MONITORING SYSTEM FOR DIAGNOSING MACHINES IN NON-STATIONARY STATES

Wojciech BATKO*, Witold CIOCH*, Ernest JAMRO**
Department of Mechanics and Vibroacoustics*
Department of Electronics**
Akademia Górniczo-Hutnicza – University of Science an Technology,
Al. Mickiewicza 30, 30-059 Kraków
email: cioch@agh.edu.pl

Summary

Monitoring the operation of machine tools, such as grinders used for jet-engine turbine blades is vital for demanded product quality and economic expenses associated with defected products and production stoppages. In the technological process of grinding, even wear of tools does not always occur, and machine tools definitely work in non-stationary conditions. Self-induced vibrations are often observed. Therefore monitoring system of module structure was designed, dedicated to non-stationary signal processing. The system is composed of modules for recording and preliminary hardware signal processing, database servers and user's terminals.

Keywords: monitoring, diagnostics, grinding machine.

SYSTEM MONITORINGU MASZYN W NIESTACJONARNYCH STANACH PRACY

Streszczenie

Monitorowanie obrabiarek takich jak szlifierki łopatek silników lotniczych ma szczególne znaczenie ze względu na wymaganą jakość produktu, jak również koszty ekonomiczne związane z wytwarzaniem braków oraz przestojów produkcyjnych. Podczas procesu technologicznego szlifowania następuje nie zawsze równomierne zużycie narzędzi, a obrabiarki pracują w warunkach niestacjonarnych. Często występują również drgania samowzbudne. Dlatego stworzono system monitorowania, dedykowany przetwarzaniu sygnałów niestacjonarnych o modułowej budowie. Składa się on z urządzeń do rejestracji i wstępnego sprzętowego przetwarzania sygnałów pomiarowych, serwerów bazy danych i terminali użytkowników.

Słowa kluczowe: monitoring, diagnostyka, szlifierka.

1. INTRODUCTION

Despite varied production technologies, machining is still commonly applied nowadays. It is the result of the fact that it provides a very high accuracy, high efficiency and could be easily automated. Perfect examples of devices carrying out machining process are grinding machines for aviation turbine blades.

Problems regarding grinders operations can have various causes. They can be associated with machine-tool defect, tool wear processes or self-induced vibrations [3]. Hence it is advisable to diagnose machine-tool condition not only before machining process but also during the actual process. The condition of machine tool is vital for the product quality and for continuity of production process, the stoppage of which would bring significant economic losses.

Monitoring systems enable to detect changes in condition or operation parameters of machine tools [2]. Based on data collected, it is also possible to project the technical condition, which is important for production-process planning. It is of great significance in aviation industry, where manufactured elements are of high quality and precision. Therefore their production is expensive and loss of the whole batch of product is not acceptable.

Machine tool condition and machining process characteristics are vitally affected by dynamic phenomena. Hence vibration is a basic quantity measured in a monitoring process. Vibration is also measurement quantity bringing the most valuable diagnostical information [5]. Monitoring tool condition and self-induced vibrations is still an unsolved problem.

The most significant features, determining functional properties of monitoring systems are according to [4]:

- purpose (machine tool, machining type),
- type of selected diagnostical signals and their measurement manner,
- signal transformation methods,

- method of determining boundary values,
- diagnostical inference methods,
- maintenance characteristics, interfaces.

Having those items in mind, an innovative monitoring system for grinder machine of aviation turbine blades has been designed.

2. THE STRUCTURE OF THE DURATIVE MONITORING SYSTEM

The monitoring system for grinding machine includes methods and algorithms for signals acquisition, pre-processing; data transmission, processing and storage.

Consequently, the whole system consists of the following modules:

- Programmable Unit for Diagnostic (PUD)
- Dedicated server for data collection and processing
- Dedicated server for data storage with limited users' access.
- External user terminals for diagnostic signals analysis.

The block diagram of whole system is presented in Fig. 1.

3. PROGRAMMABLE UNIT FOR DIAGNOSTIC (PUD)

Programmable Unit for Diagnostic (PUD) is an electronic device which core is an FPGA chip [6]. The block diagram of the PUD is shown in Fig. 2 and it incorporates the following parts:

- Four independent analog / digital modules on separate PCB
- Two independent SDRAM memory banks, 64MB each, employed to store acquired data from analogue / digital modules and other temporal data,
- CPLD (Xilinx XC95144XL device) – module employed to configure FPGA and to control the PUD in power stand-by mode,
- Flash memory (4MB) to store FPGA configuration, MicroBlaze program and other non-volatile data,
- Hard Disk Drive (HDD) to store high volume data,
- LCD display employed to visualise the state of the device and results for acquired data,
- Keyboard – allows user to control the PUD and to start / stop data acquisition,
- PC computer communication by Ethernet, Parallel or Serial Ports.

