Monitoring systems for wind power plant generator

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Objectives

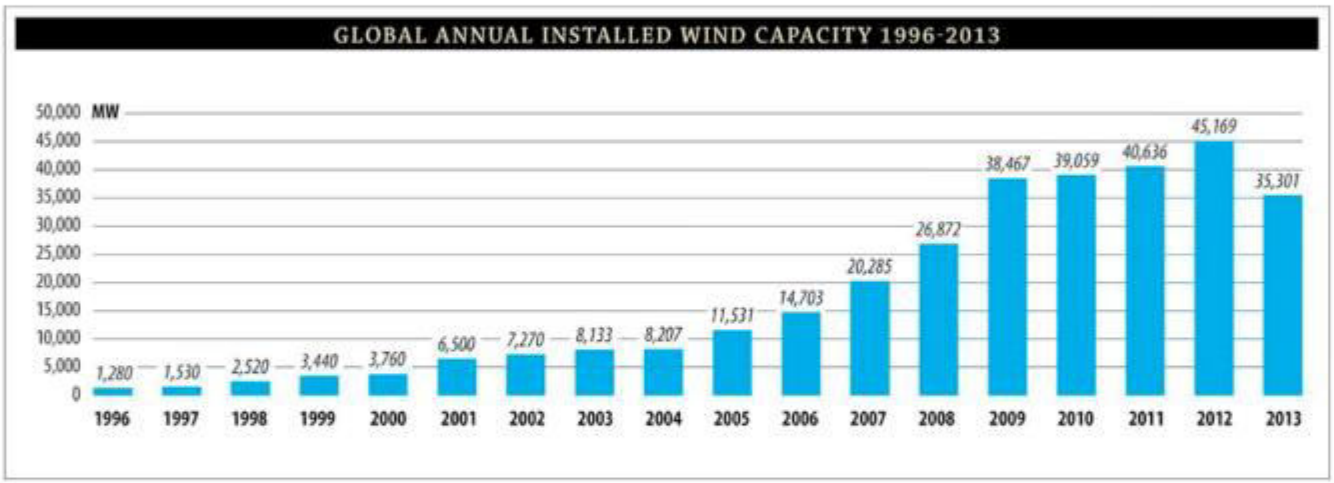
- Wind Power Plant in Electric Power System
- Types of electrical machines used in wind power plants- asynchronous generator
- Monitoring system of asynchronous generator

Energy power system

- non-renewable and renewable energy, wind power technology (wind turbine types, wind turbine subsystems, blades, generator,etc).
- future technology related to improving performance and reducing costs in wind power plants.

Global cumulative wind power capacity

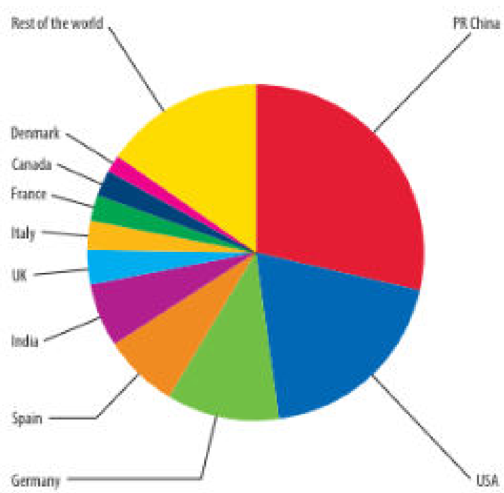
2013 growth: - 21%



18 yr avg. growth: 23.7%

Top 10 cumulative & new installed capacity

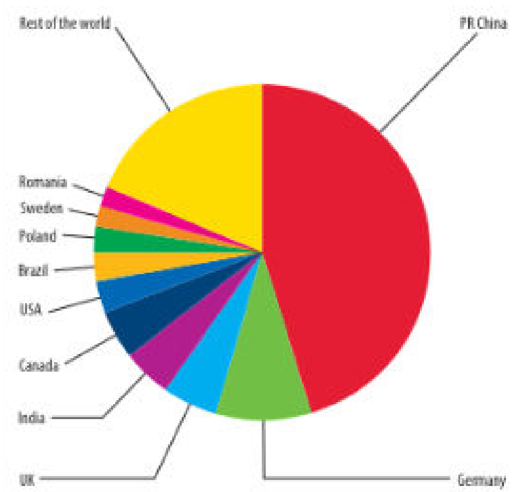
TOP 10 CUMULATIVE CAPACITY DEC 2013



Country	MW	% SHARE
PR China	91,424	28.7
USA	61,091	19.2
Germany	34,250	10.8
Spain	22,959	7.2
India	20,150	6.3
UK	10,531	3.3
Italy	8,552	2.7
France	8,254	2.6
Canada	7,803	2.5
Denmark	4,772	1.5
Rest of the world	48,332	15.2
Total TOP 10	**269,785**	**84.8**
World Total	**318,117**	**100.0**

Source: GWEC

TOP 10 NEW INSTALLED CAPACITY JAN-DEC 2013



Country	MW	% SHARE
PR China	16,100	45.6
Germany	3,238	9.2
UK	1,883	5.3
India	1,729	4.9
Canada	1,599	4.5
USA	1,084	3.1
Brazil	953	2.7
Poland	894	2.5
Sweden	724	2.1
Romania	695	2.0
Rest of the world	6,402	18.1
Total TOP 10	**28,899**	**82**
World Total	**35,301**	**100.0**

Source: GWEC

- **Wind definition**: a natural movement of air of any velocity; *especially* **:** the earth's air or the gas surrounding a planet in natural motion horizontally (according to Merriam –Webster dictionary)
- **Wind energy** : wind is a form of **solar energy**.

Winds are caused by:

-the uneven heating of the atmosphere by the sun,

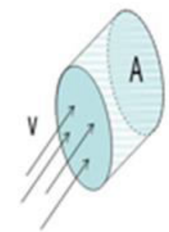
-the irregularities of the earth's surface,

-rotation of the earth.

Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover.

This wind flow, or motion energy, when "harvested" by modern **wind turbines**, can be used to generate **electricity**.

Equation of wind power



Kinetic energy: $E_c=1/2\ mv^2$
Power= E_c per unit time
Fluid mechanics gives $P=1/2\rho\ Av^3$
ρ -air density

