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DIAGNOSTIC MEASUREMENTS OF CURRENT SUPPLYING AN ELECTRIC MOTOR

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Abstract - The object of the investigation presented in the paper are measurements related to diagnostics of induction motors. The described system is based on the measurement and spectral analysis of current feeding an electric motor. Diagnostic methods of motor windings making use of the current analysis are already known. The author proposes involving in this method also examination of mechanical defects, in particular, damages caused to bearings. In order to obtain positive results it is necessary to theoretically obtain information referring to the type of components that accompany the current spectrum in certain sorts of faults. This can be accomplished by tests on a motor model. The model tests should be followed by creating an appropriate measuring system sensitive to the spectral components responsible for some specific damages . Due to the fact that the amplitude of the network voltage basic harmonic in the current spectrum is high, there has been proposed a preliminary elimination of this component from the analog current signal. The proposed filter and its characteristics are shown in the paper. Further processing of the signal is carried out numerically. The paper presents also the measuring system and provides results of the investigations carried out on real objects, i.e. faultless motors, and those encumbered with specially prepared defect.

Keywords: motor, current spectrum

1. INTRODUCTION

Present-day problems of technical diagnostics are connected with great measuring complexity accompanying the diagnostic tests, and also with some difficulty to put an interpretation on the results, which requires treatment of the signals measured to obtain some definite diagnostic information.

There are a number of diagnostic methods which make it possible to estimate the technical condition of an induction motor, between them: vibration measurements, flux measurements, temperature measurements.

The sphere of interest of the author is diagnostics of induction motors using spectral analysis for measuring the motor feed current. This procedure enables to find out the following failures in a machine:

- Faulty winding
- Damage to bearings
- Other mechanical defects

The occurrence of a certain type of motor failures can result in distortion of the supply current [1, 2]. In the case of damage to the motor's winding, the supply current spectrum carries data related to frequency components informing about the existence of the failure. Unlike faults in winding, mechanical defects, e.g. a defect in a bearing, the problem is different. The spectrum of the current supplying the induction machine also reveals components that signal such a damage. The amplitudes of these components are very small in comparison with the dominant network component, in particular, at the outset of the failure growth. This creates some problems connected with the measurement of the components. In order to find a solution, it has been proposed that the network component be reduced already in the analog part of the system and that the remaining signal be next amplified and subjected to spectral analysis.

Moreover, it is necessary to determine the theoretical relationships that describe current variations related to specific types of failures [3, 4, 5].

In the paper [3] there are suggested frequencies connected with bearings faults according to formulas:

$$f_s = |f_n \pm 1 \times f_x| \tag{1}$$

$$f_s = |f_n \pm 2 \times f_x| \tag{2}$$

Where:

f_s – component of current spectrum,
f_n – the frequency of supply net,
f_x – the frequency of vibration connected with defined fault of bearing, known from mechanic theory,

Special mathematical model of object was created for induction motor diagnostics by current measurements. The simulations for defined types of bearings faults were carried out on the model. The results of the simulations are similar to the information from publications.

From the first estimation (confirmed later by model investigations) it was expected, that values of measured quantities should be in the range of amplitudes between –100 dB and –60 dB, when the frequency range is 20 – 3000 Hz.

Values are defined as a relation between measured components and main net component of amplitude 10V.

2. THE DIAGNOSTIC SYSTEM

The following assumptions for constructing the measurement system were chosen:

- for conserving the necessary distance between the signal and noise of the system, the total noise of the system should not exceed –120 dB and the range of measured frequencies should be of 20 Hz – 3 kHz
- to insure flexibility, the possibility of extension of software and further automatization of measurements, the measurement system should be computerized, based on virtual instruments. In the future, such computerized system deprived of stationary equipment will allow field tests.

For realisation of computer measurement system, the hardware produced by National Instruments and software environment LabVIEW [6, 7] of the same producer were chosen. The quality of their products decided, as well as the great experience of the authors working in this environment.

Tests were carried out to determine the usefulness of data acquisition cards with A/D converters of 12 and 16 bit. Because of decidedly better noise characteristics, for further works there was chosen the card type NI6052E , with 16 bit converter.

