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TELEMETRY IN DIAGNOSIS OF ASYNCHRONOUS MOTORS

TELEMETRIA W DIAGOSTYCE SILNIKÓW ASYNCHRONICZNYCH

Streszczenie: Aby poprawić niezawodność działania maszyn elektrycznych w długim okresie eksploatacji, należy systematycznie przeprowadzać testy diagnostyczne. Uzasadnia to monitorowanie maszyn, zwłaszcza tych, które nie mają rezerwy w miejscu pracy: agregatów prądotwórczych, maszyn wyciągowych w kopalniach itp. Problem monitorowania i diagnostyki maszyn elektrycznych koncentruje się na ocenie stanu technicznego układu mechanicznego i obwodu elektromagnetycznego. W artykule opisano cele zdalnego monitorowania i diagnostyki stanu technicznego maszyn elektrycznych. Opisano również urządzenia stosowane przez pracowników Laboratorium KOMEL do monitorowania i diagnozowania maszyn elektrycznych, wyniki badań przeprowadzonych na maszynach elektrycznych w różnych stanach technicznych. Do monitorowania wykorzystuje się sieć GSM z transmisją danych. Sygnały diagnostyczne i infrastruktura techniczna do przesyłania danych pomiarowych jest również opisana w artykule.

Abstract: To improve operational reliability of electrical machines over a long period of time, the diagnostic tests should be performed systematically. This justifies the monitoring of machines, particularly those which do not have the reserve at the workplace: the power generators, hoisting machines in mines, etc. The issue of monitoring and diagnostics of electrical machines is focused on assessing the technical condition of the mechanical system and the electromagnetic circuit. In this article the objectives of remote monitoring and diagnostics of technical condition of electrical machines are described. Devices used by staff of Laboratory of KOMEL to monitor and diagnose electrical machines, results of tests performed on electrical machines in different technical condition are also described. In order to run monitoring, GSM network is used. Diagnostic signals and technical infrastructure for the transmission of measurement data are described in the article.

Słowa kluczowe: *pomiar prądu, systemy danych, maszyny elektryczne, telemetria, pomiar drgań*
Keywords: *current measurement, data systems, electric machines, telemetry, vibration measurement*

1. Introduction

Diagnostic tests of electrical machines, are part of improving the operational safety of these devices in the long term. They allow for rational planning of inspections and repairs, and the range of repair. Unfounded replacement of the machine in good technical condition for the new one, or the winding repair when it is good, exceed many times the costs of diagnostic tests.
On the other hand, in case of failure of the electrical machine during operation, production losses occur, and they are usually much higher than the price of the new machine. This is the reason to use the monitoring equipment, in particular on those machines that have no reserves in the workplace: the power generators, hoisting machines in mines, engines rolling in mills and others.
Problem of the monitoring and diagnosis of electrical machines is focused on the assessment of technical condition of the electromagnetic circuit and the mechanical system. Developed algorithm to obtain information concerning the technical condition of electrical machine and transmission of those data to a monitoring centre, allows the remote monitoring of electrical machines technical condition, and registers warnings of the deterioration of the diagnostic parameters of the machine before it will damage.

2. Diagnostic parameters for monitoring purposes - examples

The aim is to obtain information about the technical condition of the machine. From the damage statistics of electrical machines [10], for induction machines failures are caused by damage of:

- bearings - about 40%,
- stator windings, about 35%,
- rotor - approximately 10%,
- other damages - about 15%.

Therefore, diagnosis should be focused on the first three issues.

All the "diagnostic indicators" can be built basing on an analysis of the stator current. Motor current is a parameter that can be easily recorded and processed. There are numerous publications in which the authors present the methods of current analysis to determine the damage of individual elements of electrical machine [1, 2, 5, 6, 8, 9, 10, 11].

