Cracow University of Technology

Faculty of Electrical and Computer Engineering

Measurement system for diagnosis of rotor cage defects in induction motors

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Presentation plan

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3. Specification and components of measuring device - NI DAQ
4. Specification and components of measuring device – SENSORS
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Statement of conformity

The developed instrument complies with the following Standards

1. PN-EN 61010-1:2011 Safety requirements for electrical measuring instruments, automation and laboratory equipment -- Part 1: General requirements.
2. PN-EN 50191: 2011 Installation and operation of electrical test benches
3. PN-EN 61000-6-4:2019 Electromagnetic compatibility (EMC) -- Part 6-4: General standards -- Emission standard for industrial environments
4. PN-EN 61000-6-2:2019 Electromagnetic compatibility (EMC) -- Part 6-2: General standards -- Immunity in industrial environments

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Specifications and components of the measuring device – PC

Fig. 1: Lenovo ThinkPad X280 mini laptop computer

Fig. 2: Docking station Lenovo ThinkPad Pro Dock 65W

***Lenovo ThinkPad X280* specifications**	
Processor	Intel Core i7-8650U 4x 4.2Ghz
Matrix	12,5'' FULL HD IPS 250NIT
HDD	SSD M.2 - 240GB
HDD 2	empty slot
RAM	8GB DDR4 2400MHz
Graphics	Intel HD Graphics 520
Warranty	36 months (On-Site)
System	Windows 10 Pro 64 bit PL
Weight	1,46 kg
Measurements	Width: 310mm, depth: 220mm, height: 18m
Ports	HDMI, USB 2.0, USB 3.0, USB 3.1 typ A, USB 3.1 typ C, Thunderbolt, minijack 3,5 mm (audio), docking connector
Media	memory card reader, camera, speakers, microphone
Communications	WLAN: Intel®Dual Band Wireless-AC (2 x 2), Bluetooth 4.2
Tools	Backlit keyboard, TouchPad + TrackPoint

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Specification and components of measuring device - NI DAQ

Fig. 3. NI USB-6361 measurement card

Counters / Timers	
Watchdog Timer	Yes
Counters	4
Buffered Operations	Yes
Debouncing / Glitch Removal	Yes
Max Source Frequency	100 MHz
Pulse Generation	Yes
Size	32 bits
Timebase Stability	50 ppm
Logic Levels	TTL
Timing / Triggering / Synchronization	
Triggering	Analog, Digital
Synchronization Bus(RTSI)	No

General	
Product Family	Multifunction DAQ
Measurement Type	Digital, Frequency, Quadrature encoder, Voltage
Form Factor	USB
Operating System / Target	Windows
RoHS Compliant	Yes
Isolation Type	None

Analog Output	
Number of Channels	2
Resolution	16 bits
Maximum Voltage Range	-10 V - 10 V
Minimum Voltage Range	-5 V - 5 V
Update Rate	3.33 MS / s
Current Drive Single	5 mA

Digital Input	
Input Type	Sinking, Sourcing
Maximum Voltage Range	0 V - 5 V
Digital Output	
Output Type	Sinking, Sourcing
Current Drive Single	24 mA
Current Drive All	1 A
Maximum Voltage Range	0 V - 5 V

Digital I / O	
Bidirectional Channels	24
Input-Only Channels	0
Output-Only Channels	0
Timing	Hardware, Software
Clocked Lines	8
Maximum Clock Rate	1 MHz
Logic Levels	TTL
Programmable Input Filters	Yes
Supports Programmable Power-Up States?	Yes

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Specification and components of measuring device – SENSORS

Fig.4. Fluke 80i-110 current probe

Fig.5. Rogowski coil of CWT series

General	
Output Voltage	max. 1 V
Connector	BNC
A/AC Measurement range	0.05 - 100 A
A/DC Measurement range	0.05 - 100 A
Power supply	Block battery 9
Class of insulation	CAT IV 300 V
Clamp	
Basic accuracy	3 %
Weight	330 g
Measurements	(DxSxW) 231 x 36 x 67 mm

General	
Measurement range	300mA do 1.2kA
Output signal	± 6V for max current
Frequency band	0.1Hz - 16MHz
Accuracy	± 1% (measured value)
Linearity	± 0.05% (full scale)
Coil cross section	8.5 mm or 14mm with sleeve (10 kV resistance)
Operating temperature of the coil	-20°C...+100°C
Operating temperature of the power supply	0°C...+40°C
Connector	BNC

Proprietary software – CAGELab

Dedicated software for measurement data collection, analysis and preparation of reports with test results. Software functions to determine current diagnostic indicator values and automatically evaluate the condition of tested machines.

