STRUCTURAL MONITORING OF WIND TURBINES USING SENSORS CONNECTED VIA UTP CABLE

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Abstract: Unpredicted faults that may occur at the wind generators elements affect their economic operation. A promising approach that avoids these faults is the real-time vibrations monitoring. Data measured by the sensors can be transmitted to a monitoring station using wireless techniques, or optical fiber, or UTP cable. The last possibility is the cheapest, but it permits connecting the monitoring station at a limited distance with respect to the monitored turbine. The paper presents the components of the monitoring system and the experimental results related to the monitored wind turbine.

1. INTRODUCTION

Amongst the mechanical components of wind turbines, the biggest percent of faults occurs in the gear box. In [1], is shown that the principal reason of these faults comes from the ball bearings, which determine the lack of reliability of the gear boxes and consequently the longest time of stagnation of the wind turbines.

For the monitoring and the diagnosis, the measurement and the analysis of the vibration spectrum is used [2]. The vibration spectrum offers information regarding the incipient faults and contributes to the formation of a reference signature, which may be used in further monitoring processes. The vibration spectrum of an equipment containing faulty ball bearings has one or more frequencies generated by the faulty element. Most often and especially when a fault occurs in an incipient stage, the vibrations determined by the faulty balls will be reduced in amplitude, compared to the vibrations of the moving components, like shafts, cogwheels, etc. The frequencies denoting the faults cannot be noticed using the time or the spectrum analysis of the vibrations.

The processing techniques of such a signal have several limitations. For instance, some faults cannot be diagnosed using the fast Fourier transform (FFT), if the load value is reduced or if the fault is not too severe. Thus, in these situations it is preferable to use other techniques, like: the Wavelet transform, the Cepstrum analysis or the Hilbert transform.

The monitoring method, based on wavelet transform presents a high sensitivity, a short detection time and can be easily applied for online monitoring. This method is based on the principle of the restoration of all the signals in sets of signals of different dimensions and amplitudes, but constants in form.

In the last years, the Wavelet transform techniques have been used to analyze the nonstationary vibrations, generated by faults occurring on the external periphery of the ball bearings [3]. In [4] the properties of the bandwidth of the vibrations are analyzed and in order to identify the ball bearings faults, the Wavelet transform is applied. These studies demonstrated that the time-frequency analysis of the vibrations signals, generated by ball bearings, provides a large amount of information related to the conditioning of the component elements of the ball bearings. In [5] the identification of the faults in a gear box is presented, the approach being performed using the amplitude and the frequency demodulation of the current of an induction motor which is driving a gear box. The discrete Wavelet transform is applied in order to cancel the unwanted noises from the current signal and uses a certain level of the frequency spectrum, to detect the possible faults in the gear box. This is somehow a singular study in the literature, because the majority of the studies state that the faults in the gear box cannot be detected by analyzing the current signals of the generator connected thereto.

Since the modern wind electric generators, capable to develop powers of megawatts are available on the market, efficient maintenance and fault detection methods are needed. The online monitoring systems offer a new prospect on maintenance and fault prevention strategies. Using new monitoring systems, the faults can be detected in incipient stages, even before being visible or noticed from the acoustic stand point. Therefore, preventive maintenance measures can be used, before the fault would degenerate in a secondary fault. Thus, the maintenance overall cost is significantly reduced. Using these systems, the maintenance plan can be extended to larger periods of time, avoiding accordingly premature alteration of the functional components. Replacing the main components can be an extremely expansive and time consuming process. At the same time an online monitoring system may offer certain advantages:

- prevention of secondary and/or major faults;
- reduction of the maintenance costs by applying the conditioned maintenance;
- remote survey and diagnosis;
- detailed information related to the performance of the equipment and to its vibrations.

