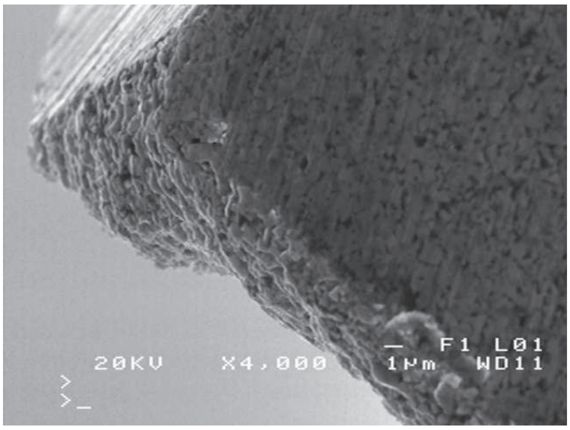

Fig. 5. Zoomed in edge of damage tool.

Designed, for leading such diagnostic procedure, system is based on analysis of measured, using miniature accelerometers (model 325B10 made by PCB brand) attached to the servo drive corps, spindle vibrations signals. It is assumed that the measurements are made when the proper spindle velocity is achieved. In the figure number 6 the example of time domain signals in the axis "Y", recorded at the speed of 24,000 RPM, for the three diagnosed states are presented.

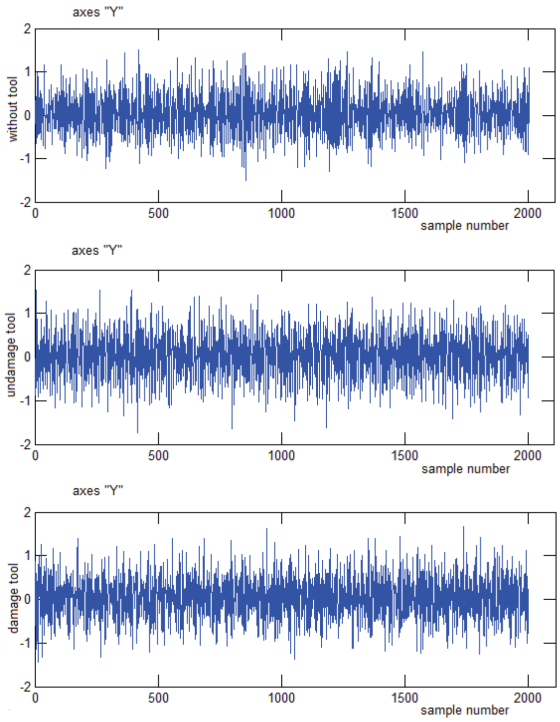

Fig. 6. Time domain signal in the axes "Y"

The proper velocity related to the sampling parameters, the spread of the FFT window and expected value of first harmonic of the vibration signal. Assuming that in the spindle is mounted the tool with 2 edges and the measurements are conducted with sample rate of 51,200 SPS resulted in obtaining the spindle velocities values: 96,000 RPM, 48,000 RPM, 24,000 RPM and 12 000 RPM as a guaranties correct form of the diagnostic signals. For that signals parameters the integer number of samples per period for first harmonic and integer number of periods of first harmonic in the window set up for FFT are obtained. The value 4096 samples for FFT analysis were chosen due to guarantee on the one hand high speed of working diagnostic algorithm and on the other hand as that one which allows to obtain enough thin bands (high enough resolution) in spectral characteristic. The figure number 4 presents examples of the spectrum charts with different FFT window spread. Moreover into investigation was taken the issue of using window before FFT. Windows such as Tukey or Taylor among others are using in case of eliminations negative influence of FFT algorithm assumptions. All kinds of window available in Matlab environment were checked and it was found that it is enough to us the rectangle kind of window. The spectral characteristics for different type of window are presented in the figure number 7.

The diagnostic system is using the information obtained from the results of the leaded in advance spectral analysis (FFT). Similar approach to the diagnostic issue is presented for instance in [1]. Such procedure of analyzing the spectral signals could be leaded not only before starting tooling, but also each time when the micro tool do not have a contact with the tooling object due to the program path.