The following modules are available to the user:

- Measurement Module - a module for initiating a measurement and performing the diagnostic process,
- Database module - a module for managing measurement results.

Fig.6. CAGELab logo

CAGELab software was developed using the MATLAB environment. The recipient receives a compiled application that runs independently. The consumer does not need to own the MATLAB environment.

The consumer receives a complete manual of the software along with technical support.

The software is versatile and can be expanded for the specific needs of the consumer.

The software is currently in Polish but an English version can be created to meet the needs of the customer.

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CAGELab - Database module

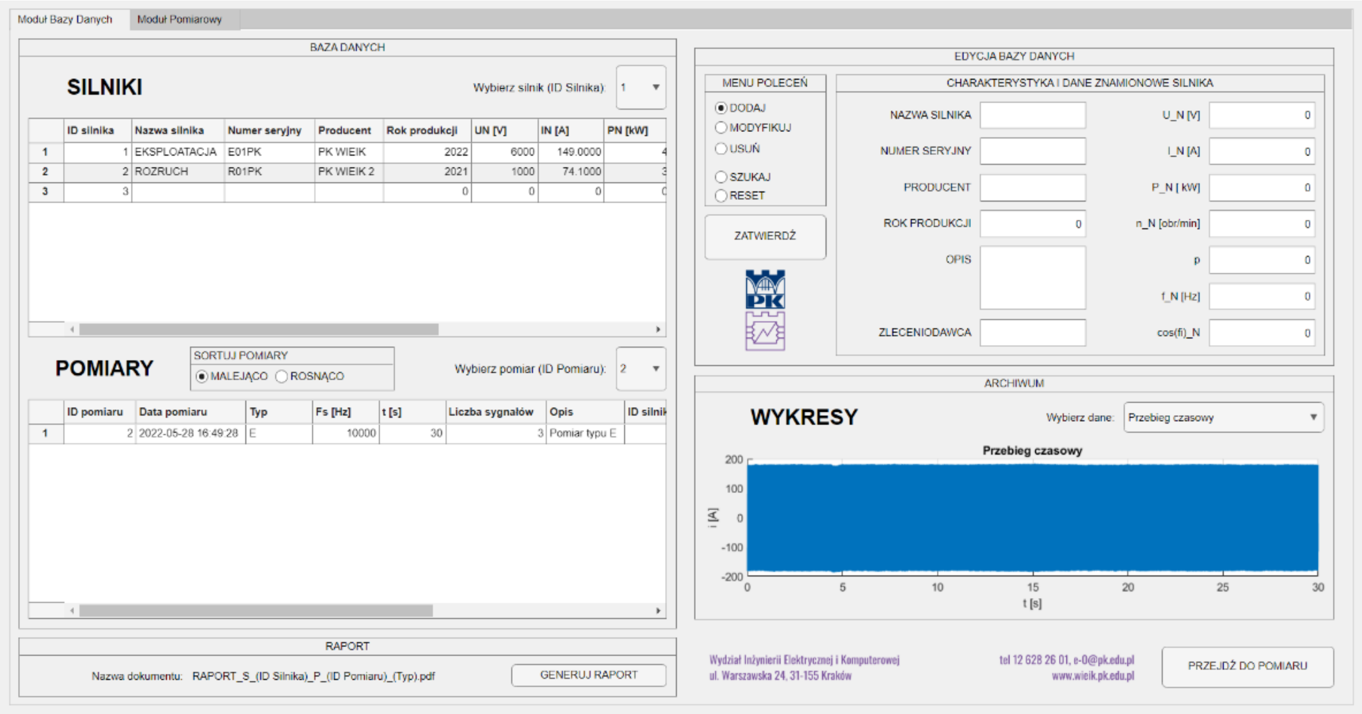

Fig.7 Database module

The database module is responsible for storing data about the tested machines and the diagnostic measurements made for them. This module displays records containing engines and measurements associated with a given engine.

The measurements are displayed on a chart accordingly. The user has the ability to add a new record - an engine - to the database, modify an existing engine record or delete it.

This module provides to the main functions of the application, the base parameters (ratings) necessary to make the corresponding measurement. In this way, the user gains time when operating the application and minimizes the possibility of entering wrong parameters.

