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THE SOFTWARE FOR INDUCTION MOTORS DIAGNOSTIC SYSTEM BASED ON ELECTRICAL SIGNALS ANALYSIS

Introduction. Nowadays induction motors (IM) are most widely used consumers of electric energy. According to last researches, they consume over 80 % of the total amount of electric power. Induction motors widely used because of their reliability and relatively low cost. Creation of speed-controlled electric drive systems resulted in increased usage of IM because of the simplicity of their implication into such systems. However, different damages could be caused to IM parts under operating conditions. They could lead to untimely motor failing. Every year as a result of failures about 20-25 % of induction motors fails. Thus, there is an important task of creation reliable IM diagnostic system. In many manufactures sudden failure of the motor could lead to shutdown of the technological processes. Operation of electric motors under unsatisfactory technical condition results both in direct financial losses and in considerable (about 5-7 %) indirect expenses of the electric energy. On this and other reasons there is a necessity of IM diagnostics under operating conditions. The most convenient and reliable IM diagnostic methods are based on the electric signal analysis [1–4]. In order to utilize such methods for practical usage, there is task of development the software for simplifying and automation diagnostic operation.

Purpose of the work. The software development for IM diagnostic systems.

Material and results of research. The idea of IM fault detection methods based on the electric signals analysis consists in correspondence of IM defects to certain harmonics in electric signal spectra. Each damage type causes modulation of motor electric signals with unique frequencies. The most popular diagnostic method, based on electrical signals analysis, is Motor Current Signature Analysis (MCSA). The idea of this method is supervision of changing the motor current waveform [2, 4]. Fast Fourier Transform (FFT) of motor current gives a current spectrum for fault detection procedure. Thus, presence in a motor current spectrum specific harmonics and their sidebands shows presence of electrical or mechanical damages. In papers [2, 4] the equations for determining fault frequencies in current signal caused by rotor bar breaks, rotor eccentricity, stator windings short-turns and bearings damages are described. All these equations are presented in tab.1, column "*Current frequencies caused by damage*". All these frequencies lead to current modulations. In tab. 1, column "*Current modulations, caused by damage*" there are equations for calculation the current modulations caused by each considered damage type. It should be mentioned, that IM diagnostic based on current analysis depends on supply voltage quality, and in some cases could lead to wrong results [1, 2].

Lacks of the previous methods can be avoided using the diagnostics on the basis of the Instantaneous Power Spectra Analysis (IPSA) using methods, proposed in [2, 4]. Instantaneous power spectra analysis allows both detection of fault presence and estimation of damage level by analysis of proper harmonic value. Thus, it allows one to make estimation of the energy of fault and the correlation of this energy to additional damage of IM parts under influence of additional vibrations caused by proper harmonic. Moreover, the instantaneous power spectra analysis allows analyzing of IM operation modes under significant nonlinearity when it is incorrect to use superposition principle for current harmonics. Also, instantaneous power analysis is more reliable, it is less dependent on noise, and gives additional harmonic components for analysis [1, 2]. In papers [2, 4] the expressions for calculation of instantaneous power of motor, operating with damage, were described. These expressions are presented in tab. 1, column "*Instantaneous power of motor operating with damage*".

Basing on the expressions for the correspondence of fault type and electrical signal harmonic component known from the MSCA analysis method and the IPSA method, the software for IM fault detection system was developed. The user interface is shown in Fig. 1, 2. This software allows one direct measuring of electrical signals while working as a part of physical diagnostic equipment, or uploading preliminary measured data for analysis (Fig.1). Basing on the given signals, the program calculates FFT transformation and shows the signal spectra for each phase of the electric signal (Fig. 1) and all three phase instantaneous power signals (Fig. 2). According to developed algorithms (Fig. 3), the program gives a diagnostic result based both on the MCSA and IPSA methods (Fig. 2).