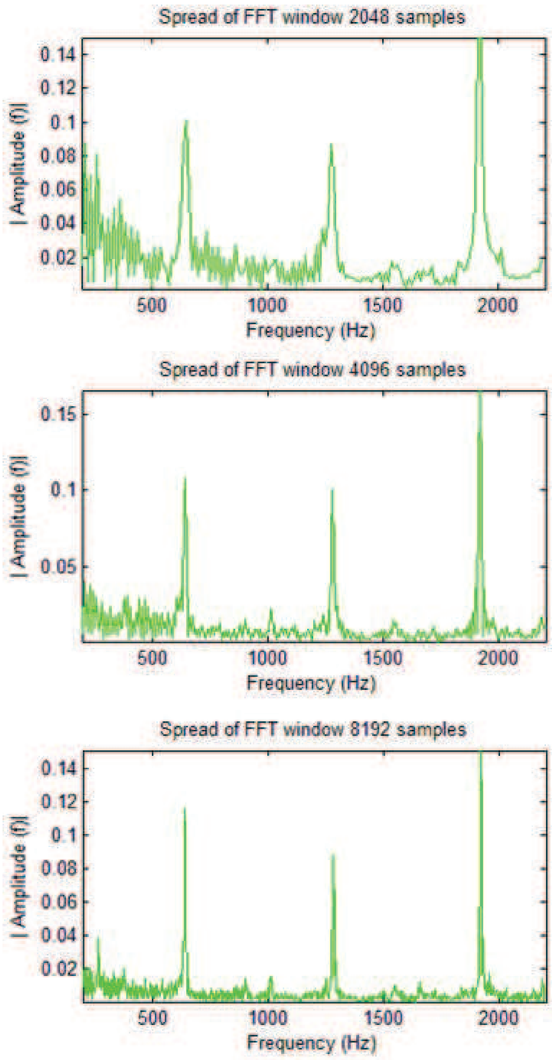

Fig. 7. Spectral characteristic for different spreads of the FFT window

Such test and analysis could give us a chance to state if in the grip there is no tool or in the grip is the tool which is undamaged or damaged. The spectral charts for those cases are presented in figure 8. To achieve efficiently working diagnostic system recognizing mentioned above three potential states it is necessary to collect data reflecting different tools occurring on the market. Due to find the best source of diagnostic information not only spectra recorded signals were taken into consideration but also signals forming by using the mathematic operation on the elementary, recorded signals. To find the best form of symptoms following signals were investigated:

– signal recorded in the "X" axis,
– signal recorded in the "Y" axis,
– signal formed as a result of summing signals recorded in axes "X" and "Y",
– signal counted as a amplitude of resultant vector formed from signals recorded in the axes "X" and "Y", i.e. √(X*X+Y*Y),

- signal counted as a amplitude of resultant vector formed from signals recorded in the axes X, Y and Z, i.e. √(X*X+Y*Y+Z*Z).