National Instruments gives the following figure for appraising the accuracy of measurement made with data acquisition cards :

Absolute Accuracy = ± [(Input voltage % of reading) +*
+ (Offset+Noise+Quantization+Drift)] (3)

Where:

Absolute Accuracy – maximum, total measurement error

Input voltage – measured voltage,

% of reading – relative error, referred to the present, measured value (from producers specification),

Offset – constant displacement of all measurement results,

Drift – displacement of characteristic connected with variation of temperature. If the temperature falls within +15° to +35°C drift is taken into offset,

Noise + Quantization – component based on noise, relates to the number of averages of each measurement.

In producer's specification there are given two values of this component: for a single measurement and for 100 averages.

Measurement accuracy of acquisition card type NI 6052E was estimated up to the formula (3) as follows:

Coefficient „% of reading" from producer's specification is 0,0371% (for measuring range + 10V taking 1 year after calibration, for measured value 10V).

It gives the value of the first component of formula (1):

- Input Voltage * % reading = 10 * 0,000371 = **3,71 mV**

On the basis of the first current measurements it was decided, that the current analysis would be made for 10 averages. It requires the re-counting of the coefficient from the specification according to formula :

Noise + Quantization (for x averaged points) = Averaged Noise + Quantization (from table)* $\sqrt{100/x}$ (4)

In this case :

- Noise + quantization (for 10 averaged points) = $=87\mu V * \sqrt{100/10}$ = **275 μV**

Offset (from producer's specification) is 947 μV. Due to comparative character of the planned measurements the offset can be neglected.

Assume that the temperature during measurements is in the range + 15°C to + 35° C drift has been already taken into account in the offset so it can also be neglected.

In total the maximum positive error of measurement in these conditions is:

- Absolute accuracy at full scale = ± (3,71 mV + 275 μV) = **± 3,985 mV**

The assumed range of measured components value – 100 to – 60 dB in the linear scale indicates the magnitude 0,1 to 10 mV.

These are small values in comparison with the absolute measurement error. For reduction of the relative measurement error, the input voltage must be increased.

Because of the existence of the outstanding basic component in the signal, which in this case does not carry useful diagnostic information, to be able to increase the signal, it is necessary to reduce the outstanding component in advance. The filtering followed by the amplification of the signal should be performed on the analogue side of system. The maximum possible value of the gain is restricted by harmonic current components (3, 5 and 7 harmonic), the amplitudes of which are smaller than the first harmonic by about 40 dB.

After filtering the outstanding component and amplification of the rest of signal by 40 dB, the measured signals will be in the interval of 10 mV – 1 V.

The relative measurement error of these components, according to their value, will be within the interval 40 % to 0,4 %. Further reduction of measurement error of diagnostic current components would be possible after successive filtering and amplification of the harmonic current components.

The simplest scheme of the measurement system is shown in Fig.1.

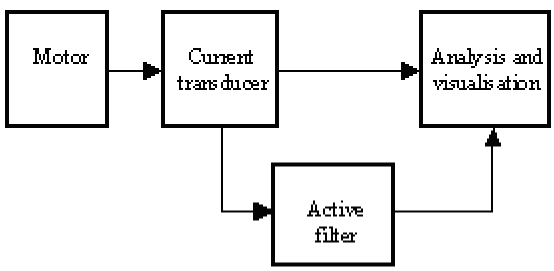

Fig.1. Idea of the measuring system.

The system consists of current transducer, low-pass filter, an acquisition card and the software. Such a system was created for initial investigations.

The object of testing was an asynchronous machine the power of which was 1,1 kW. While carrying out the tests, Hall-effect transducer was used as current converter. In the solution proposed for the measuring system advantage was taken of a narrow-band active filter based on a special UAF42 integrated circuit of Burr Brown production. The filter was designed so as to suppress the network component. There was applied a filter of Butterworth type. The frequency characteristic that was obtained as a result of simulation using Pspice program is shown in Fig.2, while the real one prepared on the basis of the measurements is given in Fig.3. The differences between the two characteristics result from the various tolerances of elements fed into the Pspice program, and the tolerances of elements in the real system.

