Measurement of Dynamic Characteristics of Screw Conveyor

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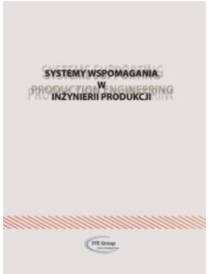

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Abstract: A machine has always been, is and will be the technical progress. The basis of every economy is the progressiveness of manufacturing engineering since it manufactures components for all industries. Technical requirements in manufacturing engineering are constantly leading to an increase of the technical level of manufacturing equipment. Profound knowledge of scientific fields precedes a successful fulfilment of the technical requirements. Structural units of manufacturing machines are complex mechanisms that must work reliably and safely with an emphasis on their important function. These units create new objectives for their research and optimization.

Keywords: software, modal analysis, screw conveyor, vibration

INTRODUCTION

A machine can be defined as a system performing mechanical motion that is essential for a manufacturing process. The current aspiration of designers is to focus on improving outputs of manufacturing machines and to ensure their operational reliability. The relevance of dynamic processes' knowledge of the given manufacturing machines with divergent operating modes is growing for this reason. A dynamic process is mainly an oscillation that occurs in the examined system [16].

Output of a manufacturing machine is possible to increase by:

- increasing working velocity of structural units,
- increasing dimensions of machines.

The increase of working velocity also increases excitation frequencies; and the increase of machine dimensions and effort to save material results in a system decrease of circular frequency ensuing in an increasing risk of resonance. Transient processes that include start-up, rundown and reversal are clearly affected by dynamic load. For a suitable design, it is crucial to analyse the influence of its elementary structural units and external load at the whole machine function. A machine system can be defined as s system consisting of a source, a transformer and an energy appliance. A machine system, especially in manufacturing engineering, is a system that consists of a drive part – a drive, gear mechanism and a driven part - a working machine. A machine is a complex mechanical system with

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a large number of structural units in motion. Each unit of a real mechanical system has its specific resilience and damping parameters and there are clearances in the connected units. If all the facts are taken into an account, then the model of a mechanical system is a system of structural units with resilience bonds and clearances in which a dynamic calculation is realizable only by means of the computing technology. The basic law of a mechanical system's motion is determined by motion of the greatest mass with the greatest clearances and the smallest firmness. In a computational model it is possible to replace a mechanical system with two-body or three-body model with their masses, equivalent resilience bonds and a resulting clearance which are reduced to the main element of a machine. A replacement of a real machine by a computational model is conditioned by the equivalence of a replacement and a real system which is the law of kinetic and potential energy conservation, as well as the law of output equality of external forces. The computing technology is a means of solving complex tasks; however, it is possible to obtain analytical results in a closed form via computing models which represent the basis for compiling analytical dependencies of dynamic system's parameters for their further optimization [1, 3, 5, 8, 10, 11, 16, 17, 21].

DYNAMIC CHARACTERISTICS IN MANUFACTURING ENGINEERING

There are dynamic effects that cause oscillation during operation of all machinery. A variable load which stresses structural units during their operation has usually a complex time course. Dynamic characteristics can adversely affect life and reliability of these machines, therefore it also reduces the quality of manufacturing. Due to the fact that oscillation cannot be completely eliminated, there are normative parameters of an oscillating event, the observance of which guarantees their long-term trouble-free operation. The main difference between the static and the dynamic analysis is that during the dynamic analysis:

- load forces vary over time,
- movements, velocities, accelerations, deformations and stresses are time-dependent,

a task is solved in a specific time interval.

The knowledge of the origin and patterns of oscillation allows designers to design structural units and machines in such a way that there is an effective reduction in oscillation intensity during operation of this equipment. Analytical, numerical and experimental methods are used to solve oscillation problems [2, 4, 9, 18, 19, 20].

Oscillation and Modal Analysis of Components in Manufacturing Engineering

Physical events in the field of manufacturing engineering are often complex; therefore it is convenient to separate them from a complex system and work with each of them respectively. One of these spheres is research of oscillation of structural units. Oscillation in manufacturing engineering only proves its importance by increasing output of manufacturing equipment. Elimination of hypertrophic oscillation is related to perfect understanding of the physical process. The physical basis of oscillation is a constant conversion of a system's potential energy to kinetic energy and vice versa. Oscillation of a system's structural units occurs by their disruption from their static equilibrium state. The disruption occurs by deviation from equilibrium position or by setting in motion without external forces; i.e., without excitation. The given oscillation is called free oscillation of a system. However, forced oscillation is oscillation evoked by excitation forces which are defined by obligatory motion of points. Oscillation in specific application can be differentiated in terms of predominant type of motion into rotary, bending, longitudinal, transverse, torsional or combined [4, 6, 7, 8, 15]. Oscillation in a system of structural units can be divided from the physical point of view into:

- natural oscillation (undamped, damped),
- forced oscillation,
- self-excited oscillation (caused by its own operation).

