GALAXY INTERNATIONAL INTERDISCIPLINARY RESEARCH JOURNAL (GIIRJ)
ISSN (E): 2347-6915
Vol. 11, Issue 03, March. (2023)

BASIC MATHEMATICAL PRINCIPLES OF THE DIAGNOSTIC METHOD BASED ON THE SPECTRAL ANALYSIS OF THE ASYNCHRONOUS MOTOR STATOR CURRENT

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ABSTRACT

This article analyzes the main methods of diagnosing asynchronous electric machines and explains the importance of these diagnostic methods. In addition, the main achievements of the diagnostic method based on the spectral analysis of the stator current using current modern technologies are described in detail. In this article, the problems of the signal processing techniques used for the diagnosis of the electric machine operating under variable time conditions are firstly analyzed: the limits of the Fourier series, the use of multiple frequency bands to monitor a single fault component. The main concept that should be emphasized in the implementation of spectral analysis is their distribution along the Fourier series, the characteristics of the mathematical model of spectrum analysis through this method directly depend on the components of the current. One of the most modern methods of analysis of Fourier series is the technique created by Denis Gabor, by means of which it is possible to calculate Fourier series with the least relative errors. The results obtained through the conclusions and concepts arising from the above are presented in this article.

1. INTRODUCTION

Monitoring the state of electric machines is becoming one of the most important modern technologies of technical maintenance of electromechanical systems, its main features are early identification of defects that may occur in electric machines and prediction of dynamic performance indicators. The diagnostic methodology discussed and recommended in this article can be used for any machines working in induction mode. As an example, any type of alternating current electric machines can be cited. In general, electrical machines can experience various faults, including: high resistance between two phases, between phases and body, between phase and ground, and many stator coil faults. Electrical defects of the rotor are failure of the insulation of the phases, short circuits, or demagnetization of the rotor windings through the connection of high resistance for phase-rotor machines. For short-circuited rotors, mechanical defects such as breaking or buckling of the rods, fractures at the joining points of the rings, static and dynamic eccentricities. The above-mentioned defects can occur in electric machines used in any industrial sector, and as a result, the failure of the entire electromechanical system and the deterioration of product quality can be observed [1]-[4]. In a recent reliability study [4], the distribution of defects in an asynchronous motor was determined, as shown in Figure 1.1.

In recent years, a large number of scientific and practical works have been carried out to eliminate the shortcomings of traditional diagnostic methods, to create new methods of monitoring the condition of asynchronous motors and drives, and these works are still being continued. From this point of view, various diagnostic methods have been developed, which are currently less effective. , designed to measure values such as vibration. Of course, although these values are not sufficient for the diagnostic analysis of the complete state of the electric machine, they are considered sufficient for the initial analysis [5]-[8]. The problem of diagnosing electric machines and thereby preventing defects attracts many scientists around the world with its attractiveness. In recent years, the weight of electric machines in the industry has increased significantly, according to research, in 2018, the number of electric machines in industrial sectors was more than 30 billion, and by now, these values have increased by approximately 25%. It is clear from the above that a lot of work has been done in this field, but the human factor is felt in the process of analyzing the spectra of the stator current, therefore, insufficient attention is paid to the automation of work in this field through artificial intelligence. In this article, the distribution of the spectra of the stator current according to the Fourier series and the process of their analysis are explained.