The module also allows you to generate a report of the measurements and analysis performed. The target file has a PDF format, which includes graphs, descriptions, parameters and diagnostic recommendations based on legal standards.

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CAGELab - Measurement module

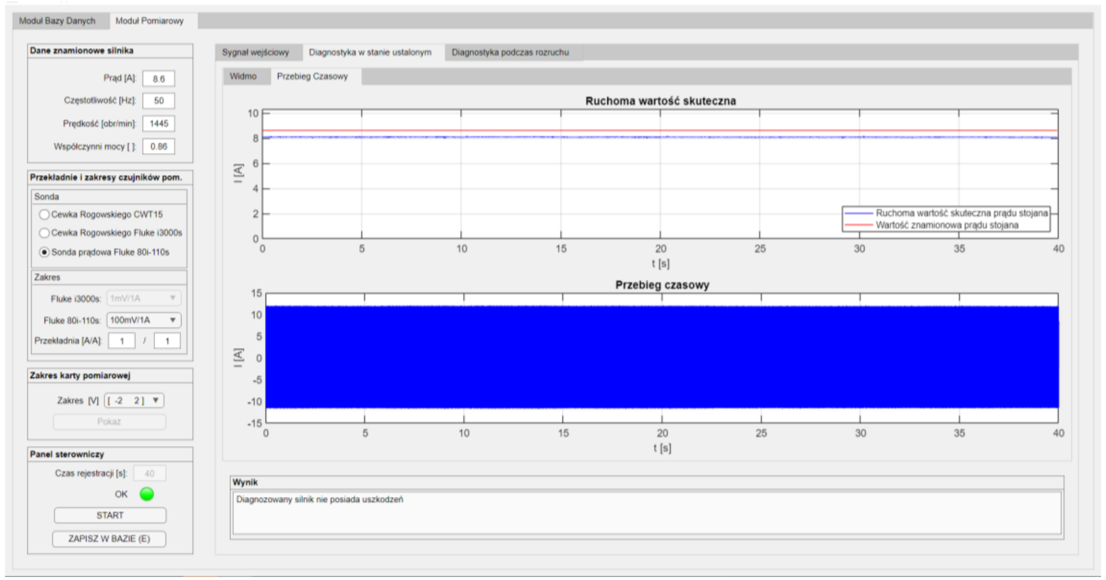

Fig.8. Measurement module - Steady state diagnostics

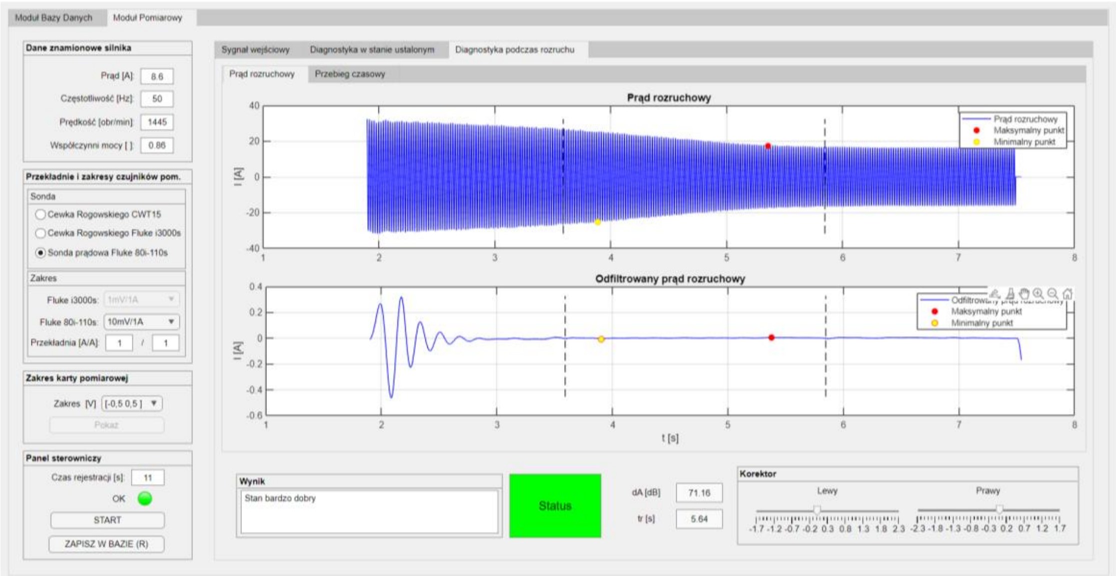

Fig.9. Measurement module - Diagnostics during startup

The Measurement Module is responsible for performing signal acquisition using Rogowski Coils or Current Probes.