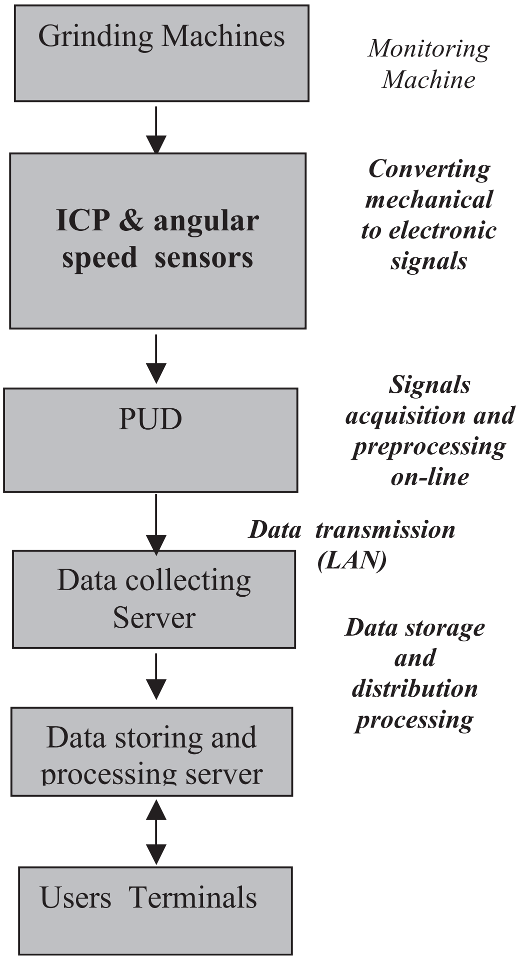

Fig. 1. The monitoring system block diagram

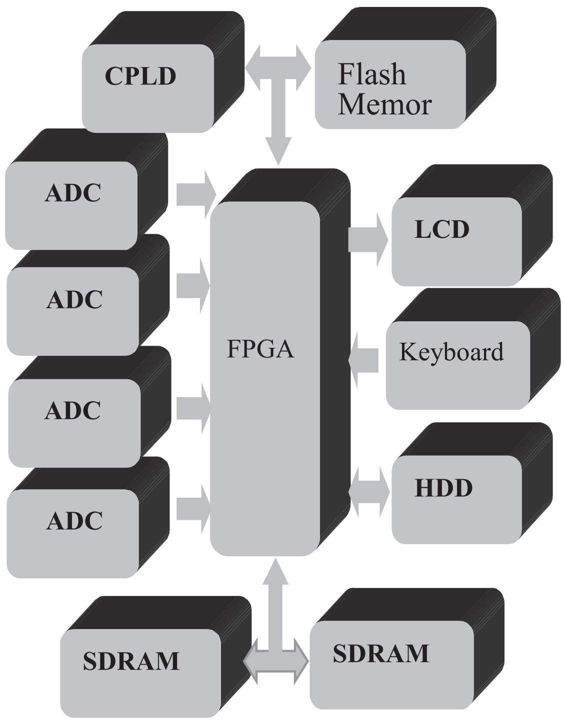

Fig. 2. Block diagram of the Programmable Unit for Diagnostic (PUD)

Besides, the PUD incorporates some optional devices: Compact Flash memory, VGA display, PC keyboard, and Ethernet and Radio Communication modules.

The PUD incorporates four independent analog /digital boards. These boards include Analog Digital Converters (ADC), input signal amplifiers with digitally controlled level of amplification and ICP sensor interface. Each analog board incorporates 2 channels 16-bit 500kS/s each or 4 channels 16-bit 250kS/s each, consequently up to 8 (16-channels) can be acquired by the PUD. It should be noted that changing analog / digital board requires FPGA configuration to be changed. Fortunately modular design in EDK significantly reduces the design time.

One of the most significant feather of the PUD is hardware implementation of selected signal processing procedures. Consequently these procedures calculation time is significantly reduced. Besides Xilinx Embedded Development Kit (EDK) design software was employed to reduce design time. The EDK supports modular design and incorporates a great number of pre-design modules such as external memory interface and the MicroBlaze soft-processor. The MicroBlaze is a master micoprocessor which configures and controls all other hardware modules.

One of the most important digital processing procedure adapted on the PUD is the Procedure of Linear Decimation (PLD) [8]. Therefore this procedure was implemented directly in hardware. This implementation can be divided into three separate tasks:

- Marker logic detection – rotation period indicator,
- Anti-aliasing filter,
- Linear decimation.