Basing on the analysis of stator current following diagnostic information could be specified:

- break in the stator windings, lack of contact at the terminals,
- damage of the rotor cage,
- damage of the bearing elements,
- static eccentricity,
- dynamic eccentricity,
- asymmetry of power,
- interwinding short circuit in the stator.

Information about the technical condition of bearings can be obtained from the measurements of vibration, temperature and analysis of the stator current. Deteriorating condition of the bearings generates increased amplitude of vibrations. The exact analysis of stator current waveform and understanding of relationship between vibration and these current waveforms, make it possible to identify the technical condition of bearings on-line.

Technical condition of the rotor cage is most accurately assessed by analysis of the starting current [2, 3, 8]. The phase currents of stator contain many diagnostic information about asymmetry of electrical and magnetic circuits of the stator and rotor.

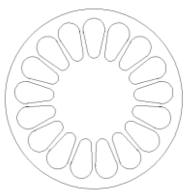
In the event of damage of the rotor cage bars, additional frequency occurs in the spectrum of phase current, described by following relationship:

$$f_{br} = (1 \pm 2 \cdot s) \cdot f_s \qquad (1)$$

where: fs - frequency of the stator current, s - slip.

The cross section of the rotor of asynchronous motor with intact bars and the starting current waveform is shown in the Figure 1.

a)



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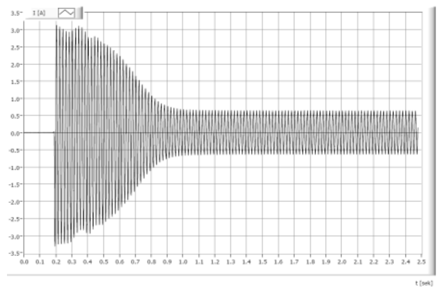

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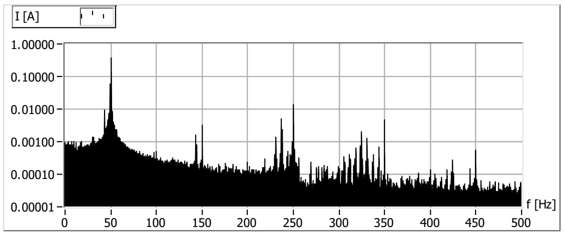
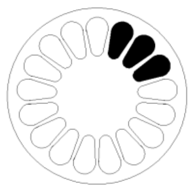


Fig. 1. The rotor with intact bars (a) and stator current waveform (b) during start-up and harmonic analysis of idle current (c)

a)



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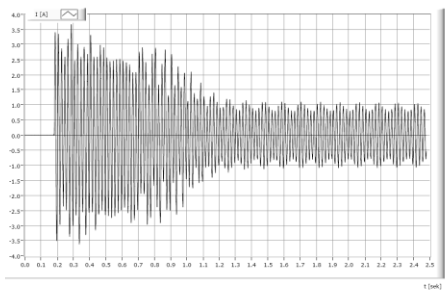


c)

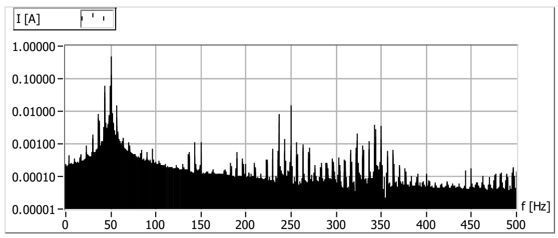


Fig. 2. The rotor with three broken rotor bars (a) and stator current waveform (b) during start-up and harmonic analysis of idle current (c)

Figure 2 shows the cross section of the rotor of asynchronous motor with damaged three neighbouring bars and the starting current waveform.

Figure 3 provides analysis of stator current with characteristic frequencies in the case of revealing the asymmetry of the rotor winding.

Figure 4 shows tested motor with its rotors (fig. 4a) and cross-section of bad made bar of cage (fig. 4b).

