UNIVERSITY OF PETROSANI

DOCTORAL SCHOOL

Doctoral Field: Industrial Engineering

" CONSIDERATION ON THE PROACTIVE MAINTENANCE OF INDUSTRIAL AXIAL FANS. VOD 2.1 FAN CASE STUDY"

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2022

Contents

Keywords: *measurement systems, mechanical vibrations, axial fans for the mining industry, data acquisition, alignments, vibro-mechanics diagnostics, signal processing*

INTRODUCTION

Exploitation of coal deposits occupies a priority place in order to ensure the internal needs of electricity from own resources, in a proportion as large as possible. This is also supported by studies developed by the International Energy Agency.

To achieve this objective, technologies and machines of great complexity and productivity are used in the mining industry, which, through a high degree of mechanization, leads to an increase in economic efficiency.

The safety and stability of underground mining depends mainly on the ventilation system. The Analyzing specialized literature it was revealed that axial mining fans are used in the aeration system in a proportion of 30%

In the current stage, there is a transition from extensive to intensive use, which leads to an increase in production not only through investments, but especially by increasing the utilization indices of installations and equipment. This also implies an increase in reliability during the exploitation phase, which ensures a correct operation in the technological process, without breakdowns, the shutdowns to be made according to the planned overhaul and repair programs.

In our country, there is a reduction of investment programs in the mining industry and a direction of funds, to a small extent, towards the purchase of new machinery manufactured in the country. This strong downward evolution of investment funds from the budget was due both to the economic crisis, the financial blockade, and to the reduced degree of promotion of exports.

In this economic context, due to the prices of materials, mechanical and electrical components and the quota of imports, the real value of the equipment intended for coal extraction is very high, which leads to the limitation of the possibilities of acquisition by potential beneficiaries.

For these reasons, current global trends have been directed towards other priorities, such as:

♦ modernization of existing machines

♦ automation and remote data transmission

♦ the provision of machines with equipment for monitoring and controlling the operation

♦ performing preventive checks and technical diagnostics to avoid accidental stops

In our country, action is being taken to solve some of the previously presented requirements, at the present time the objective being the modernization of the existing machinery and equipment in operation.

The breakdown statistics for these types of machines reveals that the majority were of a mechanical and electrical nature.

Through the action of modernization, the aim is to increase the lifetime of the machines with a beneficial effect, both from the economic point of view and as far as the reliability in operation is concerned.

Due to the fact that the most important element determining the lifetime of a machine is the metal structure and its various mechanical sub-assemblies, it is imperative to develop a methodology for real analysis of the dynamic regime in order to determine the duration of their safe use. A series of factors such as overloads, shocks, material fatigue, corrosion, etc., act on the machines over time, leading to their destruction.

The problem of brittle breaks in metal constructions began to be carefully investigated only after the occurrence of serious technical accidents, when large machines were destroyed.

The analysis of these accidents and damages revealed that, in the case of complex welded constructions, the calculations of strength and stability are not sufficient to guarantee the safety of the construction, although they are indispensable, being absolutely necessary that they be supplemented with a series of measurements of mechanical vibrations.

The necessity and opportunity of the topic chosen for the doctoral dissertation is supported by the prospects of mining in Romania, given the fierce competition on the energy market, as ecological restrictions against mining become less and less optional, as the global price of is increasing unprecedentedly from one day to the next, the price per m^3 of natural gas is also increasing, the production of electricity based on coal from the total energy represent quite tangible arguments to confirm the place and importance of coal in Romania's electricity production.

The purpose of this paper is to establish, through modern methods of investigation, the weak points in the operation of VOD fans in the mining industry, to make specific proposals on vibro-mechanical diagnosis, balance and alignment issues, to improve those in order to increase performance and reliability.

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The doctoral dissertation was developed within the University of Petroșani, under the direction of Associate Professor Engineer Ilias Nicolae, PhD.

On this occasion, I would like to thank Associate Professor Engineer Ilias Nicolae, PhD. for the proficient and permanent guidance throughout the period of preparation and drafting the dissertation, as well as for the way in which he managed to direct my activity as a doctoral student, to obtain results of theoretical and practical value.

