Analysis and Discrimination of Operating Noise at AE Monitoring of Static Facilities

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Abstract. AE monitoring of static facilities of polypropylene production is under discussion. To enhance the reliability of source detection and the validity of signal interpretation the simultaneous and consistent processing of both, periodic noise and random AE data, recorded by the same acoustic channels is carried out. It is shown that in spite of high frequency filtering applied at data acquisition, periodically recorded noise contains relevant information about low frequencies of working mechanisms. It was supposed that extraction and analysis of these frequencies related to certain mechanical components may be successfully used in a way similar to that applied at the vibration condition monitoring and diagnostics techniques. Data processing methods used in the study include digital simulation, phase and amplitude waveform analysis, correlation techniques and digital filtering.

The patterns of the simulated AE and noise waveforms were recorded during the shut-down period of the facility and at the operating conditions, correspondingly. The results of filtering and pattern recognition show that these types of signals can be easily distinguished both in time and frequency domain only when AE source is located in the proximity of the sensor.

Special autocorrelation function of hit sequence(s) and its spectrum were estimated to obtain characteristic operating frequencies directly from AE data. Results were the same as obtained from periodic noise, showing that most of the recorded signals correspond to the fluctuations of the operating noise.

Studies have shown that the application of various processing procedures to all data recorded during AE monitoring improves the quality of monitoring and can serve for diagnostics purposes of operating condition of the facility.

Introduction

The ability of remote test of hazardous crack-like defects by means of acoustic emission (AE) makes this method a unique technique for structural integrity assessment and at the same time serves as the basis to use it for continuous long-term monitoring of static facilities. However widespread application of AE method during monitoring is constrained by different factors, in particular, the presence of high fluctuating noise, which masks the signals from genuine emission and therefore reduces both, the sensitivity of the method and the confidence of the testing results. Another limitation of the method is that only a very small portion of the recorded data is processed as valuable information. In fact the majority of signals collected during AE monitoring relates to the operating noise, whereas true emission from fracture processes occurs rarely. However, the periodically recorded noise, which usually serves only as auxiliary information at AE testing practically, contains relevant data about working facilities and mechanisms. Thus, it can be advantageously analyzed together with AE hits and digitized waveforms and used for diagnostic purposes. In this regard, without abandoning conventional ways of recording and analysis of AE data we propose to perform noise testing of dynamic characteristics of a facility by means of monitoring and processing the noise data. Basically, such testing may be done in a way that is used at vibration diagnostics of dynamic equipment and mechanisms, which is a commonly applied technique examining the individual frequencies present in the detected signal. Simultaneous multi-channel measurement and processing of AE signals and fluctuating acoustic noise can be used as a measuring base of comprehensive monitoring.

The paper discusses two problems arising at data processing during AE monitoring in the presence of high nonstationary noise. The first concerns the extraction and discrimination of useful AE signals from noise for the purposes of structural integrity testing; the second is the analysis of on-site noise itself to provide integrity condition monitoring of the facility.

Data processing methods used in the study include digital simulation, spectral and correlation techniques, digital filtering [1] and pattern recognition.

1. AE Monitoring Procedure

The subject of the study is a chemical reactor in which a continuous propylene polymerization reaction proceeds producing solid powder particles of polypropylene (PP). Reactor is equipped with a stirrer, consisting of a plurality of pairs of blades (4 in the set), located on the rotor rotating at a frequency of 0.25 Hz. Each pair of blades rotates at a rate of 0.5 Hz, and the entire set of blades (eight pieces) blades rotates at a rate of 2 Hz.
The most probable failures of equipment refer to the faults of pump, compressor, propylene leakage and formation of agglomerates in a layer of polypropylene powder.

AE data is recorded by a multichannel AE monitoring Sensor Highway II System™ produced by MISTRAS Group, Inc. The sampling rate is set to 2 MHz, frequency band is 150-500 kHz, 300 KHz resonant sensors are used. With account of the observed attenuation of acoustic waves AE sensors are mounted on the surface of the reactor at a distance of 3-4 m from each other, forming a regular AE array.