Components described by formula (1), characterizing the degree of damage of the rotor cage may be found in the spectrum of current consumed by the engine. Diagnostic instruments which determine the degree of damage of the rotor cage basing on the starting current are known.

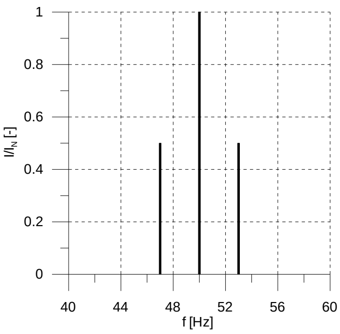


Fig. 3. The spectrum of the stator current during operation of the damaged rotor cage

a)

b)

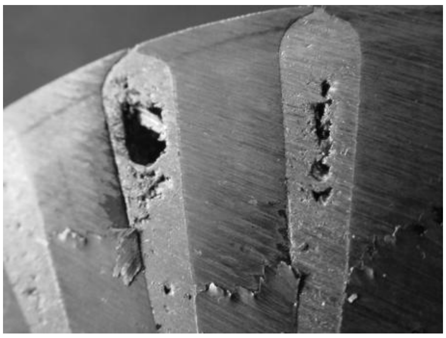


Fig. 4. Tested motor with damaged rotors (a) and a sample of bad made bar of cage (b)

Another incorrect state of the engine is eccentricity. It is a state of the machine in which the air gap between stator and rotor is uneven. Eccentric position of the rotor in induction motor introduces asymmetries (Fig. 5). There are three types of eccentricity [4]:

- static,
- dynamic,
- mixed.

Static eccentricity occurs when the position of minimum air gap is fixed relative to the stator.

Dynamic eccentricity occurs when the centre of the rotor is not in centre of the stator and the minimum air gap moves around the perimeter of the stator. The most common case is the simultaneous presence of static eccentricity and dynamic, ie. mixed eccentricity [4]. This asymmetry as a result of interaction between the stator and rotor windings affects the shape of the stator current. For induction machines characteristic frequency can be described by equations [4]:

- for static eccentricity

$$f_{es} = f_s \cdot \left(1 \pm k \cdot N_r \cdot \frac{1-s}{p}\right)$$

- the dynamic eccentricity

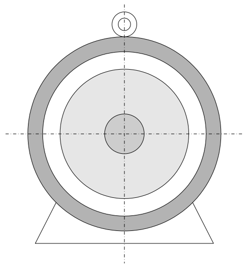
$$f_{ed} = f_s \cdot \left(1 \pm k \cdot \frac{1-s}{p}\right)$$

- for mixed eccentricity

$$f_e = f_s \cdot \left[\left(k \cdot N_r \pm n_d\right) \cdot \frac{1-s}{p} \pm n_w\right]$$

In the formulas 2, 3, 4 are marked: f_s - frequency of the stator current, s - slip, p - number of pole pairs, k = 1,2,3 ..., N_r - number of grooves of the rotor, n = 1,2,3,4 .. , n = 1,3,5,7...

a)



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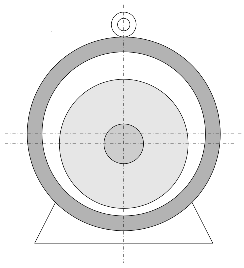

Fig. 5. Setting the concentric rotor (s) and eccentric (b)

The research conducted within the framework of the project grant, should develop and validate a comprehensive method for assessing the current technical condition of the monitored machine.

The aim is to develop a method and algorithm for transmission of measurement data and information about events occurring on the monitored machine to a computer database of the person or institution responsible for monitoring the technical state of the machine. The events that are important from the standpoint of measurement data are: start-ups, gradual or sudden increase of "diagnostic indicators", exceeding the alarm values, etc.

