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MONITORING OF TECHNICAL CONDITION OF MOTORS AND BEARIGS OF WOODWORKING EQUIPMENT

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ABSTRACT

This article describes how to solve problems of diagnostics motors and bearings in equipment for woodworking based on the method of artificial intelligence focusing on methods of fuzzy logic.

Woodworking equipment operation - the presence of wood dust, which is abrasive and lead to increased wear on mechanical components of woodworking equipment. A logical-linguistic diagnostic model of electric motors and bearings has been developed on basis of fuzzy logic. The calculated rules determine relationships between the technical condition and the diagnostic parameters and parameter trends. Experimental results of technical condition diagnostics are discussed.

Example of described diagnostic methods is its application in the diagnosis of BWS sander machine 6/190 BISON WERKE company with parameters: grinding width is 1900 mm,induction motor with power is 90 kW, synchronous speed of motor is 1500 rpm, Plate feed speed is 20 ms^{-1}. Vibration measurement was performed on the stationary part of the motor during grinding operations.

Keywords: woodworking equipment, monitoring of technical condition, temperature and vibration diagnostics, bearings, induction motors.

INTRODUCTION

One of the most important factors of the efficient work of automated woodworking plants is their reliable operation. Modern woodworking equipment is represented by continuous automated production lines that should maintain their high reliability.

Equipment diagnostics is the most promising and rapidly developing trend in modern woodworking. To avoid production stoppage resulting in downtime and cost increase, equipment diagnostics is required to predict unit failures that may arise during the operation of woodworking machinery (COWAN − WINER 2013, DOVBAN − VESELOV 2012, MICIETA − STOLLMANN 2009, KOŚCIELNY 2004, KVIETKOVÁ − BARCÍK 2011).

The most common diagnostic parameters of electric motors and bearings woodworking equipment and automatic production lines in large modern wood processing enterprises are temperature and vibration.

Issues of bearing, induction motor and mechanical unit diagnostics are discussed in CAMERON *et al.* 1986, HETMANCZYK − SWIDER 2014, HETMANCZYK − SWIDER 2014, HUGHES 2006, KRISHNAN 2001, KURFESS *et al.* 2006, LEE − KIM 2007, NANDI − TOLIYAT

1999, PENNACCHI *et al.* 2011. Modern diagnostic tools apply artificial intelligence techniques (REILLY 2011, STEPANOV − NIKITIN 2014, SWIDER − HETMANCZYK 2011). Fuzzy logic system is one of the efficient tools of equipment diagnostics (NURIEVA − NIKITIN 2012, NIKITIN − ABRAMOV 2010, NIKITIN − ABRAMOV 2011).

Modern diagnostic system was designed, which was tested on the sander machine BWS 6/190 BISON WERKE company. It is woodworking machine of older manufacturing date, where downtime, due to disturbances, presents serious problem manifesting itself by shortfalls in production, by worsening of economic indicators and ultimately in customer dissatisfaction. The proposed diagnostic system can be applied to monitor the technical condition of the modern automatic lines with dust extraction, which will contribute to a better assessment of the investment costs.

In this article are presented theoretical as well as practical results obtained by applying the method of fuzzylogic in the monitoring system of technical state of electric drives and mechanical parts in equipment for woodworking.