Different types of data were recorded and processed, including noise (random mean square, RMS) that was periodically recorded by temporary decimation and averaging the digitized data obtained from the ADC output; sequences of AE hits and AE waveforms. RMS decimation was carried out with a sampling interval of 10 ms that enables to analyse noise frequencies up to 50 Hz.

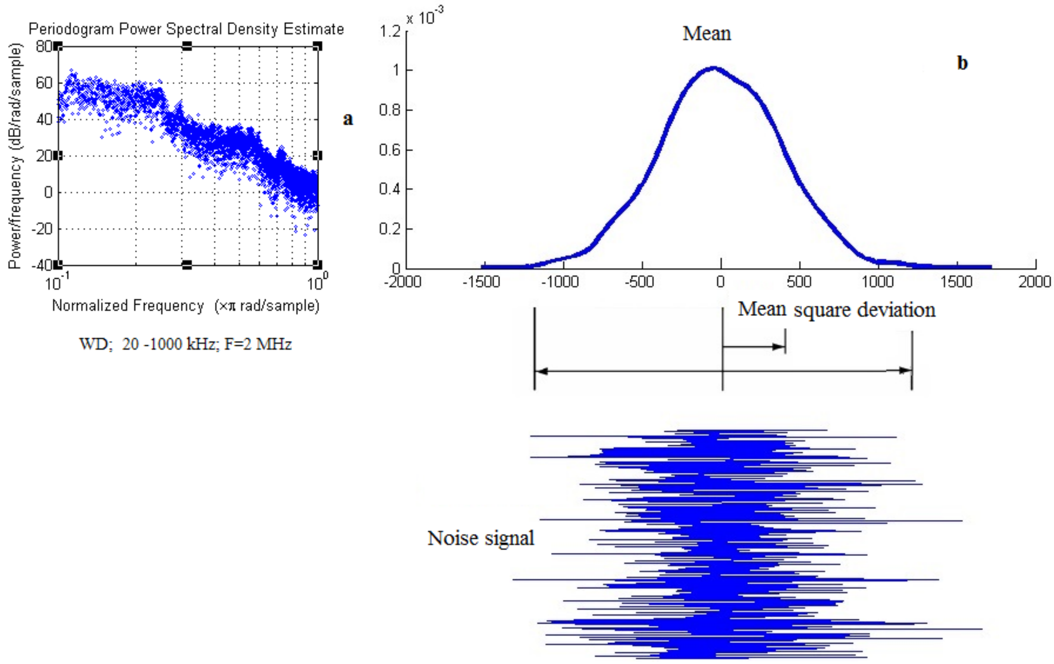
2. Types of the Operating Acoustic Noise

Among the different kinds of noise, including electrical noise, electromagnetic interferences, mechanical noise, which can be recorded by AE system, mechanical noise is of special interest to be focused as it is often hardly distinguished from the genuine AE because of a similar mechanical nature. Noise study showed the presence of two types of mechanical noise, recorded during the operation of the reactor.

2.1 Characteristics of the continuous noise from the stirrer

Main continuous noise is induced by stirring of the product. It is caused by the motion and the collisions of small PP particles suspended in a fluid and moving under the influence of

random forces. High amplitude fluctuations of this noise relate to the impacts of a great mass of particles against the reactor wall.
Reactor noise recorded at the preliminary study by means of wideband AE channels (20 kHz - 1 MHz) had the amplitude level of up to 65 dB. Analysis of waveforms related to noise fluctuations showed that this nonstationary noise refers to the so called "colored" noise, which, unlike the white noise has a power dependence of power spectral density (PSD) on frequency: PSD ~ 1/fn, with exponent n ~ 6, Pic. 1a.