Systems of structural units can be divided based on the number of degrees of freedom into:

- discrete (their parameters are concentrated, their elements are considered to be perfectly stiff)
- continuous (their parameters are continuously distributed - continua, their elements are flexible bodies).

Systems of structural units can be divided according to the mutual relationship between system forces, deviations and velocities into:

- linear,
- non-linear.

Screw conveyors

Screw conveyors are characterised by a simple construction. They are manufactured in various structural forms. This type of conveyors is designed for horizontal and inclined transport. There are bulk, dusty, small and granular materials transported. They are used separately, e.g., for filling truck trunks; or they are integrated into an automated production line. The base of conveyor is formed by a pipe inside of which there is a working rotating screw. A screw conveyor is on a shaft which is connected to an electric gearbox. Screw conveyors are designed on the basis of specific customers' requirements, according to already specific outputs, requirements for the length criterion of transported material and, of course, according to specifics of the given material. Material is transported in a screw conveyor by friction against the surface of a screw. Rotational motion performed by a screw in a pipe is designed for a material transport from an input to an output. The gravitational force of which proper operation is conditioned by continuous screw filling is used. Screw conveyors are used in various industries, such as automotive, wood processing, pharmaceutical, chemical, nuclear, food, metallurgical, construction, agricultural etc., all shown on Figure 1 [12, 13, 14].

Fig. 1 Examples of screw conveyors utilization

Source: [14]

DYNAMIC ANALYSIS OF SCREW CONVEYOR DRIVE

The dynamic analysis of the screw conveyor drive was performed only after the evaluation of the results from the strength control. Based on the fact that the given structural unit is stressed by a variable load, the first step of the dynamic analysis is the modal analysis determining the natural frequencies of the given structural unit.

Modal Analysis of Screw Conveyor Drive

Knowing the safety and reliability of structural units in manufacturing engineering is a necessity, since it is then possible to prevent undesirable conditions in the manufacturing area. Structural units must work in such a way, so they can resist vibrations and resonance. The application of modal analysis was an indispensable part of the dynamic analysis. Modal analysis of the drive was performed via Autodesk Inventor software (Fig. 2).

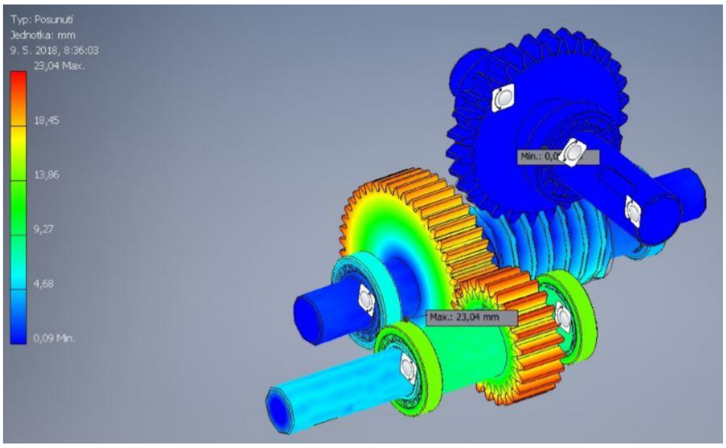

Fig. 2 Drive oscillation at the frequency F1 – 898.22 Hz

The main goal was to obtain the values of the natural frequencies of the gear mechanism which could then be compared with the frequencies obtained by the experimental measurements. The number of modes was set to 8. It is important to note that the deformations which occurred during the modal analysis are only relative and they cannot be considered real; therefore, they serve to get a better grasp about the drive vibration.
The results of the modal analysis are stated in the following Table 1

Table 1 Natural drive frequencies

Frequency	Frequency value
F1	895.22 Hz
F2	1790.86 Hz
F3	1809.22 Hz
F4	2144.98 Hz
F5	2345.45 Hz
F6	2352.00 Hz
F7	2433.75 Hz
F8	2612.85 Hz

The results of the drive modal analysis point to the size of the resulting deformations when compared to the original shape of the drive. These are modal deformations and their size is only relative. The resonant frequencies which are an undesirable phenomenon of the drive can be analysed based on the natural frequencies.

Application of Experimental Analysis

The device used for measuring vibrations was the SKF MicroVibe P system shown on Figure 3, which has software for measuring vibration parameters on site. Its great advantage is the quick evaluation of the information obtained from the measurement.

