UTILIZATION OF THE ACOUSTIC AND VIBRATION SIGNAL FOR OBSERVING TRANSPORTED MATERIAL USING BELT CONVEYORS

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Our paper is aimed at a carried-out analysis of both acoustic signals and mechanical vibration, which are formed within a technologic process on an open pit mine; and special attention is paid to the material quality

Introduction

What is characteristic of any technological process as well as any equipment is its acoustic manifestation in the course of operation. This signal is a manifestation of the function of equipment, its condition and impacts on material treated. The acoustic signal arises due to mechanical vibrations; the acoustic signal being, as a matter of fact, mechanical vibration of the air.

On the basis of analysis of acoustic signals and mechanical vibration developing in the technological process at the opencast mine, especially in the course of long-distance belt transport, information on material mined was searched for. I have concentrated upon signals within the audible range; it means sounds and corresponding mechanical vibrations.

History of devices

In the year 1976 an idea appeared at the Department of Automated Control Systems at VŠB – Technical University of Ostrava to utilise operational sounds and signals occurring when transporting materials by long-distance belt conveying and in transfer points for distinguishing the kinds of materials transported. Subsequently, next measurements were taken and analyses were done. The measuring recorder with the direct "D" amplifier made the measurement of acoustic signals. As sensors, the microphone and the piesoceramic vibration pickup were used.

The evaluation of the signal was made on the frequency analyser. The obtained frequency spectra were compared and differences were found in the character of the envelope of particular frequencies. With the frequency spectrum of a coal fall, a decrease in the domain of higher frequencies was evident. Similarly, the analysis of the signal obtained from the piesoceramic sensor was done. The extending of the spectrum to higher frequencies manifested itself. When comparing the frequency spectra of particular materials transported, the dependence similar to that of signals from the microphone appeared. Thus it was possible to state that each material had its own characteristic spectrum. On the basis of information acquired, a device ISAI 1 was designed for identifying specific acoustic signals.

In virtue of requirements from practice due to the transition to the gobs of former underground mines and the connected heightened problems of separation of large intervals of waste rocks in the flow of mined material, a new device ISAI 24 was designed. As for the device, the customer had the following requirements. A simple and cheap solution. The distinguishing of two or three quality levels (waste rock, coal 1 and coal 2).

The design of the device rested upon conclusions listed in the previous part, namely that for distinguishing the kinds of material, the amplitude of the part of the frequency spectrum more than 4 kHz was crucial. With regard to the variable quantity of transported material that influenced functionally the whole frequency spectrum, it was necessary to find a method how to remove this influence. At the fall of material on the directing shield, this was excited by the sequence of complex impacts. The stochastic mechanical vibration developed that was a function of transfer properties of the shield, the type of fallen material, the velocity of the fall and the lumpiness. The amplitude at the resonance frequency was, however, affected almost totally by the impact force. On the basis of this finding it was then possible to normalize the whole frequency spectrum by the amplitude of the resonance frequency and thus to obtain the frequency spectrum independent of the impact force and, at the constant belt rate, independent of the quantity. It was the variable lumpiness of material that brought a certain inaccuracy.

Analysis of information

For the setting of devices and the next development, measurements on directing shields of long-distance belt transport were taken. The requirement was to obtain a representative sample of measurement. The measurements were carried out on a similar type of the directing shield of long-distance belt transport. Shields of the same type, wear and the mode of mounting were selected. Before measuring, the check on the shield mounting had been done.

As reference information, values measured by the belt balances and the radiation ash content-meter were used. These instruments had been calibrated before measuring to ensure their accuracy as high as possible.

Results from the belt balances and the ash content-meter covering the information and the time of measurement at the interval of 1 minute were recorded and printed out.

On the basis of the acquired information an analysis was done. The analysis was done at the time interval of 2 minutes as a mean value. After checking, analyses corresponding to various levels of quality or quantity were selected. The check consisted in the deletion of duplicate pieces of information being congruent in the level of input and analysis of the signal. The result was a set of 54 representative samples of signal and their analyses.

The frequency analysis itself was done for the mean values of a section of the signal record. For the analysis a digital wideband low-frequency parallel analyser was used that worked with 42 third octave bands for average frequencies of 1.6 Hz – 20 kHz. With regard to another processing, the spectrum tables were transcribed to the the Excel program.

In virtue of the knowledge from previous works, I did an analysis of information obtained at measurements in the transfer points of long-distance belt transport. With the processed data, I subsequently searched for dependences on quality and another information. At first sight it was clear that the whole spectrum was influenced by the quantity. This information only confirmed the initial assumption of signal standardisation.

