Journal of Energy

VOLUME 67 Number 4 | 2018 Special Issue

journal homepage: http://journalofenergy.com/

SAŠA NIKOLIĆ
RADOŠ ĆALASAN
Elmins doo
NikoleTesle 99,89240 Gacko
Bosnia and Herzegovina
office@elmins.ba

Motor Current Signature Analysis in Predictive Maintenance

SUMMARY

The aim of this paper is to draw attention to the possibilities offered by spectral analysis of current and voltage in the predictive maintenance of the electric motor. Motor Circuit analysis (MCA) and Motor Current Signature analysis (MCSA) are innovative and non-invasive methods that enable diagnostics and assessment of the condition of the electric motor. The main advantage of the method is that the test is carried out during the normal motor operation, without downtime. All motor defects can be detected at the earliest stage. This enable planning the overhaul according to the condition which can make significant savings. Advanced MCSA analysers enable diagnostics of electric motors that are powered either via a soft starter, frequency inverter or directly from mains. So, it is possible in a simple and reliable way make an condition assessment of frequency inverters. In addition, it is possible to detect faults of driven machine, like misalignment, imbalance, blade faults, belts, bearings issues etc. Theoretical basis and tests that are carried out are explained in the paper..

KEYWORDS

Predictive maintenance, Spectral analysis, MCA, MCSA

INTRODUCTION

In order to achieve market competitiveness, there is a constant pressure to reduce maintenance costs and prevent unplanned production losses, leading to loss of production, increased maintenance costs, and financial losses. In recent years, *online* maintenance strategies are in use. However, with such maintenance, the operator makes the final decision when it will stop the equipment and enter it for overhaul. Also, these *online* monitoring systems are mainly based on monitoring mechanical parameters, that is vibration and analysis of vibration spectra. When it comes to pure mechanical systems, this approach gives good results. However, when it comes to complex systems that include an electric motor, this approach is not enough. Namely, it may happen that measuring vibration determines the defect of the system and incorrectly estimates the cause.

A typical example is the occurrence of a second harmonic in a vibration spectrum that does not have a mechanical cause.

Symbols			
P	Number of motor poles	*%FLA*	Percent of full load, A
f	Mains frequency, Hz	*fp*	Pole pass frequency, Hz
f_{sync}	Synchronous speed, Hz	*f ecc*	Frequency of eccentricity, Hz

On the other hand, it is true that electrical defects are manifested through the occurrence of certain harmonics in the vibration spectrum, but their occurrence can therefore only be detected when the damage reaches a serious extent.

The essential thing for a spectral analysis of an electric motor's current is that each failure of the electric motor modulates the flux of the motor, creating the rotating components of the flux which further produce characteristic current components that superimpose the basic harmonics. By detecting and separating these current components, an electric motor defect can be detected, such as a rotor bar damage, an inter-turn short circuits of the stator winding or eccentricity of the rotor. Measurement is performed during normal operation of the engine, without stopping and interrupting the production process. It does not matter how far the measuring point is from the motor. By measuring from the distribution cabinet, the status of the circuit current (MCA) is additionally performed.

Defects that can be detected through components in the electric motor current spectrum are [1], [2], [3]:

- Damage to the rotor bars,
- Static eccentricity,
- Dynamic eccentricity,
- Damage to the core,
- Stator winding defects,
- Damage to the bearings,
- Missalignment / imbalance,
- Loose foundation,
- Problems with the working machine.

Spectral analysis of the motor current can detect these defects at a very early stage, preventing further secondary damage and complete failure of the electric motor. Damage to the rotor bar will affect the vibration spectrum of the engine, but since the vibrations are traditionally measured on bearings and since for each electric motor there is a different mechanical stiffness between the electromagnetic forces caused by breaking the rotor bar and the place where vibration is measured, this further complicates the attempt to quantitatively define level of damage through vibration analysis. Vibrations caused by damage of rotor bars are a secondary effect and often the damage reaches a serious level before it is detectable in the vibration spectrum.

Due to all this, spectral analysis of motor currents and online monitoring can serve for quality monitoring of the condition of the electric motor and maintenance according to the condition.This system, along with online vibration monitoring, can completely prevent unplanned downtime of the electric motor and thus reduce the maintenance costs to a minimum.

THEORETICAL BASIS

The electric current signal is ideally the right sinusoid with a frequency of 50Hz, which of course depends on the frequency of the power supply network. A graphic, current signal can be presented in the time and frequency domain.