A-rotor swept area

v-speed of air

Wind power technology

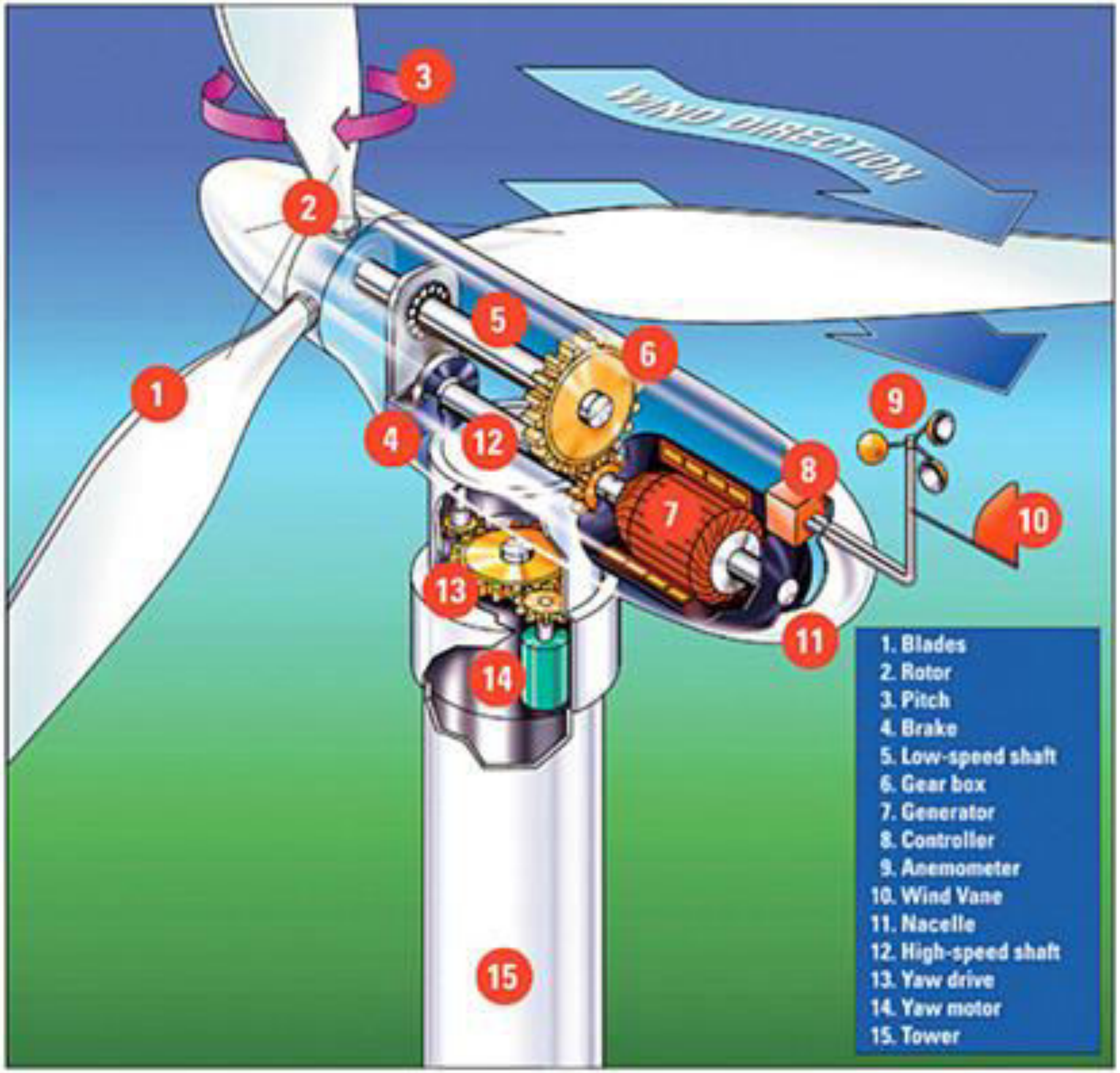
- Horizontal axis

- Vertical axis

-Darrieus rotor

-Savonius rotor

Wind turbine subsystems



Electrical generator

- Synchronous/permanent magnet generator

-potential use without gearbox

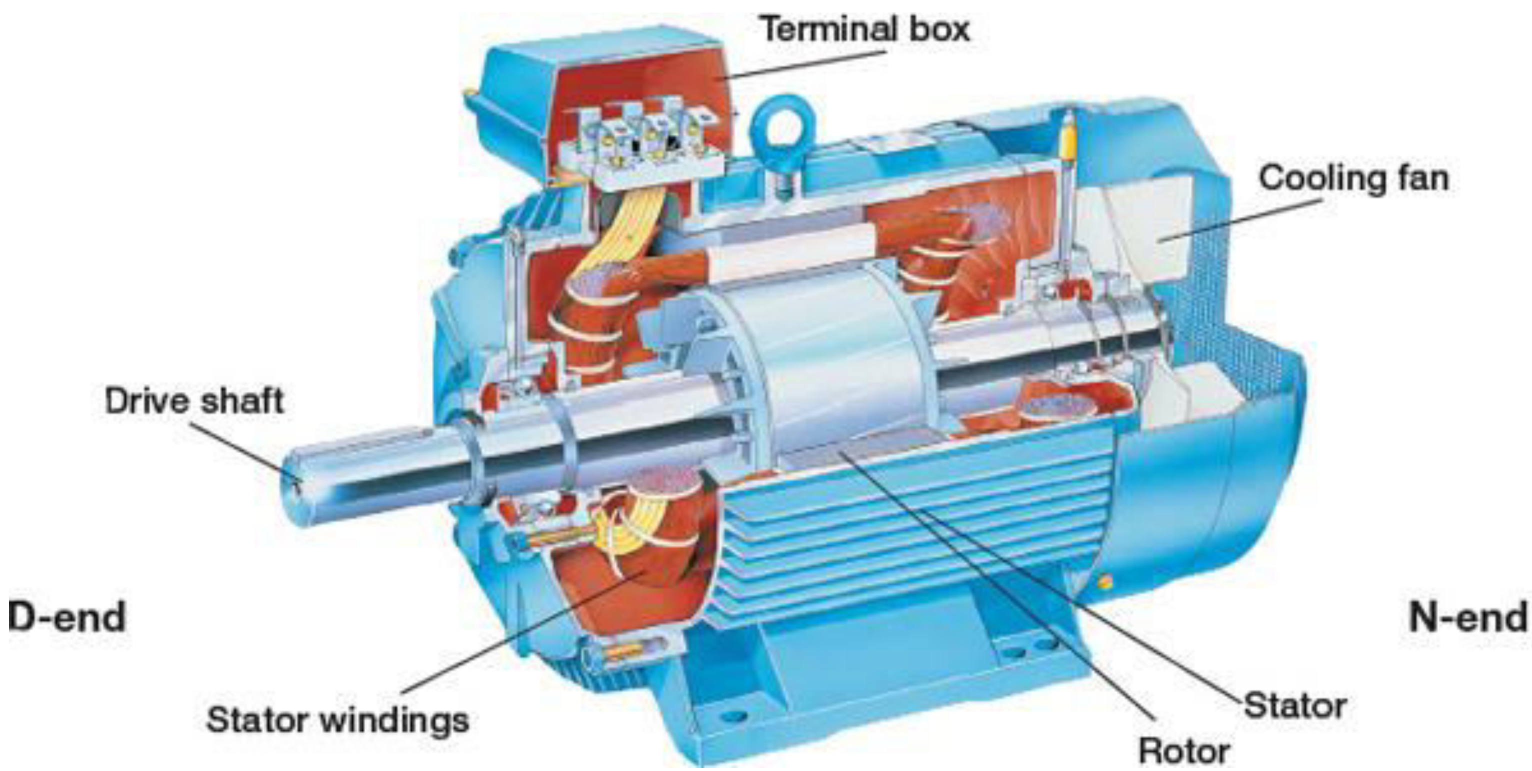
-high cost

- Asynchronous/induction generator

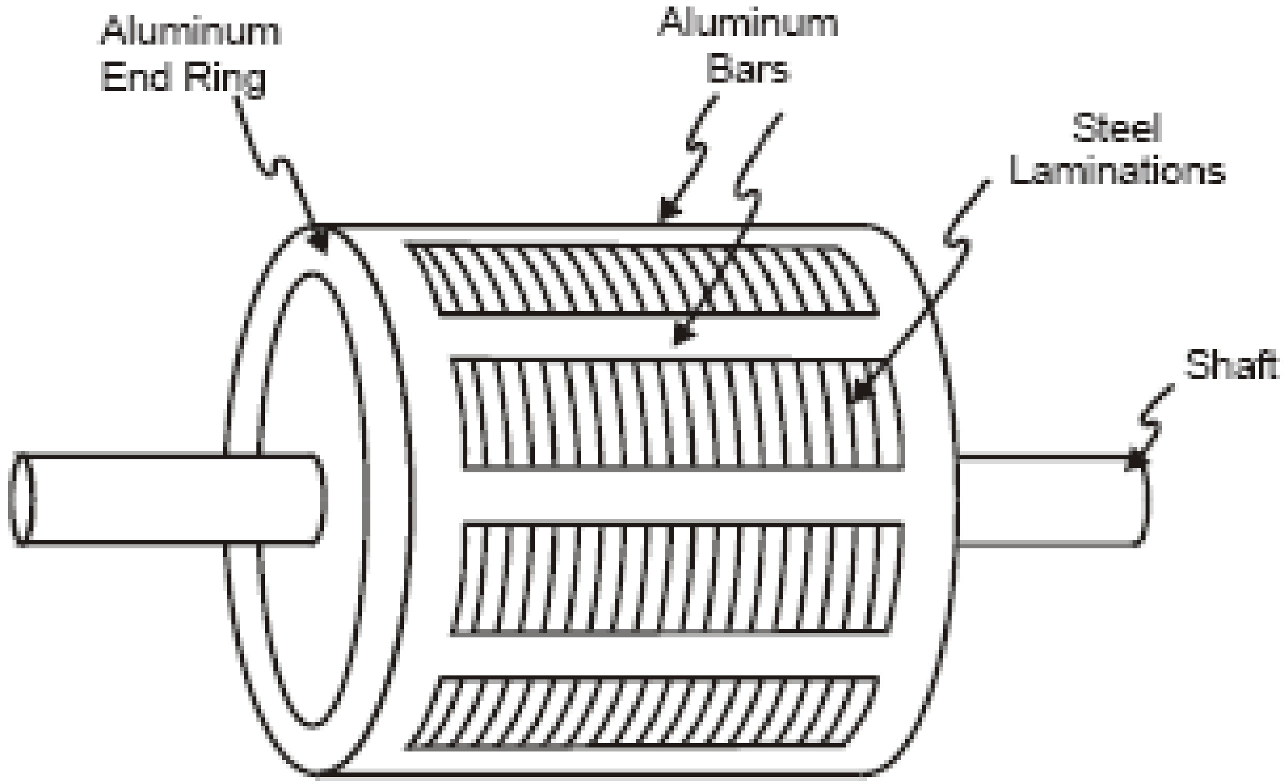
-slip (operation below synchronous speed possible)