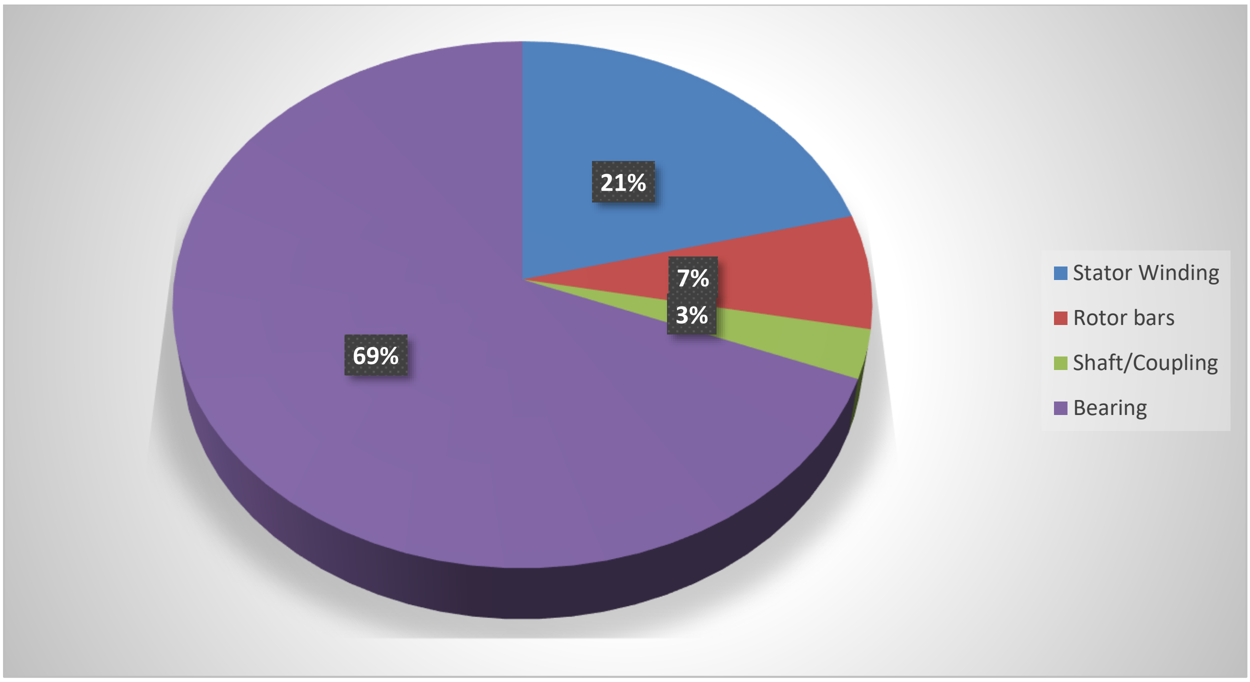


Fig. 1.1 Distribution of failures by motor component

2. THEORETICAL BASIS

Under normal operating conditions, it is common for electric machines to be exposed to symmetrically distributed magnetic fields and mechanical forces. After errors appear in the stator and rotor parts of the motor, they become symmetrical, and the effect of this asymmetry causes electrical and mechanical quantities to deviate from the nominal conditions, for example: currents, forces, torque, magnetic field strength or vibrations.

In practice, by observing these signals, you can find information about the methods of detecting and eliminating defects that can be observed in the stator and rotor of electric machines in many literatures. The harmonic composition of signals received during processing is presented in the first table. Since the vibrations of many bearings have a periodic characteristic, the analysis of vibration spectra is widely studied [1]-[3].

Table. 2. 1 Fault harmonics Classification in term of Adopted input signals for processing

Fault	Signal	Characteristic Frequency
Stator asymmetry	Stator current	$(f_{kss} = \pm(1-k)f)_{k=0,1,2,...}$
	Rotor current/voltages	$(f_{krs} = (s \pm 2k)f)_{k=0,1,2,...}$
Rotor asymmetry	Stator current	$(f_{ksr} = (1 \pm 2ks)f)_{k=0,1,2,...}$
	Rotor current/voltages	$(f_{krr} = \pm(1 \pm 2k)sf)_{k=0,1,2,...}$
	Vibration	$(f_{kvr} = (6-2ks)f)_{k=,1,2,3,...}$
Mixed eccentricity	Stator current	$\left(f_{kvr} = (\lvert f \pm kfr \rvert)\right)_{k=,1,2,3,...}$
Bearing outer race	Stator current	$f_{mob} = \lvert f \pm mfv \rvert_{m=1,2,3...}$
	Vibration	$f_{vob} = \left(\frac{N}{2}\right).fr.(1 - b_b \cos(\beta)) / dp)$
Bearing cage	Vibration	$f_{vcb} = \left(\frac{1}{2}\right).fr.(1 - d_b \cos(\beta)) / dc)$
Bearing inner raceway	Vibration	$f_{vib} = \left(\frac{Nb}{2}\right).fr.(1 - d_b \cos(\beta)) / dc)$
Bearing ball	Vibration	$f_{vib} = \left(\frac{dc}{db}\right).fr.(1 - d_b \cos(\beta)) / dc)$
Magnetic demagnetization	Back-emf	$\left(f_{kdem} = f(1 \pm -k/p)\right)_{k=0,2,3,...}$