At the same time, I wish to express my full gratitude to those who helped and supported me during the preparation and drafting of the dissertation.

Content of the dissertation

The objective of this doctoral dissertation was to establish a unitary system and methodology for the analysis, diagnosis, and vibro-mechanical monitoring of VOD axial fans in mining operations.

From the study of the literature in the field of air supply installations in mining enterprises and of vibration measuring instruments and equipment, I reached the following main conclusions:

1. There is no universally accepted system and methodology to diagnose the technical operating condition of VOD axial fans.

2. Companies producing equipment for vibro-mechanical diagnosis, Bruel Kjaer, Schenk, etc., do not offer a uniform methodology for vibration measurement and analysis.

3. The high value of the equipment and related software produced by these companies increase the operating costs of axial fans with direct implications on production costs.

As a result of the above, in this paper I have proposed a methodology of vibro-mechanical diagnosis of the technical operating condition of VOD axial fans. At the same time, I have also designed and implemented a minimal measurement system.

The thesis is structured in five chapters, an introduction, and a chapter of final conclusions.

In the first chapter named **"General considerations about fans"** I have highlighted the purpose and importance of the fan both in buildings and industrial premises that have the possibility to use air conditioning systems, as well as in areas belonging to commercial and industrial premises where the use of air conditioning systems is impossible or too expensive, such as mining operations, underground car parks, subways, gyms.

At the same time, although seemingly simple from a construction point of view, fans pose demanding aerodynamic problems, which led me to choose the subject of this dissertation.

Reviewing the literature in the field, I have described in this chapter the main types of fans, their set-up and mounting positions, as well as the main applications in which fans are used. Taking into account these aspects I have also analysed and presented general information, the operation of centrifugal and axial fans (on how the suction and discharge of air is done), classification, construction variants, operation, and adjustment in the network, as well as the fundamental relationship and construction parameters.

Figures 1 and 2 below show the operating modes of networked fans.