3. Simulation of the node bearing degradation and the influence of changes on the machine vibrations

Simulation has been studied for bearings: new (Fig.6, 7, 8, 9), with the lack of lubricant, with several degrees of contamination (Fig. 10, 11, 12, 13) and a few cases of unbalance (Fig. 14, 15, 16, 17). The results are presented for the no drive side because the changes in the bearing were followed from this side.

A. New bearing

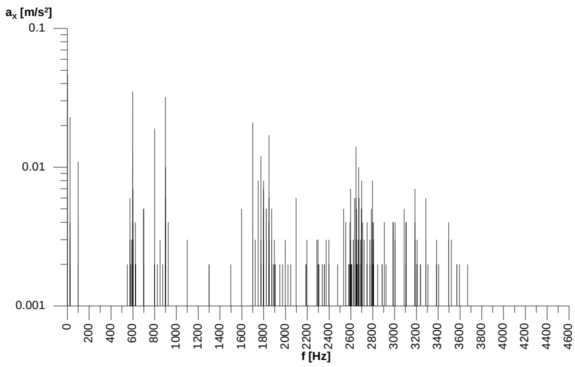

Fig. 6. Frequency spectrum of vibration acceleration in the axis "X"-and harmonic-599.31 Hz (0.047 m/s2)

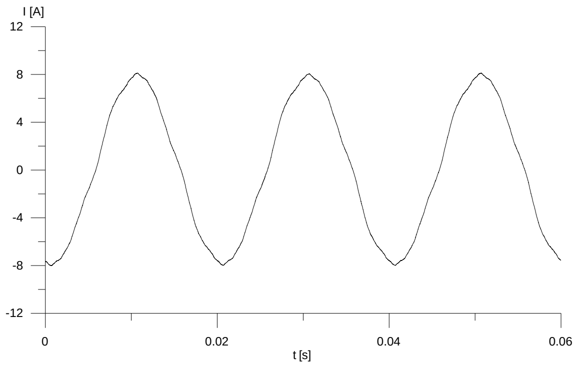

Fig. 7. Time waveform of current I_{RMS}= 5.55 A; THD_I = 3.07%

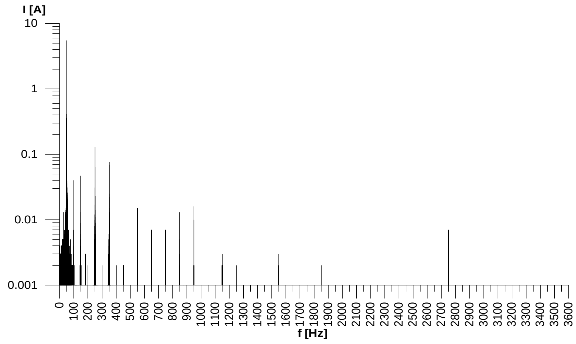

Fig. 8. Power spectral analysis - I $_{harm}$=50.01 Hz, I = 5.55 A

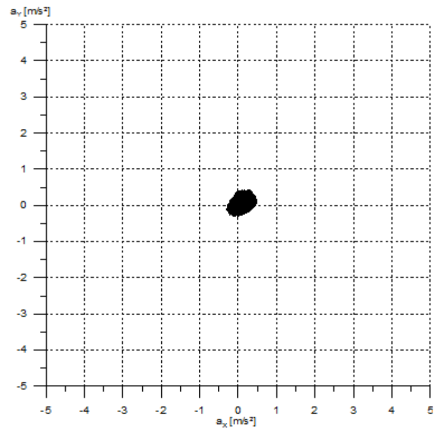

Fig. 9. Graph of the acceleration a_y=f(a_x)

