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Intelligent Sensorless Fault Diagnosis of Mechatronics Module Wavelet Transformation Based

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Abstract: This study describes a fault diagnosis system for mechatronics modules realized through the combination of wavelet transformation, fuzzy logic and neural network techniques. As a reference base we have selected Daubechies wavelet. Fault diagnoses accomplish the characteristic frequencies using the fuzzy logic in aggregate neural network. The combination of advanced techniques reduces the learning time and increases the diagnosis accuracy. The experimental results indicate that the proposed method is promising for the mechatronics modules.

Key words: Wavelet transformation, fuzzy model, fault diagnosis, mechatronics module, stator current signal, sensorless control

INTRODUCTION

The modern development of automation and robotics demands the raised accuracy of the executive mechanisms. In this context mechatronics modules are widely used in the actuator systems. Mechatronics modules are functionally and structurally independent product to implement motion with interpenetration and synergistic hardware and software integration of its constituent elements having different physical nature. The elements of different physical nature include mechanical, electrical, electronic, digital, pneumatic, hydraulic and information components. The simplest version of this module includes an electric motor with integrated speed sensor. Long operation activity of mechatronics modules can produce faults (Ho and Randall, 2000). Therefore it is necessary to supervise technical condition which diagnosing system.

One of the most simple and accessible methods of diagnosing is the method of analysis of stator current signals (Petuchov and Sokolov, 2005) as it does not require additional sensors and can be made directly on the working equipment (Shayhutdinov *et al.*, 2015; Shaykhutdinov *et al.*, 2015 a, b).

The spectral analysis of the current signals allows carrying out diagnostics of the electrical equipment and the connected mechanical devices. The received data are converted into the frequency domain using the Fourier transformation (Korner, 1988). This transformation is widely used but has the disadvantages listed as:

- The fourier transform provides the frequency information which is contained in the signal, but cannot determine the time of occurrence of this frequency
- Limiting descriptiveness analysis of non-stationary signals. There is no possibility to analyze characteristics of the signal because the frequency-domain signal drop occurs over the entire frequency range of the spectrum. In addition to the noise generated from “parasitic” high-frequency components
- Harmonic basis functions decomposition is not able to display signals with slope type rectangular pulses
- Simultaneously, producing temporal and frequency analysis is impossible
- Frequency analysis obtained using the Fourier transformation is complex and requires experienced specialist to understand it which entails additional expenses

These disadvantages do not exist in the wavelet transform approach. The wavelet transform is a special case of the fourier transform (Peter *et al.*, 2004). Wavelets are generic name of a family of some form of mathematical functions.

For the troubleshooting is necessary to fix localization signal in frequency and time, therefore it is recommended to use quadrature mirror filters. From all existing wavelets of this group of the most reliable are

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daubechies wavelets (Liu and Ling, 1999), so it is advisable to use them as a original wavelet for troubleshooting electrical equipment. For troubleshooting electrical current, it is necessary to recalculate the frequency scale of the Fourier transform in the wavelet transform.

For the allocation of frequencies in the scale wavelet analysis, this permits to localize the fault c using wavelet features (Daubechies, 1990, 1992). Determine the fault, the amount of energy of the wavelet must be found, i.e., coefficients in the characteristic scale and must be compared with those for the serviceable object. If the sums of wavelet coefficients at all typical scales are decreased and energy is increased the fault has come.

MATERIALS AND METHODS

To diagnose mechatronics module on the stator current must perform the following steps:

- Calculate the characteristic frequencies for the operating speed
- Transfer characteristic diagnosis frequency wavelet scale
- Calculate the wavelet transform coefficients for each of the typical scales
- Calculate the energy value and the sum of the coefficients of the wavelet transform for each scale
- Compare the energy value and the amounts of the wavelet coefficients in the characteristic scale for the diagnosed and the reference object by means of fuzzy logic model

As the input of fuzzy logic systems determine the status of the scale are given and the amount of deviation of the energy of the wavelet coefficients of the standard. The calculation is carried out according to formulas.

$$\Delta E = \frac{E_d 100\%}{E_s} - 100\% \quad (1)$$

$$\Delta S = \frac{S_d 100\%}{S_s} - 100\% \quad (2)$$

Where:

ΔE, ΔS = Deviation of the energy and sum for diagnosed and standard objects
E_d, S_d = Energy and sum for diagnosed object
E_s, S_s = Energy and the sum for standard object

If increasing the energy value or the amount of relative standard deviation is positive. If the value decreases negative deviation. Deviation 100% indicates an increase in value of 2 times. In the case of deviations of >100% in one direction or another, we assume that the deviation is 100% which corresponds to the maximum deviation. Based on this input linguistic variables for the "Energy" and "Sum" is selected interval [-100, 100] and is given five fuzzy terms, shown in Fig. 1a. Input variables are defined by the following terms: BN-a large negative; MN-Mean Negative; Zero-no change; MP-average positive; BP-a Big Positive.

Sugeno fuzzy inference is used to formalize fuzzy sub model (Kruglova, 2015). The relationship between inputs and output variables are written with the help of fuzzy knowledge base presented in Table 1. Developed sub-model allows us to estimate the presence of a defect in a given scale but each fault is characterized by several scales. Mechatronics module can be in one of four states: "Norma" the object is fully functional, "NWD" normal with the deviation, the object is operational; "NSD"-rule with a significant deviation requires constant monitoring; "Limit"-an object is defective, in need of repair.

For the formalization of the second phase of the diagnosis is necessary to create a fuzzy system narrowed. The number of inputs equal to the number of characteristic scales for selected fault. The output is the current level of an object fault. For each input on the interval [-1,1] defined the S-shaped membership function "enable" and Z-shaped membership function "disable" (Fig. 1b).

The output of the fuzzy model is a fault condition number: "1"-Norma", "2"-"NWD", "3"-"NSD"; "4"-"Limit" (Kruglova *et al.*, 2015). Mechatronics module MAXON MOTOR EC 60 was diagnosed. For finding faults using wavelet transformation it is necessary to make transform frequency to the scale of the wavelet (Table 2).

For the analysis of the results it is necessary to carry out a comparative analysis of the sum and energy of wavelet coefficients at each characteristic Scales (1), (2). Figure 2 shows the results of the data analysis parameters. Substituting the values obtained in the diagnosis model, with the following results: Commutation faults-"NWD"; Rotor faults-"Norma"; Voltage ripples-"Norma"; Coupling faults-"Limit"; Commutation faults "Norma". The technical condition of mechatronics module is disabling. The reason is coupling faults. Diagnosis result was confirmed by the inspection of the module.

Table 1: Fuzzy knowledge base for the sub-models scale rating

Sum energy					
Energy	BN	MN	ZERO	MP	BP
BN	+	+	+	+	+
MM	+	+	+	+	+
Zero	+	+	+	+	+
MP	-	-	+	+	+
BP	-	-	+	+	+

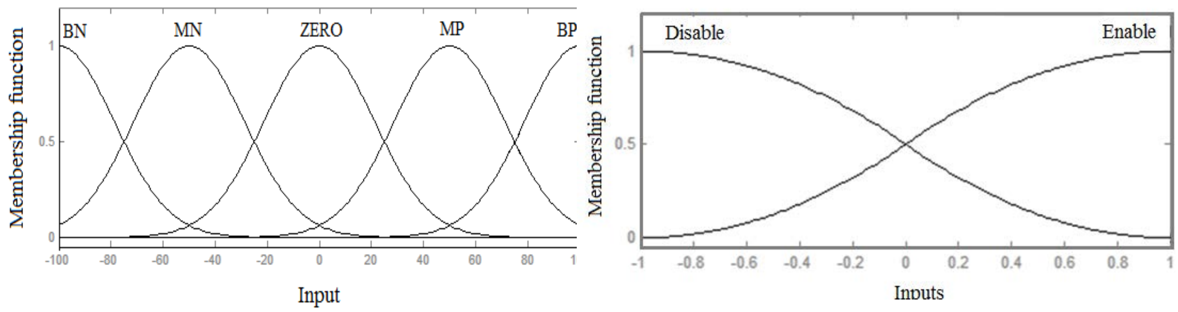

Fig. 1: Membership functions of input: a) variables "Energy" and "Sum" fuzzy sub models scale rating; b) development of mechatronics module fault