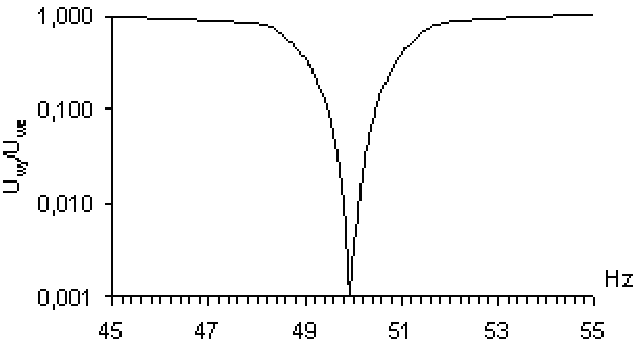

Fig. 2. Filter characteristic obtained from the mathematical model

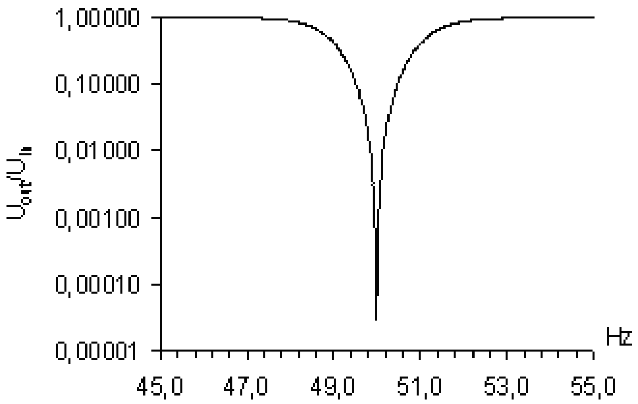

Fig. 3 Characteristic of the real filter

On the basis of the opening tests applied to the system according to Fig. 1 there was put into practice an improved system for current tests and motor voltage. This is shown in Fig. 4.

Motor current measurement system using tuned frequency filters has four analogue lines. Three for current measurement signals (8A DC/AC) and one for voltage measurement signal (400V DC/AC).

It enables the motor current measurements to be made in three phases, and voltage measurement in one supply net phase. In each measuring line there are antialiasing filters with the possibility of choice frequency cutting – off from among 200 Hz, 1 kHz, 10kHz, 20 kHz. Every filter is of low-pass Butterworth's type.

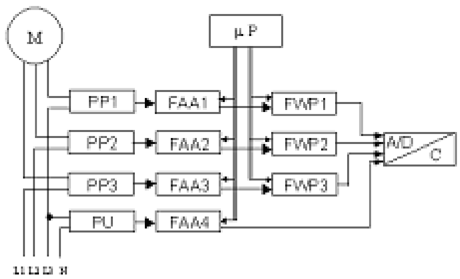

Fig. 4. Current measurement system for induction motor.

Where :

M - induction motor,
μP - microprocessor,
PP1 - PP3 - transducers for current measurements,
PU - transducers for voltage measurements,
FAA1 - FAA4 - antialiasing filters,
FWP1 - FWP4 - narrow band filters,
A/D - data acquisition card,
C - computer

The current measurement lines contain notch-type filters with automatically tuned cut-off frequency to about 50Hz (frequency of motor supplying network).

The notch filter is based on integrated universal continuous time filter UAF42 of Burr-Brown's production. Its topology is compatible with Butterworth's second order filter. 10 bit converters C/A AD7533 were used for numerical controlling of the cut-off frequency.

The program applied in the microprocessor performed adjustment of filter frequency according to present supply net frequency. The measurements and adjustments are realized separately in each current phase. This enables the adjustments to be independent of the tolerance of components used for setting the filter frequency.

In each line there are amplifiers, which can increase the signal by 40 dB.

Next the signal is transferred to the measuring card situated in the computer of PC class. Fig. 5 presents the

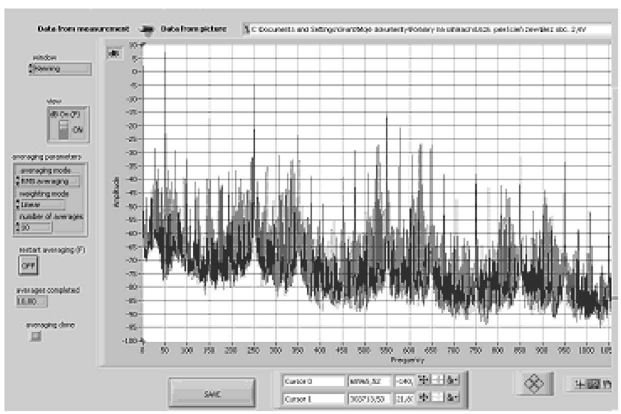

Fig.5. The panel of virtual instrument for current investigations.

panel of virtual instrument for current investigations.

Then, the system created in LabVIEW environment carries out the spectrum analysis. The data processed in this way are displayed on the monitor in the form of the current spectrum.