B. Moderately dirty bearing

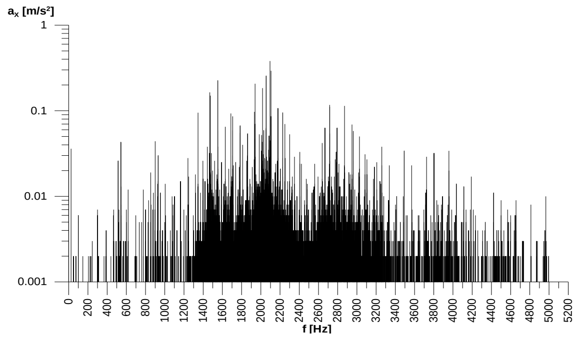

Fig. 10. Frequency spectrum of vibration acceleration in the axis "X" - and harmonic - 2095.2 Hz (0.38 m/s2)

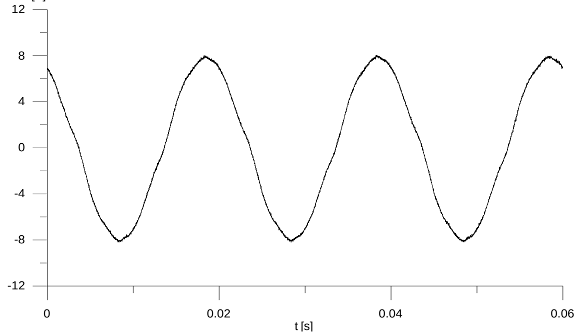

Fig. 11. Time waveform of current I_{RMS}=5.56 A; THD_I = 3.36%

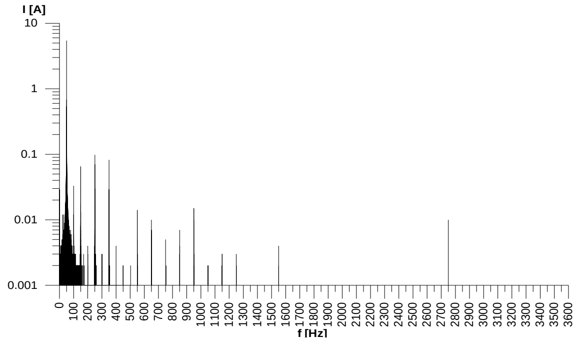

Fig. 12. Power spectral analysis- I_{harm}*=50.02 Hz, I = 5.55 A*

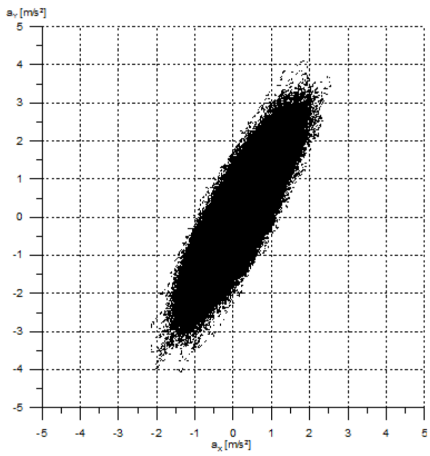

Fig. 13. Graph of the acceleration $a_y=f(a_x)$

C. Unbalance.

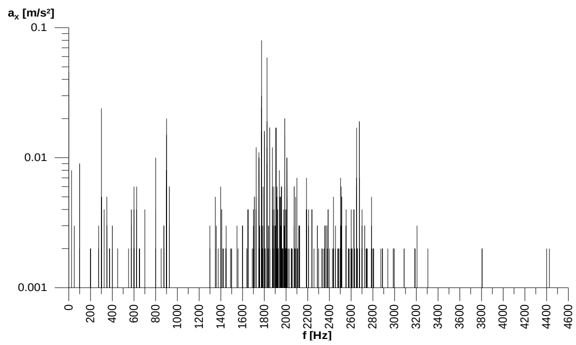

Fig. 14. Frequency spectrum of vibration acceleration in the axis "X" - and harmonic - 1775.06 Hz (0.09m/s2)