MATERIALS AND TECHNIQUES

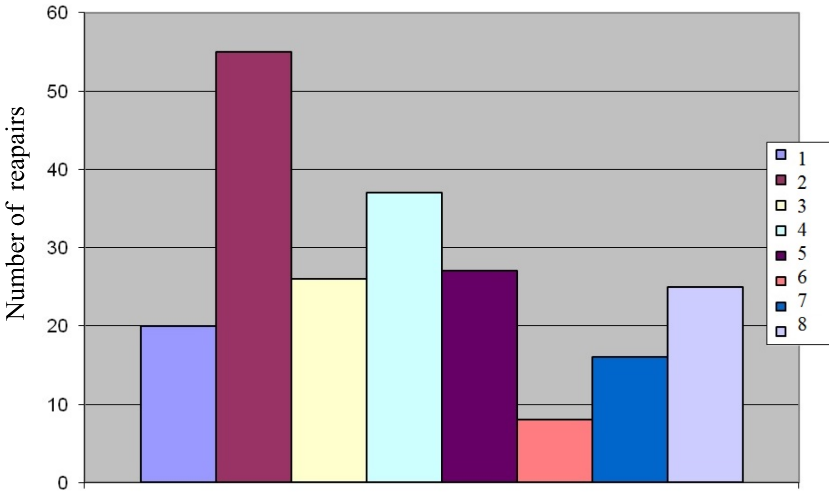
The manufacturing process of particleboard based graded density particleboards with fine-grained surface requires miscellaneous equipment: processing machines, forming stations, sanders, etc. Woodworking equipment is comprised of various units and mechanisms, such as induction motors, mechanical transmissions, bearing units, etc. According to analysis results, bearing units and induction motors are the units that most often fail in particleboard production. Due to various types of fuzziness related to various physical processes in equipment, the fuzzy set theory should be applied for making decision regarding the technical condition of the equipment. This theory allows adequate taking into account the available types of fuzziness. The fuzzy set apparatus enables analysis of technical condition of various components – mechanical, electromechanical, electrical and electronic ones (NIKITIN − ABRAMOV 2011).

Reliability analysis of woodworking equipment in particleboard production over the past 5 years revealed, that considerable proportion of failures occurs due to wear of rolling bearings, chain drives and electric motors, while the utilized time of the units does not exceed 50 % of the guaranteed life and 18.2 % of the overhaul life. At the same time, practice of the equipment operation shows that under favorable conditions (high-quality assembly work, compliance with operating and maintenance rules, etc.) the bearing units are able to fully utilize their guaranteed-, overhaul- and even total designed life.

According to the analysis results of woodworking equipment failures, temperature and vibration are informative diagnostic parameters. Relationships between failures and diagnostic parameters have been analyzed. A rule base of a fuzzy logic system has been built for evaluating the technical condition of the units.

A bar chart in Fig. 1 represents the results of a statistical analysis of woodworking equipment (equipment of BISON WERKE company) repairs conducted in 2008–2012.

One can see in the chart that rolling bearings and rubber seals in various machine parts are the most often failed and consequently the most frequently serviced units. Other units, listed in the descending order of failure rates, are: chains, gearboxes, rollers, sprockets, belts, induction motors. Chains, rollers, sprockets and belts do not require any special equipment for diagnostics. Failures in these units result from wear and can be easily recognized visually, by the amount of chain slack that depends on the rate of the wear. Therefore, diagnostics of bearing units and induction motors is of particular importance in particleboard production.



Obr. 1 Početnosti opráv výrobného zariadenia - brúsky: 1 – reťazové koleso, 2 – prevodovka, 3 – ložiská, 4 – tesnenia, 5 – reťaz, 6 – indukčný motor, 7 – remeň, 8 – kladky.
Fig. 1 Number of manufacturing equipment repairs of a sander machine: 1 – sprockets, 2 – bearings, 3 – gearboxes, 4 – seals, 5 – chains, 6 – induction motors, 7 – belts, 8 – rollers.

For reliable recognition of the condition of bearing units and motors in particleboard production a diagnostic system should provide diagnostic measurements in a wide frequency range covering not only a shaft rotation frequency and its harmonics, but also characteristic frequencies related to other parts of machine: bearings, gears, seals.

It has been chosen a rather wide range of vibration acceleration values (6.3 – 1250 Hz) in which the failures of diagnosed equipment units may occur. An example of a monitored object, an induction motor of a sander machine, is shown in Fig. 2.

Grinding plates is carried out on wide sander machine (model BWS 6/190 BISON WERKE company). Grinding width is 1900 mm. Induction motor power is 90 kW, synchronous speed of motor is 1500 rpm. Plate feed speed is 20 ms^{-1}. Vibration measurement was performed on the stationary part of the motor during grinding operations. Plate feed rate is 20 ms^{-1}.Cutting depth of particleboard is 0.2−0.8 mm.