Diagnostics allows the analysis of measurements made:

- in steady state,
- during machine startup.

Registration of diagnostic signals

Registration of stator currents for the above-mentioned types of rotor cage condition tests can be performed in two ways:

a) at the switchgear - by recording the current in the secondary circuits of current transformers using current probes (Fig.1).

b) (b) at the motor - by means of Rogowski Coils hooked up to the power wires at the point where the wires are not shielded (Fig.2).

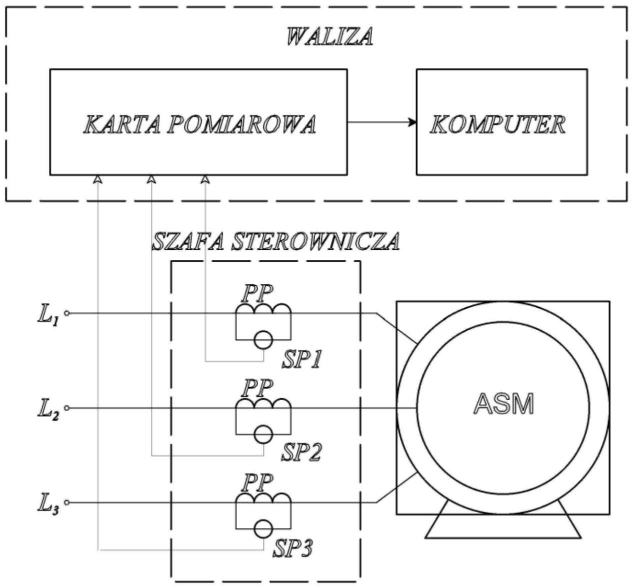

Fig. 10: Schematic of the measurement system using current probes, where: SP1, SP2, SP3 - current probes; PP - current transformer, ASM - induction motor.

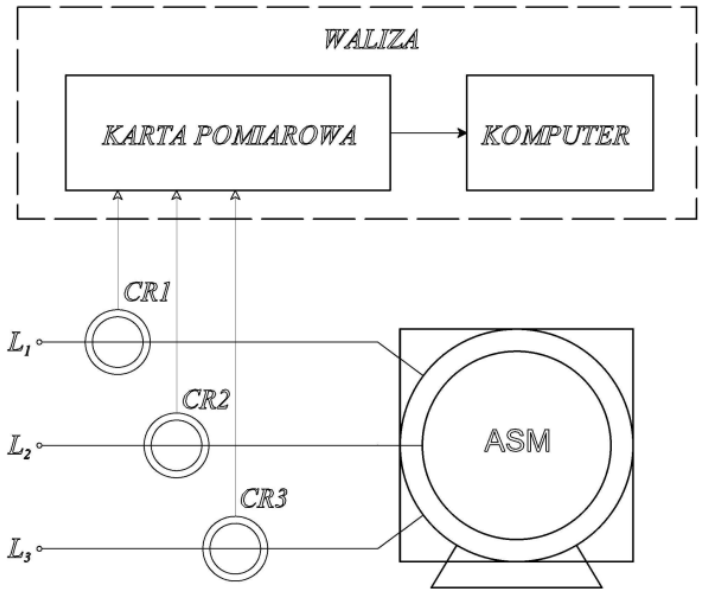

Fig. 11: Schematic of the measurement system using Rogowski Coils, where: CR1, CR2, CR3 - Rogowski coils; ASM - induction motor

Requirements for the diagnostic process

1. **Steady-state diagnostics**

During the steady-state diagnostic process, the motor must be supplied with the rated rms voltage and frequency. The rms value of the stator current during registration should be greater than 70% of the motor's current rating. However, it is best to load the motor so that the stator current takes the rated value. This will allow the most accurate determination of the motor's slip and, consequently, the precise determination of slip harmonics.

2. **Diagnostics during startup**

For the diagnostic process during startup, the motor must be supplied with voltage at the rated frequency. It is permissible to start at a voltage lower than the rated voltage in order to extend the starting time, if under rated power supply conditions this time is less than 2.5s.

Starting with variable frequency, e.g. U/f = const, is not allowed.

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Definition of the RFI diagnostic indicator

The algorithm to assess the condition of the cage uses the so-called **RFI (Rotor Fault Index)**, which is expressed by the formula:

$$RFI = \frac{\max\left(A_l, A_p\right) - A_{szum}}{A_0 - A_{szum}} \cdot p$$

The **RFI** is based on the ratio of the relative value of the maximum band to the relative value of the fundamental harmonic multiplied by the number of pole pairs. Relative - means measured from the signal noise level A_{szum}.