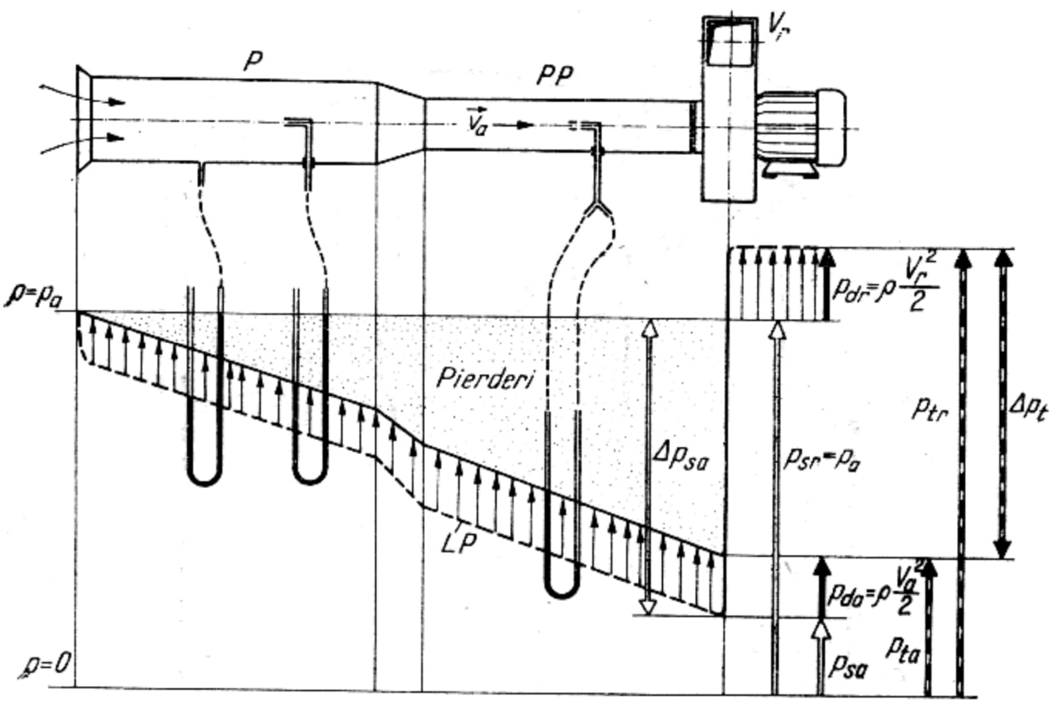

Fig.1. Fan with aspirating duct

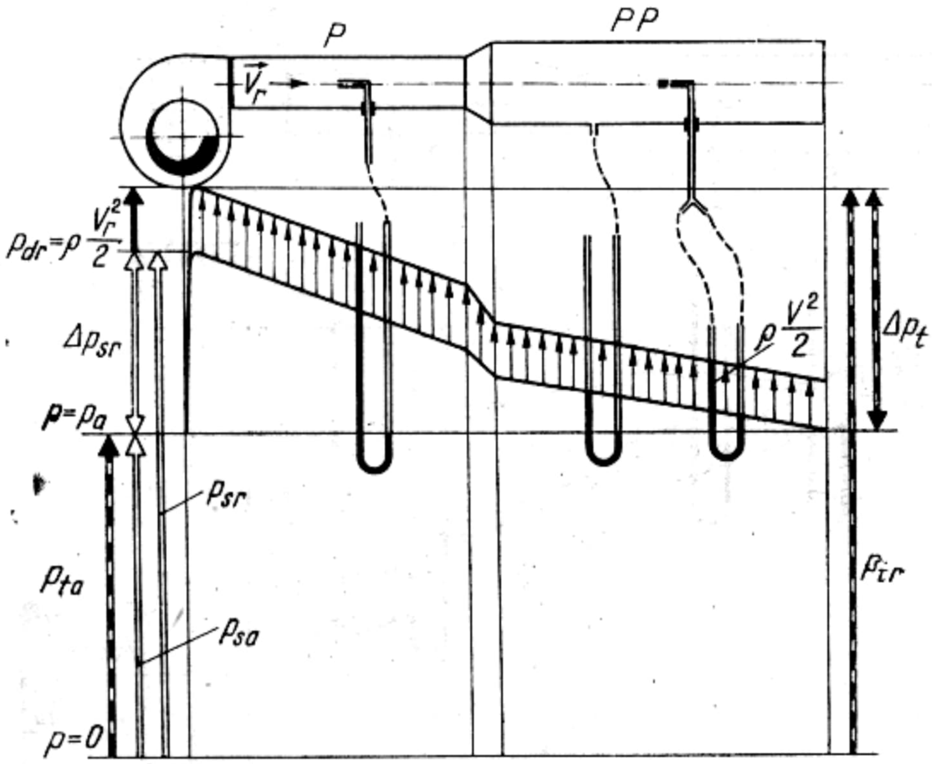

Fig.2 Fan with discharge duct

The subject of this thesis refers to VOD fans, axial fans, and I have presented the purpose of their use, the operational process, construction types and elements, operating parameters, aerodynamics, air flow and drive power calculation, adjustment methods of axial fans. Figure 3 shows the constructional assembly of an axial fan.