2. VIBRATIONS MONITORING

The structure of a vibrations transducer has as a significant feature the fact that the sensitive element provides at its output a mechanical value: force or displacement. In order to obtain an electrical signal, able to be processed by an adapter, an intermediary converter, that converts a mechanical value to an electrical value is needed. The separation between the element sensitive to vibrations and the intermediary converter has a functional character, but from the constructive standpoint, the two parts, usually form a single unit. The most often the intermediary converter is a piezoelectric one, determining an electric polarization noticeable between the two opposite surfaces of the crystal perpendicular to the faces submitted to a mechanical force. The polarization value is proportional to the applied force and it changes its direction with the direction of the force as well. The piezoelectric effect is explained by the deformation of the crystalline grid, which determines the deterioration of the electrical equilibrium established between the grid atoms.

The functional properties of a piezoelectric converter may be deduced if the mechanical parameters describing its operation are set equivalent to the electrical parameters. This can be done using the electro-mechanical analogies, based on the formal identity of the differential equations that describe a mechanical system and an electrical circuit. Starting from these analogies and taking into account the operation of a piezoelectric crystal, the equivalent electric schematic may be drawn, *fig. 1*.
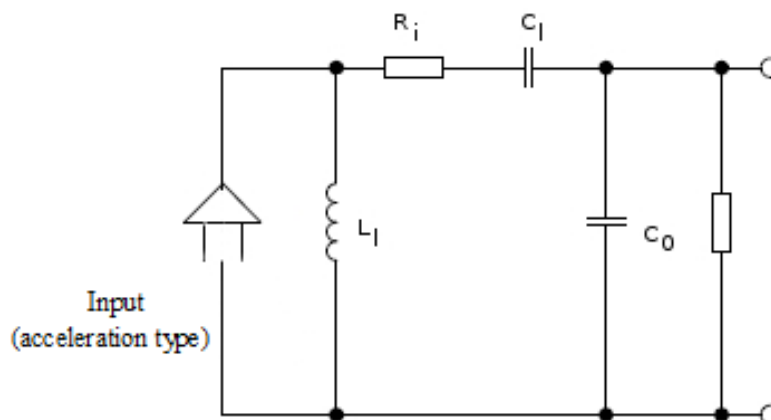
Fig. 1. Equivalent schematic of the piezoelectric converter.

The equivalent circuit of a converter, cable connected, is presented in *fig. 2*. The piezoelectric element acts like a capacity C_a parallel connected with a high value equivalent parallel resistance R_a (EPR). The piezoelectric element can be considered as a charge source Q_a, or a voltage source V_a. As one can notice from *fig. 2*, the voltage V_a is dependent of the cable capacity. Thus, the calibration factor for determining the voltage sensitivity of the

convertor, must take into account the connection cable. If different cables than those specified are used, correction coefficients depending on the capacity of the new cable must be introduced, or a new voltage sensitivity must be considered.

An important parameter for achieving a proper operation of the converters is the transverse sensitivity, determined versus the applied acceleration under square angles with respect to the main axis. It is expressed in percent versus the load sensitivity or the voltage, measured with respect to the main direction. It must be mentioned that the maximum sensitivity is not obtained versus the main direction of the piezoelectric crystal, in which, maximum and minimum directions of sensitivity exist. Usually, the minimum sensitivity direction is labelled on the device housing. For an ideal piezoelectric material, the transverse sensitivity is zero, but in reality, due to the fabrication imperfections, it differs from zero, reaching three percent of the main sensitivity. The dependency of the transverse sensitivity versus frequency is depicted in the catalog sheet of the producer.
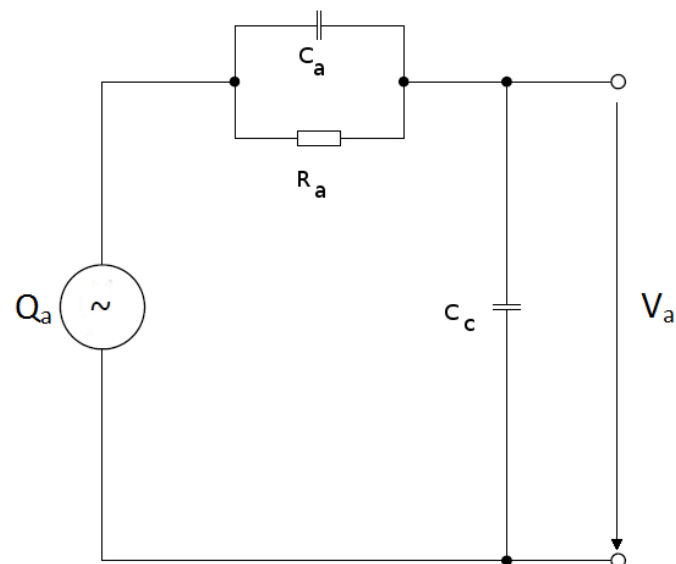
Fig. 2. Equivalent schematic of the voltage generator.