Pic. 1. Statistic characteristics of wideband operation noise on the chemical reactor: a) power dependence on frequency; b) Amplitude distribution.

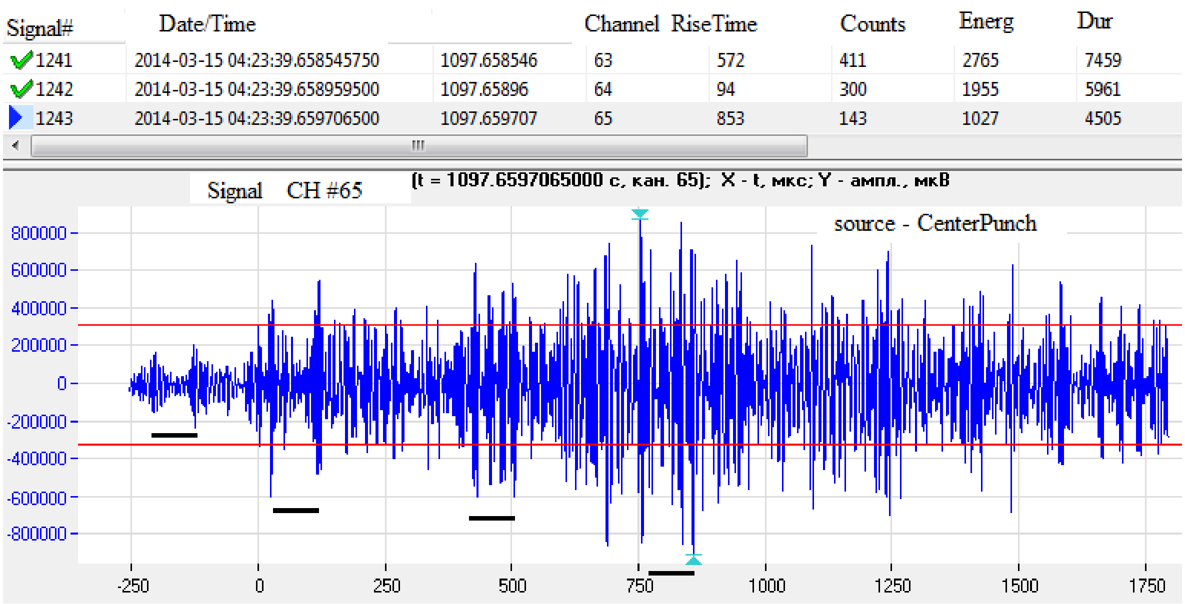
Amplitude distribution of the noise is shown in Pic.1b. Due to the large number of random collisions of PP particles, the distribution of noise amplitudes given in Pic.1b, may be considered a Gaussian as consistent with the central limit theorem.

Considering both the obtained amplitude-frequency dependence of the PSD and wave attenuation, the optimum frequency range of AE tract was determined as 150 kHz-500 kHz, giving more than 12 dB noise reduction, i.e. amplitude level of about 53 dB.

2.2 Characteristics of impacts of rigid objects

The second type of the examined mechanical noise refers to impacts of solid objects against the surface of the structure. External impacts are often observed at the maintenance of the facility, whereas internal impacts can be caused, e.g., by the formation of large agglomerates of PP and their collisions with the inner surface of the reactor. Study of the characteristics and distinguishing features of AE signals generated at collisions of solids is given in [2]. It was shown that elastic (quasi-elastic) impact with recoil produces two high frequency wave fronts, first relate to the loading, second to unloading of the surface coming with delay equal to the contact period. Waves are generated at the moments corresponding to discontinuities of the perturbation function. The lower is the order and the higher is the value of the discontinuity, the higher is the amplitude of the wave front, i.e. the amplitude of AE signal. While the deformation of the surface is a continuous function, its first derivative velocity has two ordinary discontinuities at the initial and the final moments of the impact contact time. Besides, the high frequency (AE) tract is known to be more sensitive to derivative of the function, than to the function itself meaning AE amplitude of the first peak is proportional to the velocity of the body or to the rate of deformation. As it was shown earlier the amplitude-velocity relationship together with the delay-based peak measurements of impact duration, enables one to estimate the maximum indentation and the impact force, thus impact hazard.