If there are filters that prevent external signals, the system of monitoring the machine through the use of current can be successfully used. The measured or observed electromagnetic torque is widely studied for the purpose of diagnosis.[6]

Available quantities for conventional electric machines are three line voltages $i_a,\ i_b, i_c$ and three line voltages $u_a,\ u_b, u_c$. Real quantities must be changed to obtain time-invariant coefficients. In addition, the transformation reduces the number of dimensions of the state variables, and a reference frame can be obtained to simplify the machine model according to the required information. For example, in field-oriented control, the correct choice of reference frame leads to separation of current and torque.

Fourier series transform signals into sinusoidal signals of different frequencies. In other words, it converts signals from time to power source. The basis of this method is the output of signals to orthogonal trigonometric basis functions. Fourier transform control capability of continuous signal x(t):

$$X^{FT}(f) = \int_{-\infty}^{+\infty} x(t).e^{-j2\pi ft}dt \qquad (2.1)$$

Ushbu transformatsiya asl vaqt domen signalining global chastota taqsimoti ifodalaydi $x(t)$. Tajribalar asosida olingan signallarning ko`pchiligi vaqt bo`yicha uzluksiz emas balki diskret vaqt oralig`i ΔT sifatida tanlanadi. Shunga qaramasdan, ushbu signallarni $N = \frac{T}{2}\Delta T$

oraliqlariga bo`lingan va umumiy o`lchash vaqti T bilan chegaralangan uzluksiz signallar deb qarash mumkin. Diskret signallarni 2.2 chi formulada keltirilgan diskret Furye qtransformatsiyasi orqali aniqlash va chastota domenini tahlil qilish mumkin. Signal namunalari tufayli chastota spektri davriy ko`rinishda bo`ladi, shububg uchun tahlil qilinadigan chastotalar cheklangan bo`lishi kerak. DFT diskret chastotalar bilan aniqlanadi $f_n = \frac{n}{T}$, $n = 0,1,2,3 \ldots \ldots, N-1$.

$$X^{DFT}(f_n) = \frac{1}{N} \sum_{k=0}^{N-1} x(k). e^{-j2\pi k \Delta T} \qquad (2.2)$$

Calculating the DFT can be very time consuming for large signals (large N). The fast Fourier transform (FFT) algorithm does not accept arbitrary N intervals, it can only accept N = 2m, m ∊ N intervals. Acceleration of the FFT can occur due to the increase in the number of intervals. The disadvantage compared to a simple DFT is that the signal must be sampled by 2 μm, but this is not a problem at all. FFT is widely used for diagnostics of electric machines and is considered to be a very effective method for extracting the state of the machine and non-nominal operating modes. ***[8]-[9]***

Another problem in the closed loop is that the control itself causes changes in electrical variables, and because of this factor, the need for new diagnostic methods is felt. There is a new approach to diagnose stator and rotor faults under steady-state conditions based on the analysis of rotor modulation signals under the influence of current regulators[9]. One of the main goals of this thesis is to extend this approach to time-varying operating conditions using a new signal processing technique to investigate control variables in this context. Also, vibration signals are considered for rotor mechanical fault diagnosis to evaluate the effectiveness of the proposed approach.

Various signal processing methods for diagnosing electric machines presented in the literature are mainly divided into three categories: time-domain analysis, time-frequency domain analysis and frequency domain analysis. As mentioned earlier, this article analyzes the method of frequency domain analysis and the characteristics of this method. In the following, a detailed discussion showing the necessity and advantages of migration from frequency domain analysis (represented by Fourier transform), to time-frequency domain analysis (represented by Wavelet Transform), [10]-[13].