A special attention must be paid to the measurement of the chokes and of the transients, since important errors may occur, like for instance the displacement error in relation to zero, or the ringing error.

The displacement error in relation to zero is due to the phase nonlinearities generated in the amplifier by the low frequency components of the real signal. These distortions don't affect the average value, but they can influence the accurate determination of the peak value. In order to maintain these errors in certain imposed limits, it is compulsory that the inferior limit of the preamplifier be lower than a value inverse proportional to a choke or to the period of a transient. It is also recommended the use of acceleration type sensitive elements, because the integration of a single choke in order to obtain velocity or displacement, introduces phase nonlinearities.

The displacement in relation to zero may be produced by the converter itself, especially when high level chokes are applied, determining that only a fraction of the charge stored in the piezoelectric element to be transmitted for measurement.

The ringing error occurs when the frequency spectrum of the choke contains frequency components close to the mechanical resonance frequency. In order to make errors less than an imposed value, a preamplifier and a low pass filter in the input are needed.

If the piezoelectric converters are used beyond the maximum temperature specified for piezoelectric materials, the piezoelectric elements depolarize themselves, determining a permanent loss of the charge and consequently the lowering of the sensitivity. The explanation of this phenomenon consists in the modification of the electric permittivity of the material versus temperature. An analysis regarding this phenomenon shows that the Rochelle salt can't be accepted as a piezoelectric sensitive material, due to its instable properties versus the temperature. There are also several varieties of barium titanate having a different behavior versus temperature. Conversely, the lead zirconate-titanate has practically the same stability as the quartz. One solution in increasing time stability of the sensitivity versus time and temperature consists in the artificial aging.

3. ANALOG TO DIGITAL CONVERSION

Monitoring the operating conditions of an electric machine may estimate the moment of the maintenance process. A periodic monitoring of the operation parameters of the equipment, using analysis vibration techniques, makes possible the detection of the problems associated to the wind electric generators. Consequently, the possible issues can be previewed and detected fast enough, in order to draw a repair planning, instead of a preventive maintenance. Measuring vibrations in different locations of the wind electric generator and tracking their intensity in time, represent a reliable and efficient approach, indicating the weary state of an equipment and its time involution. Using a vibrometer permits the visualization of the measurement results, directly in situ. Modern vibrometers have the possibility to store the measurement results in the internal memory of the vibrometer in different equipment, USB connected thereto. The saved results of the measurements can be downloaded later through a communication port and a RS 232 serial interface or a USB interface, provided at the new generation of vibrometers.

Connecting the vibrometer to a PC and using one of the available communication ports, permit also to download and save the data. In order to use a USB communication port, a dedicated driver, delivered by the producer, is compulsory to be installed. For the serial communication port, RS232, the special drivers are not needed. The data being stored in the PC, the user can export them in special application, able to view and compare them with other previous similar data.

Each producer of measurement equipment has developed applications, which are working together with the equipment in order to extract and export data. These applications are most often closed source, meaning a compiled ready version, unmodifiable by the user for his special needs. The closed source applications save data in specific files. Thus, the user is forced to use the applications provided by the manufacturer.

Some vibrometers have the ability to transmit the measured and amplified signals to a special analogic port in order to be processed by further equipment. This signal can be taken over by an acquisition board, that converts an analog signal into a digital one.

Such an acquisition board is 232M1A0CT [6]. The acquisition board, *fig. 3,* has eight analog inputs and ten digital inputs. The analog inputs are unipolar and admit voltages between 0 and 10 Vd.c. The board is supplied by a direct current voltage, in the range from 7.5 V to 24 V and a direct current of 50 mA.