AE signals from impacts recorded by the remote sensors also contain pairs of peaks, which are observed in different Lamb modes. Signal delays between each pair of peaks of Lamb modes are equal to the signal delay measured proximate to the impact source, thus to the contact time. Typical signal from the impact of center-punch against the reactor wall is given in fig. 2 where several pair of peaks referring to different wave modes could be observed, though may be not as clear-cut as in the model experiment.



Pic. 2. Signal from the remote Center-punch. The pairs of different modes with same delays are marked by black closed interval.

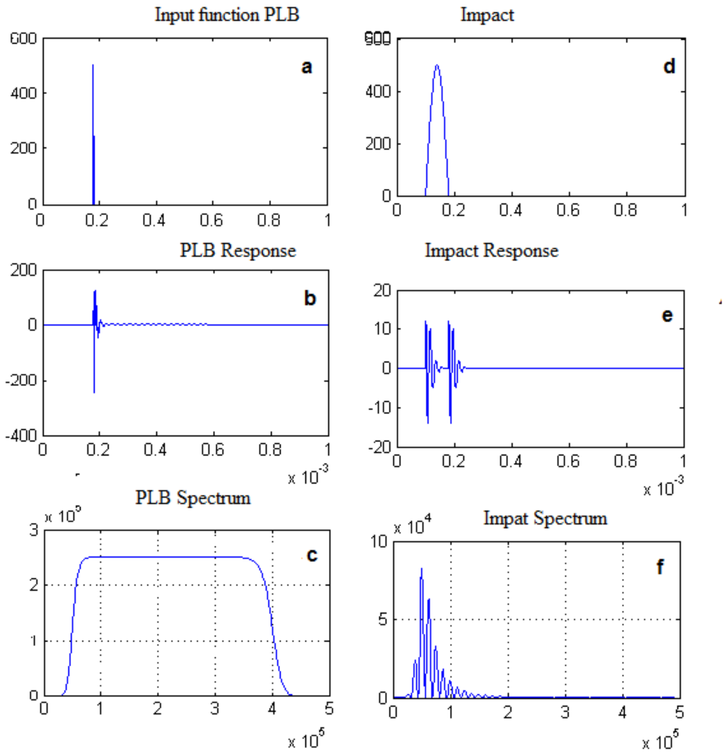
Besides, it was shown that the frequency range and the contact time are related inversely at collision, meaning the shorter is a contact time, i.e. the higher is a velocity of the colliding body, the higher is AE amplitude and the broader is the impact spectrum. Pic.3 shows the modeled PLB (pencil lead break) and impact signals and their corresponding spectrums obtained by high frequency channel with a frequency band of 50 - 400 kHz. One could see that the signal from impact has a distinctly narrower spectrum, shifted to the left. This shift is used as a diagnostic feature to differ a true AE from impact.

Above consideration shows that signals from elastic and semi-elastic impacts, which are characterized by the limited contact time (without cohesion) can be rather easily distinguished from the other sources both in frequency and time domains.

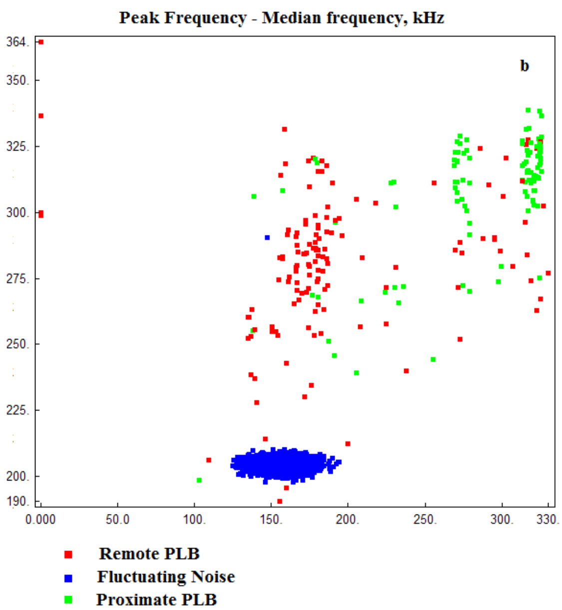
2.3 Recognition of signals produced by the different sources