-reduce gearbox wear

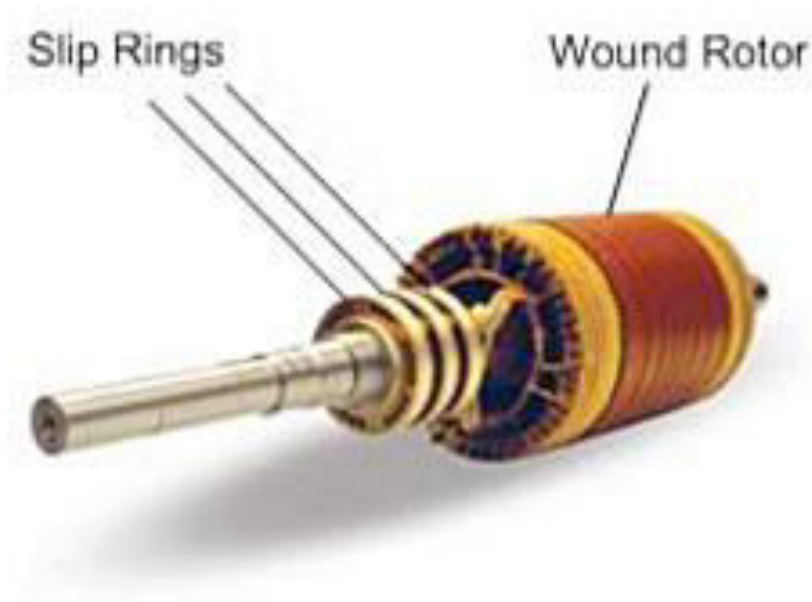
Components parts of induction generator



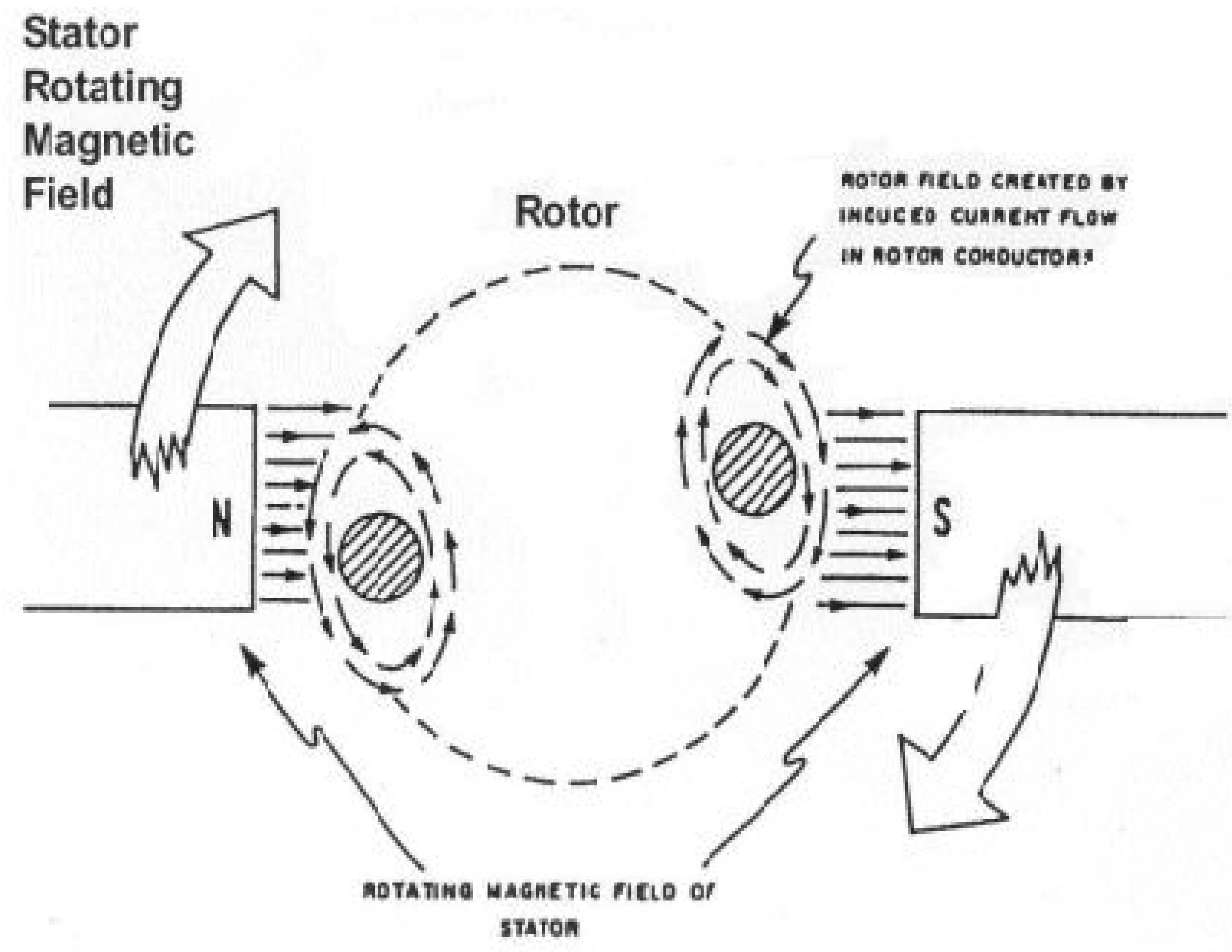
Squirrel cage induction machine rotor



Wound rotor induction generator



Operating principle of induction machine

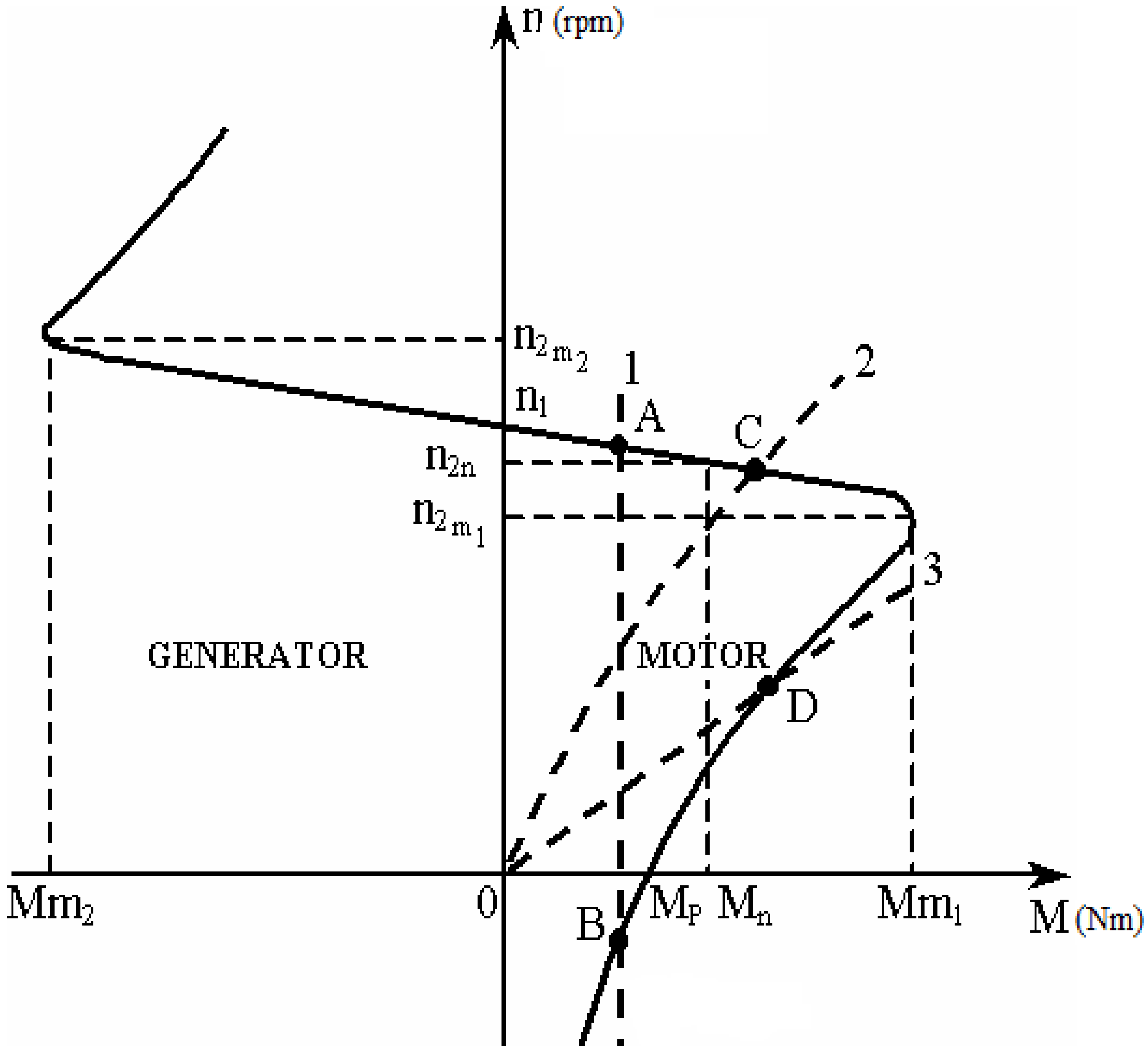


Synchronous speed: $$n_s = \frac{60 f_1}{2p}$$

$$f_1 = \frac{\omega}{2\pi}$$, stator current frequency

$$s = \frac{n_s - n}{n_s} 100\%$$ Slip of induction motor

Load characteristcs of induction machine



Basic problems of the induction machine fault’s

1. Winding faults:

- short-circuits of stator windings,
- **short-circuits of rotor windings, broken rotor bars**,
- broken rings of the rotor.

2. Faults of the magnetic circuit:

- air-gap asymmetry
- stacking clearance.

3. **Faults of the machine mechanical system (mainly bearing failures).**

The techniques used to detect the presence of bearings and rotor failure

- vibration spectrum
- noise spectrum
- monitored stator current – rms value
- monitored stator current spectrum

Fast Fourier Transform

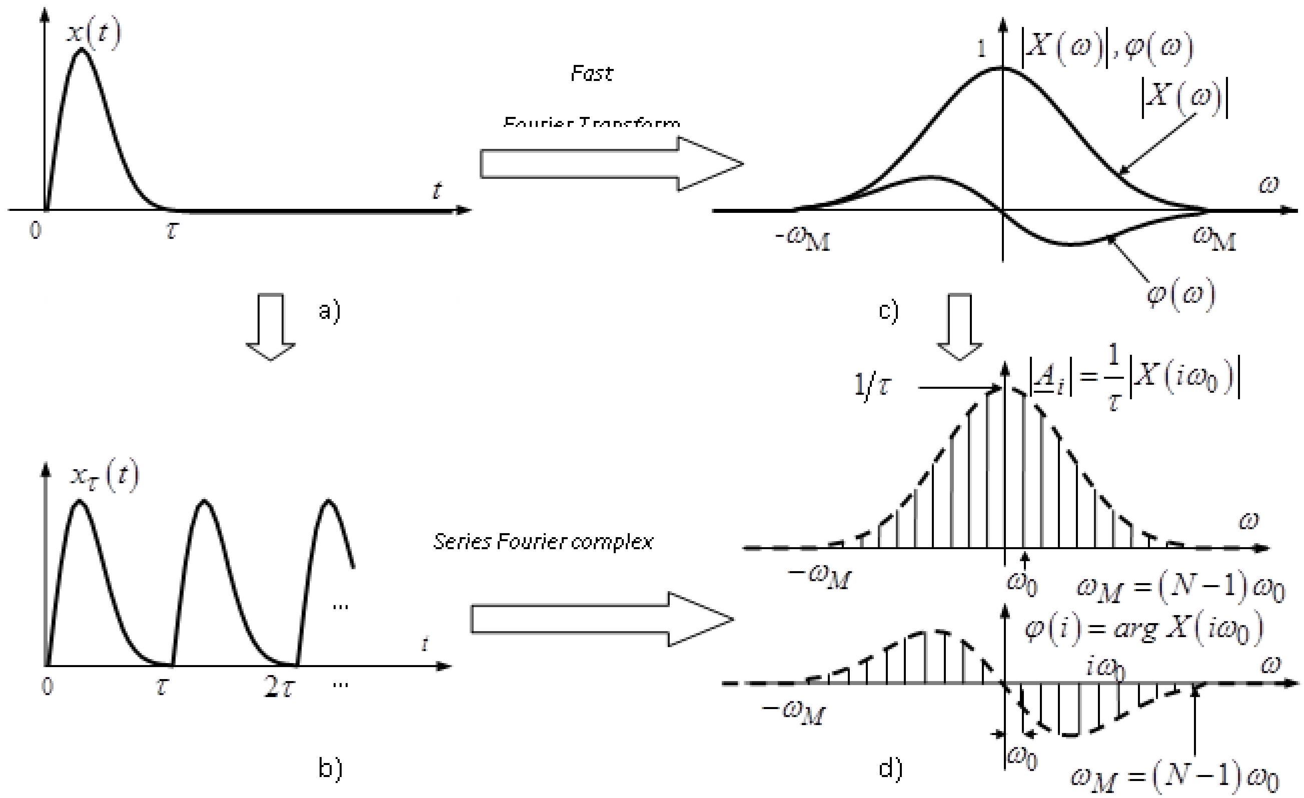
$$x_\tau(t) = \sum_{m=-\infty}^{\infty} x(t - m\tau)$$

$$x_\tau(t) = \sum_{i=-\infty}^{\infty} \underline{A}_i e^{j i \omega_0 t} \qquad \omega_0 = \frac{2\pi}{\tau}$$

$$\underline{A}_i = \frac{1}{\tau} X(i\omega_0)$$

$$x_\tau(t) = \frac{1}{\tau} \sum_{i=-\infty}^{\infty} X(i\omega_0) \cdot e^{j i \omega_0 t}$$

Fast Fourier Transform



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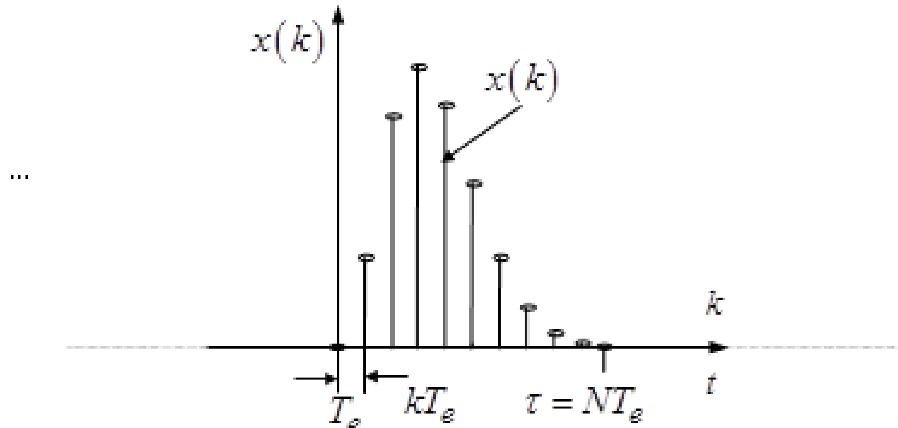

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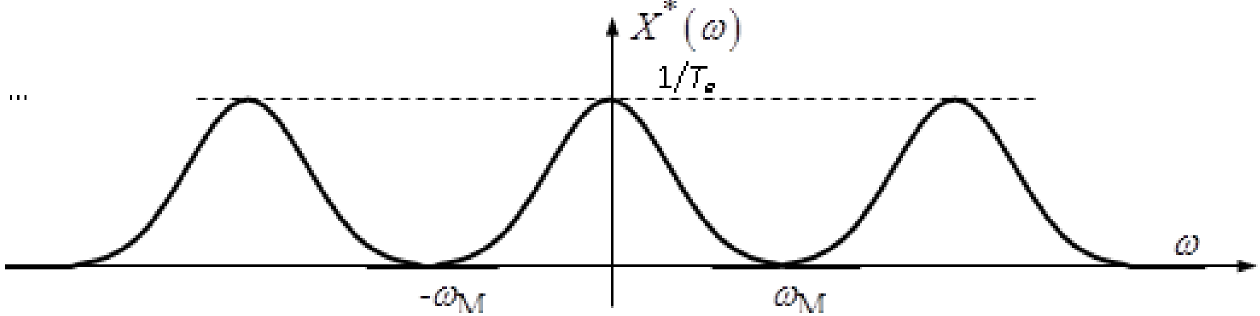


$$x(t)=\begin{cases}\dfrac{1}{\tau}\cdot\sum\limits_{i=-\infty}^{\infty}X(i\omega_0)\cdot e^{ji\omega_0 t}, & 0\le t\le\tau\\ 0, & \text{în rest}\end{cases}$$

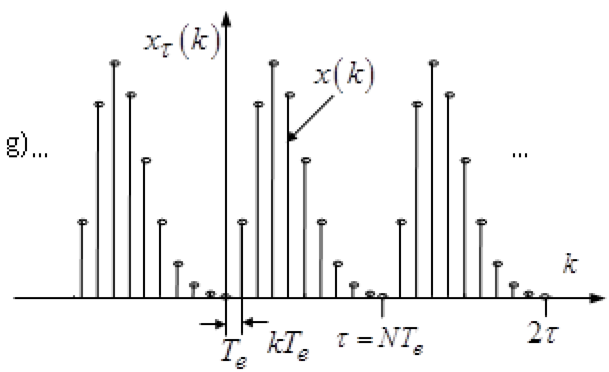
$$T_e=1/2f_M \qquad f_M=\omega_M/2\pi$$

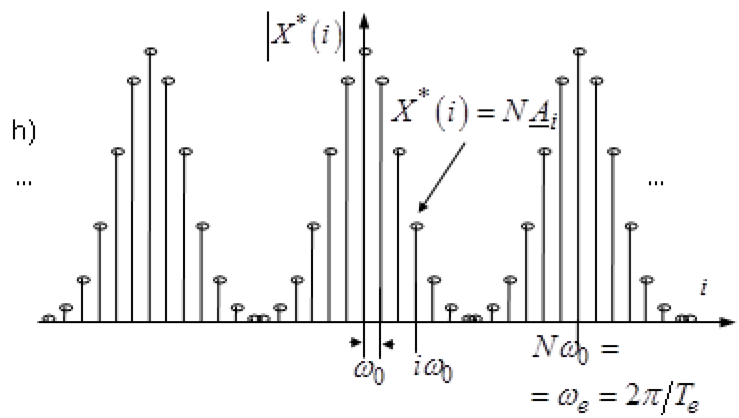
$$N=\tau/T_e \qquad t=k\cdot T_e$$

$$X(\omega)=T_e\cdot\sum_{k=0}^{N-1}x(k)\cdot e^{-j\omega kT_e}$$

$$X^*(i)=\sum_{k=0}^{N-1}x(k)\cdot e^{-jik\frac{2\pi}{N}},\quad i=0,1,2,\ldots N-1$$

Spectral characteristic of the signal





Rotor bars diagnosis in induction machine based on the vibration and current spectrum analysis

The reasons for rotor bars breakage

- Magnetic stresses caused by electromagnetic forces, unbalanced magnetic pull, electromagnetic noise and vibration;
- Thermal stresses due to thermal overload and unbalance, hot spots or excessive losses, sparking ;
- Mechanical stresses due to loose laminations, fatigued parts, bearing failure ;
- Residual stresses due to manufacturing problems;
- Environmental stresses cause for example by contamination and abrasion of rotor material due to chemicals or moisture;
- Dynamic stresses arising from shaft torques, centrifugal forces and cyclic stresses.