The communication with the monitoring system is made via a RS232 interface. The transmission is made in duplex synchronous mode, each transmitted or received word containing eight data bits, one parity bit and one start/stop bit.
The interface RS232 permits the connection of the monitoring system at a maximum distance of 15 m.

Communication through the RS232 port uses three wires: the first for transmitting data, the second for receiving data and the third for grounding. Between the transmitting and receiving wires and the ground, one can measure values between -8 V and +12 V, respectively +8 V and -12 V. The more complex applications impose a confirmation method of the transmitted data, for preventing the buffer overflow and for verifying the equipment status as well.

In order to control the flux of data between the two equipment the standard words Request to Send-RTS and Clear to Send-CTS are used. The words Data Set Ready-DSR and Data Terminal Ready-DTR are the most used words to call and to answer to the interrogations.
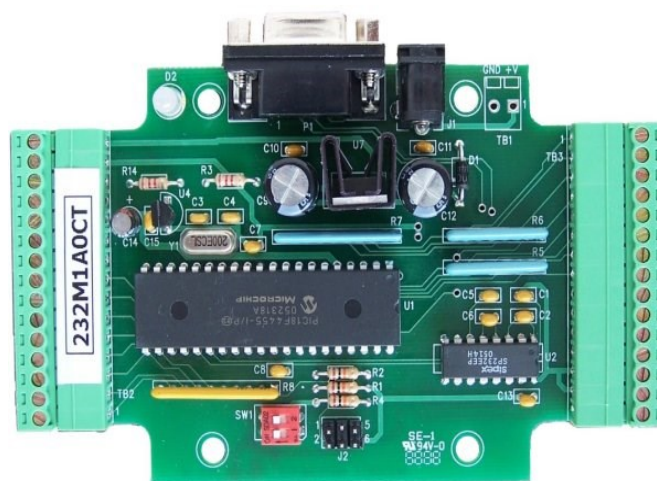
Fig. 3. The acquisition board is 232M1A0CT

4. REMOTE DATA TRANSMITTING TECHNIQUES

If the monitoring station is situated at a distance of more than 15 m related to the measuring point, the following methods of data transmission can be used:

- Wireless data transmission;
- Optical fiber data transmission;
- UTP cable data transmission.

Wireless grids represent networks of interconnected equipment by radio waves, infrared waves and other wireless methods. In the last years, the wireless techniques have greatly developed, being a reliable and simple alternative solution to cable links. Wireless connections become more and more popular, while they solve problems that appear in the case of large grids of several devices. Modern technologies are able to interconnect equipment situated at small to large distances.

A Wireless Local Area Network- WLAN represents a communication system implemented like an extension or an alternative to a cabled LAN, in a building or a campus, combining connectivity at high speed, providing the mobility of the users in a more simplified configuration. Obvious advantages, like mobility, flexibility, simple commissioning, reduced maintenance costs and scalability have imposed WLAN as a more often used solution.

There are two types of wireless transmitting/receiving equipment:

- Base Stations;
- Subscriber Units.

The base stations antennas have usually a wide angle, ranging from 60 degrees to 360 degrees capable to assure the connectivity of all the customers in a certain area. The base stations can be connected to an optical fiber cable network or radio relays.

The antennas of the subscriber units have a much narrower angle and therefore they have to be oriented towards the base station.

Optical fibers are used on large scale in telecommunications, permitting long distance transmissions having higher band widths than other media communication. Through optical fibers, a signal is transmitted with reduced losses, being immune to electromagnetic interference as well. Consequently, they are used instead of the electrical cables, in lighting technique and images transmission, permitting the visualization in narrow areas. Some of special designed optical fibers are used in several applications, including sensors and laser applications. The waveform in the optical fibers is directed through the core of the fiber using the total reflection, which leads to a waveguide behavior of the optical fiber. The fibers that support several propagation or transverse modes are the so called multimode fibers – MMF, and the fibers that support only one propagation mode are the so called single mode – SMF. The multimode fibers have in general a larger diameter of the core and are used in short distance

communications and in applications in which a higher transfer of power is needed. The single mode fibers are used in communications at distances over 550 m.