From above it follows that the most difficult discriminated mechanical sources that have high amplitudes are impacts with cohesion. In fact, they cannot be well distinguished in time domain (signals are characterized by only one peak occurring at loading) and they have rather wide spectrum at rapid loading. Besides, spectrum of remote genuine AE source also shifts to the left due to attenuation of high frequencies at wave propagation, i.e. it becomes similar to that of impact. Our study performed on the reactor showed that the most informative spectral parameters capable to discriminate fluctuating noise from true AE (here PLB imitator) are median and peak frequencies.

Clusterization of 3 types of signals obtained from impacts of mass of PP and both proximate and remote PLB in the space of these frequency features are given in Pic.4. It was determined that at an appropriate signal to noise ratio, when AE peak amplitude exceeds a threshold by more than 10 - 12 dB, the major portion of the fluctuated noise can be discriminated from AE data by means of pre-filters and simple post processing recognition procedures.



Pic. 3. Modelling AE signals from different sources. Signals from PLB (a) and impact of 11 mm metal sphere against a thick aluminum plate (d), their responses (b) , (e) and spectrums (c),(f) correspondingly.



Pic.4. Distributions of 3 types of sources in 2D spectral feature space.

3. RMS Analysis and Interpretation

The study of large samples of continuous noise recorded periodically on the working reactor showed the presence of definite low frequencies inherent to the working mechanisms of the reactor. Because of high pass filtering applied at data acquisition (150 kHz cutoff of HPF) these frequencies exist as modulation frequencies of high frequency wideband noise discussed above, which serves as a carrier to them. Such background noise recorded as RMS generally used just as accompanying information at AE testing. However, practically, it contains relevant data thus can be analyzed together with AE hits and waveforms and used for diagnostic purposes.

To extract low modulation frequencies a detection procedure has to be applied to the sampling data. Time driven data, which is random mean square decimated data obtained from initially digitized data (initial sampling rate is 2 MHz) keep all the features, required for extraction of low modulation frequencies. In fact, a possibility of detection, i.e. demodulation of modulating frequencies laid in the principle of RMS calculation, which basically, is a "linear" detector [3]. Besides, a decimation down to the frequency F_d, where F_d /2 is greater than the modulation frequency f enables to extract the latter.