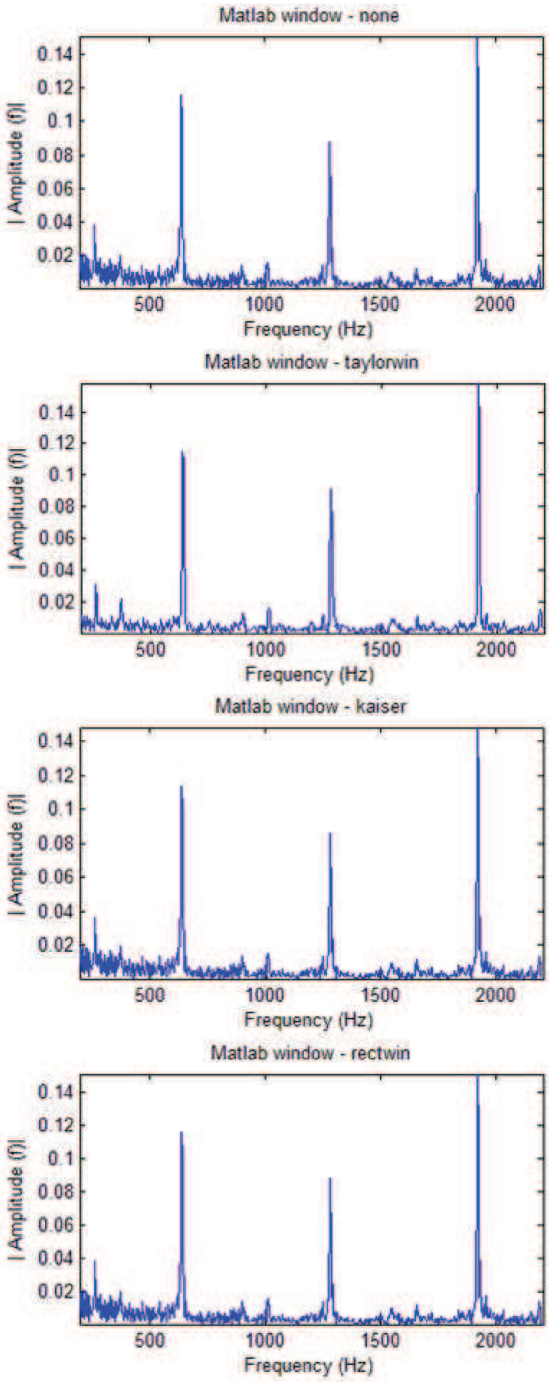

Fig. 8. The spectral characteristics for different type of window

For mentioned above signals spectral characteristic were counted and chosen parameters of that characteristic were used to assemble learning patterns for the process of learning artificial neural networks. What is more analyze of the shape of many plotted spectral characteristic leads us to the view that more efficient neural system could be designed using proportions of the characteristic parameters (integral of specific areas around main harmonics on the spectral characteristic) then just directly parameters. The investigated relations:

- quotients of area value around first, second, third harmonic and the sum of whole chart area (1h/sum, 2h/sum, 3h/sum),
- quotients of area around second harmonic and area around first harmonic with quotient of area around third harmonic and area around first harmonic (2h/1h, 3h/1h),
- quotients of sum area around first and third harmonic and area around second harmonic with sum area around second and third harmonic and area around first harmonic ((1h+3h)/2h, (2h+3h)/1h). For the speed 24.000 RPM the first, second and third harmonic are 400 Hz, 800 Hz and 1200 Hz, respectively.

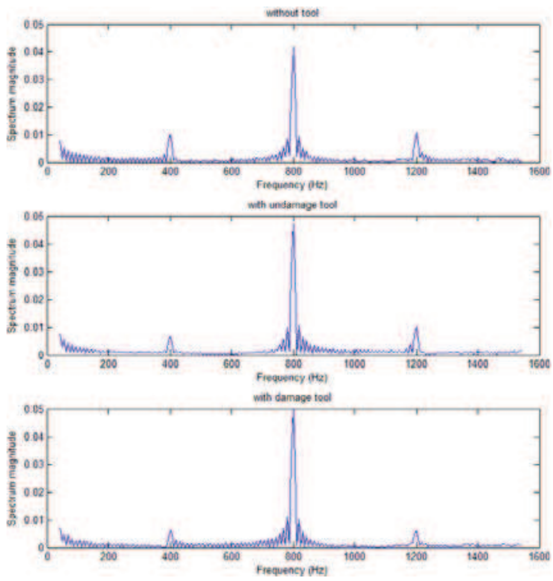

Fig. 9. The spectral characteristics for different machine states

Moreover analysis of the charts shows that the plots are not constant from window to window. For that reason for diagnostic system also average values and deviations counted for spectral characteristic were taken into account.

Having all above descripted assumptions about form of potentially useful signals the structures and types of neural networks were chosen. Only forward kinds of nets were investigated. Table number 1 presents the list of researched neural networks.

Looking for the net capable to correct recognition of the machine state above listed types and structures of the nets were researched in addition with combination of also previously described form of input signals.

Finally as the best kinds of nets were calculated nets:

- with signal on the input:
- rotary velosity 24,000 RPM,
- with operation 2h/1h, 3h/1h (2 dimensional input vector),
- measurement of the acceleration in the „X" axis,
- feed-forward type,

– only 1 hidden layer with 3 neurons,
– with outputs coded as -10 / 10.