The junctioning of the optical fibers is a more complex process than the junctioning of the conventional cables. The extremities of two optical fibers cables must be properly prior prepared and afterwards welded using an electric arc technique. Special connectors, suitable for flexible connections, are used.

Data transmission via optical fiber is performed using both types of fiber, both having the same diameter of 0.12 mm.

The multimode fiber has a larger core diameter, usually of 62.5 µm, but there are also optical fibers having the core diameter of 50 µm, used together with LED lighting sources, having wavelengths of 850 nm and 1300 nm for low speed connections and with laser sources, having wavelengths of 850 nm and 1300 nm for high speed connections of several gigabytes per second.

The single mode fiber has a thinner core, of only 9 µm, and the waveform is transmitted in one flux. It is used together with laser sources having wavelengths between 1300 nm and 1550 nm.

In order to connect the acquisition board with the monitoring station via optical fiber, a pair of RS232 and RS485 converters is needed. The connection between the acquisition board and the monitoring station could be achieved with lower costs using a UTP cable. This connection is possible only for distances of maximum 15 m, without ancillary equipment, with a maximum baud-rate of 115200 bauds/s. If the baud-rate is lower, the equipment can be connected at a longer distance. For instance, for a baud rate of 9600 bauds/s the possible connection distance becomes 150 m.

In order to maintain a high value baud-rate, a current loop converter can be used, *fig. 4*. The converter performs the conversion between the RS232 serial interface to the current loop of 20 mA or 60 mA. This device need an external supply source as well.

Two such converters are needed. The first is needed for transmitting signals from the RS232 port of the acquisition board and the second for receiving data at the RS232 port of the acquisition board.

Fig. 4. RS232 to current loop converter.

5. EXPERIMENTAL SETUP

The experimental setup using a UTP cable connection is composed of the following elements:

- Piezoelectric transducer Dytran 3100B 6221;
- Sound and vibrations analyzer Svan 912 AE;
- Oscilloscope Fluke 196;
- Acquisition board 232M1A0CT;
- Calibration generator vibrometer RTF.

The piezoelectric transducer is connected via a coax cable to the input port of the sound and vibrations analyzer, Svan 912AE. The analyzer is provided with a converter, that converts the electrical charge to a voltage, which permits the charge measurement. The converter can be also connected to analog measurement instruments via a BNC connector. This feature is used in the experimental setup to connect an oscilloscope. *fig 5,* represents a picture of the experimental setup.

Fig. 5. Experimental setup, simulating the wind turbines vibrations monitoring.
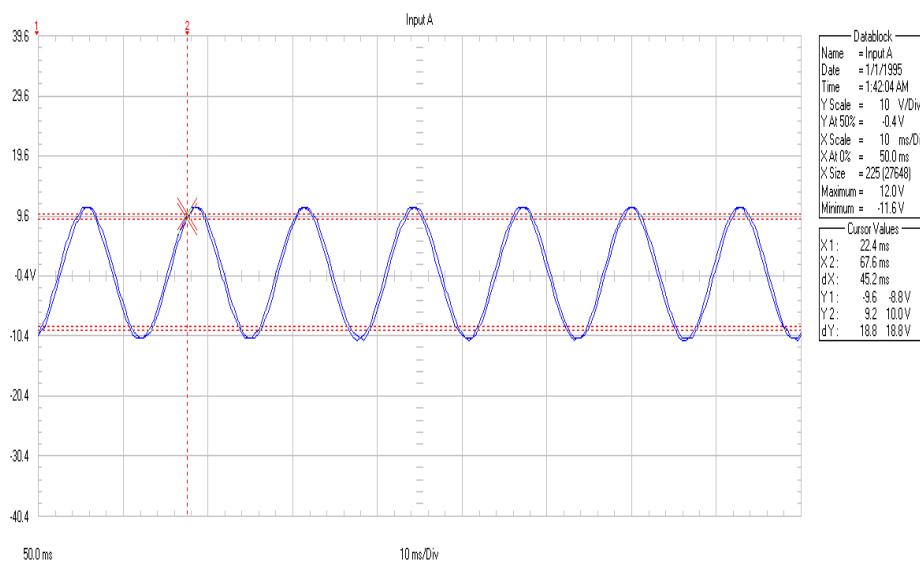
Fig. 6. The sinusoidal vibration oscillogram.