Figure 1. An ideal time diagram of the current and its spectrum is shown. It is noted that there is only one component in the spectrum, which is the basic harmonic at a frequency of 50Hz. All other components in the spectrum are equal to zero. In practice, the current signal is »contaminated« by a number of components having different causes. In addition to harmonics on the integers of the fundamental frequency, subharmonics occurs in the spectrum of the current. Separating and identifying these subharmonics is key to evaluating the health of the motor.

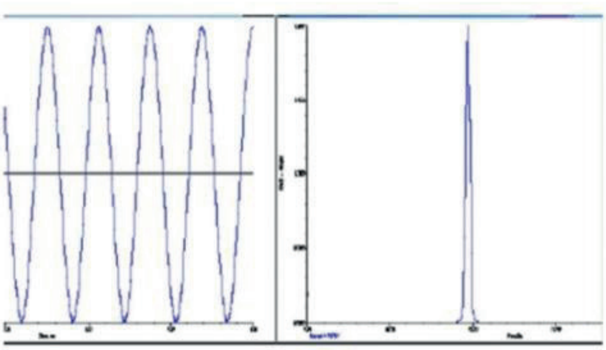
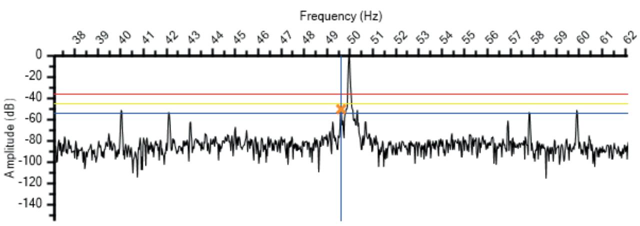


Figure 1. An ideal sinusoidal signal and its spectrum

During the motor operation, several components, or harmonics, will appear in the current spectrum. The current spectrum will consist of several



peaks including the component on the network frequency and its harmonics. This is known as the *Motors Current Signature*. The analysis of these harmonics after the amplification and processing of the signal allows detection of various electric motors faults.

Figure 2. Spectrum of real current signal

Certain harmonics are always present in the network voltage as a result of harmonic network pollution. However, these harmonics are negligible. In contrast, other harmonics are generated by various electrical and mechanical defects. All errors cause a change in the internal distribution of flux, which further generates harmonics in the motor current. It should be noted that the spectrum also includes inter-harmonics, which can not be detected by standard spectrum analyzers. Kako se harmonici karakteristični za određene defekte pojavljuju u strujnom spektru a ne i u naponskom, onda se upoređivanjem strujnog i naponskog spektra mogu izdvojiti harmonici koji su posledica defekta a ne zagađenja napajanja.

MEASUREMENT SETTING

The basic instrumentation system for measuring the spectrum consists of:

- Current transformer CT for signal measurement,
- A resistive shunt mounted at the CT outlet,
- Spectrum Analyzer.

Figure 3 is a schematic representation of the basic measurement setting.

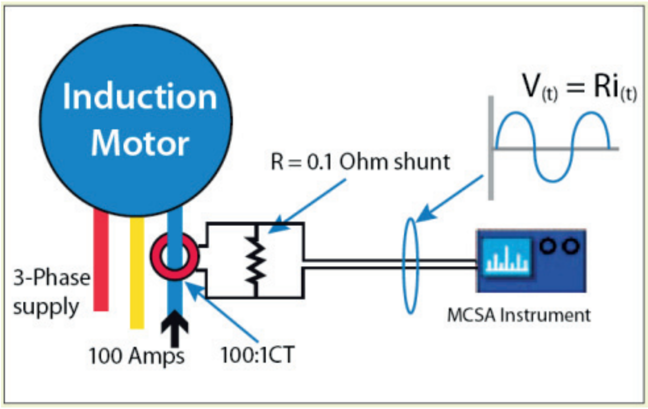


Figure 3. Instrumentation setup

The system can also include voltage measuring transformers VT, if it is a medium voltage motor. Depending on the real situation in the plant, the current transformer can be a type of clip-on and is mounted on one phase of the motor, or if a current measuring transformer is already installed in the plant, which is usually the case with large motors, then a probe is mounted on secondary current transformer. It is noted that only one current transformer is sufficient to analyze the spectrum of only one phase of the motor. The main reason for this is that each defect produces a rotating component of a flux that intersects all three phase windings of the motor and induces in it an appropriate component of the current that represents the occurrence of the defect. For a successful spectral analysis, standard commercial current transformers are sufficient. Although one phase analysis phase is sufficient, it is better to measure all three phase currents for a complete analysis.