The techniques used to detect the presence of rotor bars failure

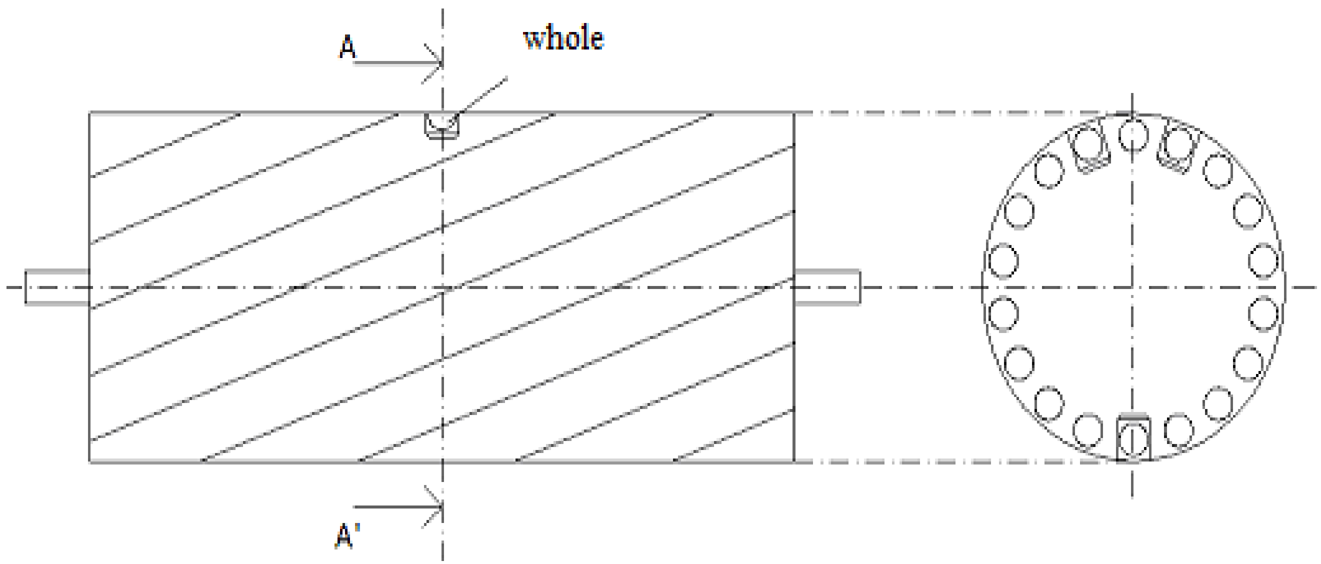
- -vibration spectrum
- -noise spectrum
- -monitored stator current spectrum

The vibration analyses

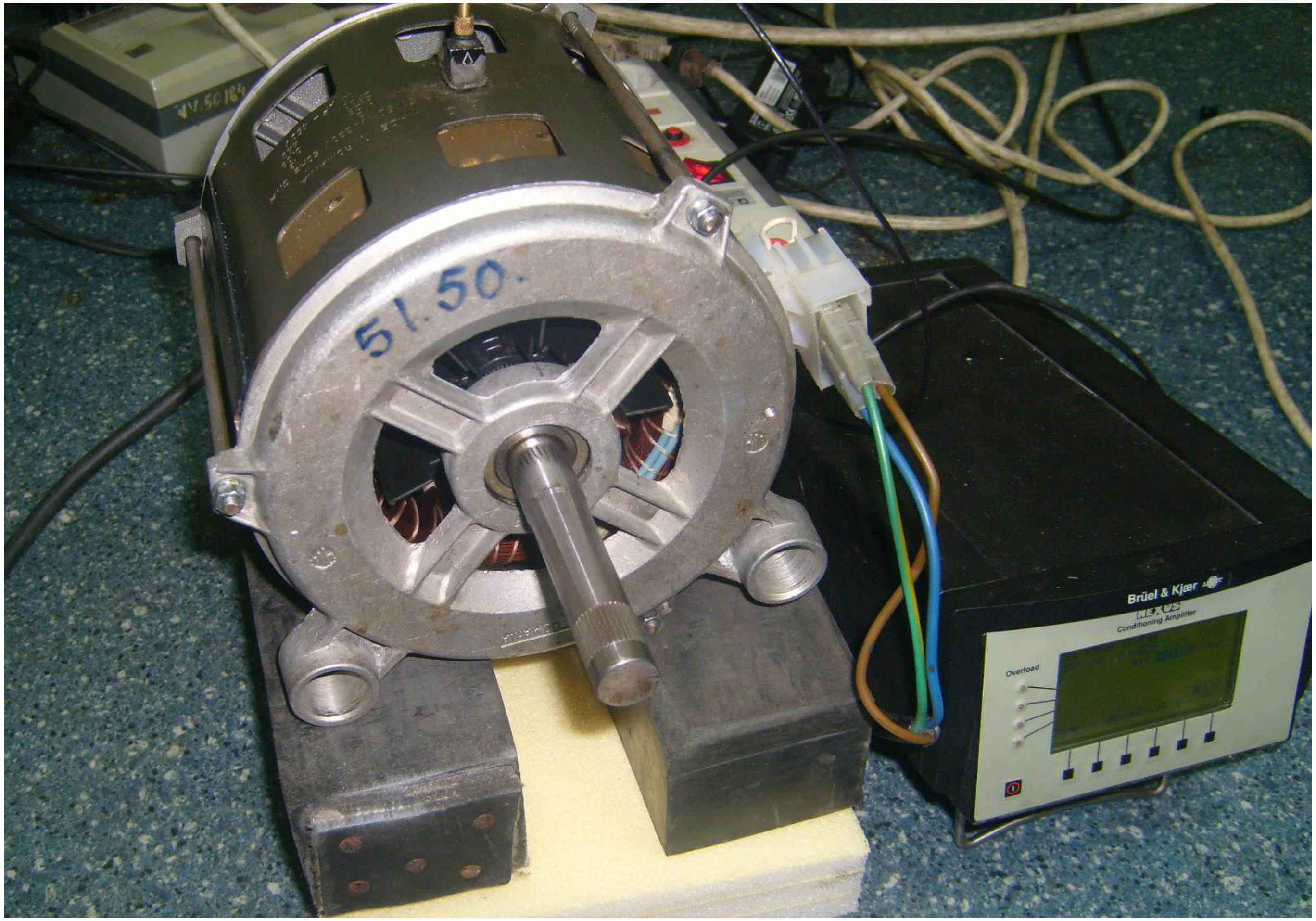
Operations that instruments must perform are the following:

- Measurement of overall vibration level in a standard frequency range and using the units required by these standards;
- Spectral analysis of the vibration, by using FFT.
- Analysis of the oscillation power of separate vibration components extracted preliminary from the vibration signal. The analysis of the spectrum of random high frequency vibration signal is usually used;
- Spectral analysis of the stator current, by using FFT

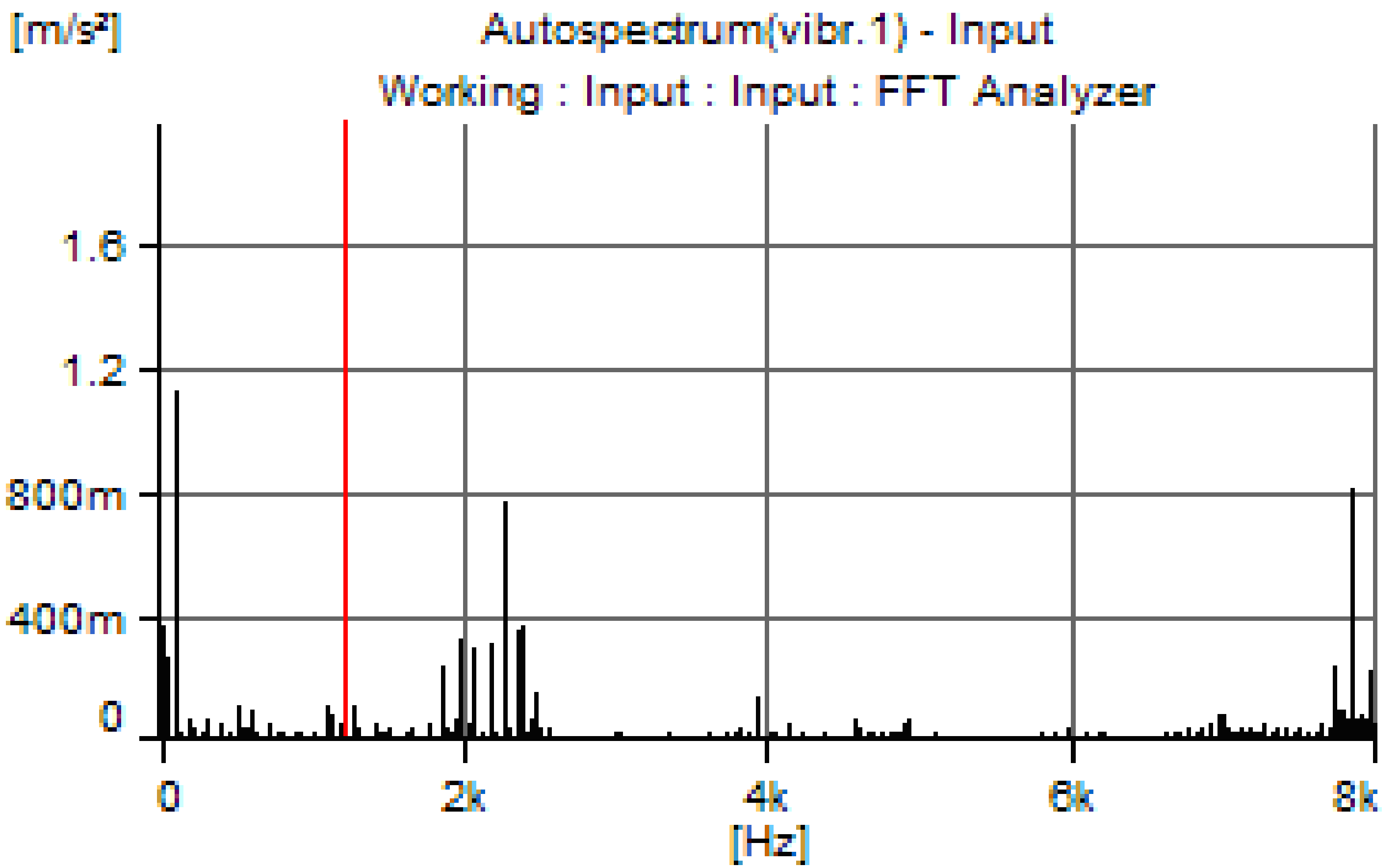
Rotor cage representation with broken bars