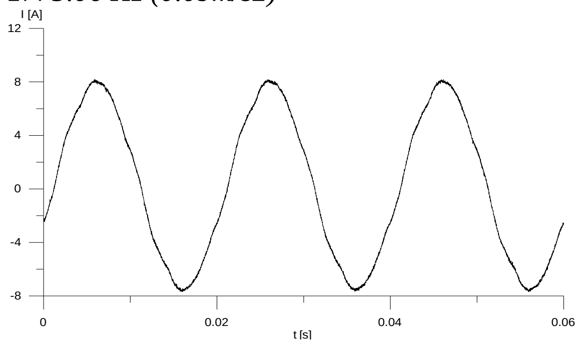

Fig. 15. Time waveform of current I_{RMS} *= 5.40 A;* THD_I *= 3.67%*

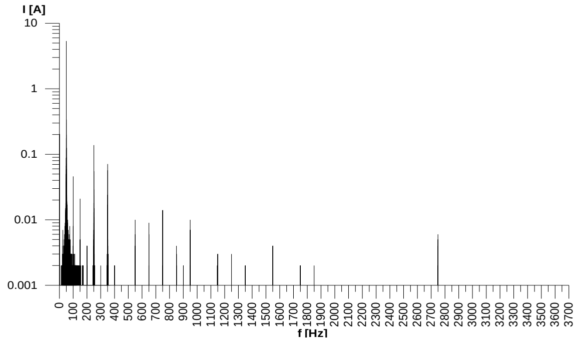

Fig. 16. Power spectral analysis-I $_{harm}$*=50.01 Hz, I = 5.39 A*

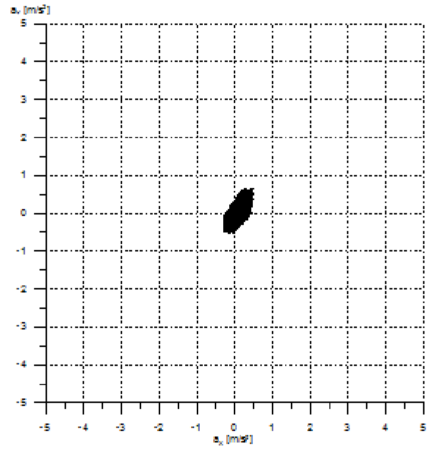

Fig. 17. Graph of the acceleration $a_y=f(a_x)$

4. Telemetry system

The dynamic development of mobile networks and their digital signal transmission, through the introduction of the GSM operators the possibility of data transmission, has contributed to the favourable opportunities readily achievable of measuring systems. In order to adapt remote monitoring system to grade requirements, it is necessary to appropriate facilities to enable logging and data transmission to the GSM network. Such devices are telemetry modules. Example of telemetry module, which is available on the market is shown in Figure 18. It is necessary, if telemetry module is to work properly, to put in the module a suitably configured SIM card provided by GSM operator offering services in data transmission [12]. It is also necessary to configure SIM card in the APN to obtain a static IP address. Assignment of IP address enables the transmission of telemetry to other modules, and servers running on the same APN. Sufficient signal strength at the area of the telemetry module antenna is strictly necessary for correct operation of the measuring system. Using the module in areas with very weak signals can lead to breaking the transmission, and in extreme cases, loss of data and can also lead to additional costs.

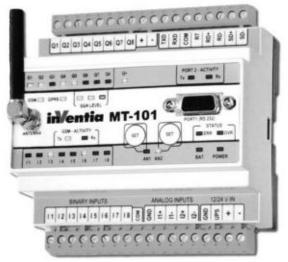

Fig. 18. Telemetry module

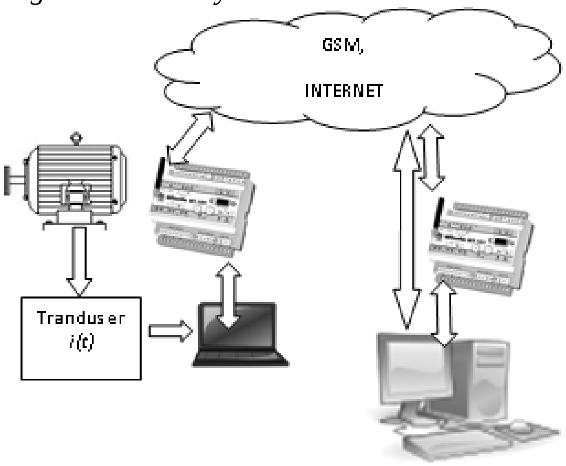

Fig. 19. Schematic telemetry measurement system

GSM technology seems to be an ideal technology for monitoring and telemetry systems. Its advantages include:

