Abstract

In this paper is presented method of nondestructive diagnostics, which uses to determination of actual devices state spectral density analysis. To evaluate of the method is used clustering analysis and as results are areas with higher response intensity to input impulse in given frequency range. This information will then be served as support for control of metallurgical process.

Keywords: Simulation, Fourier transform, signal spectral density, continuous casting, FFT, power spectrum

1. INTRODUCTION

The potential nondestructive diagnostics of solid objects is discussed in this article. The complex modeling and simulating tools exploration in tasks of modeling and simulating of technological devices is growing in the present time. The important property of this systems is their comprehensive conception, possibility to connect it to the existing automation and measurement systems, sufficient wide pallet of tools enabling analyze, synthesis and next export of models to the common programmable languages a thereby theirs usage in current technical praxis. This paper is focused on one area of technical diagnostics, which task is assessment of technical lifetime of crystallizer on continuous steel casting devices. This task is solved in program environment of MATLAB program using fast measuring card MF624. The whole process is accomplished by consecutive steps involving software analysis of the vibration power spectrum (eventually acoustic emissions) created during the normal operation of the diagnosed device or under unexpected situations. Another option is to create an artificial pulse, which can help us to determine the actual state of the diagnosed device. The main idea of this method is based on the analysis of the current power spectrum density of the received signal and its post processing in the Matlab environment with a following sample comparison. The last step, which is comparison of samples, is the most important, because it is possible to determine the status of the examined object at a given time. Nowadays samples are compared only visually, but this method can’t produce good results. Further the presented filter can choose relevant data from a huge group of data, which originate from applying FFT (Fast Fourier Transform). On the other hand, using this approach they can be subjected to analysis with the assistance of a neural network. If correct and high-quality starting data are provided to the initial network, we are able to analyze other samples and state in which condition a certain object is. This kind of detection can provide significant financial savings in certain cases.

By continuous casting steel, the steel casts from a ladle trough a tundish to the water cooled crystallizer instrumental as mould. In the crystallizer the surface layer of steel solidifies. At the output of crystallizer the temperature of the blank surface reached to 1200 °C and the core of blank is still liquid. The mould is necessary furthermore to cool in the section of secondary cooling, where using nozzles the water is fed to the mould surface and by this way it is cooled. The mould moving is established by the traction rolls. At the end of secondary cooling the mould has to be solidified all over cross-section and after this it is cutting to required length pieces.

Crystallizer is during his life time gradually worn away. This degradation is not linear and is finding out during dead plate by measuring. In now days, when there is a push to increase technological usability of equipment,
is logical push to minimize or remove this dead plates. We are trying to develop of such methods, which would be sufficient exact and would be able to determine real abrasion of crystallizer. Presented diagnostic tool are focused on searching for those frequencies, which can be responsible for crystallizer's surface damage. It not mean, that the frequencies cause the damage, but the damaged surface generate these frequencies as a secondary symptom. We are trying to present this correlation by the form of picture with help of fast Fourier transform (FFT) and power spectrum density (PSD).

This article is devoted to the technical diagnostics of a device using analysis and evaluation of its vibration spectrum or acoustic emissions. The vibration spectrum and acoustic emissions have various origins (Fig. 1). When analyzing a vibration spectrum, the response of a system (of an object) to an artificially created impulse is recorded. On the other hand, acoustic emissions mainly originate spontaneously, for example, by creating a crack on a pipe’s surface during mechanical stressing (in plastic deformation position), etc.

On the basis of the problem definition provided by an external company, the task was to find out whether it is possible to detect the internal conditions of an object using vibration spectrum analysis. The object consisted of a metallic skeleton connected by screws placed on the edges. When a screw is loosened, the diagnostic system should define precisely the position or side where the screw (or simply the defect) is located. Many articles have been published considering this topic, [1] [2] [3], but most of them address specific problems and this translated into very specialized solutions.

Fig. 1 Two approaches, how to detect the surface abrasion or damage.

The main advantage of our solution is the possibility of preventing the formation of limiting states and also the prevention of dangerous situations and device damage. Whilst the authors of the aforementioned article are trying to preclude greater damages after the formation of a crack, our option tries to prevent the condition from happening.

The principle of this method comes from measuring a system’s (examined object’s) response to a Dirac impulse. The first experimental results were presented in [4]. An ideal Dirac impulse is replaced by a real impulse which is generated by a firing pin that is excited by a magnetic field (Fig. 2).

Fig. 2 Pseudo Dirac impulse realized by a firing pin which is controlled by a Siemens PLC. T is the pulse period and n is a number of pulses.