Fig. 3 SKF CMVL 3850 vibration measuring device

The first measurement was the SKF vibration measurement via the SKF CMVL 3850 device shown on the Figure 3. The given vibrometer records and evaluates measured data on the site. The mentioned measurement was also divided into two parts, namely during operation of the conveyor with no load and during operation of the conveyor loaded with road salt. The velocity V ($mm \cdot s^{-1}$) and the vibration acceleration A ($mm \cdot s^{-2}$) were recorded.

The Figure 4 shows the data from the SKF vibrometer; the most important values for the measurement evaluation are the vibration velocity V, the vibration acceleration A. Other data are the average vibration value and acceleration – RMS, and the value PEAK that provides the highest measured value of the given parameters.

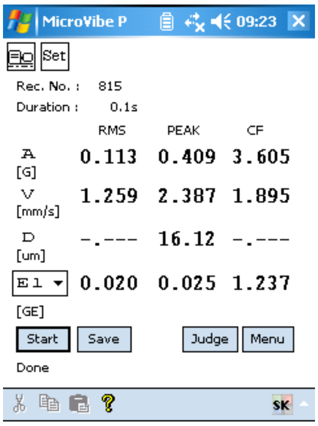

Fig. 4 SKF no-load vibration measurement

The parameter D indicates the value of the deviation, the parameter E1 is the measurement filtration used for reducing the noise content during the measurement. CF is a crest factor that provides information about the ratio of the highest measured value to the average measured value.

The Figure 5 shows the selected acceleration parameter A in the frequency range up to 5 kHz and its analysis is displayed by the red-coloured amplitude. The dashed line indicates the values of X1 and X2 representing the important frequencies. The important is the frequency X1 value of 100 Hz, and the X2 value being of 2353.13 Hz in this measurement.

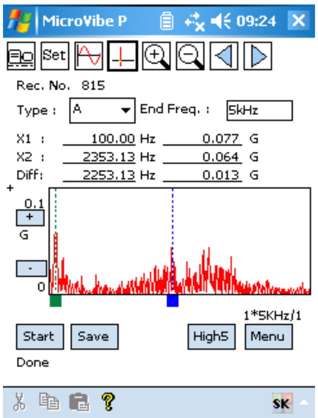

Fig. 5 SKF vibration acceleration measurement during unloaded operation

The figure Figure 6 shows the selected velocity parameter V in the frequency up to 1 kHz and its analysis is displayed by the red-coloured amplitude. The dashed line again indicates the values X1 and X2 which represent the important frequencies.

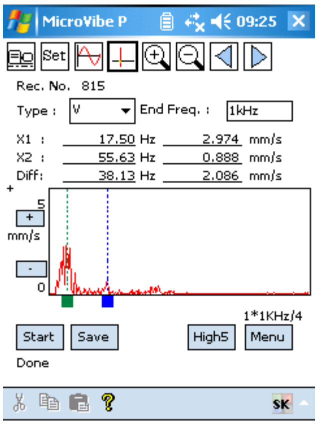

Fig. 6 SKF vibration velocity measurement during unloaded operation

The given parameter is of relatively low values in this case as can be seen from the measurement.

The following Table 2 provides the most important values for measuring the drive vibrations.

Table 2 SKF vibration measurement results with no road salt load

	a (up to 5 kHz) vibration acceleration	v up to (1 kHz) vibration velocity
X1	100 Hz	17.50 Hz
X2	2353 Hz	2.63 Hz

Vibration measurement during operation of drive loaded with road salt

The second measurement was the measurement of vibrations during the drive operation of the conveyor with the whole volume filled with sanding salt. The methodology was the same as in the previous measurement (Fig. 7).

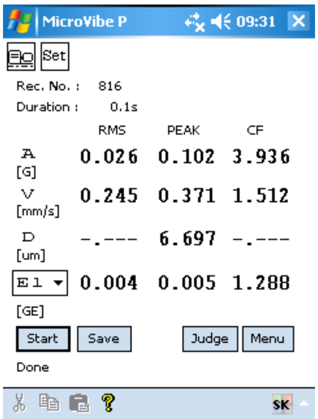

Fig. 7 SKF vibration measurement of conveyor loaded with road salt

The Figure 8 shows the selected acceleration parameter A in the frequency domain and its analysis is presented by the red amplitude. The dashed line indicates the values of X1 and X2 representing the important frequencies.