- the possibility of using the existing transmission network structure,
- a large network coverage,
- low costs of construction and operation of the system,
- no need to use special antennas,
- the ability to create network systems
- full access protection,
- high availability of a variety of transmitting and receiving terminals,
- fee for the actual amount of data.

Perfect environment to achieve the mentioned goal is LabView. LabView is a graphical programming environment. It can be used to develop measurement, test, and control systems. LabView has intuitive graphical icons and wires that resemble a flowchart. It offers integration with different hardware devices and provides hundreds of built-in libraries for advanced analysis and data visualization. The programme created in LabView is called Virtual Instrument [14]. LabView offers communication through Internet. That means that Virtual instrument, which works far away from diagnostic centre can send messages, results of measurements and alerts to be analysed by people who make diagnostic tests for long periods of time. It is an excellent tool for making tests of electrical machines [13]. Operation of telemetry system must be implemented with high precision, high speed and the measurement data must be in easy way received and displayed for further analysis. To perform such task there must be specified assumptions for the recording equipment:

- DIN rail mounting,
- rechargeable battery + external power supply,
- real-time clock,
- at least two input channels with variable range,
- input voltage range of + /-10V,
- the possibility of FFT analysis to 1kHz,
- frequency of at least 10kHz per channel,
- writing to external flash memory,
- the ability to define circumstance that the measured signal will be recorded,
- writing to the flash card is followed by the measured signal exceeds the threshold value of a user-defined time before and after the event,
- communication with PC (USB or Ethernet),
- sending an SMS to a defined number with information on the occurrence events,
- sending recorded files over the Internet – e-mail (if available).

Many of telemetry devices meet only a part of these requirements because of very wide range of activities which the device must perform. In order to present the principle of operation and the components of the device. The block diagram of a recording device that meets all the assumptions (for measurement and data processing) listed above is shown in Figure 20. The heart of the system is a digital signal processor (DSP). It is a specialized chip for processing digital signals. One chip includes:

- control system,
- arithmetic logic unit,
- ROM and RAM memory,
- integrated output.

Why DSP?
Such processors have features that are not found in other types of processors [7]:

- split the program and data memory,
- filters signals,
- Fourier transform,
- pipelined instruction processing.

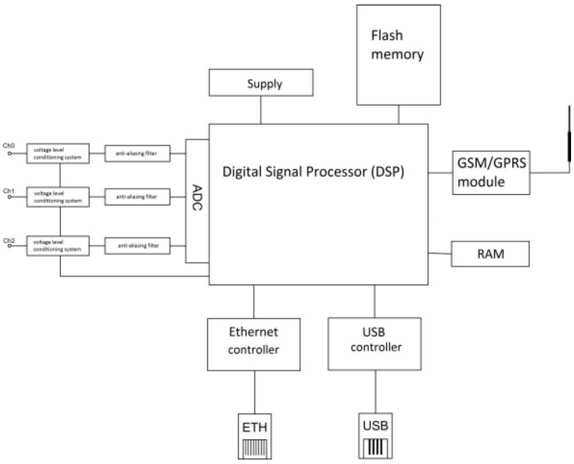

Fig. 20. Block diagram of the device for recording, processing and transmission of measurement results.