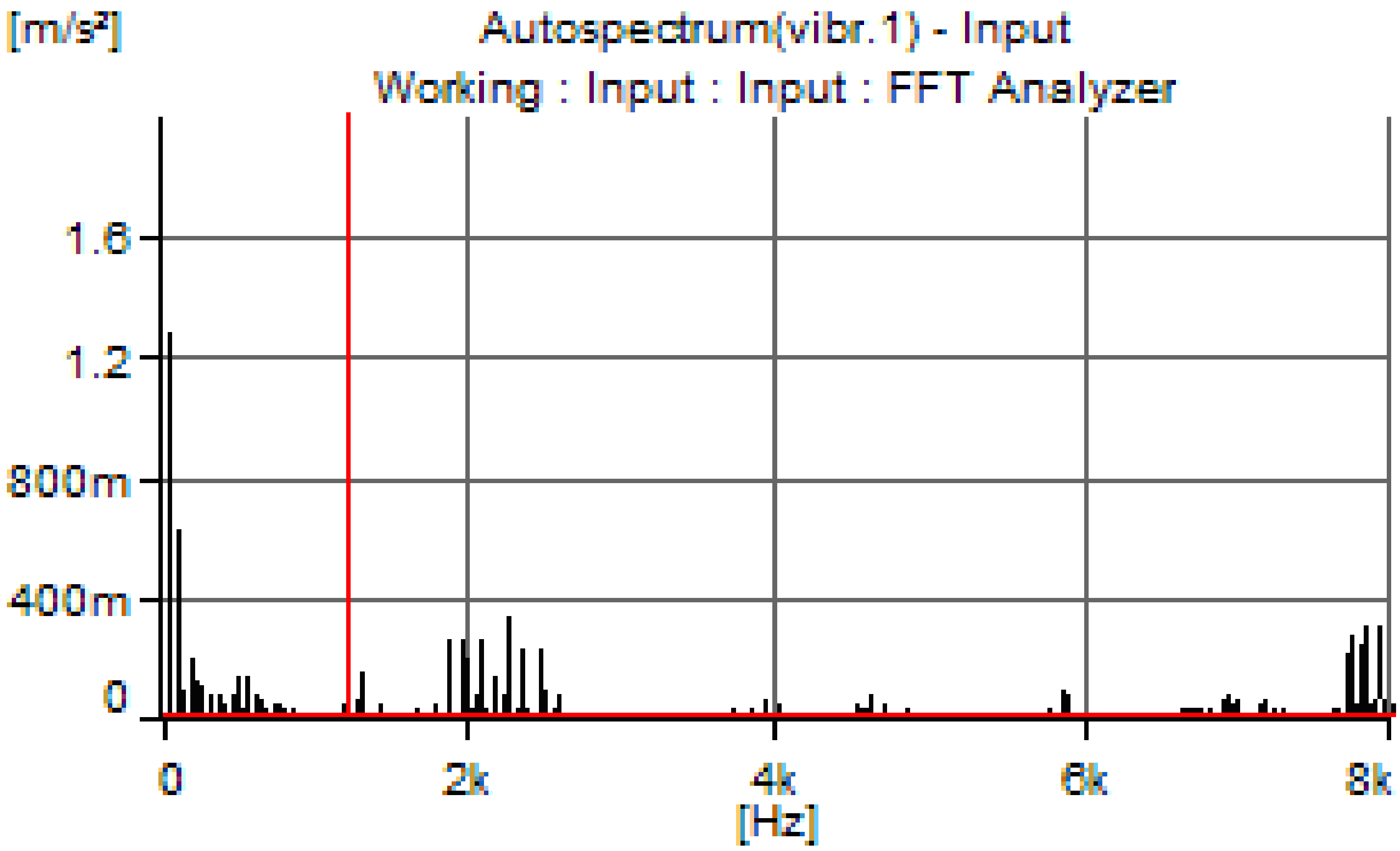
Vibration motor’s measured stand



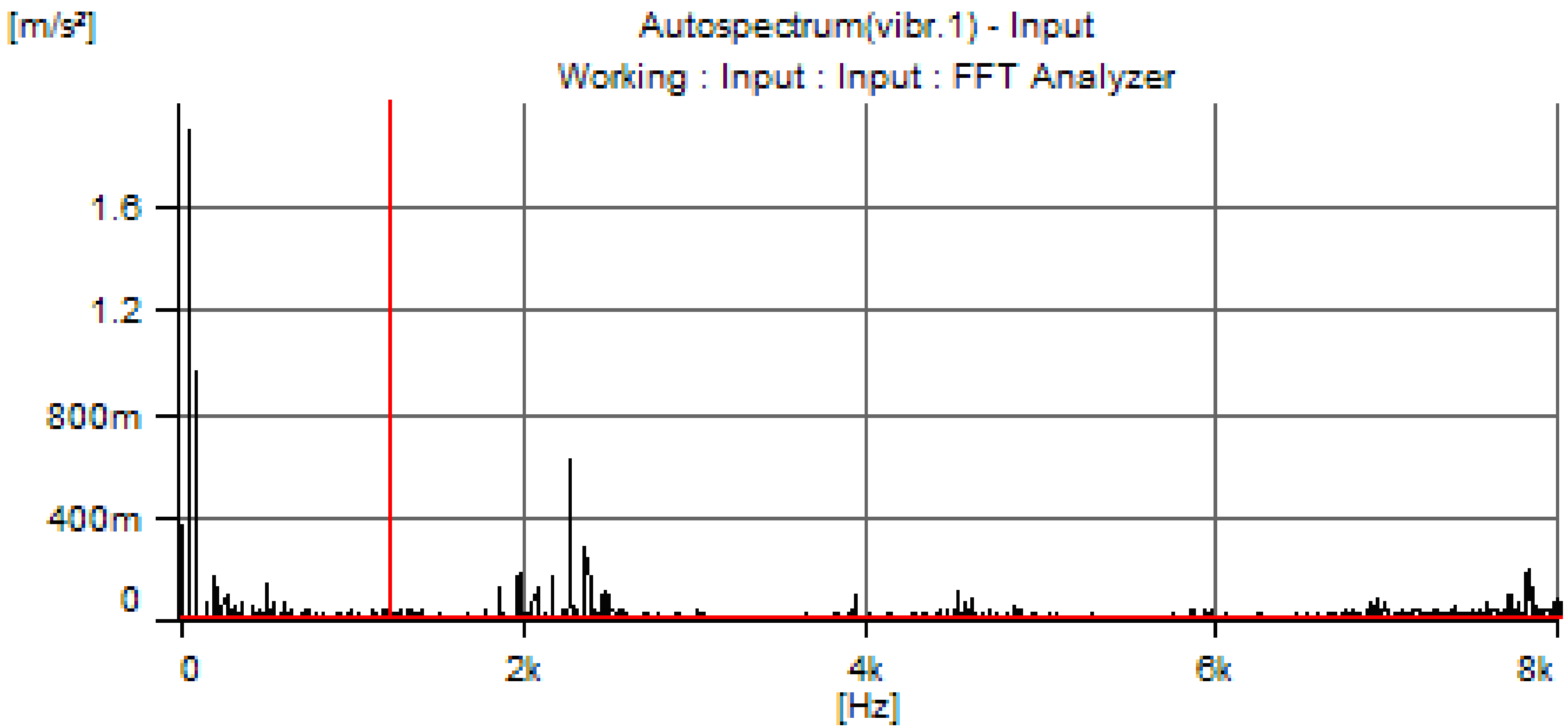
Harmonic vibration spectra for "healthy" induction machine



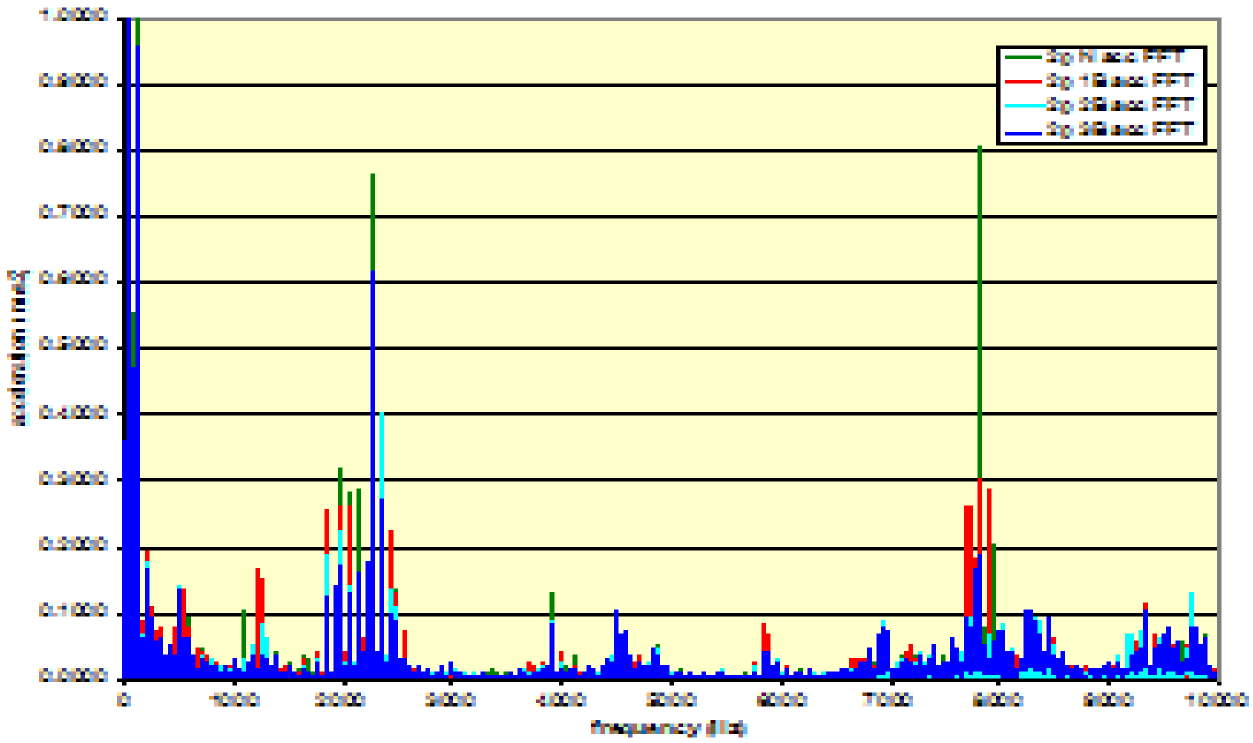
Harmonic vibration spectra for induction machine with one broken bar



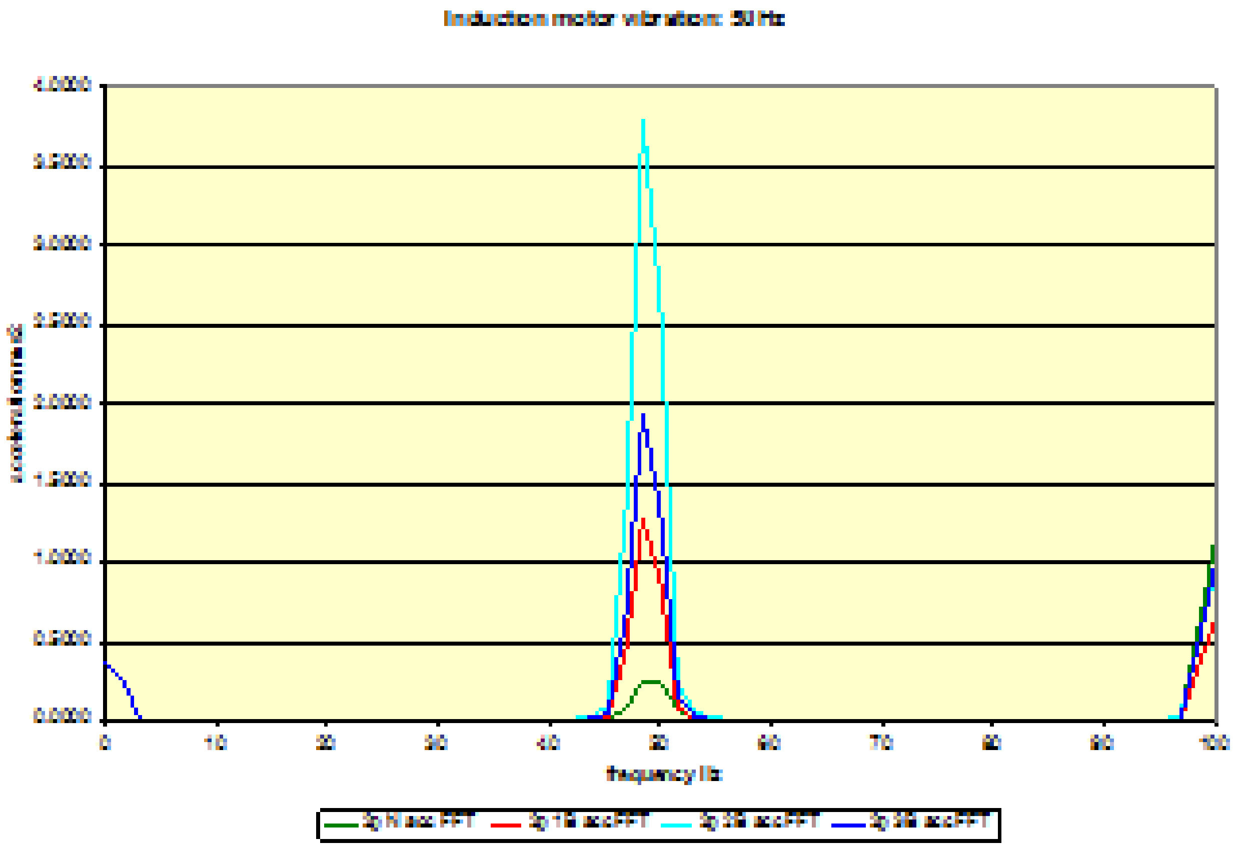
Harmonic vibration spectra for induction machine with three broken bars