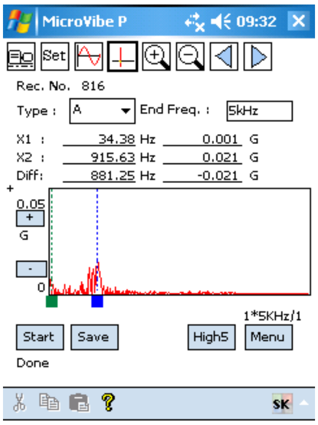

Fig. 8 SKF vibration acceleration measurement of conveyor loaded with road salt

The Figure 9 shows the selected parameter V in the frequency domain and its analysis is represented by the red amplitude. The dashed line indicates the values of X1 and X2 representing the important frequencies.

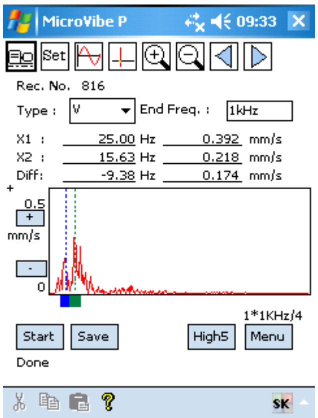

Fig. 9 SKF vibration velocity measurement of conveyor loaded with road salt

As can be seen from the above measurement, the given parameter again acquired relatively low values; however, lower than those of the no-load drive measurements, which may be caused by the damping effects of the salt in the screw pipe during operation. The results of the measurements of acceleration and velocity of the SKF vibration of the drive loaded with road salt are shown in Table 3.

Table 3 Results of SKF vibration acceleration measurement of drive loaded with road salt

	a (up to 5 kHz) vibration acceleration	v up to (1 kHz) vibration velocity
X1	34.38 Hz	25 Hz
X2	915.63 Hz	15.63 Hz

CONCLUSION

The results of the modal analysis, i.e. the resulting natural frequencies, were compared to the results of the experimental drive measurements. The first natural frequency of the drive being of 895.22 Hz approximately corresponds with the frequency obtained during the second measurement using the SKF vibrometer in which the frequency of 915.63 Hz was indicated. Therefore, the drive works close to the frequency range as can be stated from the given finding. The second natural frequency of the drive had value of 1790.86 Hz, the third natural frequency was evaluated at 1809.22 Hz, the fourth natural frequency was evaluated at 2144.95 Hz, the fifth natural frequency of the drive had value of 2352.00 Hz, the sixth natural frequency of the drive had value 2352.00 Hz, the seventh natural frequency was evaluated to 2433.75 Hz and the eighth natural frequency was evaluated via the software to be of 2612.85 Hz. Given the values and the measured data, the natural frequencies occur also in the drive transient states which include the switching on, i. e., the start-up of the drive; however, they also occur during the drive operation. Such an example is the frequency 2353 Hz obtained via the SKF vibrometer when measuring the drive with no salt load which is identical to the sixth natural frequency of the drive. Based on this it can be inferred that the drive resonates during a certain activity or operates close to the resonant area, hence it can result in an increase in the drive oscillation. However, the complex dynamic events that occur during operation of the given screw conveyor and also the drive are complicated, since the resulting amplitude is composed of a large number of events that affect it. These events include the fact that each element of the structural unit oscillates at its own frequency; and if the same frequencies occur, they are added, thus the frequencies being several times higher. The results are also affected by the fact that the conveyor is placed in exterior environment on four rubber and plastic wheels. The important results of this work also include information about the input shaft oscillation, the tooth frequency, the oscillation of the drive second stage and the oscillation of the output shaft. The input shaft oscillates at the frequency of about 24 Hz being an approximate value obtained during the SKF measurement with the vibration velocity set to up to 1 kHz in the first measurement with no load; hence the value X1 was 17,50 Hz; and in the second measurement, i.e. under load, the frequencies were 34.38 Hz and 25 Hz. Therefore, it can be assumed that this is the frequency of the input shaft. The tooth frequency was calculated to be 582 Hz and it occurs in the measured values; thus it can be assumed that the tooth frequency of the first stage occurs in the measurement results. When evaluating the oscillation of the drive second stage it was determined that the tooth frequency of the second drive stage, i.e. of the screw drive, corresponds with the input shaft frequency that evidently causes an increase in the drive oscillations as well. The resulting frequency of the output shaft and also the conveyor screw is 0.866 Hz, which was also demonstrated in the measurement results. This frequency is dominant even in steady operation, thus the demonstration is visible mainly in the time domain. Hence, it can be assumed that the screw in the conveyor pipe is probably bent ,and the screw comes into contact with the pipe at each of its turns, thus it is also demonstrated in the measurement results. The bending of the conveyor screw has probably effects on the shaft, or the drive screw as well; therefore, it affects its geometric characteristics. Since the assumption is that the input torque is 38 N.m and the output torque is up to about 1000 N which cause the excessive drive oscillation, thus the frequency increase.

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