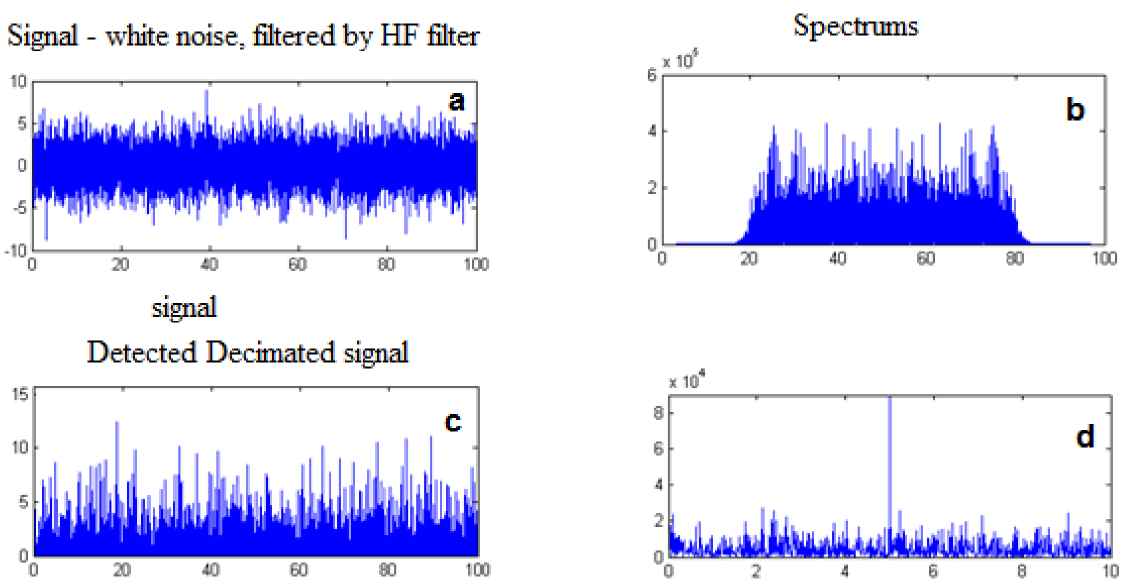
3.1 RMS modelling

The validity of this statement can be demonstrated by modelling the process of noise modulation:

$$Y=\{1+\sin(2\pi f\cdot t)\}\cdot 3\cdot White\_Noise$$

Here Y is the output amplitude; f is the frequency of the modulation sinus function = 5Hz; t is a current time, with time discrete dt = 1/F, where F is a sampling rate of 1000Hz; White_Noise is a simulated wideband noise.

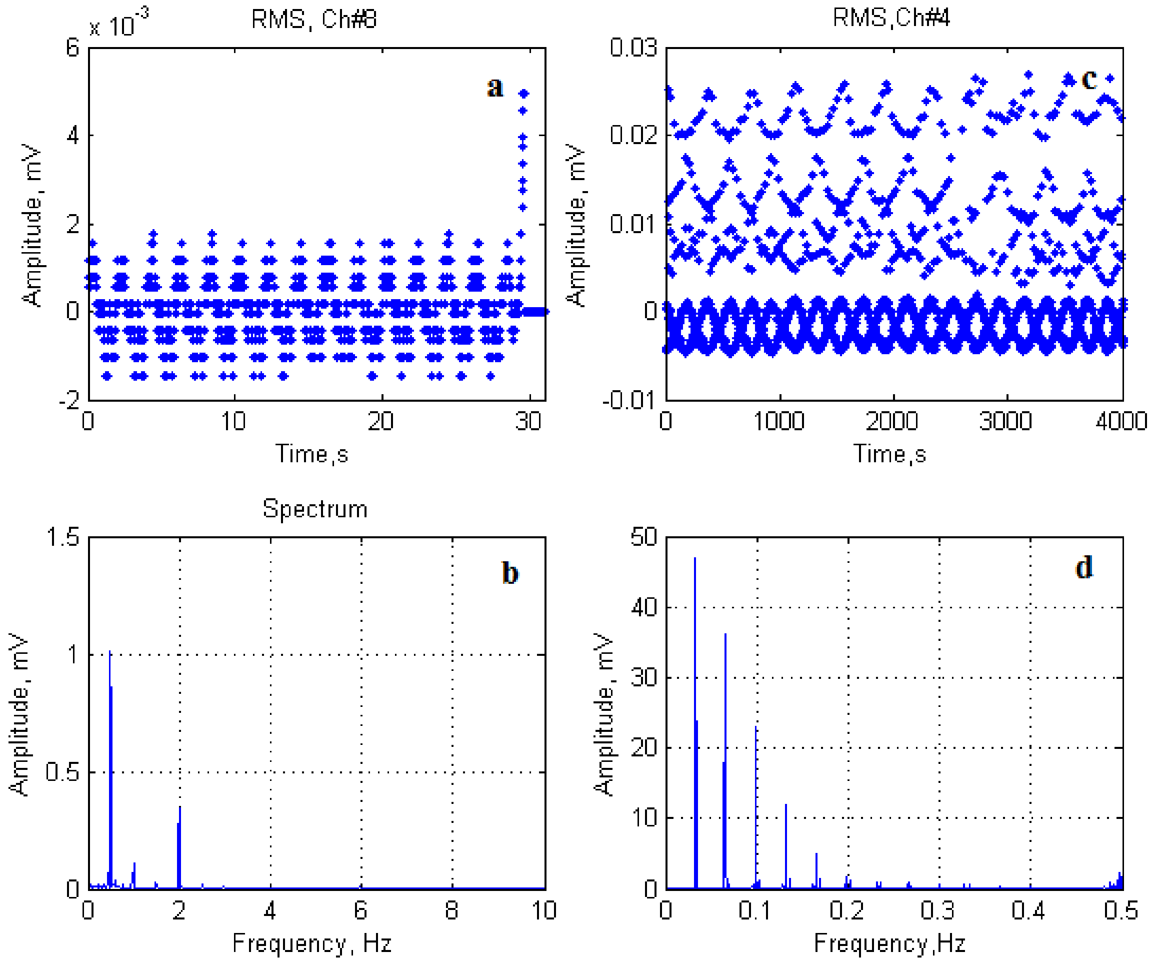
To model AE measurements at monitoring of the reactor, the obtained output Y is then passed through a HPF with 20Hz cutoff and decimated. The initial white noise and the resulting RMS with their spectrums are given in Pic.5a-d illustrating the presence of the modulation frequency equal to 5 Hz in Pic.5d.