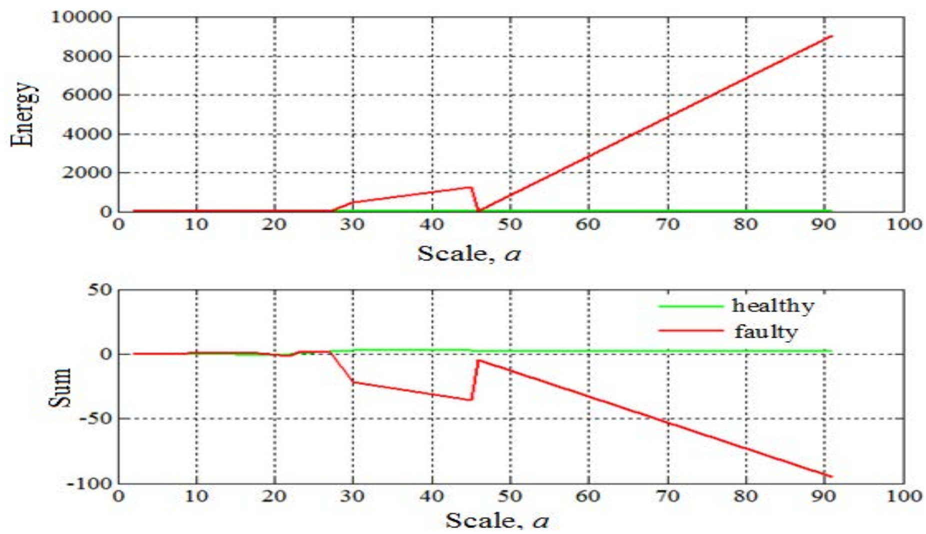

Fig. 2: The energy and sum of the wavelet coefficients for the healthy and defective actuator to the characteristic scale

Table 2: Faults of the mechatronics module in frequency and wavelet scales

Faults	The characteristic frequencies of the fourier analysis	The scale of the wavelet
Commutation faults	60	22
	120	11
	180	8
	15	91
	30	45
	45	30
Rotor faults	60	23
	215	6
	430	7
	645	3
	185	2
	370	8
	555	4
	75	18
	90	15
	105	13
Voltage ripples	50	27
	100	13
	150	9
Coupling faults	15	91
	30	45
	45	30
Commutation faults	100	14

RESULTS AND DISCUSSION

Proposed method mechatronics module sensorless diagnosis allows the measured current signal to find all faults with the wavelet transform and fuzzy logic model. Laboratory research have confirmed the adequacy and accuracy of this method of theoretical developments and adopted technical solutions. The result of evaluating the reliability and accuracy of the diagnosis showed that the probability of a false rejection is 0.94%, the probability of undetected faults is 0.38% and diagnosis reliability is 98.7%. The results of theoretical analysis and laboratory experiments showed that:

- Technical conditions mechatronics module can be determined without sensors by analyzing the stator current signal during its operation
- Wavelet analysis of the stator current signal allows to automate the troubleshooting process mechatronics module

- Wavelet characteristic scale can be obtained by recalculation of frequencies for fourier analysis
- For diagnose mechatronics module appropriate to apply daubechies wavelet allowing to analyze the signal in time and frequency domains
- For troubleshooting is necessary to calculate the sum and energy of the wavelet coefficients for each scales and compare them with standard
- When the energy of wavelet coefficients are increases and the sum are d decreased on the typical scale the fault has come
- For technical condition analyze the appropriate to apply a hierarchical fuzzy model

CONCLUSION

The study describes the intelligent diagnostic method for current signals of a stator which wavelet transform. The described fuzzy model of diagnosing allows determining the technical condition, using stator current signal of the steady-state module, from which the normalized typical values are determined. The latest ones constitute an adequate input for the applied fuzzy model. In this study, we have offered number of experimental researches proving that when a fault occurs, the energy of the wavelet coefficients is increased and the amount decreases.

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