2.1 Furier Transform

The current method of analyzing small parts of signals (2.3) is the work of Denis Gabor, this method consists in multiplying the Fourier transform of real signals by a non-zero window function of the main function to obtain exact values. More specifically, for calculations and support, the signal x(t) starts the expansion with the window g(t) from the marking at time t. And three symbols * indicate a conjugated complex. FT signal to deliver the frequency content of the signal from the mirrored signal to the playing time interval.

$$X^{FTCT}(\tau, f) = \int_{-\infty}^{+\infty} x(t). g^*(t-\tau) e^{-j2\pi f t} dt \qquad (2.3)$$

As shown in Fig. 2.1, the start of the STFT two-dimensional function turning signal. These functions consist of instantaneous time and frequency. Due to the play axis, the time is the same for all frequencies and therefore, a short window creates a clear time interval. But in this case, it is impossible to get exact speeds on specific frequencies, but on short frequencies.

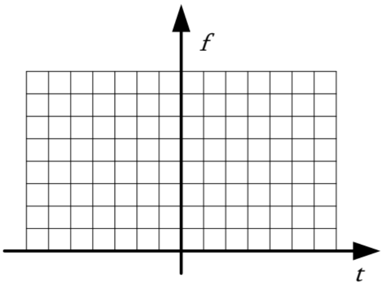


Fig. 2.1 Constant resolution in time-frequency plane using Short-time Furier Transform

2.2 Wavelet Transform

The main feature of wavelet analysis is the analysis of the transformed dimensional versions of the so-called mother wave propagating from the source of the waves. A wavelet is a finite time special function with zero mean and asymmetric waveform. It can be understood that this type of wave is completely different from the infinite, continuous and smooth sinusoidal wave. The complete cycle time change (CWT) of the function F(t) can be defined as the integral of the signal in watts. The scaled and shifted versions of the wavelet function are multiplied by Ψ and the similarity between them is calculated. This formula is given below (2.4)

$$C(scale, position) = \int_{-\infty}^{\infty} f(t)\, \Psi(scale, position)dt \qquad (2.4)$$

The wavelet coefficient can be considered as the result of CWT. Enhancing the visualization of each coefficient with the corresponding scaled and shifted waveforms produces a complete signal (from this physical property, mapping the Fourier coefficient to the corresponding frequency of the sinusoidal function gives the sinusoid of the new signal). Scaling is a mathematical function of treating or compressing the range of a signal. If we look at frequency in relation to the definition of wave transformation, it can be observed that scale and frequency depend on low scales for high frequencies, and high scales for low frequencies. In conclusion, we can come to the conclusion that the signal can be analyzed in different dimensions and at different frequencies. Fig. In 2.2, the time-frequency dependence can be seen in the multi-resolution evaluation mentioned above.[5]

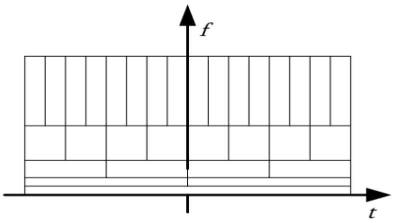


Fig. 2.2 Multiresolution in time-frequency plane using Wavelet Transform

It is a very complicated process to find the correct coefficients at the desired scale and position. For this purpose, the benefit is collected based on a subset of measurements and positions (diabatic selection) with dual power. In this case, Fig.2.3 This method is considered to be the best current method for detecting faults in the stator and rotor parts of the asynchronous motor. However, the possible size of the selected window, the high level of obtaining this results and the largest volume of costs remain a major disadvantage of this method. There are three ways in which electricity can be advanced. In this case, special approaches are required due to the origin of these signals. Because for low-frequency signals, it is necessary to travel through a wide time interval, and for high-frequency signals, it is necessary to travel through a relatively small time interval.