This impulse is far from the ideal shape, but for these purposes it is sufficient. Individual pulses are operated by a Siemens PLC which generates a series of impulses with a period of 2 s (Fig. 2). Unwanted offset and relatively uneven progress of individual strokes are among the basic disadvantages (only when comparing amplitude envelope).
An impulse is a source of vibrations (or also specific acoustic emissions [5]) with a wide range of frequencies. All of the components of the whole spectrum would be represented in an ideal pulse (theoretically a white noise generator). The components up to several kHz are represented in our case. Moreover, there is uneven representation of individual components. An analyzed object behaves as a selective band-pass filter after the activation of pulse or after the formation of an acoustic emission. The recorded amplitude's envelope is modified and the FFT is applied.

The final power spectrum density (PSD) is then subjected to examination and modification. Some vibrations (at certain frequencies) pass without significant changes, some are heavily suppressed. In order to work more synoptically with the received data, it is necessary to modify the PSD. After the application of the suggested filter, the irrelevant data are removed from the PSD and the result is saved in a matrix form. The suggested filter scans each pulse record (it's PSD) and searches for specific values of the individual spectrum's components. Positions of points (their corresponding frequencies) are very important for the next analysis of the PSD.

A schematic of the measurement series is depicted in (Fig. 3). Vibrations are scanned with the assistance of a type 4332 accelerometer from Bruel & Kjaer. This sensor is unique for its high frequency range, which exceeds 25 kHz. Indeed, there are cheaper types of accelerometers from various companies on today's market, but most of them are only suitable for scanning frequencies up to 600 Hz (mobile applications) which is not convenient for the declared purposes [6].

After the signal amplification (the sensor only produces tens of mV) the signal is digitalized with the help of a NI PCI 624 multi I/O card from National Instrument. This card has 16 analog inputs which run at 250 kHz. Only one channel that works with a sample frequency of 100 kHz was used for the given purpose. With regard to the estimated and scanned frequencies on the order of tens of kHz (maximum around 20 kHz) five time oversampling is sufficient. A driver algorithm was created in the Matlab — Simulink environment and adjusted in such a way that the trapped data are saved for a period of 600 s. The subsequent processing of results was already running offline.

The algorithm is evaluated in Matlab. Firstly, it is necessary to extract relevant data, records of pulses and save them separately into a matrix. A routine serves for this purpose. It looks for initiation of pulses and then saves identically long blocks of data into the beforehand set positions in the matrix:

\[
\text{start}_i = \text{if} \left( \text{abs(DATA}(j) - \text{DATA}(j + 1)) > (\text{noise.level} \cdot \sigma) \right)
\]

(1)

where:

<table>
<thead>
<tr>
<th>DATA</th>
<th>Is a matrix with the record of pulses</th>
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</thead>
<tbody>
<tr>
<td>i</td>
<td>Index of variable start, sequential number</td>
</tr>
<tr>
<td>j</td>
<td>Sequential number of sample in the record</td>
</tr>
<tr>
<td>σ</td>
<td>Is a constant derived from medium level of noise in signal and states that: ( \sigma &gt; 2 )</td>
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</tbody>
</table>

After extraction of individual records, a Fast Fourier Transformation is applied and its results are saved into the next matrix. Each individual line of the matrix corresponds to values of one pulse (its PSD). The calculation consists of the division of the signal into M segments which may partly overlap. From each
segment the middle value of the square of the normalized and amplitude spectrum is calculated. The results for each segment are averaged and deflections made by the used window are removed.

From the already made signal spectral densities, it was necessary to extract the relevant data and to separate the useful signal from noise or residues formed by surrounding noise or insufficient shielding of an object from surrounding vibrations. This part is quite difficult, because it was not possible to find a suitable routine in Matlab or in the literature concerned with these problems. The question is how to find the position (frequency) of individual points. These points are greatly important for us and directly reflect the real condition of an object. The classic definition of local maximum failed due to the above mentioned problems. It states:

\[
\text{maximum}_{\text{local}} = \text{if}(f_{(x-1)} < f_{\text{maximum}}, \text{local} > f_{(x+1)})
\]

where:

<table>
<thead>
<tr>
<th>maximum_{local}</th>
<th>Is a local maximum position</th>
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<tr>
<td>f(x)</td>
<td>Is a value of a function at point x</td>
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Therefore, it was necessary to find a different method. Human perception of this problem meant great inspiration. When looking at the graph of the power spectrum density, the individual maxima are obvious. After some simplification it is possible to say that perception of individual extremes is due to their position with respect to other values. Even though, the amplitudes of two sharp local maxima which are next to each other are very high, it is possible to ignore them, although if the local maximum is isolated and it has a significantly lower amplitude than the global maximum, it is perceived as sharp. Obtaining relevant points from the PSD is crucial. It is only their position which guarantees correct learning by the neural network or regressive detection and marking of the result. Nowadays, there is a “flag” assigned to each local maximum which states for how long it is valid. In the future, the algorithm will be extended by the option of working in narrow zones and choosing of local maximum more accurately than now. The value of flag is incremented in the case when:

\[
\uparrow n_{\text{flag}} = \text{if}(f_{PS(i)} > f_{PS(i-1)})
\]

Then the position of a local maximum must fulfill the following criterion:

\[
\text{maximum}_{\text{local}} = \text{if}(f_{PS(i)} > f_{PS(i+1)} AND n_{\text{flag}} > n_{\text{ser}})
\]

where:

<table>
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<tr>
<th>n_{\text{flag}}</th>
<th>Actual value of variable n which indicates the operating period of a given maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_{PS(i)}</td>
<td>Is a value of a function (curve PS) in point i</td>
</tr>
</tbody>
</table>

Individual results are saved again into a rectangular matrix. With regard to the fact that the filtered spectrum has a number of irrelevant local maxima (the noise component cannot be neglected), it is necessary to apply a final modification which means removal of all local maxima that do not fulfill the criterion:

Furthermore, it is necessary to add that values of frequencies and amplitudes are only relative. By recalculating them it is possible to obtain real frequency and amplitude values. However, this is not necessary for this analysis and it would be more difficult to calculate. Therefore, the values on the axis do not have units (only their relative values are important).
These results have only static meaning. It was need to insert relation to process time. Created PSD and its peaks reflect one single state in time. Time axis is absolute mandatory, if we want to involve time behavior of the current process. Representation of single PSD is relatively easy. The fast Fourier transform is applied on acquired signal and then it is need to convert image data from conjugate imaginary numbers to real numbers and its result is presented in (Fig. 4).

This figure is only for illustrated purposes. On the X axis is relative frequency and on Y axis is amplitude of single component. These PSD is relatively clean, without expressive noise with several local maxims in defined sectors. It is important to defined, what is the useful signal and what is the noise. Peak on 160Hz can be assumed as a local maximum without any doubt, but looking for local maximum in the range from 100Hz to 120Hz is very tricky, because we are not able to tell, what is the noise and what is the signal. There has to be a rules on the start, according which can be determined how to process PSD data a how to evaluate it. The simple solution is to make a horizontal surface at specific level, and display only these data, which has the amplitude higher than this level. That surface has to be optional, consequently its level, and in a several attempts can be examine proper value as it is presented on (Fig. 4). As result, it will be a bitmap picture, where on X axis is frequency and on Y axis is time. Basically we moved from the time domain to frequency domain thanks to FFT and now, we are moving back, because the time is important to evaluate created PSDs. One example, which were made on laboratory model and data from this attempt are presented on (Fig. 5).

**Fig. 4** Power Spectrum Density of single data segment of exact length.

**Fig. 5** Different expression of PSD on the basis of amplitude threshold level

When the amplitude threshold (horizontal surface) is decrease, the more picture point is displayed. On the (Fig. 6) left upper picture has this surface at the lowest level. Number of display pixels is at its maximum. From this picture can be seen, that some frequencies are presented almost constantly through the process time and some frequencies draft lightly. Other points displayed in picture, which has random character are at the high probability the noise. As the surface level arise, these points disappear and the picture become more clear. If the threshold level is set to high, then disappear even a data, which carry valuable information (right down picture).
2. CONCLUSIONS

The purpose of this project was to verify whether it is possible to find out the condition of a diagnosed device (presence of inner defects, surface defects or critical conditions) on the basis of analysis of its vibration power spectrum (acoustic emissions). It is clear from the measurement results that in the frequency area there are some similarities. We are planning another processing of results with the assistance of a neural network with vision of better results. The condition of an object may be found and whether some critical condition or breakdown has occurred. By future development of filters and modification of computational algorithms it will be possible to increase the success rate and identify with certainty the condition of an object without requiring a shut-down or by interfering in other ways into its inner structure. Therefore, this method will be useful in places where it is impossible or economically inefficient to shut-down the process due to preventive maintenance or replacement of device or its parts. For example, this is a continuous steel casting, cracks in pipes and fluid leaks. From the development is obvious, that static PSD generation is good for actual device’s state, but it can't inflict dynamism of the process. Displaying many PSD as a function of time gives us good picture of the running process with all of the variables, which are involved - surface degradation, speed fluctuation and so on.

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BIBLIOGRAPHY