In order to verify developed software, a series of experiment were done using previously developed diagnostic equipment [2, 3] and previously measured data of damaged motors with preliminary known damage types. A comparison of diagnostic results obtained using developed software, which implemented both MCSA and IPSA methods, leads to the following conclusions. Both methods could be used for detection of the most common motor damages. However, current spectra analysis in some cases could lead to wrong diagnosis because of small amplitude values of harmonics related to damage. Power spectra analysis allows avoiding such mistakes, and it could be considered as more suitable and reliable method for IM fault detection. Developed software allows obtain diagnostic results calculated basing on both MCSA and IPSA methods and get most reliable diagnostic result.

Table 1 Correspondence of IM faults to current and instantaneous power harmonics and modulation frequencies

Damage type	Current frequencies caused by damage	Current modulations caused by damage	Instantaneous power of motor operating with damage
Broken rotor bars	$f_{bb} = f_s[1 \pm 2s]$, where f_s is the supply fundamental frequency, s is the motor slip.	$i_{bb}(t) = i(t)[1 + I_m \cos(2\pi f_{bb} t)] = i(t) + \frac{\sqrt{2}}{2} I_1 I_m \begin{bmatrix} \cos(2\pi(f_s - f_{bb})t - \varphi) + \\ + \cos(2\pi(f_s + f_{bb})t - \varphi) \end{bmatrix}$, where I_m is the modulation index; f_{bb} is the modulating frequency.	$p_{bb}(t) = i_{bb}(t)u(t) = P_0 + U_1 I_1 \cos(\varphi)\cos(2\omega t) + U_1 I_1 \sin(\varphi)\sin(2\omega t) + \begin{pmatrix} I_1 I_m U_1 \cos[2\pi(f_s - f_{bb})t - \varphi] + \\ + I_1 I_m U_1 \cos[2\pi(f_s + f_{bb})t - \varphi] \end{pmatrix}\cos(2\omega t).$
Air gap eccentricity	$f_{eccen\_fun} = f_s \pm k f_r$, where $f_r = \frac{1-s}{p}$, where s is the motor slip, p is the number of pole pairs; $f_{eccen\_prin} = \left[\left(kR \pm n_d\right)\left(\frac{1-s}{p}\right) + \eta\right] f_s$, where R is the number of rotor slots; k is the positive integer number; n_d is an integer due to dynamic eccentricity; η is the time harmonics present in the motor supply.	$i_{ecc}(t) = i(t) + \frac{\sqrt{2}}{2} I_1 \sum_{k=1}^{K} \begin{bmatrix} I_{e1k}\cos(2\pi(f_s - kf_r)t - \\ - \alpha_{e1k} - \varphi) + \\ + I_{e2k}\cos(2\pi(f_s + kf_r)t - \\ - \alpha_{e2k} - \varphi) \end{bmatrix}$, where I_{e1k}, α_{e1k} are the current amplitudes and the initial phase angle for frequencies $f_s - kf_r$; I_{e2k}, α_{e2k} are the current amplitudes and the initial phase angle for frequencies $f_s + kf_r$.	$p_{ecc}(t) = i_{ecc}(t)u(t) = P_0 + U_1 I_1 \cos(\varphi)\cos(2\omega t) + U_1 I_1 \sin(\varphi)\sin(2\omega t) + \sqrt{2} U_1 \cos(2\omega t) \sum_{k=1}^{K} \begin{bmatrix} I_{e1k}\cos\begin{bmatrix} 2\pi(f_s - kf_r)t - \\ -\alpha_{e1k} - \varphi \end{bmatrix} + \\ + I_{e2k}\cos\begin{bmatrix} 2\pi(f_s + kf_r)t - \\ -\alpha_{e2k} - \varphi \end{bmatrix} \end{bmatrix}.$
Stator windings short turns	$f_{st} = f_s\left[\frac{n}{p}(1-s) \pm k\right]$, where f_s is the supply main frequency; n is a positive integer number (1, 2, 3…); k can be equal to 1, 3, 5 or 7.	$i_m(t) = i(t)[1 + I_m \cos(2\pi f_{st} t - \varphi)] = i(t) + \sqrt{2}/2\, I_1 I_m [\cos(2\pi f_{st} t - \varphi)]$, where f_{st} is the modulating frequency.	$p_m(t) = i_m(t)u(t) = P_0 + U_1 I_1 \cos(\varphi)\cos(2\omega t) + U_1 I_1 \sin(\varphi)\sin(2\omega t) + 1/(2 I_1 I_m U_1 \cos[2\pi f_{st} t - \varphi]\cos(2\omega t)).$
Bearing damage	$f_{brg} = \lvert f_s \pm m f_{i,o} \rvert$, where $m = 1,2,3...$, and $f_{i,o}$ is one of the characteristic vibration frequencies, which are based upon the bearing dimensions: $f_{i,o} = \frac{n}{2} f_v\left[1 \pm \frac{bd}{pd}\cos\beta\right]$, where n is the number of bearing balls; f_v is the mechanical rotor velocity in hertz; bd is the ball diameter; pd is the bearing pitch diameter; β is the contact angle of the balls on the races.	$i_{brg}(t) = i(t) + \frac{\sqrt{2}}{2} I_1 \sum_{k=1}^{K} \begin{bmatrix} I_{b1k}\cos(2\pi(f_s - kf_{brg})t - \\ - \alpha_{b1k} - \varphi) + \\ + I_{b2k}\cos(2\pi(f_s + kf_{brg})t - \\ - \alpha_{b2k} - \varphi) \end{bmatrix}$, where I_{b1k}, α_{b1k} are the current amplitudes and the initial phase angle for frequencies $f_s - kf_{brg}$, I_{b2k}, α_{b2k} are the current amplitudes and the initial phase angle for frequencies $f_s + kf_{brg}$.	$p_{brg}(t) = i_{brg}(t)u(t) = P_0 + U_1 I_1 \cos(\varphi)\cos(2\omega t) + U_1 I_1 \sin(\varphi)\sin(2a + I_1 U_1 \cos(2\omega t) \sum_{k=1}^{K} \begin{bmatrix} I_{b1k}\cos(2\pi(f_s - kf_{brg})t - \\ - \alpha_{b1k} - \varphi) + \\ + I_{b2k}\cos(2\pi(f_s + kf_{brg})t - \\ - \alpha_{b2k} - \varphi) \end{bmatrix}$