Obr. 2 Indukčný motor brúsiaceho stroja.
Fig. 2 Induction motor of a sander machine.

A soundmeter and vibrometer OCTAVA 110A-Eco was used for diagnostic data acquisition. The device allows real-time data collection and their storage in a binary file. The file can be later converted to .txt or .xls format by Signal+ application. The data are separated by frequency and time. Low frequency vibration range includes frequencies from 6.3 to 12.5 Hz. Medium frequency vibration range includes frequencies from 12.5 to 630 Hz. High frequency vibration range includes frequencies from 630 to 1250 Hz. The measurement data are processed by a MatLab-based fuzzy logic system.

Parameters of input linguistic variables for the "MOTOR" fuzzy logic system are listed in Table 1.

Tab. 1 Parametre vstupných lingvistických premenných fuzzy systému "Motor".
Tab. 1 Parameters of input linguistic variables for the "MOTOR" fuzzy logic system.

	Low vibration level (L)	Middle vibration level (M)	High vibration level (H)
Low frequency vibration range (LFVR)	75−95 dB	85−110 dB	100−115 dB
Medium frequency vibration range (MFVR)	85−110 dB	90−115 dB	105−125 dB
High frequency vibration range (HFVR)	100−115 dB	105−130 dB	120−135 dB

A trapezoidal function is used as a membership function for input and output linguistic variables, since the maximum compliance level is reached rather quickly and with several values. Technical condition *z* of a unit (a motor or a bearing) is defined by the output linguistic variable as follows:

z is *L* (the unit (motor or bearing) is in serviceable condition), if $0 < z < 0.4$.
z is *M* (the unit has minor defects), if $0.3 < z < 0.7$.
z is *H* (the unit is in fault condition), if $0.6 < z < 1$.

The fuzzy logic system evaluates the technical condition *z* of a unit (a motor or a bearing) according to measured and temperature and vibration data and their trend.

The value of *T* linguistic variable (temperature) is defined as follows:
T is *L*: temperature less than 75 degrees Celsius.
T is *M*: temperature from 75 to 95 degrees Celsius.
T is *H*: temperature is above 95 degrees Celsius.
The value of *D* linguistic variable (vibration trend) is defined as follows:
D is *L*: no increase in vibration amplitude within the specified time span.
D is *M*: slight (up to 10 dB) increase in vibration amplitude.
D is *H*: considerable (over 10 dB) increase in vibration amplitude.

Technical condition *z* of the unit (motor or bearing) is defined by the following constructed rules:
If (T is L) and (LFVR is L) and (MFVR is L) and (HFVR is L) and (D is L) then (z is L)
If (T is M) and (LFVR is L) and (MFVR is L) and (HFVR is L) and (D is L) then (z is M)
If (T is L) and (LFVR is M) and (MFVR is L) and (HFVR is L) and (D is L) then (z is M)
If (T is L) and (LFVR is L) and (MFVR is M) and (HFVR is L) and (D is L) then (z is M)
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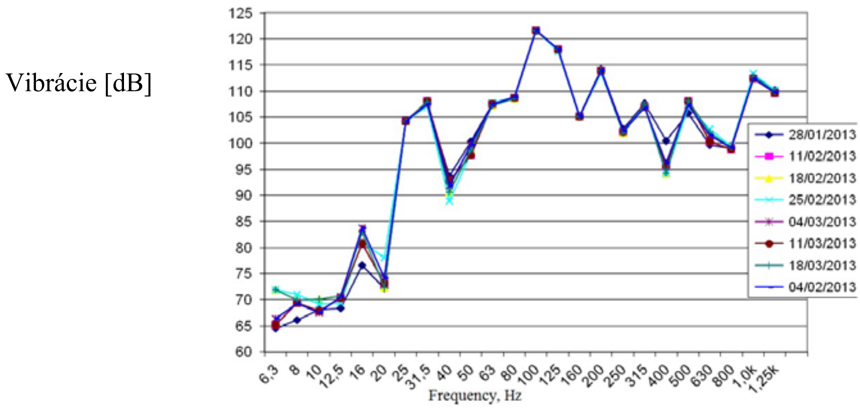
If (T is L) and (LFVR is L) and (MFVR is L) and (HFVR is L) and (D is M) then (z is M)
If (T is H) then (z is H)
If (LFVR is H) then (z is H)
If (MFVR is H) then (z is H)
If (HFVR is H) then (z is H)
If (D is H) then (z is H)