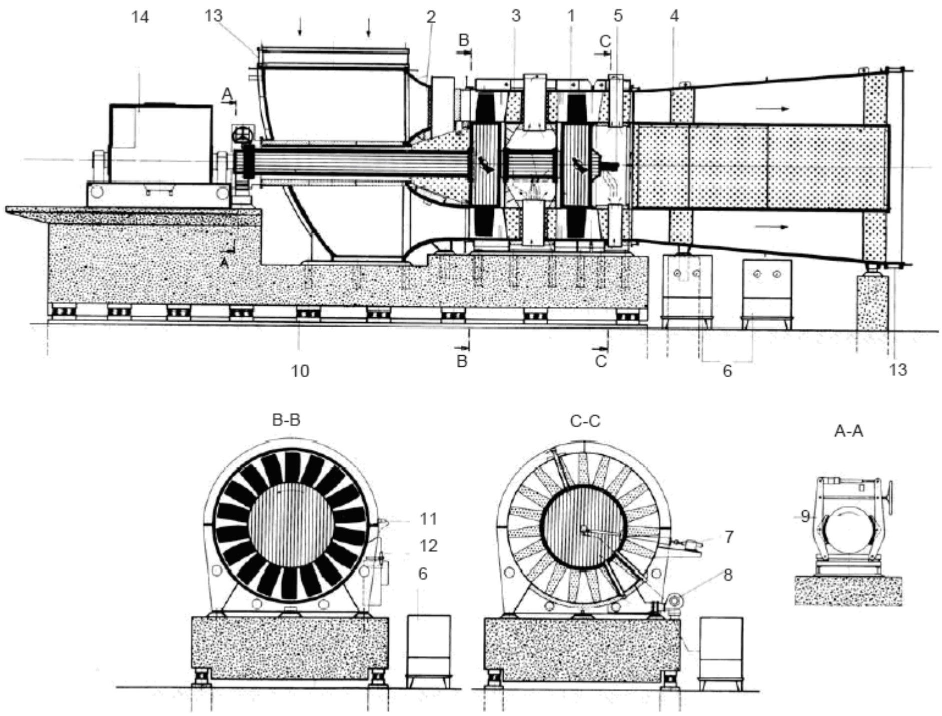

Fig.3 The constructive assembly of the axial fan

Overall analysis and statistical data processing does not solve the problems of diagnosing the technical condition of axial fans in mining enterprises. Such data can only be obtained by using complex and methods of acquisition as varied as possible, obtained by direct measurements (vibration, noise, temperature) carried out on the machine as a whole or on the component parts presented in chapter two **"Study of theoretical aspects of vibro-mechanical diagnosis and monitoring of fans"**.

Several types of analysis are used to process the measured data, such as:

♦ frequency domain analysis

♦ time domain analysis

♦ amplitude domain analysis.

The performance of these surveys requires the use of specialised software for vibro-mechanical analysis.

Simultaneously with the spectral analysis, an analysis of the frequencies must be done to determine the resonance phenomenon.

In order to separate the components of different frequencies when using analogue equipment, several “band-pass” filters tuned to different frequencies are used. In modern technology this is done using Fourier transform and digital filters.

For each fan a reference spectrum must be established against which all vibration measurements are compared.

The structure of an acquisition and control system can be seen in Figure 4 and is made up of:

♦ measuring elements (temperature transducers, differential pressure transducers, vibration transducers) with unified signal adapters

♦ position sensing elements for flaps and for execution elements

♦ execution elements (reversible actuator)

♦ local control and signalling panel which includes in its configuration:

- programmable automatic with analogue and digital inputs and outputs
- electronic adaptation and multiplexing circuits for analogue and digital quantities
- signalling and alarm circuits
- communication interfaces for remote data transmission.

Functions to be performed:

♦ control of measuring loops

♦ data acquisition in the PLC (temperature of the bearings, inlet and outlet air pressure, vibration level, status information, noxae)

♦ supervision of the compliance of the operating parameters with the limits

♦ control of the execution elements

♦ optical and audible alarm

♦ selection of operating modes (automatic/manual)

♦ communication with the computer.