After acquisition of the current signals, FFT is performed for separating the spectral components. The motor condition is evaluated through a series of tests in which the engine elements are evaluated individually[4]. These tests are described below.

OVERVIEW OF BASIC TESTS

Rotor evaluation test

In the Rotor Evaluation Test, an analysis of the current spectrum is performed in order to determine the condition of the rotor and to detect possible damage. The spectrum is shown in the coordinate system Hz-dB. The main component of the current is displayed at a frequency of 50Hz and with a weakening of 0dB. All other components of the spectrum are shown by the weakening in relation to the basic harmonic. The weakening is expressed in decibels (dB).

The greater the attenuation, the component's amplitude is smaller. In this test, the spectrum of the current around the basic harmonic is observed. The frequency of the pole pass is identifying (pole pass). If the component of the spectrum is at a distance from the basic harmonic below the 54 dB line 54 dB, then the rotor is considered to be in good condition, with no signs of damage and increased resistance. If these symmetric components are in the range between 45 dB and 54 dB, this means that there are signs of initial damage and places with increased resistance on the rotor bars and end rings.

This situation still does not require urgent intervention. It is necessary to monitor the development of defects and in case of progression to react in time, before the fatal damage of the rotor bars. The level of the spectral components at distancesfrom the base accordion, which is larger, that is, the attenuation of less than 35dB, indicates significant damage to the rotor bars or end rings and requires the urgent stopping of the motor and inspection of the rotor in order to detect and correct the defect.

Figure 4 shows the rotor evaluation spectrum for rotor with defect.

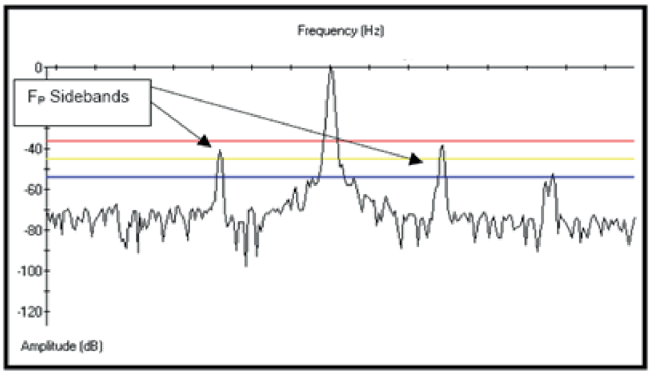


Figure 4. Rotor evaluation spectrum

Figure 5. shows a rotor with damaged rotor bars.

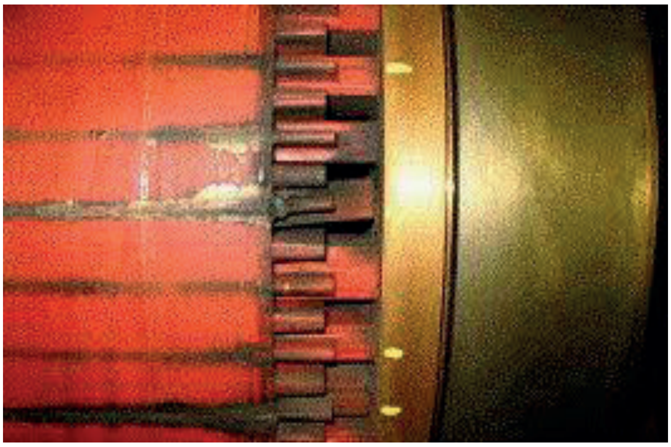


Figure 5. Rotor with broken bars

Rotor bars damage is a common practice case in cage motors. It is most commonly caused by an excessive number of direct or too frequent startups. It is very important to detect damage of the rotor bars in time, until the bar is lifted from the slot, which necessarily leads to severe or even irreparable damage of the complete engine.

Air gap evaluation test

An ideal electric motor has a uniform air gap between the stator and the rotor. In practice, this is usually not the case. The eccentricity of the air gap can be caused both factory faults, as well as the consequences of exploitation, assembly errors, etc. Of the factory defects, it is often the case of an oval rotor or stator, and as a result of mounting errors, especially in large engines where the bearings are not mounted in the bonnet, most often there is a misalignment of rotor and stator. Two type of eccentricity are existing. That are static and dynamic eccentricity. In static eccentricity, the minimum air gap is always at the same place on the stator edge. In contrast, in dynamic eccentricity, the point of minimum air gap moves during rotation of the rotor.