4. PC - PUD COMMUNICATION

The PUD devices can run in two different modes:

1) Portable standalone system
2) PC-controlled signal acquisition and processing unit.

In the standalone mode, the PUD acquires, processes and stores signals without any communication with PC. The PUD incorporates its own menu which controls the device: allows to set e.g. signal acquisition parameters: acquisition time, sampling frequency, invokes signal processing procedures e.g. PLD etc. The sequence of the commands can be grouped in a macro – the macro can be programmed directly in the PUD or on a PC. The final results can be stored on the local HDD and then transferred to the PC.

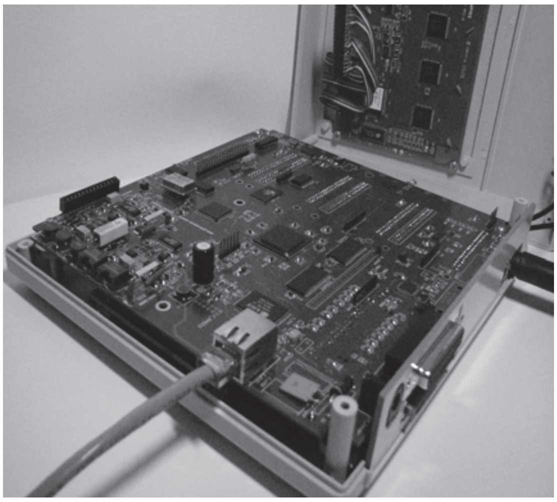

Fig. 3. PCB board and electronic devices view of the PUD

In the PC-controlled mode, the PUD is connected with the PC Fig. 4 and can be fully controlled remotely by a PC. Signal processing can be still completed in the PUD and then only final results transferred to the PC. Alternatively, raw data (signals acquired by the ADC) can be transferred to the PC where they are processed, e.g. in MATLAB.

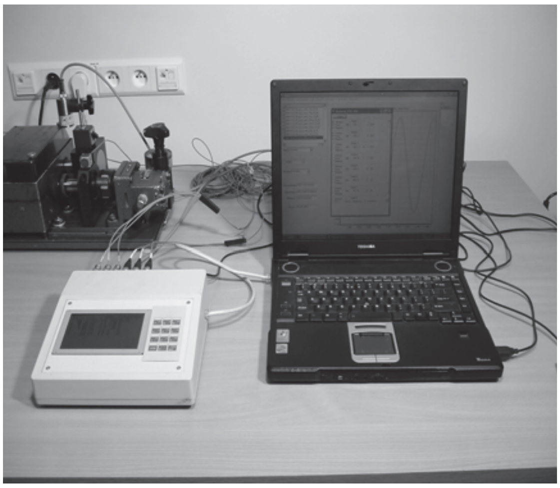

Fig. 4. The PUD device connected to PC

In the PUD signal records, apart from acquired signals some additional information, as acquisition time, sampling frequency and amplifier settings are stored. The PUD allows also to store some additional information as channel number and name, kind of signal processing procedure carried out on the signal, etc. In these records every channel can be processed independly, or a signals processing procedure can be carried out on a group of selected channels. Monitoring system used for laboratory tests is shown in Fig. 5.

Fig. 5. Monitoring system used for laboratory tests

5. DATA SERVERS

The signals acquired and processed on the PUD can be then transmitted to a computer where the database program allows to edit these signals and add additional information such as grinding machine distribution and user comments. The database allows to group selected signals as a result of acquisition time, data processing type, etc [1]. It also allows to process recorded signals by external programs such as MATLAB.

To increase data security and to improve data visualization data are stored on two independent servers. On the first server, data transmitted directly from the signal acquisition unit (PUD) are collected. Then they may be preprocessed in order to decrease the data volume and to select only important diagnostic estimates. Then preprocessed data are stored in a local database and are transferred to the second server. The main task of the second server is data backup and data distribution as a database or by HTTP protocols on WWW. As a result, end users can access data by users terminals which need not advance diagnostic programs. This solution allows controlling data access to a limited number of users.

6. SIGNAL ANALISIS

Hardware realisation of linear decimation procedure based on FPGA programmable systems gives the possibility of diagnosing cyclical machines at variable operating conditions in real time. Besides a novel Short-Time PLD method was developed, enabling to adapt the approximation to the cycle changes [8]. This method solves the problem of non-linear trend change and minimized the error resulted from the original PLD assumption of linear cycle trend in the observation window. This solution has brought the method nearer to the order analysis without the necessity of applying interpolation filters.