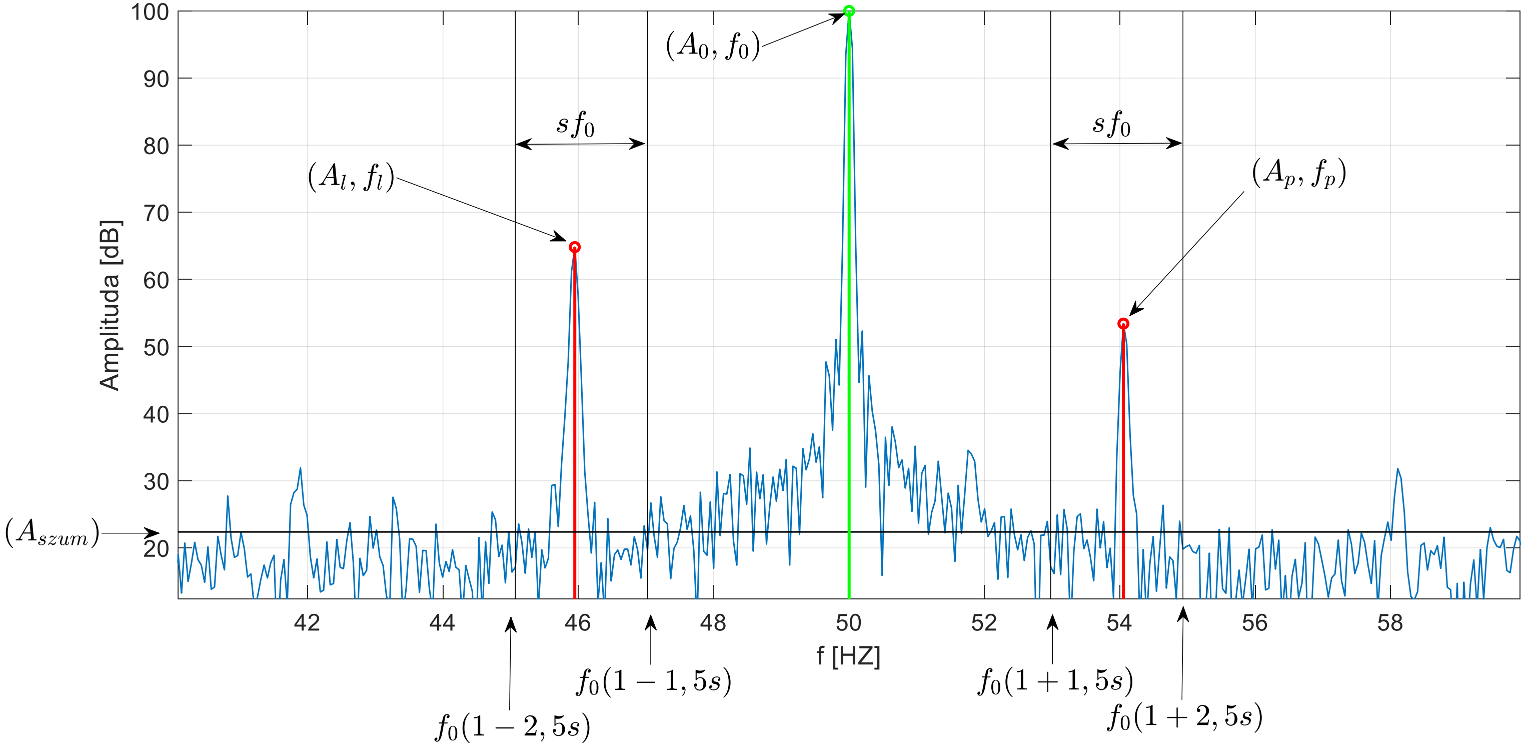

Fig. 12. Example of stator current spectrum of a motor with a defective rotor cage

The basic harmonic of the stator current with amplitude has A_0 been marked in green.

In red the sidebands - left and right with amplitudes respectively: A_1 i A_p.

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Laboratory tests - steady state

Laboratory tests of the device module responsible for rotor cage fault detection were carried out on a low-power induction motor. The motor was loaded at its rated load during the measurement. The rotor cage fault detection function was triggered manually from the user panel. Measurements were performed for four types of rotors:

a) symmetrical,

b) with one broken bar,

c) with two broken bars (case A),

d) with two broken bars (case B).