Figure 6. shows an illustration of an electric motor with an eccentricity of the air gap.

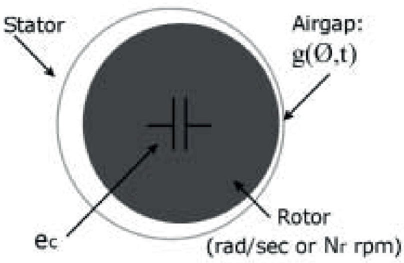


Figure 6. Air gap eccentricity

The consequence of eccentricity in an electric motor is the emergence of strong radial forces acting in the direction of the smallest air gap (*Unbalanced Magnetic Pull*). Mechanical vibrations occur at 2x frequency. These vibrations cannot be removed by balancing the rotor. For large motors, manufacturers allow the eccentricity of the rotor to be up to 5%.

By spectral analysis of the current of the electric motor, the existence of the asymmetry of the gap between the rotor and the stator can be easily and reliably determined. Figure 7 shows the part of the current spectrum of the electric motor with the presence of eccentricity.

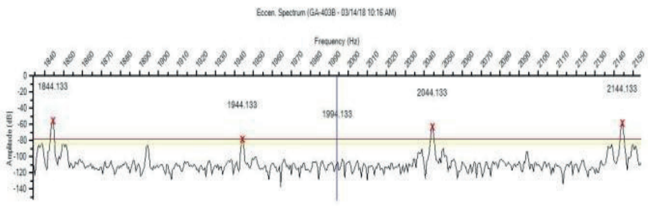


Figure 7. Eccentricity spectrum

Eccentricity indicators are four characteristic components in the spectrum at a distance of 100Hz. In the case of eccentricity, all four components exceed the permissible limit. The frequency of eccentricityis proportional to the number of bars in the rotor and is equal to the product of the number of bars and mechanical velocity in Hz.

STATOR WINDINGS EVALUATION TEST

This test is used to assess the state of the stator winding and the connecting circuit. A detailed analysis determines the condition of the winding and the connecting circuit. Calculation of the following parameters is performed:

- Voltage imbalance,
- Current imbalance,
- Impedance imbalance,
- Power factor imbalance
- THD,
- *Crest* factor,
- Positive, negative and zero current components

By analyzing the obtained results, it is possible to assess with certainty the state of the stator winding and the connecting circuit. Quantitative and qualitative analysis of these parameters determines the location and level of damage. The relation of current and impedance imbalance shows whether the fault in the connecting circuit is in the form of a point with increased resistance or is a failure in the stator windings. Also, in this test, an evaluation of the frequency regulator is performed, if present. The regularity of switching in the power block is checked. It also determines the level of higher harmonics that the regulator injects into the network, which affects the work of other devices.

Test for evaluation of mechanical parts

Mechanical defects modulate the flux of the motor that further induces the components of the current at the appropriate frequency. The problem is that the levels of these components are negligible in relation to the level of the basic harmonic and its multiplications. Therefore, in this test, the signal is separated at a 50Hz frequency band and its harmonics, making the components caused by mechanical defects visible and allowing analysis of hidden signals that are the result of a repeated load variation. Spectral analysis further determines what this load variation means and enables us to identify potential faults with the balance of the rotor, the centering of the motor shaft and the working machine, belts, bearings, gears, pumps, compressors and other mechanically generated anomalies.

Each mechanical component associated with an electric motor has its own frequency. On the Demodulation Spectrum, it is necessary to identify the increased harmonics corresponding to the frequency of the mechanical circuits associated with the working machine. The increase indicates a problem in that part.

In Figure 8, a demodulation spectrum for a motor that has a centering error is shown.

It can be seen in the figure that the uncertainty of the motor and pump rotor causes the components to emerge in the power spectrum at mechanical and double mechanical speeds. There are no significant components in this motor that would represent other defects. In the beginning part of the spectrum masked by the noise lie the components corresponding to the frequency of passing the bearings, the pump blades ...