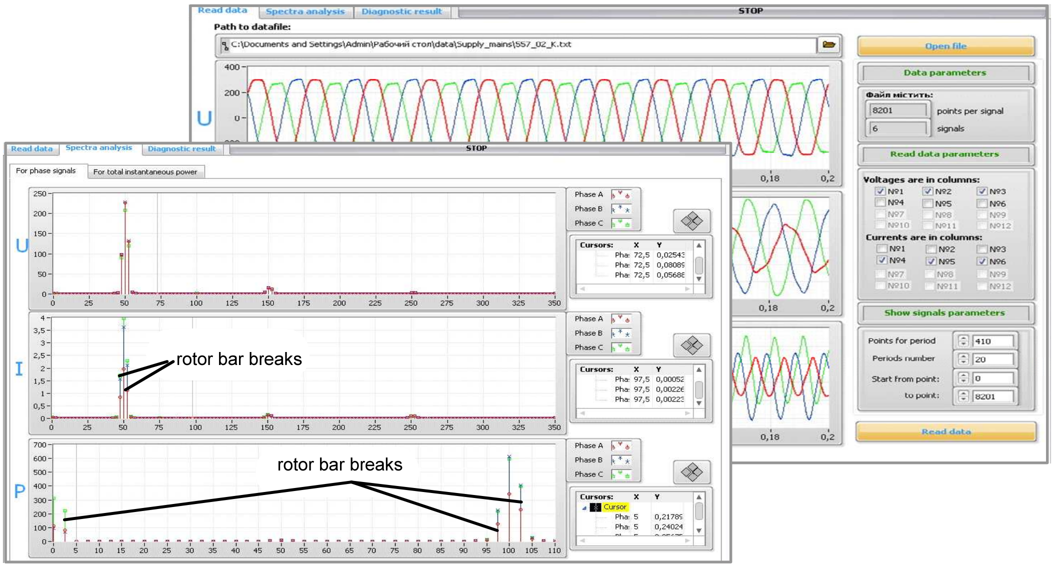
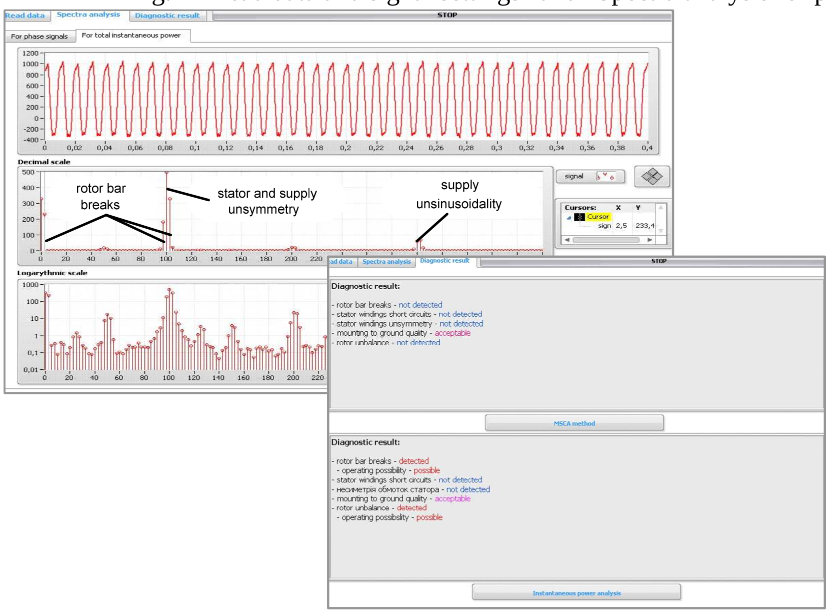