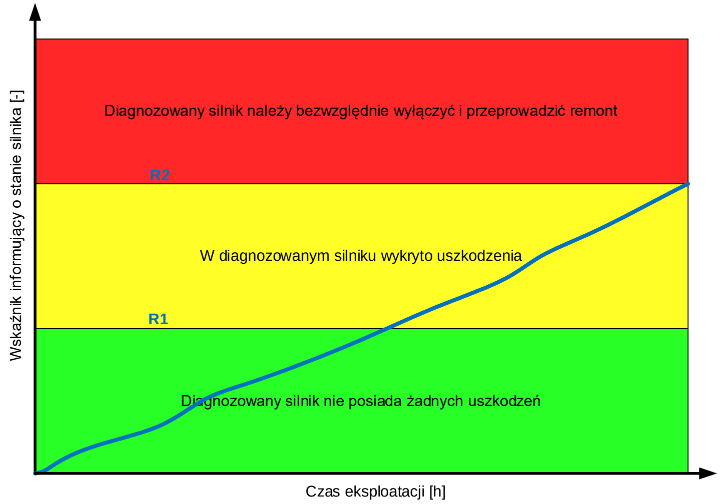

Figure 13: Illustration of the idea of machine tracking

Based on the Standards, the range of RFI coefficients for an induction motor was determined. Laboratory tests proved the validity of using the RFI index as a method for diagnosing rotor cage damage at steady state.

ROTOR	RFI
symmetrical	0,755
with one broken bar	1,097
with two broken bars (case A)	1,110
with two broken bars (case B)	1,139

Definition of the DRFI diagnostic indicator

The algorithm for detecting rotor cage damage during startup is based on measuring and analyzing the current of one of the stator phases. Based on the course of the stator current *I*, the algorithm determines the duration of the start-up. At the same time, it takes the maximum current as the moment t_p the machine is connected to the network. Then the algorithm estimates the time of termination of the dynamic state. For this purpose, it uses the properties of the moving rms value calculated for the period of the fundamental component of the network. The moment of termination of the startup t_k is considered to be the case when the difference of the rms value calculated in a given time interval to the value in the immediately preceding interval is approximately equal to zero and the calculated rms value is less than the adjustable current I_{RK} .

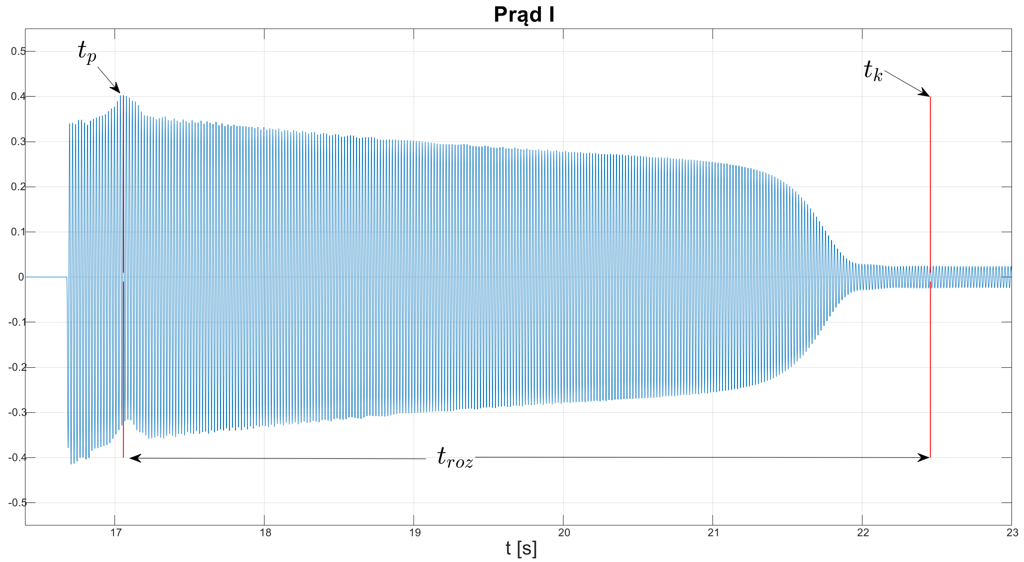

Fig.14. Stator current during start-up initiation

Further signal processing is possible if the startup time t_{roz} is greater than the adjustable minimum startup time t_{minroz}. This condition is necessary because in the case of short start-ups it is very difficult to capture the current component indicating damage to the rotor cage.