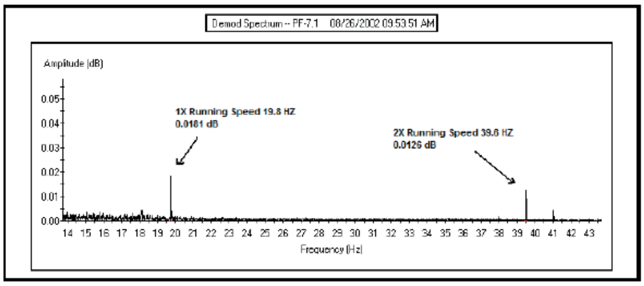


Figure 8. Demodulation spectrum

Figure 9. shows the spectrum of the same motor after centering.

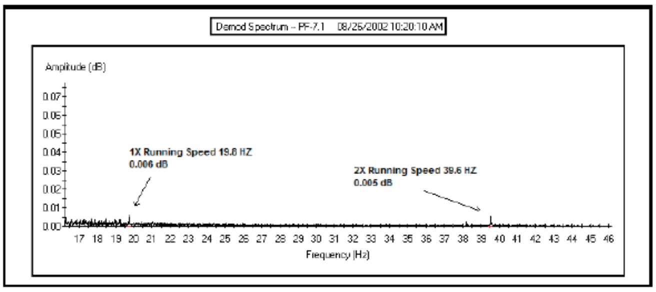


Figure 9. Demodulation spectrum after alignment

For precise identification of mechanical problems, knowledge of specific system elements data is needed. Thus, to assess the condition of the bearings it is necessary to know the type of bearings, the number of balls, the passage rate of the balls, the inner and outer paths, etc. To assess the condition of a gear unit, you need to know the number of gears and teeth of each gear and the like. Therefore, when interpreting the results obtained through the Demodulation Spectrum, it is good to consult a specialist in mechanics. By working together, a precise and reliable assessment of the condition of the mechanical circuits associated with the electric motors is obtained.

CONCLUSION

Motor Current Signature Analysis this is an innovative method that allows a thorough analysis of the condition of the electric motor. The advantage of this method is that testing is carried out during the normal operation of the motor and there is no need to stop and interrupt the production process. In our area, this method is very little represented in the process of electromotor maintenance. However, in the United States it has become a standard in the last few years. The savings that can be achieved by applying this method in the predictive maintenance of the electric motor have been recommended as a standard procedure applied in the industry. As it has become usual for us to measure the vibrations routinely, as a standard maintenance procedure, MCSA has become the standard method for testing electric motors in the US industry. Producers of advanced MCSA analyzers are still few and are all from the USA. However, the importance of this method is becoming increasingly evident in Europe and the manufacturers of these analyzers are slowly turning to our market.

The method of spectral analysis of currents, as a diagnostic method and tool in predictive maintenance does not exclude the method of vibro-diagnostics. On the contrary, this method compensates for the defects in vibro-diagnostics in the analysis of complex systems and a good combination of these methods, it is possible to accurately and reliably evaluate the state of all rotary machines driven by an electric motor.

As vibration measurement has become a widely accepted method for assessing the condition of mechanical circuits, so will the spectral analysis method of electric motors to find their place in predictive maintenance. The confirmation of this is the continuous improvement of advanced analyzers and the increasing interest of companies, which have so far solely engaged in the production of vibration analyzers, to conquer this technology and manufacture their own analyzers.

REFERENCES

1. Penrose H.W., (2006), *Evaluating induction motor rotor bars with electrical signature analysis*, Success by design, Old Saybrook, CT, USA
2. Fossum D.,(-), *Identifying Mechanical Faults With Motor Current Sigfnature Analysis*, Allied Services Group, USA
3. ThomsonW.T., Gilmore R.J., (2003), *Motor Current Signature Analysis To Detect Faults In Induction Motor Drives – Fundamentals, Data Interpretation And industrial Case Histories,* Proceedings of 32-nd Turbomachinery Symposium,USA
4. PdMA, (2017), *MCE Gold – Product Support Manual*, PdMA Corporation, FL, USA
5. Penrose H.W., (2013), *Evaluating Motor Condition With Advanced Diagnostics,* Success by design, Old Saybrook, CT, USA
6. Luo at al., (2015), *Induction Motor Current Signature For Centrifugal Pump Load,* Journal of Mechanical engineering Science
7. Penrose H.W., (2015), *Motor Circuit Analysis Concept and Principle,* All-Test Pro, Old Saybrook, CT, USA