The piezoelectric transducer is mounted on the vibrations source using a magnetic pad, consisting of a permanent magnet assuring the transmission of the vibration generated by the undistorted source.

The vibrations source is provided with a control element which is able to modify the vibrations amplitude. Using the vibrations source, the normal operation of the wind generator is simulated.
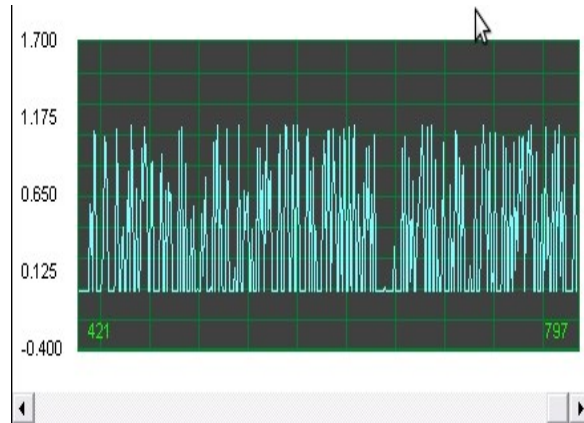

Fig. 7. Amplitude versus time spectrum at the output of the acquisition board.

Both the oscillogram of the sinusoidal vibration, *fig. 6*, and the amplitude versus time spectrum, *fig. 7*, highlight a normal operation of the wind generator. Notice that the output of the acquisition board has only a positive component, due to the fact that the input of the acquisition board admits only positive voltages, ranged between 0 Vd.c. to 10 Vd.c.

In order to simulate the faulty situation, the vibration generator generates also chokes, *fig. 8*, presenting non-sinusoidal vibrations. *Fig. 9* depicts situation in which the chokes determine the monitoring system to signal a faulty situation.

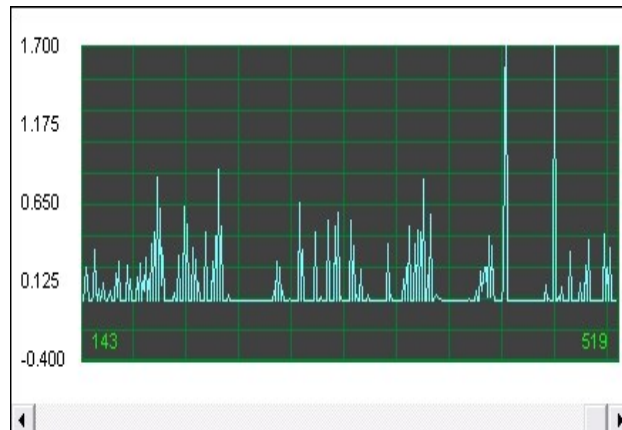*Fig. 8. The non-sinusoidal vibration oscillogram.*

Fig. 9. The amplitude-time spectrum at the output of the acquisition board in case of a fault.

6. CONCLUSIONS

In order to simulate a faulty operation, a variable vibrations source is used, the control circuit having the possibility to determine the generation of chokes, that simulate the operation of the wind turbine in case of fault.

The experimental results depicted in *figs. 6-9* highlight the role of the acquisition board in the monitoring equipment. The measured values can be saved in CVS type files, a format that doesn't need special drivers for being open and read.

Using an acquisition board capable monitoring more piezoelectric transducers mounted on the main elements of a wind generator, exhaustive information, during the operation time of the wind generator can be obtained. Therefore, the faults of these elements may be detected in incipient stages. Consequently, a repair planning can be drawn, more effective than applying simple preventive maintenance measures. Consequently, major faults that can make the wind generator inoperable could be avoided.

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