Once the condition related to the startup time is met, the current I_{roz} is subjected to low-pass filtering to look for symptoms corresponding to rotor cage damage.

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Definition of the DRFI diagnostic indicator

After final selection of the amplitudes in the signals of the separated filtered inrush current *A* and inrush current *A*₀, the **DRFI (Dynamic Rotor Fault Index)** cage fault index is calculated based on the formula:

$$DRFI = -20 \cdot \left[\log_{10}\left(\frac{A}{A_0}\right) - \log_{10}\left(\frac{A_0}{A_0}\right) \right]$$

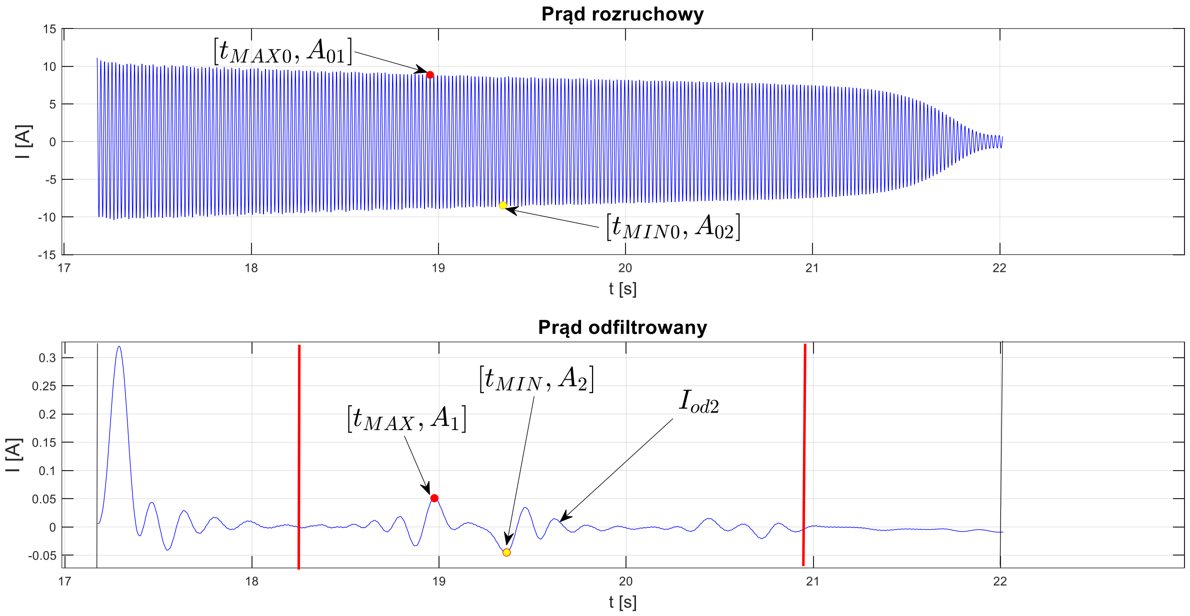

Fig.15. Visualization of the determination of indicators

The DRFI index can be cross-referenced to the MCSA standard and the condition of the rotor cage can be preliminarily determined from the table opposite.

DRFI [dB]	Rotor status - alarm
60	Very good
54 - 60	Good
48 - 54	Satisfactory
42 - 48	Occurrence of high-resistance connections, onset of rotor cage damage
36 - 42	Damage to rotor cage bars
30 - 36	Combined failure of rods and short-circuit rings

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Laboratory tests - startup

Laboratory tests of the module responsible for detecting rotor cage faults during start-up were carried out on stator current waveforms recorded during start-ups of medium-power motors in one of Poland's refineries.