Table 1. The list of examined structures of the nets

no.	Number of neurons in the layer					
	input	hidden				output
		1st	2nd	3rd	4th	
1	2, 3, 4, 6	3				3 or 1
2		6				
3	due to the set of the signal treated as a symptoms	9				3 in case of the network recognized each of the three states
4		12				
5		15				
6		18				
7		6	3			
8		9	3			
9		9	6			
10		12	6			
11		12	9			1 in case of the network recognized only state one from three
12		15	9			
13		9	6	3		
14		12	6	3		
15		12	9	3		
16		12	9	6		
17		15	9	6		
18		15	12	3		
19		15	12	6		
20		12	9	6	3	

Conducted test using wider (then during learning) sets of signals gave the results:
– the net recognized state "without tool" works with error equal to 0,
– the net recognized state "undamaged tool" works with error equal to 7,8%,
– the net recognized state "damaged tool" works with error equal to 8,0%,
– the net recognized all states works with error equal to 5,2%.

As a final solution, advisory diagnostic system is proposed in which operator would be obtaining information from all four nets. The operator in case of detecting dysfunction of the system is supported by concluding system based on fuzzy logic techniques. Such a diagnostic algorithm were implemented and tested during common operations, what is described in the next paragraph more detailed. The main implementation environment for that control and supervisory system is LabView by National Instruments.

Many more diagnostic issues were also investigated. Among others one of the important issues is to detect the point when the ending touching the object and the micro milling starts. Another one is to determine before starting the tooling if the program were written accurately and the machine and the tool do not have path with collisions. Moreover observation of actual spindle velocity in contrast with set up is next important symptom of the machine state let us to validate the efficiency of the spindle system. Algorithms for diagnosing mentioned machine states are still under investigation and implementation.

4. SUPERVISION SYSTEM FOR THE MACHINE

The main tasks of supervision system are acquisition, monitoring, analyzing and recording data during operation and communication with control system. The hardware structure was divided into three main parts, which is showed in the figure 10.

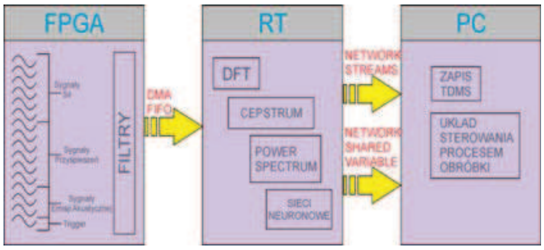

Fig. 10. Hardware structure

The FPGA module in controller PAC cRIO 9022, first section, is responsible for acquisition and filtering of the signals measured on the machine. That solution gives us a chance to measure very fast changing signals as force and acceleration with sampling rate 51,200 SPS and filtering them in real time. The second section based on working in real time regime another cRIO 9022 instance. The DMA channels are used to transfer huge amounts of data in short time without charging controller's CPU. Transition data to the third instance is realized using "Network Streams" protocol. That last instance (PC computer) is responsible for recording all collected data. That instance is dedicated to data analysis and diagnostic tasks.

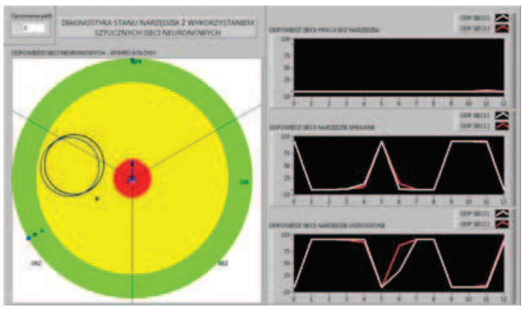

Fig. 11. The view of diagnostic screen

The important component of implemented supervision system is Human – Machine Interface. Such an interface delivers many functions improving comfort of operators work. It was assumed that HMI would have been realized on two wireless panels. To expand supervisory system on remote devices working under Windows operating system LabView Mobile Module from LabView National Instruments were used. The module supports Shared Variable Engine and cooperates with Data Acquisition devices. As an operator panel tablet Acer Inconia Tab W500 and smartphone HTC HD2 were chosen.

The interface implemented on PC and operator panel displaying results of diagnostic analysis. The example of such view is presented in the figure 11.

5. SUMMARY

As it was described a micro machine for milling were designed, assembled and tested. On the basis on the recorded signals analysis of diagnostic procedure were done. Due to that analysis diagnostic system using neural networks were designed in Matlab and implemented in LabView. Tests shows that the best results are obtained when the decision about actual state of the machine is make on the basis of combined answers from 4 nets.

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