To prediction technical state of a monitoring machine, sophisticated methods including time-frequency analysis was adopted employing MATLAB. This is possible as a history of a greate number of records is stored in the database.

The described system may check production process in order to reduce production defects by monitoring vibration parameters. Fig. 6 shows where vibration sensors are located on the grinders of aviation-turbine blades.

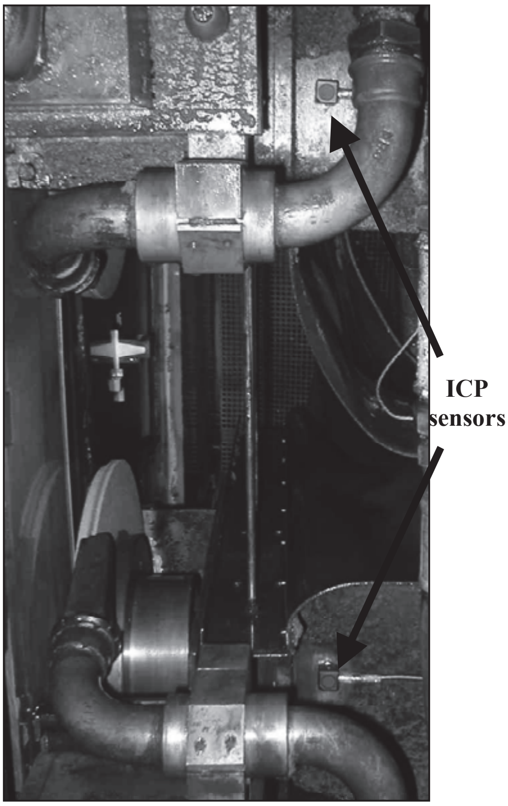

Fig. 6. ICP sensor location on the grinder machine

Examples of diagnosing non-balanced grinder disc during working state is shown in Fig. 7.

7. CONCLUSIONS

Application of the Programmable Unit for Diagnostic (PUD) into preliminary signal processing system enable to record data with high frequency and data hardware processing [7]. Using programmable FPGAs brought the possibility of non-stationary signal analysis in real time. The applied PUD module enabled, apart from measuring diagnostical signals, to record parameter signals, especially rotation speeds of spindles.

In the database part, employing two servers for data collecting and for data distribution separately improved the safety of database. It also gave the vast possibilities of processing (implementing Matlab suite) and surveying of collected signals by authorised users. Thanks to this solution, classifying grinding-machine condition and diagnosing operational process can be carried out by means of:

- numeral measures,
- functional measures,
- neural networks,
- parametrical models.

a)

b)