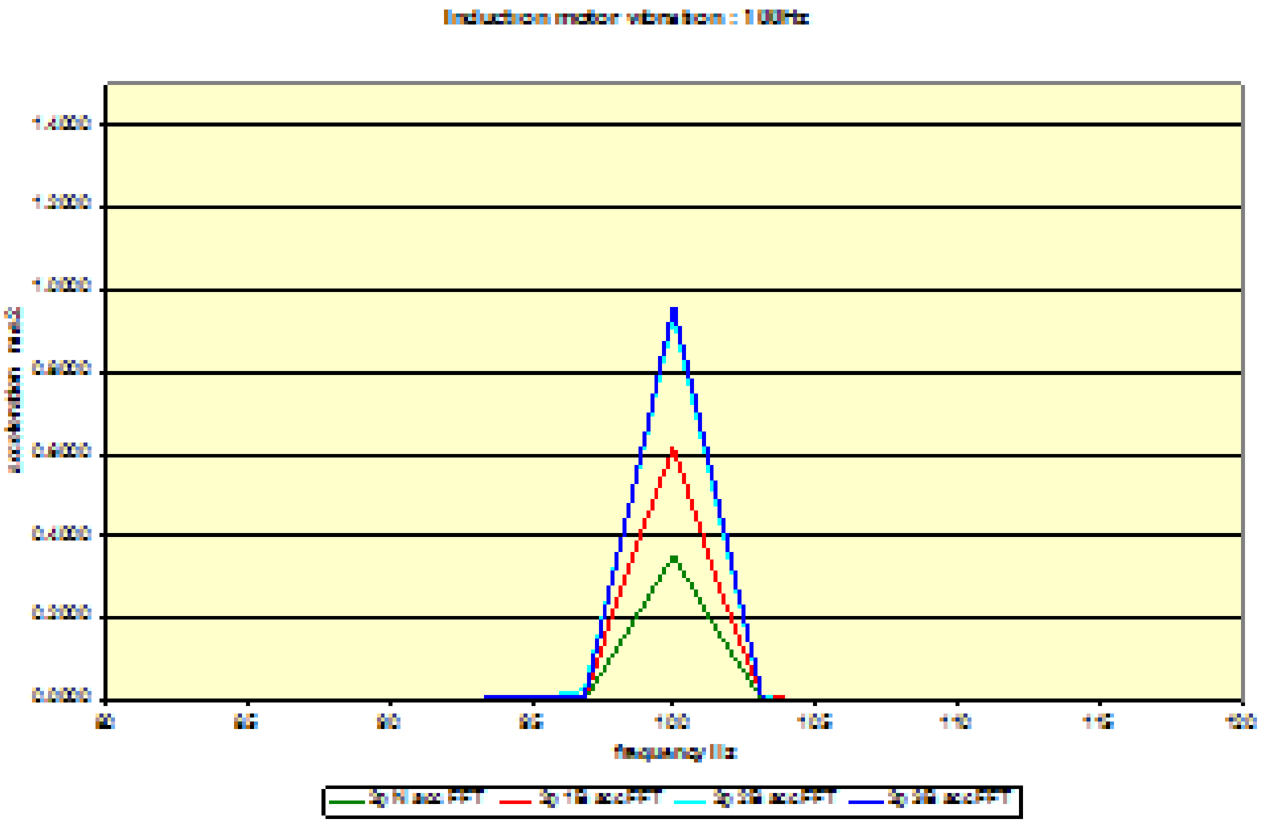
Comparation between harmonic vibration spectrums for healthy and fault rotor bars



Comparation between vibration spectrum “healthy” and rotor bars fault at 50Hz frequency

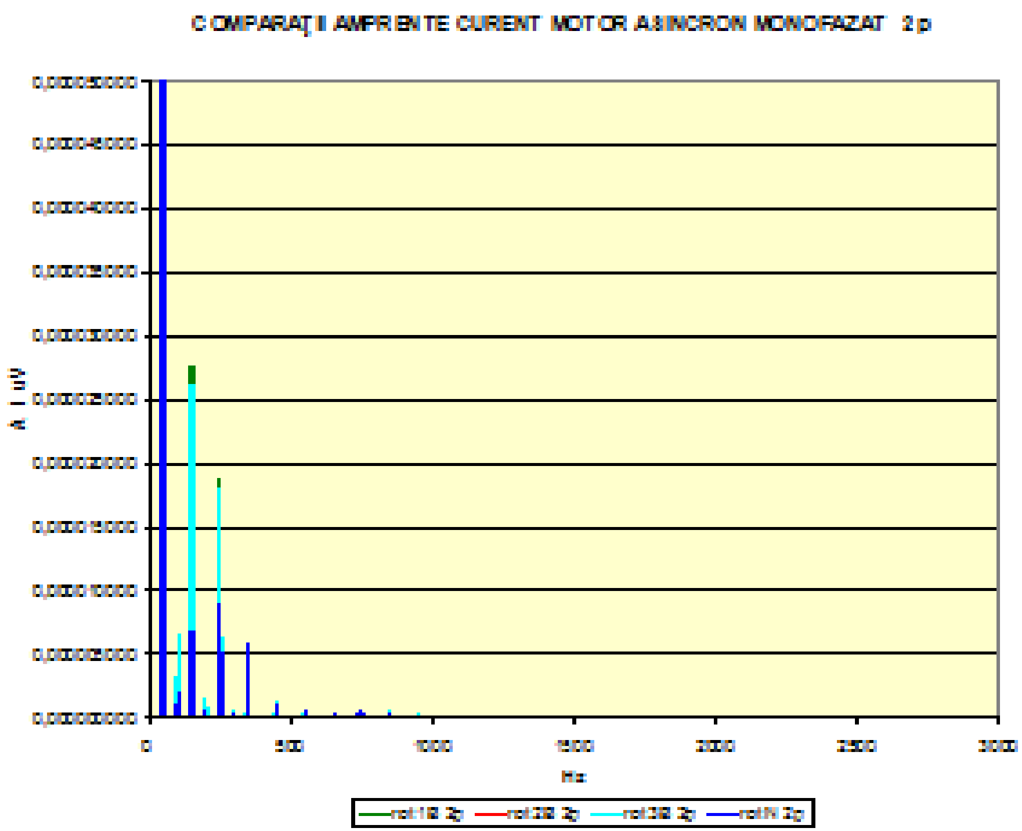


Comparison between vibration spectrum "healthy" and rotor bars fault at 100 Hz frequency

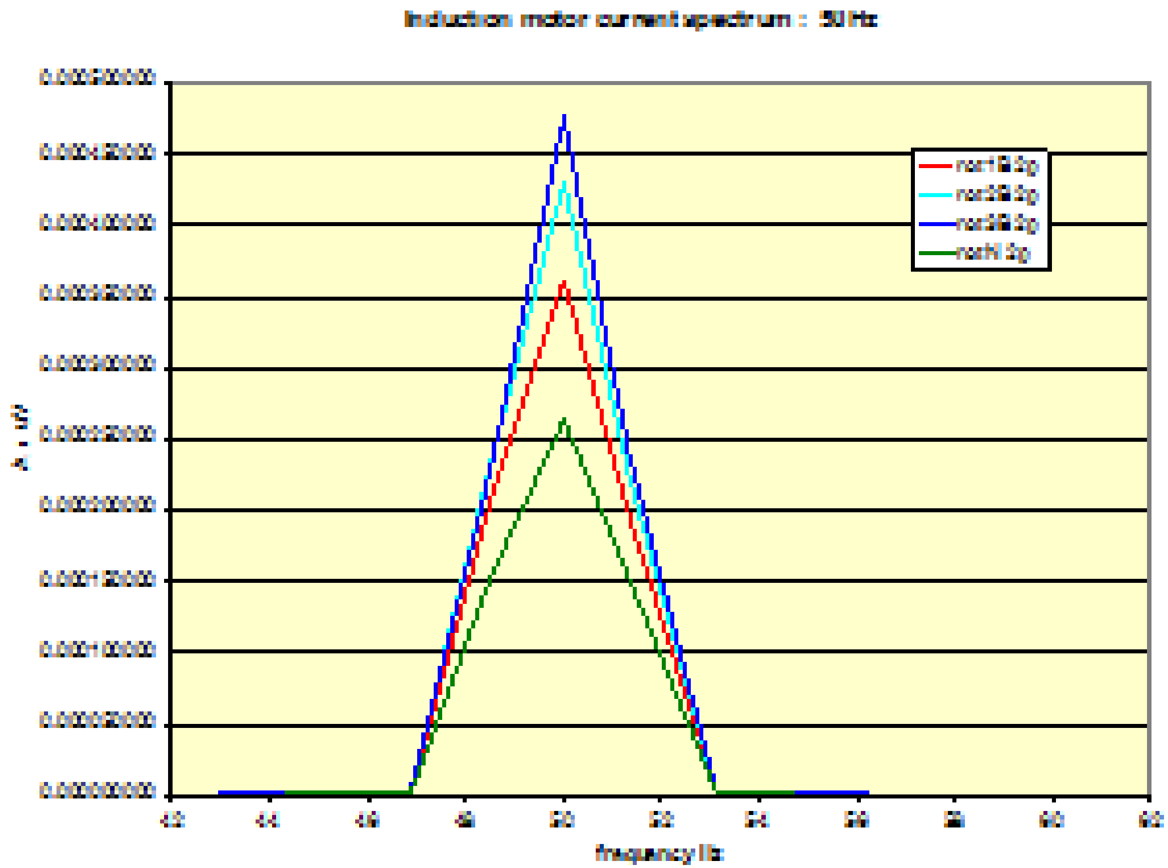


STATOR CURRENT SPECTRUM MONITORING

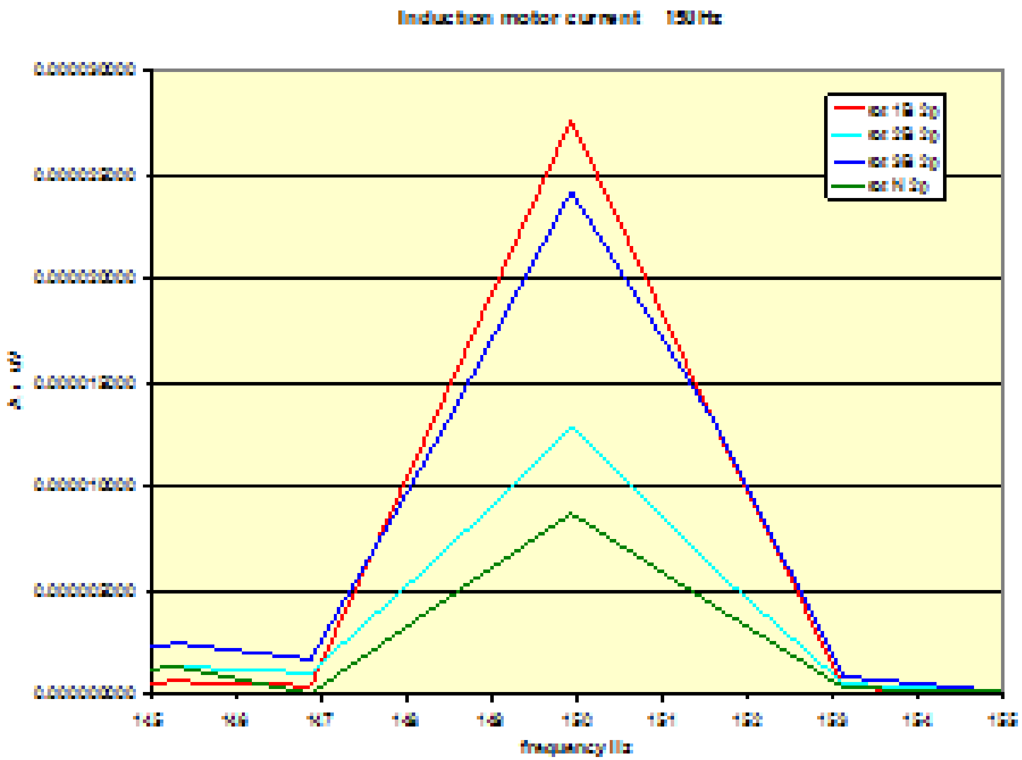
Comparation between harmonic stator current spectrums for “healthy” and fault rotor bars