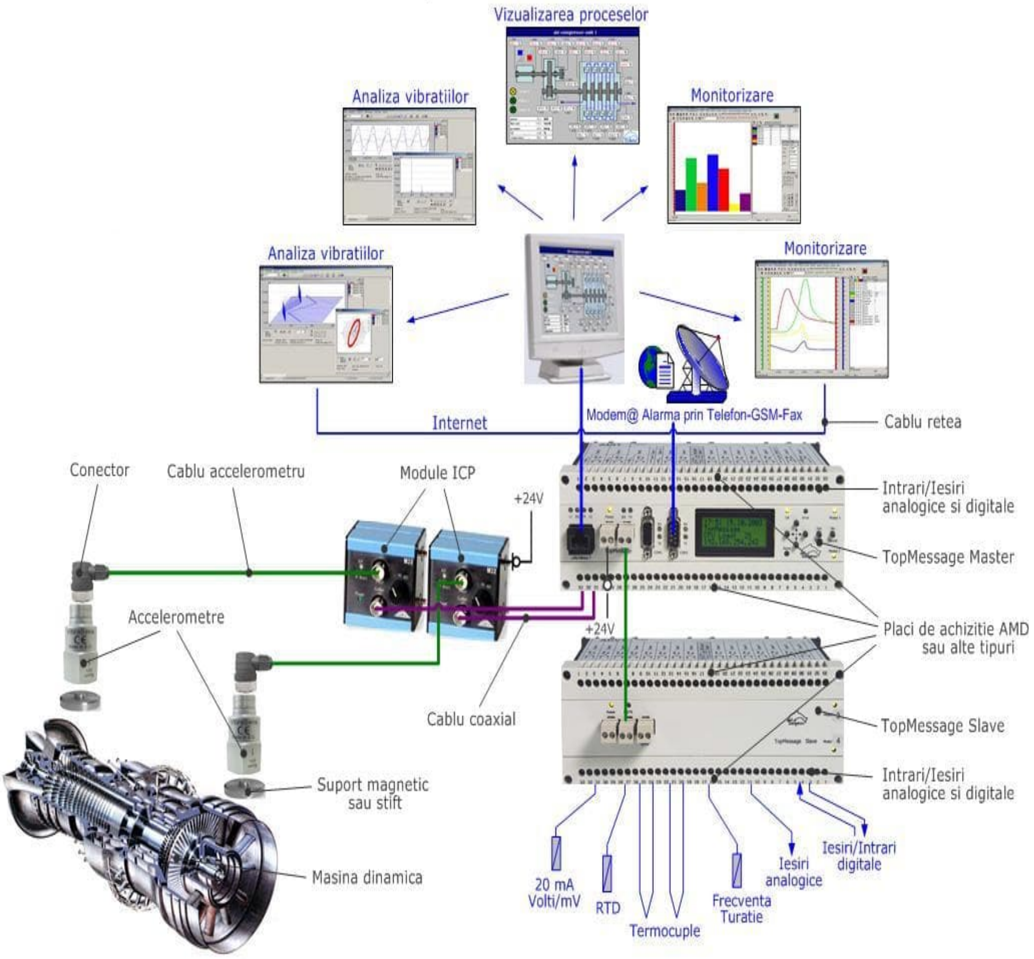

Fig.4 Fan monitoring system

In chapter three **"Electrical mechanical vibration measurement systems used in the study of fans"** the modules necessary to design and implement a minimal vibro-mechanical diagnostic system are presented.

The structure of the data acquisition system made includes transducers, signal amplifiers, analogue-to-digital converters, computer and software for the acquisition, processing, and presentation of the recorded data.

The feature of the systems for the electrical measurement of mechanical vibration consists of transforming mechanical quantities into electrical signals. This eliminates mechanical transmission and amplification that introduce measurement errors. Thus, methods of electrical measurement of mechanical vibration parameters have many advantages:

♦ high accuracy and sensitivity

♦ low sensor weight

♦ parallel and remote measurements

♦ use of analogue or digital filters

♦ amplification, automatic processing, magnetic data storage of results.

The general principles of the apparatus for measuring mechanical vibration, as described for mechanical type apparatus, remain the same.

The most significant progress in the field of transducers is their creation in integrated form, by incorporating in a miniaturised construction unit, similar to large-scale integrated circuits, both the sensitive element and the adaptor, including elements of calculation, linearisation, thermal compensation, etc. The coupling between the sensitive element and the adaptor, which in the usual transducers poses problems, has disappeared in this case. Integrated acceleration transducers are currently being produced with high performance and considerably reduced size and weight compared to conventional transducers.

The acquisition system can track 16 input signals by time multiplexing, which recommends its use for permanent monitoring of vibration, temperature and pressure levels occurring during the operation of axial and centrifugal fans.

Chapter four **"Vibro-mechanical diagnosis analysis of the main causes of axial fan vibrations"** presents the main causes of VOD axial fan vibrations. When vibration and noise issues occur, their source must be identified and located. The identification of the vibration source is done by a spectral analysis, in which the important frequencies are identified. Locating it consists of determining the cause for the production of each important frequency. Amplitude is measured only to assess the level of vibration and compare it over time to see where changes have occurred in the operation of the system.