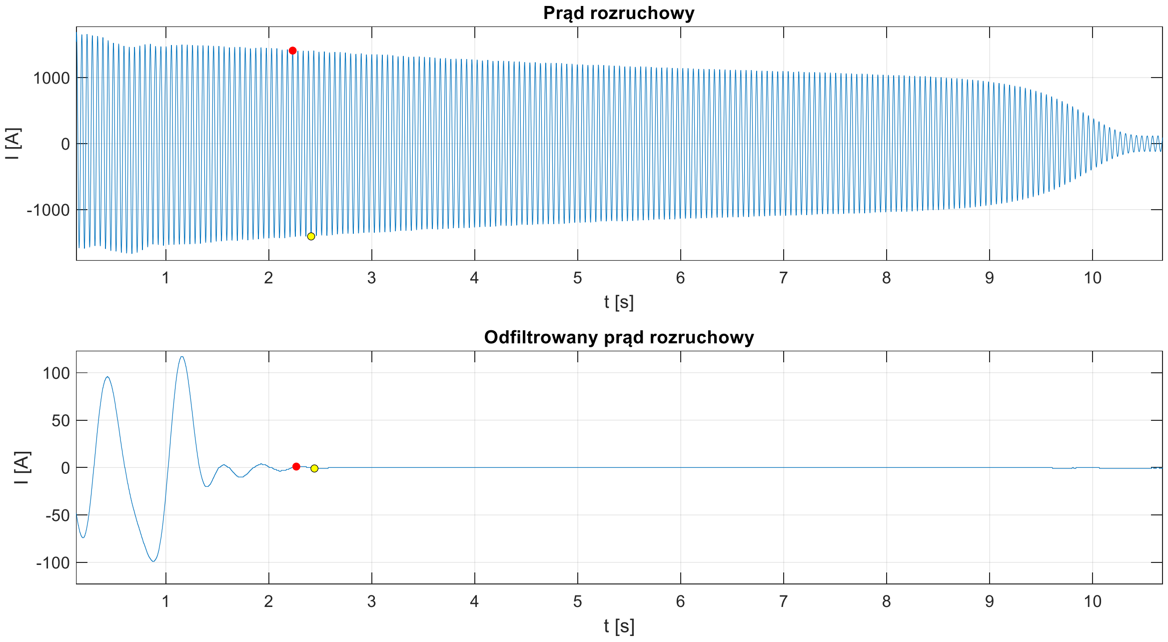

Fig. 16. Inrush current and filtered inrush current of motor No. 1 with healthy rotor cage

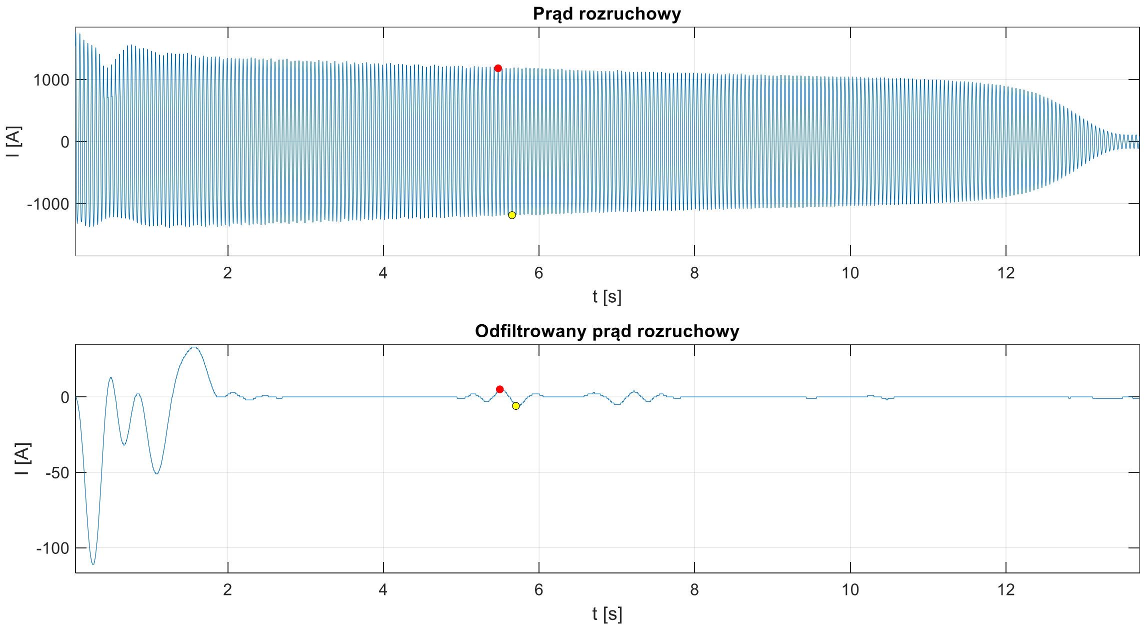

Fig. 17. Inrush current and filtered inrush current of motor No. 2 with damaged rotor cage

No.	A_1 [A]	A_{01} [A]	A_2 [A]	A_{02} [A]	DRFI
1	0	1372	-1	-12767	62,05
2	5	1181	-6	-1187	45,92

Gallery

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