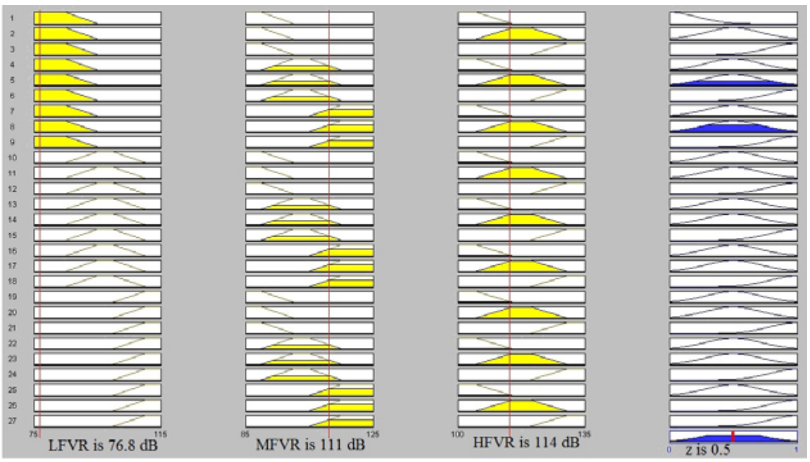
RESULTS AND DISCUSSION

An example of vibration acceleration measurements of induction motor of a sander machine is shown in Fig. 3. The data are not sufficiently informative and do not allow estimation of technical condition change of the motor. One can observe scattering of vibration acceleration data at low frequencies, while the values at medium and high frequencies are rather stable.



Obr. 3 Výsledky merania vibrácii motora brúsiaceho stroja v tretinooktávových frekvenčných pásmach.
Fig. 3 Results of vibration acceleration measurement of motor of a sander machine (in one-third octave bands of vibration frequency).

Results of the motor technical condition evaluation using the fuzzy logic system are shown in Fig. 4. Initial condition: temperature is 42 degrees Celsius, vibration acceleration at low frequencies is 76.8 dB, in the medium range – 111 dB, at high frequencies – 114 dB, vibration trend is 0. Result produced by the fuzzy logic system regarding the technical condition of the induction motor of a sander machine: minor defects (0.5).



Obr. 4 Výsledky hodnotenia technického stavu elktromotora brúsiaceho stroja.
Fig. 4. Evaluation results of the electric motor of a sander machine.

Analysis of technical condition of the sander motor shows that the unit is in satisfactory condition. However, it can be seen that the vibration level approaches the upper limit at high frequencies. There is a high probability of the unit failure in the near future. Indeed, shortly afterwards the electric motor of a sander machine was sent to repairs.

CONCLUSION

A logical-linguistic model for induction motors and bearings of the woodworking production line has been developed. The model defines relationships between the technical condition of a unit and the vibration level in various frequency ranges. The diagnostic model for induction motors and bearings is based on fuzzy logic and includes five input variables (temperature, vibration levels in low-, mid- and high-frequency ranges and the vibration trend) and one output variable (technical condition of the diagnosed unit: serviceable, incipient failure or fault). A rules base of the fuzzy logic system has been developed.

Monitoring of technical condition showed that during the reporting period (2.5 months) the vibration level of induction motors and bearings of woodworking equipment remained practically unchanged (1-2 % at average, not more than 6 %). However, some units can reach the ultimate limit state, for example the induction motor of a sander machine.

Experimental studies have confirmed the adequacy of the logical-linguistic model for the induction motor and bearing diagnostics. A direction of further research will be improvement of the model accuracy for chosen object. The model will include 24 input linguistic variables corresponding to the one-third octave bands of vibration frequency and 24 input linguistic variables describing vibration trends. For induction motors, additional input linguistic variable will be used for electric current values.

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