Comparation between stator current spectrum “healthy” and rotor bars fault at 50Hz



Comparation between stator current spectrum “healthy” and rotor bars fault at 150Hz frequency



CONCLUSIONS

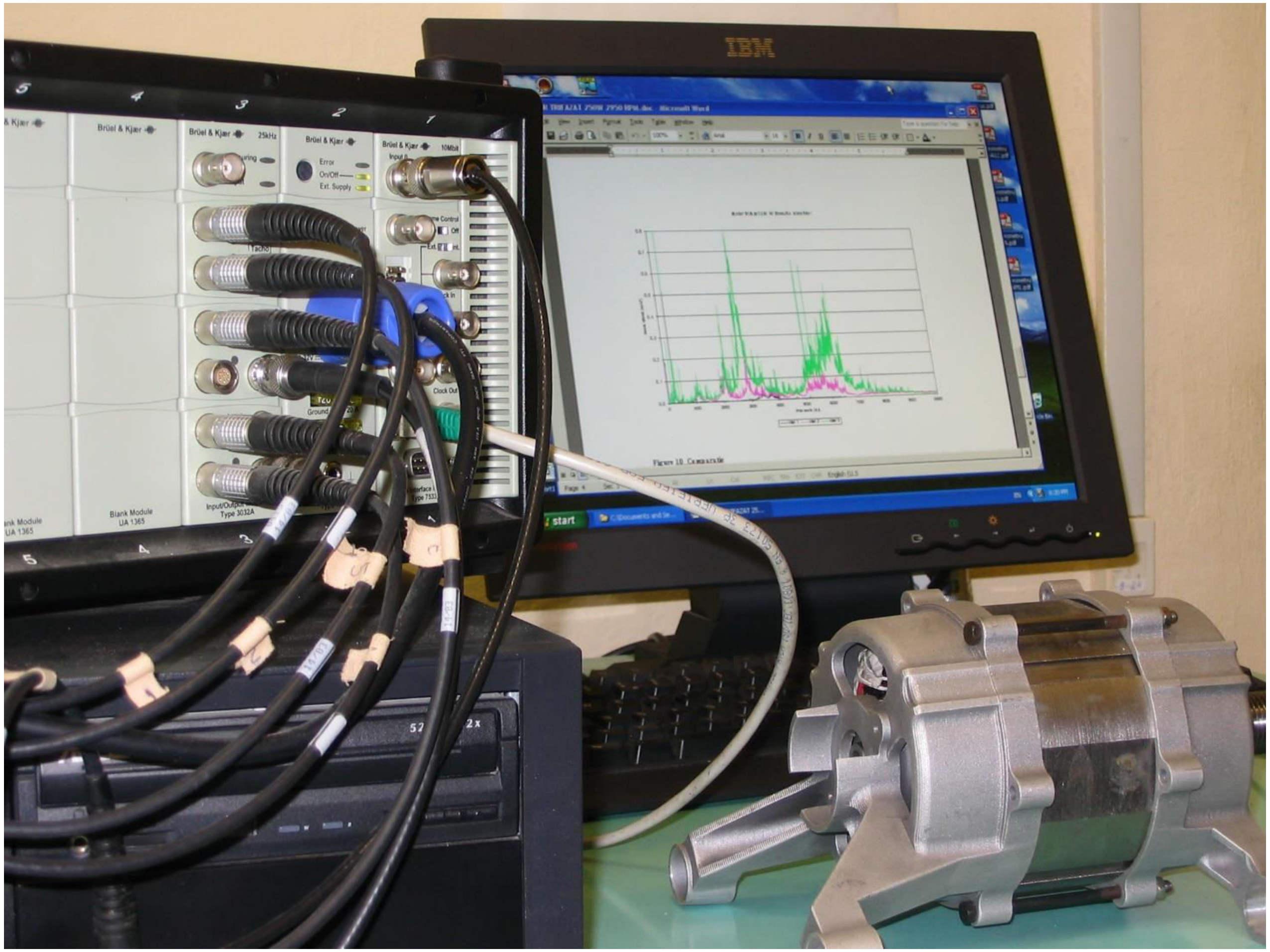
- The technique of evaluating the machine condition by performing a FFT of the induction machine vibration and the stator current has been verified by the experimental results. In this case electric machine vibration motorizing is very useful to detect rotor faults.
- By the corresponding zoom we can observe that vibration and stator current it is different at the “healthy” machine related fault motor.
- Thanks to these methods the diagnosis of broken rotor bars could be done even if the machine operated unloaded.

Vibration and Current Monitoring for Bearing Fault's Diagnosis of Induction Machine

Mechanical problems in induction machine

- Bearing wear and failure. As a result of bearing wear, air gap eccentricity can increase, and this can generate serious stator core damage and even destroy the winding of the stator;
- High mechanical unbalance in the rotor increases centrifugal forces on the rotor;
- Looseness or decreased stiffness in the bearing pedestals can increase the forces on the rotor;
- Critical speed shaft resonance increases forces and vibration on the rotor core.