In terms of the necessity of confirming the dependence, a statistical analysis of spectra was done by means of the statistical program Statgraphic. Furthermore, this program searched for models of dependences of particular pieces of information. On the strength of these models, I processed the values to find real dependences.

After that the task of statistical evaluation was to explore the relation between the quality and the quantity of material transported and the amplitude of a signal at particular frequencies or the combinations of them. Moreover, the “optimum” regression model was to be designed to describe the quantity-frequency and the quality-frequency dependence. The goal of this evaluation was thus to find such a model that could make it possible to estimate, as precisely as possible, the quality and quantity of material.

By bearing in mind that these dependences existed and that they had been experimentally verified I made the evaluation.

The first step was the application of simple regression and correlation analyses that should have shown the proximity of a quantity-frequency relation or a quality-frequency relation.

It was clear from the results that the frequencies of 250 Hz and 500 Hz carried with very good accuracy the information on the quantity; the determination of the material quantity on the belt was then possible on the basis of amplitudes of these frequencies. The dependence is, in principle, linear.

Between the sizes of amplitudes of both the frequencies, a very good race - dependence is there:

FREKVENCE_250 = 1.49 FREKVENCE_500

that describes this race by R-SQUARED = 99.94%

The amplitudes of both the frequencies carried the same piece of information of the same content value. For the model, the utilisation of one of them was sufficient. The frequency of 250 Hz was chosen.

Of the stated frequencies, the amplitudes of the frequencies of 3150 Hz, 6300 Hz and partially 10000 Hz carried best the information on quality.

Although the coefficient R-SQUARED is merely about 50%, this result corresponds to the characteristic of the correlation coefficient R = 0.7.

Between the sizes of especially the first two frequencies, a very good race -dependence exists.

FREKVENCE_3150 = 2 FREKVENCE_6300

that describes this race by R-SQUARED = 99.89%

The amplitudes of both the frequencies carried the same information of the same content value. For the model the utilisation of one of them was sufficient. The frequency of 3150 Hz was chosen.

The resultant regression model should have described a relation between the quality of mine run transported on the belt and the acoustic signal produced by the fall of material on the directing shield of the transfer point. Then quality was a dependent variable; amplitudes of particular frequencies from the frequency analysis of the acoustic signal being then independent variables. To determine the independent variables, STEPWISE regression was utilised.

As the designed model did not meet my requirements wholly, I proposed another model. At the design of it, I used practical experience, empirical results and previous laboratory measurements as a basis. Results, knowledge and experience concerning the acoustic signals and vibrations enabled me to propose a simple model. The model consisted of the same variables but it was much simpler, and thus also more suitable. I used statistics for the confirmation of its mathematical accuracy and for the specification of its designed parameters.

The form of the resultant model was as follows:

$$KVALITA = -23.13 + 39.98 \ (F\_6300/F\_250)$$

where: KVALITA = mine run quality; F_250 = the behaviour of amplitudes at the 250 Hz frequency; F_6300 = the behaviour of amplitudes at the 6300 Hz frequency

Although the model had only one regressor and was very simple, its predicative ability was high (R-SQUARED = 0.995).

Existing models are the result of studying done. They say that the dependence of the quantity on the 250 (500) Hz frequencies is, in principle, linear. Furthermore, it is evident, that a model of the dependence between the quality and the frequency of 3150 Hz (or 6300 Hz) exists depending upon the frequency carrying the information on the quantity. These results confirm the initial considerations on the standardisation of the frequency carrying the information on the quality by the amplitude of the frequency that carries the information on the quantity. Another possibility is the direct determination of the quantity, namely from the amplitude of the frequency that carries the information on the quantity. All the results confirm the initial assumption for the building of the device ISAI 24/c, and others with the exception of the initial utilisation of the upper part of the spectrum to distinguish the quality and then the second harmonic of the real carrier frequency.

The results of laboratory and operational measurements and the analysis of the results confirm that the original idea – to assess the quality of material on the basis of sounds made in the course of transport – is justified.

The final result of this study is the good accuracy of the method of checking the quality of coal at the frequency of 3150 Hz and the high accuracy of measuring the quantity at the resonance frequency of the shield, which is in my case 250 Hz.

Device design

In virtue of these results, I could design a device for observing the production from the qualitative and quantitative point of view.