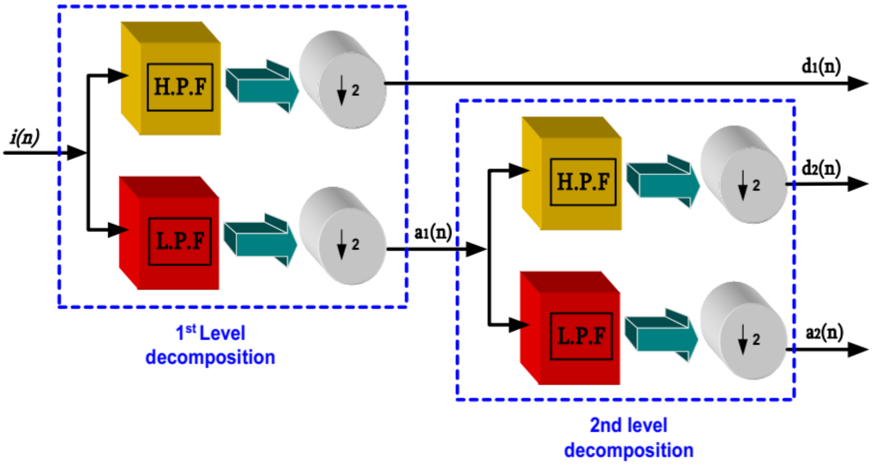
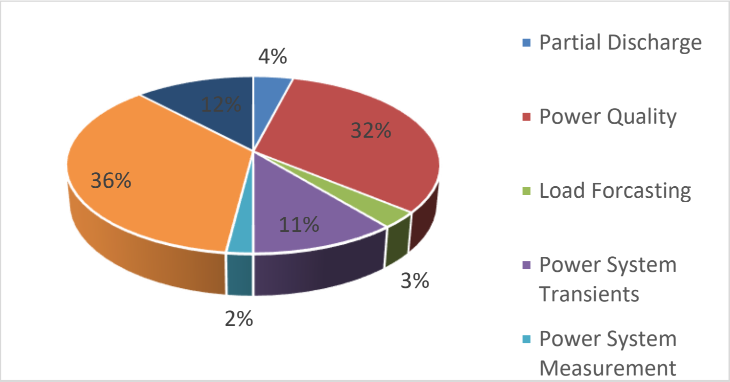


Fig. 2. 3 Wavelet Transform using a filter blanks.

In this application, the performance of the filters is an evaluation of the waveform, and therefore the accuracy and quality of the analysis is considered very important. lower frequency components of signals are called "approximation signal", and higher frequency components are called "detail signal". if there is, the signals coming out of these two filters will appear in the state where the data is significantly doubled. (If the signal consists of N inputs, the over-sampled and up-sampled input signals will remain the same with respect to the guardian value. The safety standards of providing filtered equipment for the flight process will have N/2 samples.

3. RESULTS AND DISCUSSION

The Discrete Wavelet Transform (DWT) is characterized by requiring greater time resolution for high-frequency components and greater accuracy for low-frequency components. Due to the above reasons, this method is complementary to the analysis of transient signals. As a result of the mentioned very important development, DWT has been used in various fields, especially to ensure the quality and protection of the finish. Figure 2.4 shows a diagram of DWT application in various areas of energy systems.



In the previous parts, production installation, production of new diagnostic methods for electric machines in continuous and loading conditions is considered as one of the important problems of the present time. The new diagnostic method required for the production output should be different from the currently used diagnostic methods in terms of: 1) The ability to suppress the stable monitoring of the situation over time in any working conditions; 2) Absence of a requirement for continuous approach measurement of speed or slip; 3) high accuracy of distinguishing the main frequency from additional distracting frequencies; 4) increasing the possibility of false appearances through the array, which confuses the main harmonics with other harmonic components (in conditions of variable speed, matching parts of the frequency parts are attached to one frequency range); 5) The frequency that should be taken as a sample is low and therefore the required memory size is short; 6) Producing a processing time delay (without requiring a resampling process).

4. CONCLUSION

Power for time warping techniques with discrete timing is analyzed in this paper as a perspective for signal processing. Step by step, a new effective way to implement this method was recommended and analyzed. In conclusion, it is worth mentioning that in the process of electrical diagnostics, it is necessary to pay attention to the processing machine:

- The need to constantly monitor the development of transient times over time;Tezlik yoki sirpanishni doimiy ravishda o`lchashning zarurati yo`qligi;
- Accuracy in distinguishing the main and additional halal frequencies;
- Reduction in the likelihood of false indications by avoiding confusion with other fault harmonics (the contribution of the most relevant fault frequency components under speed-varying conditions are clamped in a single frequency band);
- Low memory requirement due to low sampling frequency;
- Reduction in the latency of time processing (no requirement of repeated sampling operation).

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