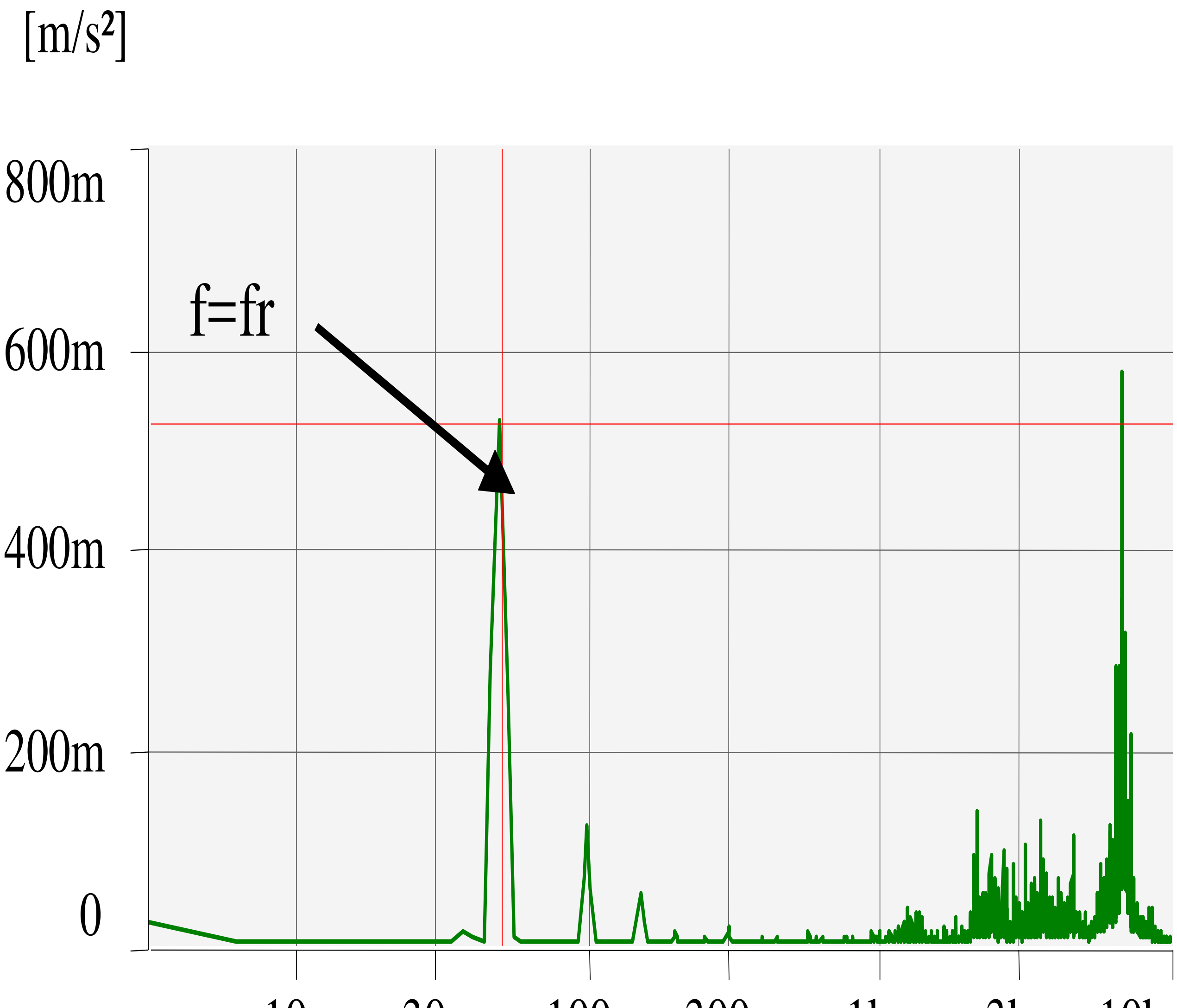
Test bench multianalyser



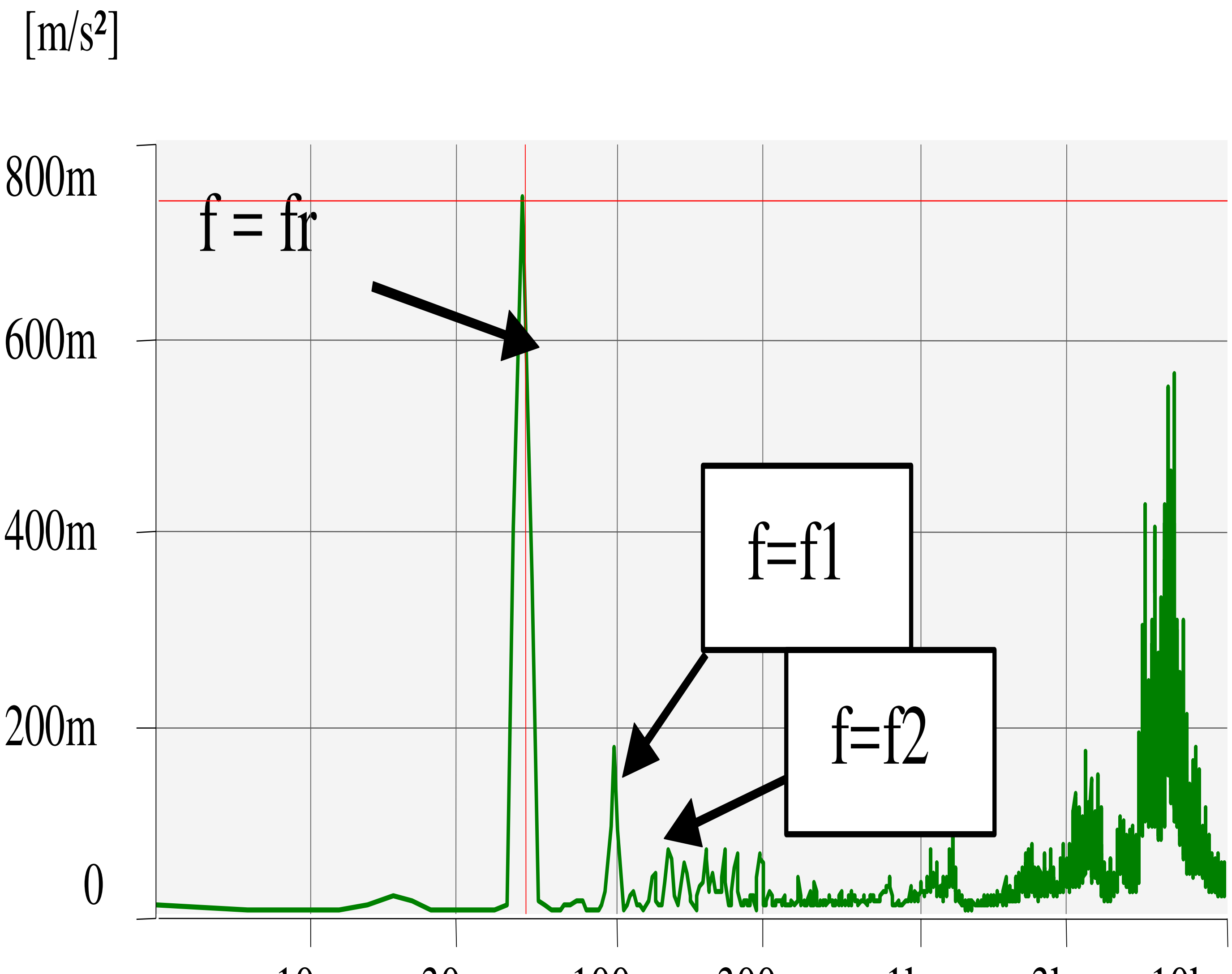
Vibration machines's measured stand

THE VIBRATION SIGNATURE OF INDUCTION MACHINE

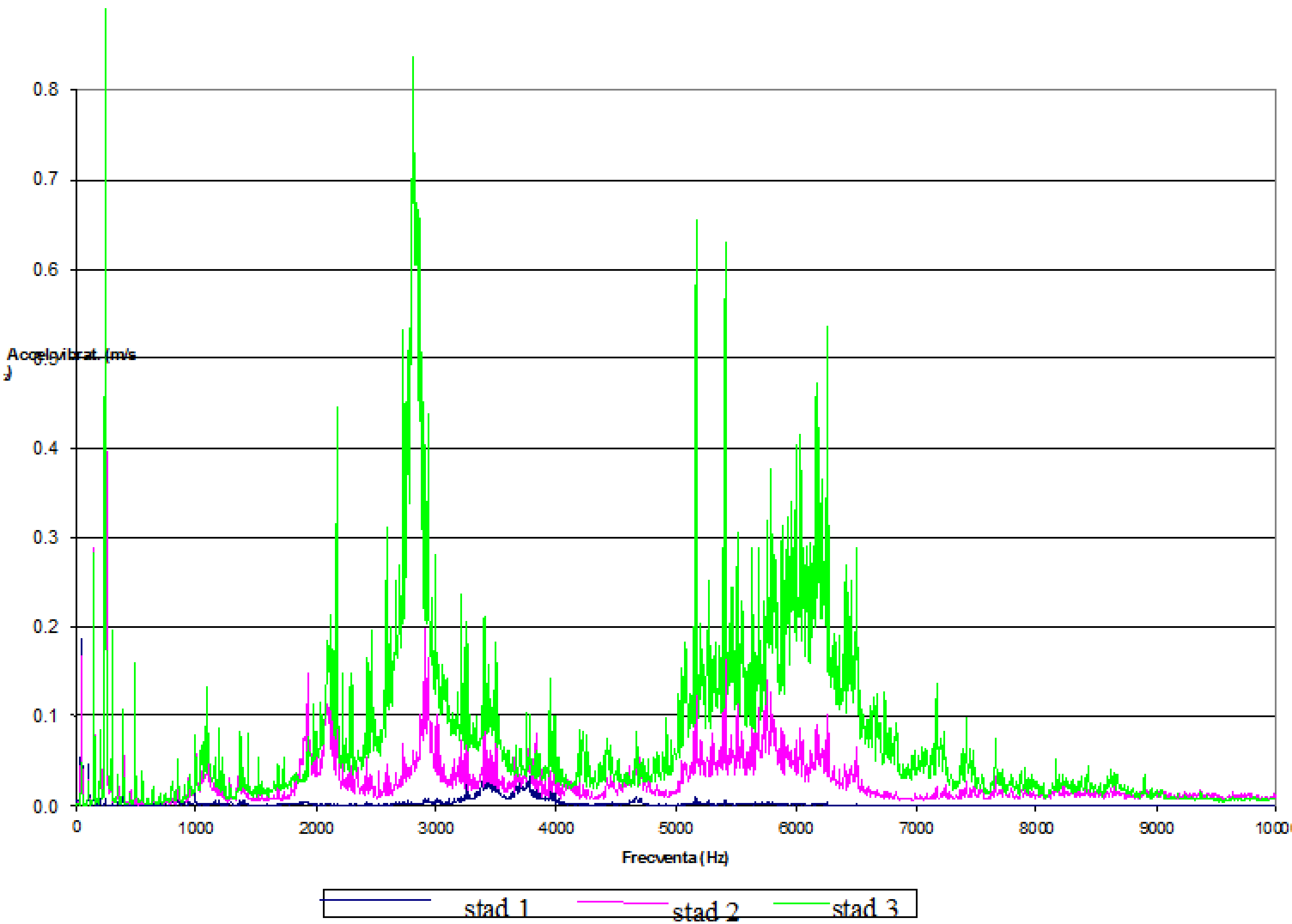
Harmonic vibration spectra for induction machine with “good” bearing



Harmonic vibration spectrum for induction motor with “bad” bearing

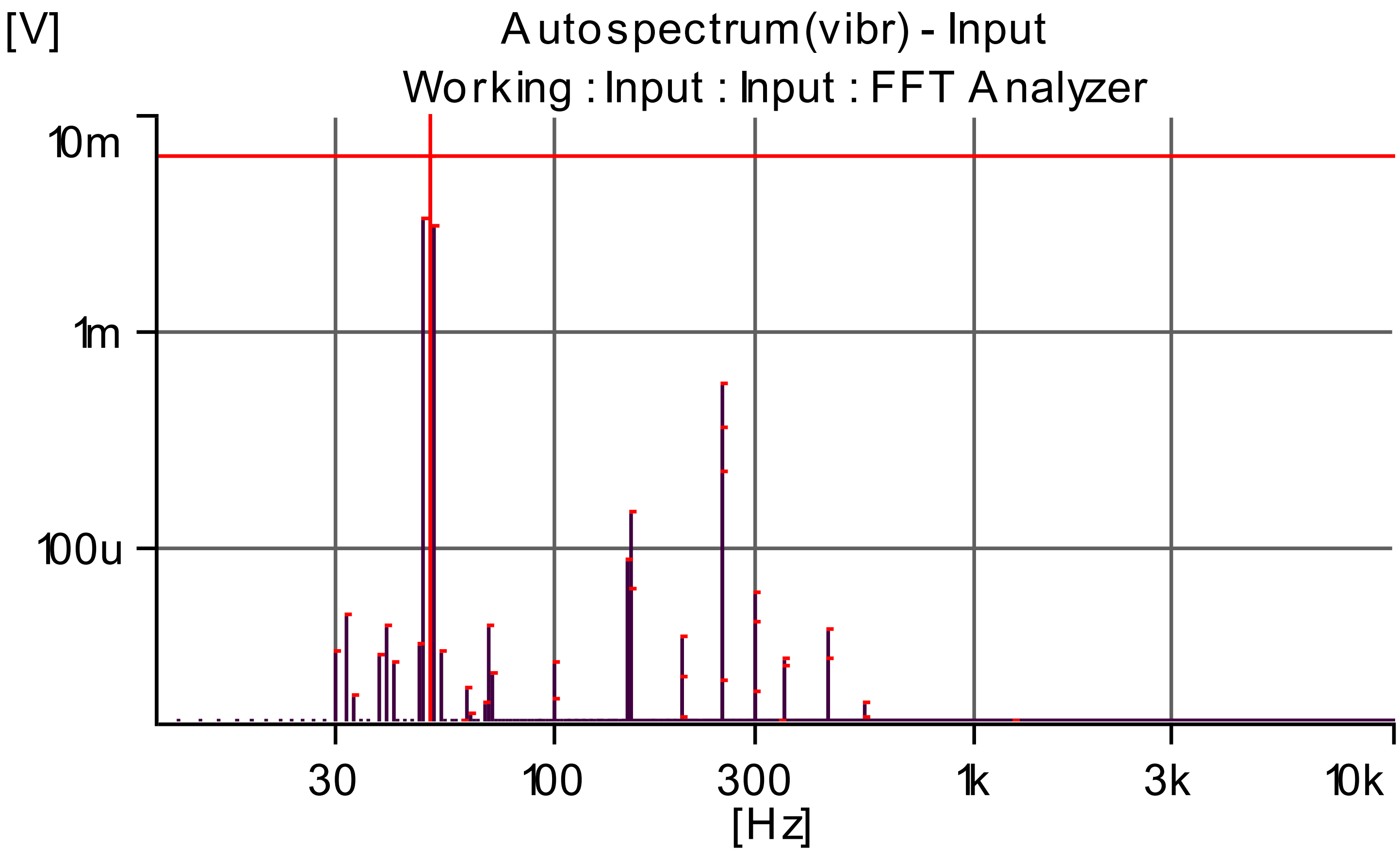


Comparation between harmonic vibration spectrums for healthy and bad bearing

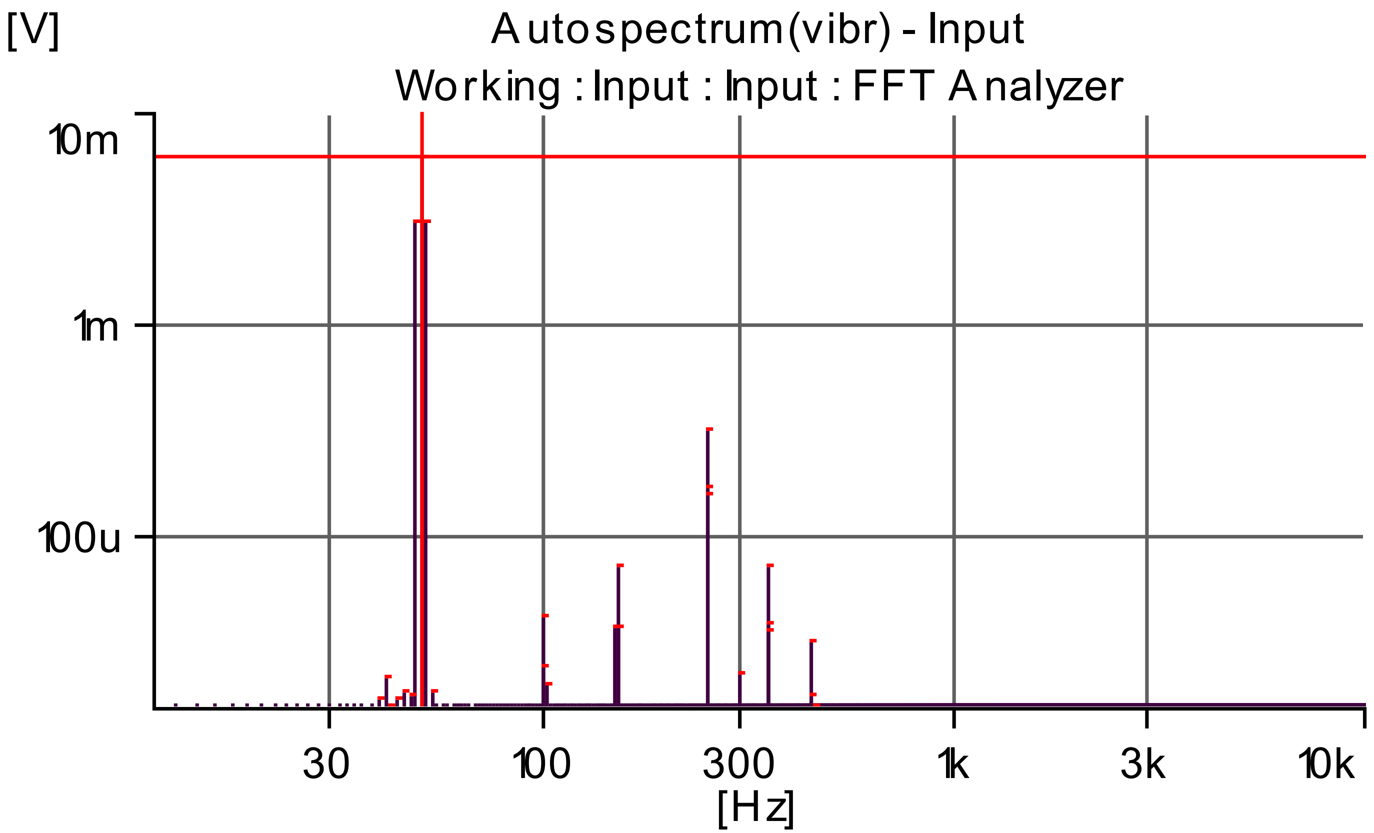


THE STATOR CURRENT SIGNATURE OF INDUCTION MACHINE

Harmonic current spectrum for induction motor with “health” bearings



Harmonic current spectrum for induction motor with “bad” bearing



CONCLUSIONS

- The technique of evaluating the motor condition by performing a FFT of the induction motor vibration has been verified by the experimental results.
- In this case electric machine vibration motorizing is very useful to detect bearing fault.
- The wind power plant maintenance can easily and successfully detect mechanical fault that lead to unexpected downtime.

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