3. INVESTIGATION RESULTS

A special virtual instrument was created in the LabVIEW environment for easy counting of the searched frequencies (described above).

The instrument panel of is shown in the fig. 6. The given frequencies are expected in current spectrum for rotational speed of 1440 RPM and bearing type 6204 with damaged outside ring.

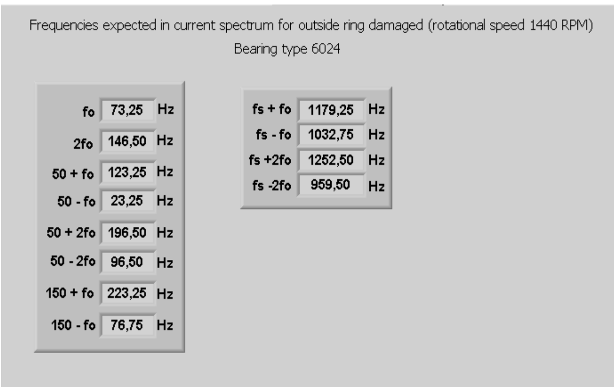

Fig.6. The panel of instrument for counting frequencies.

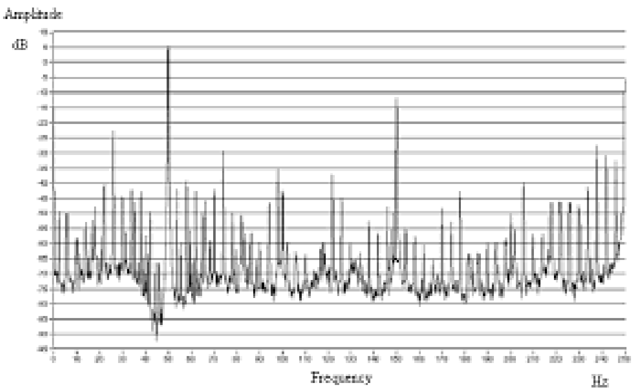

Fig. 7. The current spectrum for correct bearings.

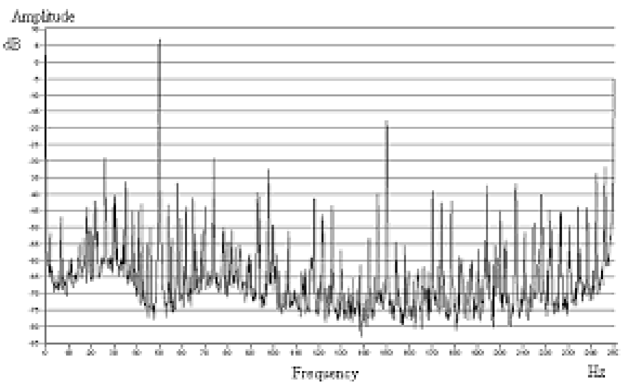

Fig. 8. The current spectrum for damaged bearing.

In the Fig. 7 there is presented an example of motor current spectrum (after filtering). The bearings in this motor were faultless.

In the figure 8 there is presented an example of motor current spectrum (after filtering) with faulty bearing – the outside ring was intentionally broken.

Fig. 9 gives comparison of amplitudes of spectra from figures 7 and 8 chosen according to formulas (1) and (2).

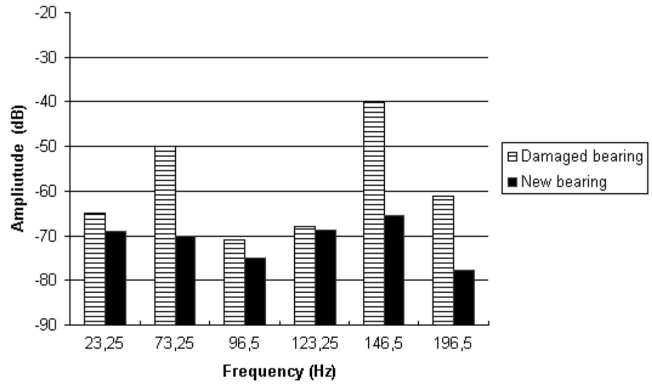

Fig. 9 Comparison of spectra amplitudes (frequencies are chosen according formulas (1) and (2)).

The results of the investigations show that using notch filter (which reduced the first harmonic of the net) enable to reveal small components of the spectrum. Measuring these components makes it possible to give diagnostics of the induction motors by current analysis.

The direction of planned development is further reduction of measurement noise.

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