Machine vibration frequencies can be classified into:

♦ excitation frequencies, generated by the movement of the whole system or the technological process

♦ own frequencies, given by the geometrical and mechanical characteristics of the system.

If the excitation frequencies are within 20% of the natural frequencies, then there are resonance problems. If it is not possible to change the operating mode of the system, then a series of passive or active dynamic dampers must be used.

Resulting from the theoretical and experimental analysis compared with the statistical data on fan failures, the most common causes of axial fan vibrations are:

♦ mechanical imbalance (static imbalance, dynamic imbalance) which can be caused by assembly fault, fault during operation, hydraulic or aerodynamic phenomena

♦ misalignment, which may be parallel misalignment, angular misalignment, combined misalignment. When there is misalignment, the first three harmonics of the rotational frequency are distinguished in the vibration frequency spectrum, even if the vibration amplitudes are small

♦ weakening of mechanical joints, occurring when the foundation is damaged or mechanically weakened, a high amplitude at the rotational frequency appears in the vibration frequency spectrum

♦ defective bearings (sliding bearings, rolling bearings).

In chapter five **"Contributions to the study of vibro-mechanical diagnosis and monitoring of axial fans used in the mining industry"** the results obtained in vibro-mechanical diagnosis of the technical condition of VOD 2.1 type fans at Vulcan Mining Operation are presented.

The fans considered for the survey are presented in the first part of the chapter as well as the establishment of the measurement points.

The two bearings and the axial fan body were chosen as measuring points.

With the help of the measurement chain made and presented in paragraph 5.3 I performed the monitoring of the motion parameters (acceleration, velocity, and movement), parameters recorded as a function of time. These parameters were measured in the 3 directions (axial X, vertical Y, and horizontal Z).

The measurements were carried out with the fans set at a flow rate of 6130 m^3/min, a value at which the pumping phenomenon does not occur.

Using the presented measuring equipment it was possible to make a series of vibration measurements:

♦ global analysis and comparison with the permissible values laid down in international standards

♦ spectral analysis to be able to separate and identify the source of vibrations as well as vibro-mechanical diagnosis.

Following the global analysis it was revealed that the overall vibration level according to VDI 2056, group G guideline is in the acceptable range, less than 4.8 mm/s.

Measurements were carried out on a newly installed VOD 2.1 fan at an interval of 6 months and on a VOD 2.1 fan that had been in operation for several years.

The new fan replaced another fan of the same type after having suffered total breakdown, detachment of the left bearing stiffening elements from the fan body, and penetration between the blades. This caused them to break, destroying the casing and leaving the fan house through the ceiling. This created a 3 m^2 crack in the reinforced concrete ceiling.

Comparing the vibration values within the six-month interval for the new fan, these vibrations have decreased, which is normal; during this period the fan has also run in.

The recordings made after 6 months showed that the vibration level is lower than at the initial time, a level that should remain constant for a very long period of time. This phenomenon is due to running-in, seating of the bearings, etc. Comparing the vibration level with the old fan shows that the vibration level is much lower.

The spectral representations for all the measurements obtained on the VOD 2.1 type fan in the Vulcan Mining Operation, considered as reference masks, are shown in the Annex.

From the spectral analysis, even in this case of **"accepted fan"**, it appears that there are a number of issues, the most important being:

♦ incorrect alignment

♦ dynamic imbalance.

Throughout chapter six **"General conclusions and personal contributions"** I concluded that the presented paper is an approach from the point of view of vibro-mechanical diagnosis and vibration level detailed on the analysis of the technical operating condition of VOD type axial fans and is characterized by the following novelties:

1. I have made a sufficiently exhaustive analysis of the current maintenance system applied to the VOD 2.1 type fans in the Mining Operations.

2. I have demonstrated the procedure for organising the collection and processing of some data sets that quickly provide information on the values of the fan failure rate and other characteristic parameters, using the Weibull distribution law (bi-parametric and tri-parametric variants);

3. In order to provide a theoretical and especially a practical basis for a procedure to determine the technical condition of VOD 2.1 fans, I designed a simple measurement and monitoring chain and a test plan that allowed the field acquisition of data files in digital format. These files contained dynamic series with a large number of performances.