5. Description of a recording device

The telemetry device is equipped with a number of features to perform the measurement, recording, storing the measurement results and inform the research laboratory of the situation on the subject of research. Analyzer software allows to set some thresholds on input signals to the device. When the measured signal exceed the threshold set, the device can do the following:

- store information about the occurrence of the event in the memory card,
- save waveform on the memory card - including defined time before the event,
- inform the research team through a short text message (SMS),
- inform the research team via e-mail,
- send the recorded results, for request.

Configurable device is high (measuring range selection, change the thresholds, change the sampling frequency, change the definition for calculation values etc.) and possible to carry through the application working on a PC. Request to generate a special report about the state of the device and the tested object can be sent via properly formatted short text message.
All these features give users the ability to remotely control the measuring device and the same measurements. The appearance of the telemetry module is shown in Figure 21. Summary, telemetry module can be used for continuous monitoring of critical drives. For example, this telemetry module has been registered 6kV, 2000kW motor start-up (current) in cement plant. The current waveform is shown in Figure 22.

Fig. 21. Appearance of the telemetry module.

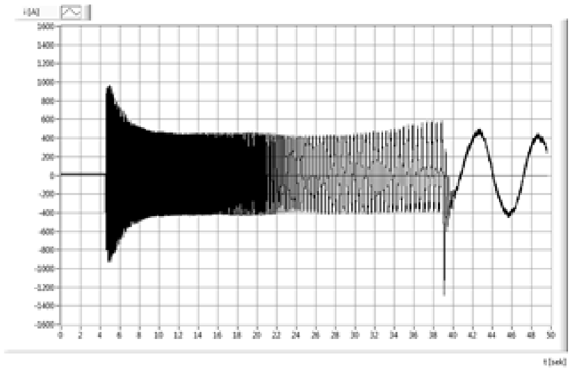

Fig. 22. The current waveform of 6kV, 2000kW motor (phase U).

6. Other telemetry devices for testing electrical motors

Telemetry systems provide also, a simple method of measuring torque or voltage signals on rotating electrical machines while operating in a contactless mode. Continuous power is supplied from little lithium battery and the signal is transmitted from the moving to the stationary component – with no brushes or wires. The wireless transfer guarantees an absolute wear-free continuous operation and accurate transmission of measured data [15].
TEL1-PCM system is easy to configure, assembly and install, and the flexibility of using battery power for the rotor electronics.
Installed and complete telemetry system for torque measurement is shown in Figure 23. Recorded waveform of the torque during startup is shown in Figure 24.

Fig. 23. Telemetry system for torque measurement

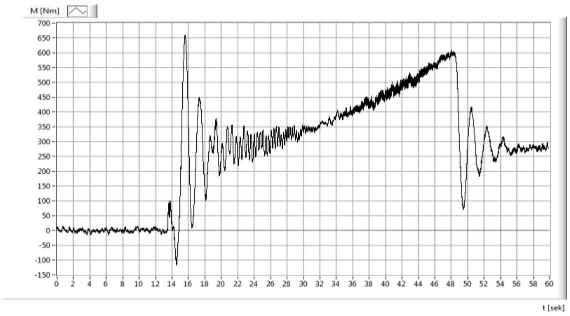

Fig. 24. Waveform of the torque during startup

7. Conclusion

Develop a method that will allow on-line assessment of technical condition, basing on measurement and analysis of operating parameters, guarantees reliable operation of electrical machines. A number of publications [3, 8, 9, 11] indicates that data relevant to condition of electrical machines (synchronous, induction, direct current) are encoded in the current and voltage waveforms. This must be acquired, processed and sent to the monitoring central. Thanks to communications over the Internet or GSM implemented systems will have the following advantages:

- low cost of remote control and monitoring system and short time for the preparation of the system,
- possibility to supplement the measurement parameters obtained from the sensors,
- possibility of notifying the services responsible for the operation of machines when emergency situations arise,
- opportunity to observe the measurement results simultaneously by many people.

8. Literatura

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