Fig. 1 “Read data and signal settings” and “Spectra analysis for phase electric signals” windows



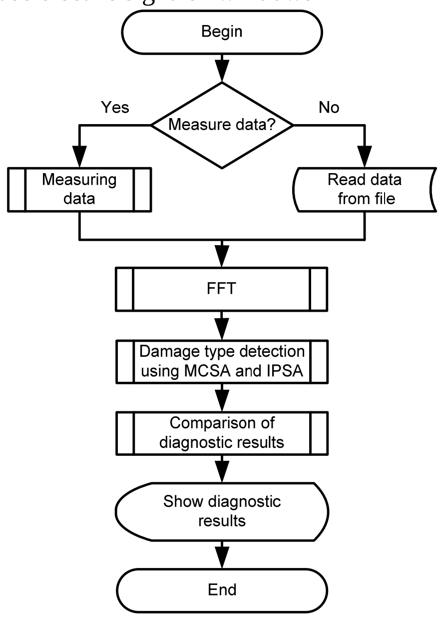


Fig. 2 “Spectra analysis for total 3-phase instantaneous power signal” and “Diagnostic results” windows

Fig. 3 The program algorithm for developed software

Conclusions. Software for induction motor diagnostic system, which implements MCSA and IPSA methods, was created. This software allows both direct measuring experimental data from real diagnostic equipment, and analyze previously stored data. Experimental results showed reliability of proposed diagnostic system results. Future work will be related to implementation forecasting algorithms into developed software in order to predict possibility of motor failure.

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