♦ I designed and implemented a mechanical vibration measurement system made of transducers, signal amplifiers, digital analogue converters.

4. The dynamic series unfiltered upon acquisition, have been previously processed in order to characterize them in general, as well as to verify their correctness and accuracy. For this purpose, using current and high-performance software products developed by the author, the following processing was performed:

♦ checking for the existence of gross errors in them due in particular to the way the measurement chain worked

♦ demonstration of the express need to perform digital filtering in the processing of these dynamic series as well as the most suitable procedure to use for filtering

♦ verification of the confidence intervals within which the dynamic series realizations lie

♦ verification of frame working data into the Gaussian distribution law by applying the Kolmogorov-Smirnov and Lilliefors tests

♦ simulating the confidence level between various correlations of the signals in the three data files

♦ a methodology was established whereby experimental data acquired in the field can be further used with some specialized software.

♦ spectral analysis, time and frequency averaging, digital filtering, standard mean value, etc.

5. The dynamic series were then processed by analysing them: in time, in frequency, using software made by the author. On this occasion it was shown that:

♦ the experimental dynamic series show very good autocorrelations

♦ there are good correlations between different magnitudes and less good correlations between others. Overall, a better correlation was found between vibration level and airflow

♦ the dynamic series contain acceptable "noises"; with a few exceptions they have useful signal values above 90% of the total signal

♦ there are non-linear components in all experimental series, these are about 3-5 % in the case of absolute fan acceleration.

6. Establishment of a vibro-mechanical reference system, vibration levels in a new axial fan

7. Establishment of some reference spectra

8. Theoretical and experimental contributions on vibro-mechanical analysis.

The measurement system developed and used to solve the research contracts is the best option from a construction point of view with implications on the acquisition cost.

The acquisition system can track 16 input signals by time multiplexing, which recommends its use for permanent monitoring of vibration levels, temperature, pressure occurring during operation of VOD-type axial fans.

The diagnostic methodology that I used to determine the causes, i.e. the faults that were at the root of vibration generation, is based on the comparison of the vibration level, the determination of natural frequencies. This identification was done by analysing the signals measured in the time domain, in the frequency domain.

Pursuant to theoretical research and experimental measurements carried out on VOD 2.1-type axial fans, I have carried out:

♦ a global analysis in the time domain, and the comparison with the permissible values provided in international standards

♦ spectral analysis in the frequency domain, to be able to separate and identify the source of vibrations as well as vibro-mechanical diagnostics.

The global analysis showed that the overall vibration level according to VDI 2056, group G is in the acceptable range and is less than 4.8 *mm/s*.

Analysing the vibration values, (acceleration, velocity, and movement) within the six-month interval, it decreased in the case of the new fan, which is normal; during this period the run-in of the fan also occurred.

Monitoring over a period of 6 months showed that the vibration level of the newly installed VOD fan is lower than at the initial time, a level that should remain constant for a very long period of time. This phenomenon occurs due to the running-in, the installation of the bearings, the outriggers, etc. Comparing the vibration level with the old fan it is revealed that the vibration level is much lower.

From the spectral analysis, even in this case of the **"accepted fan"**, it appears that there are a number of issues concerning the technical condition, the most important being:

♦ incorrect alignment

♦ dynamic imbalance.

This paper being based on the results of a theoretical analysis and the validation of the results by experimental measurements, lays the foundations of a technique for the vibro-mechanical diagnosis of VOD axial fans in mining enterprises. This paper is intended to be useful to engineers and technical personnel involved in maintaining the proper operation of fans in the mining industry.

Given that the issues addressed in the paper have a high degree of complexity I believe that they can be continued and deepened in the following directions:

♦ Implementing a system for measuring, continuous monitoring, and transmission of vibro-mechanical data to the computer network so that they can also be viewed remotely.

♦ Dynamic rotor balancing.

♦ Alignment of the motor-shaft-rotor system using specialised equipment.

♦ Implementing a mechanical imbalance tracking system.

♦ Establishing vibration levels for each individual fan of each mining operation.