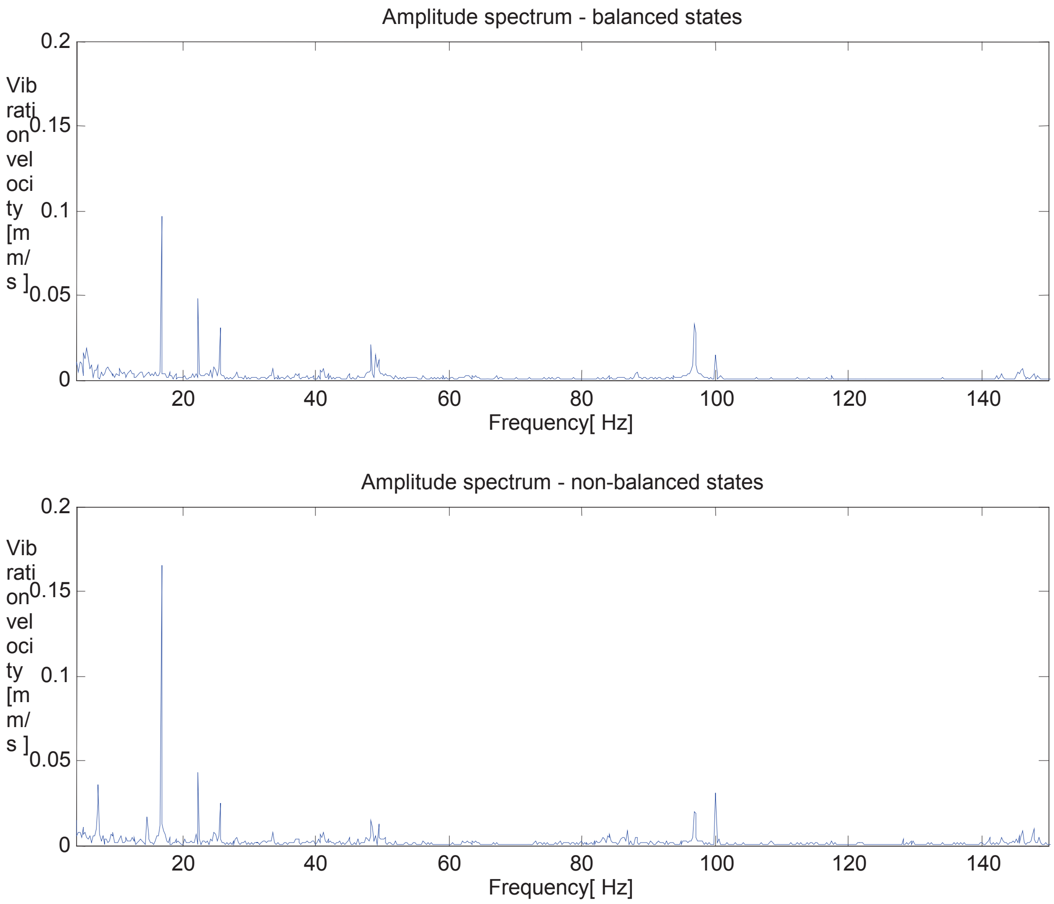

Fig. 7. Vibration velocity of grinder spindle: a) balanced states, b) non-balanced states

The modular construction of the monitoring system allows the whole system to be easily extended or modified to new grinding machines and acquisition points.

6. REFERENCES

[1]. Batko W., Głocki K., Borkowski B.: Application of database systems in diagnostic machine monitoring, Eksploatacja i Niezawodność, No 4, 2007.

[2]. Batko W., Korbiel T.: *System monitoringu diagnostycznego przekładni planetarnej pracującej w warunkach zmiennego obciążenia,* Diagnostyka nr 1(37)/2006.

[3]. Bodnar A.: *Vibration Monitoring on a Milling Machine Using the Analysis of Stochastic Features of Generated Noise,* Ninth World Congress on the Theory of Machines and Mechanisms, 1995, Milano, Vol. 4, s. 2910-2914.

[4]. Bodnar A.: *Diagnostyka i nadzorowanie drgań obrabiarek.* Materiały Sekcji Podstaw Technologii Komitetu Budowy Maszyn PAN z 50 posiedzenia w dniu 24.06.93 w Szczecinie, Prace Inst. Technologii Mechanicznej Politechniki Szczecińskiej, 1993, s. 5-16.

[5]. Cempel Cz.: *Diagnostyka wibroakustyczna maszyn*, Wydawnictwo Politechniki Poznańskiej. Poznań, 1985.

[6]. Jamro E., Adamczyk, A. Krzyworzeka P., Cioch W.: *Programowalne urządzenie diagnostyczne stanów niestacjonarnych pracujące w czasie rzeczywistym*, XXXIII Ogólnopolskie Sympozjum Diagnostyka Maszyn, Węgierska Górka, 2006 r.

[7]. Krzyworzeka P., Adamczyk J., Cioch W., Jamro, E.: *Monitoring of nonstationary states in rotating machinery,.* Instytut Technologii i Eksploatacji, Radom 2006.

[8]. Krzyworzeka P., Cioch W., Jamro E.: *Hardware abilities of Linear Decimation Procedure in practical applications.* Journal of POLISH CIMAC, Diagnosis, Reliability and Safety, vol. 2, No 2, Gdańsk, 2007.

This work has been executed as part of research project at KBN no 6T0720005C/06545

Wojciech BATKO – a professor and a head of Mechanics and Vibroacoustics Department of AGH-University of Science and Technology (AGH-UST). He is an author of over 230 publications including 12 books. His subject of interest is machines dynamics and vibroacoustics, and technical diagnostics.

Ph. D. (Eng.) **Witold CIOCH** obtained a Ph. D. degree at Mechanical Engineering and Robotics Department of AGH – University of Science and Technology and is currently in the position of the assistant professor at Mechanics and Vibroacoustics Department of AGH-UST. Member of Polish Society of Technical Diagnostics. Author of 48 publications from the realm of technical diagnostics and vibroacoustics.

Ernest JAMRO – received M.Sc. degree in electronic engineering from the AGH University of Science and Technology (AGH-UST), Cracow Poland in 1996; M.Phil. degree from the University of Huddersfield (U.K.) in 1997; Ph.D. degree from the AGH-UST in 2001. He is currently a professor assistant in the Department of Electronics AGH-UST. His research interest include reconfigurable hardware (esp. Field Programmable Gate Arays – FPGAs), reconfigurable computing systems, system on chip design.