The design of the devise rested on the principle of separation of two decisive frequencies that described the quantity and quality and the subsequent standardisation of the amplitude of the frequency carrying the information on quality by the amplitude of the frequency carrying the information on the quantity of material transported.

The device was designed in virtue of information achieved in the course of studying the given area. It is based upon practical and theoretical information applied then to get a simple and cheap solution. When designing this analog solving, I already considered the digital version of this device that could be, at the present condition of knowledge and especially at the ever-growing miniaturization of computing machinery, very suitable. With regard to the fact that since the very beginning of my work on the given problem I have concentrated to the analog solving, this device is also conceived as analog one. Possibilities of a digital solution are described below.

With reference to already stated facts I determined the following preconditions for the device:

- the input of the device adapted to the piesoelectric sensor;
- filters of the resonance and carrier frequencies tunable by a third of the octave;
- the voltage-controlled amplifier for the standardisation of the carrier signal;
- the converters of effective values to the d.c. level;
- the evaluation of signal levels.

Similarly to the previous measurement, the piesoelectric sensor is mounted on the directing shield of the transfer point of the belt line that converts the vibration signal to the electric signal. In this form the signal is brought to the input of the device.

The measuring part of the device consists of the following particular electronic modules located on individual plates; the flow chart being presented in the figure.

- the input amplifier with a high input resistance and the basic band limitation;
- the filter of the resonance frequency with the converter, the smoothing filter and setting of the control signal;
- the voltage-controlled amplifier;
- the filter of the carrier frequency of quality with the converter and the smoothing filter;
- the circuit of signal standardisation with level indication.

Using digital technology

As already mentioned, at present analog devices are replaced gradually by digital. For this purpose, digital signal processors (DSP) are used.

DSPs are processors specialised in digital signal processing. The signal processor executes one algorithm, i.e. a program implanted into it in advance that processes the input signal digitally. However, it can be reprogrammed whenever, which enables its great flexibility. The computation capacity of modern DSPs reaches, or even often exceeds the capacities of common PC processors. The sense of DSP applications consists in the fact that input signals converted to the digital form can be, on a real-time basis, adapted on one's own demand. The result of adaptations is then available as digital information on the DSP output.

Digital signal processing has, in contrast to analog techniques, many merits:

- the high rate of data processing;
- very quick mathematical operations when using both a floating and fixed decimal points;
- the ability to process large volumes of data;
- digital circuits are programmable – their function can be changed quickly and flexibly without any design changes;
- results are reproducible, which in analog circuit techniques is not usually quite common with regard to their dependence upon parameters of components. Therefore, the digital signal processing offers also a higher accuracy.;
- when processing digitally a signal, no changes in the behaviour of the signal occur in the course of component aging.

The digital signal processing enables implementations that cannot be realised with analog circuits, or can be realised merely at high costs. At our institute, we have been utilising the card EZ-KIT Lite from Analog Devices firm, on which a 32-bit processor ADSP 21031 with the working frequency of 40 MHz is fitted, already for three years. Other important circuits are the ADC/DAC converter AD1847of Analog Devices company, EPROM memory and RS-232 interface. The card has available 1 MB SRAM memories.

Subsequently to the analog device for acoustic signal processing, we settled a similar problem by means of EZ-KIT Lite. The first task was to filter off frequencies redundant for us from the spectrum. It means those frequencies that do not carry any important information for our analysis. The application enables, by simple entering the input values (range of the frequency pass band, sampling rate, filter order and number), to use the low-band filter. The coefficients of filters are computed in the MATLAB environment. The window method (weighting by a Hamming window) is employed for the ideally set frequency characteristic. No claims are laid to the user as far as the syntax of commands of the MATLAB environment is concerned, because all calculations are performed by the application automatically.

In this way, mere reprogramming can filter off any frequency bands and subsequently frequencies important for us can be analysed. Furthermore, we already can test input signals, e.g. for the presence of defined peak frequencies, amplitudes, etc. The functionality of the proposed application was, of course, checked. In our case, we used the program SpectraLAB, version 4.32.14 from Sound Technology Inc.

CONCLUSION

In addition to the above-mentioned example, within the Faculty of Automation of Control Systems, further similar research tasks in the field of coal mining industry were also solved, e.g. the observations of blasting, machines running, locomotive's travelling through a pre-selected area, drilling control, etc. More of information about these problems are on web:. homen.vsb.cz/~neu10/publikace.

A new device, equipped with digital filters and computer data processing, being suitable for general purposes, which will evaluate the acoustic phenomena, is based on a similar principle.

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