Pic.5. Modelling of high frequency white noise modulated by the periodic force. d) detection of low modulation frequency.

3.2 RMS Processing Results

At the study of real RMS data recorded during AE monitoring of the reactor it was discovered that in spite of high frequency filtering (150 kHz cutoff frequency) applied at data acquisition, RMS samples show the presence of low frequencies: 0.5; 1.0; 2; 25 Hz, corresponding to the rotation of stirrer with blades, see Pic. 6b. RMS patterns and respective frequencies were obtained at different channels when the initial digitized data were decimated by the interval of 10 ms, which is sufficient to extract frequencies up to $f = 1/(2*10ms)$ = 50 Hz .



Pic.6. Real RMS data obtained at monitoring. a)RMS decimated with the interval of 10 ms, b) its spectrum; c) RMS decimated with the interval of 10 ms,d) its spectrum.

When a decimation interval was setup to 1 sec and simultaneous averaging in a sliding window of 500 ms duration was carried out, much lower frequencies were extracted. These frequencies, which are the multiples of 0,033 Hz, apparently are the artifacts and require additional interpretation, see pic.6d. However an attractive ornament shown in Pic.6c reflects the periodic effects, each of which relates to one of the 8 blades.

4. Conclusions

Characteristics of different types of reactor noise, including continuous noise caused by stirring and collisions of polypropylene particles and the impacts of rigid bodies against reactor wall were investigated. As a result the optimum frequency range of AE tract was determined, giving more than 12 dB noise reduction.

It was found out that the less is a contact time at impact and the more is a distance from the source the less is the difference between PLB and impact signals.

Study showed that to avoid false interpretation of AE data the periodically recorded noise data, e.g., RMS, have to be analysed together with AE hits and AE waveforms, both in time and frequency domains. The resonances extracted from RMS of noise can serve as the monitoring diagnostic features.

Simultaneous noise diagnostics and AE control using the same data acquisition channel can be a useful technique for integrity condition monitoring of the facility.

References

[1] E.C. Ifeachor and B.W.Jervis, Digital signal processing. A practical approach.// Second Edition, Sheffield Hallam University, 2004, 989 p.
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[3] A. A. Kharkevich. Spectrums and analysis.// Moscow, 1962, 236 p.