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Investigation of the acoustic pressure model of the acoustic field generated by belt-drive

R. Mikalauskas , V. Volkovas

Technological System Diagnostic Institute, Kaunas University of Technology
Address: Kestucio str. 27, Kaunas 3004, Lithuania; Tel/Fax:+370 7 323 720; e–mail: romika@ktu.lt

Abstract
This work presents investigation results of acoustic fields of non-homogeneous systems (belt-drives). The received results of experimental research are compared to the results of the mathematical model of non-homogeneous system.

Key words: Belt-drive, dynamics, acoustics, FEM, diagnostics.

Introduction

The work of devices could be hardly imagined without their vibro-acoustic performance. They form a certain environment that changes depending on the working parameters of the device or its technical condition. It is a well-known fact, which gave birth to vibro-acoustic testing and new direction in the technical diagnostics.

Among various vibro-diagnostic methods there are only few that could be applied to the belt-drives, even though these belt-drives in the technology are widely used for a long time. It is related to the fact that the belts – main elements of the drives – are characterized by low stiffness, small weight (if compared to other elements) and relatively small resistance to operating dynamic forces, temperature, friction and other impacts. Besides the maintenance conditions of belt-drive are constantly changing, thus its behavior is mostly unpredictable. The recent researches [1-5] analyze the dynamic behavior of belt-drives, as well as create new vibro-diagnostic methods. The model of parametrical vibrations of belt-drives [2] and mathematical modeling of defect conditions of the belts [3] allowed creating a new methodology of vibro-acoustic diagnostics of drive belts. It includes identification of vibration spectrum of bearing housing of the belt-drive, analysis of characteristic spectrum frequencies, and comparison of its results with nomograms of vibrations – amplitudes of belt-drive indicated in advance of non-defect condition of belts, which are determined on the basis of mathematical modeling of dynamics of belt-drive with defected belt. The method has certain disadvantages, for example, the nomograms have to be formed for each belt-drive when it is started to being maintained and they have to be used for the diagnostics until the failure of the drive. There are more analogous methods of vibro-diagnostics [5, 7], but they could not be widely applied in practice due to certain shortcomings. This topical issue is analyzed in many literature sources on the basis of vibration analysis. While the acoustic emission of a belt-drive that is widely analyzed during designing and manufacturing process, is rarely encountered in the solution of diagnostic problems of belt-drives. When the testing question of belt's condition of belt-drive was discussed, this work analyzed the numerical model of the acoustic field generated by the drive. The model was formed on the basis of FEM, and the obtained results were compared to the experimental data. This allows calibration of the model of the generated acoustic field, using it for the modeling of acoustic fields of defected belts and creating methods of acoustic diagnostics, which do not possess the majority of the known shortcomings of vibro-diagnostic methods.

Results of a numerical model of belt-drive as a non-homogeneous system

The belt-drive may be modeled as a non-homogeneous system due to its elements and changing technical condition. In this case the two-dimensional model of a non-homogeneous system consists of the belt of belt-drive and surrounding air medium. In order to form a model the FEM program package "ANSYS 10" was used. In order to model the air medium the elements FLUID29, FLUID129 were used, while the belt was modeled using the elements of PLANE42type. The materials had the following characteristics: density of the belt's material ρ=700 kg/m^3, the module of belt's elasticity E=15e+7 Pa; the speed of sound in air medium c=335.28 m/s; the air density ρ_a=0.0376 kg/m^3.

During the theoretical experiment the branch of a belt was parametrically excited using different frequencies of the excitation. The parametrical excitation was modeled by rendering the displacement to the part of belt in the direction of a symmetry axis. This displacement caused the change of the meaning of the force of the initial tension of the belt's branch. The law of parametrical excitation was harmonic.

According to the results of the theoretical experiment obtained in work [6], the parametrically [7] excited belt creates the acoustic field in its environment, the character of which depends on the frequency of excitation, its amplitude and the force of tension. These parameters depend on the initial condition of the belt-drive and on the defects that arise while maintaining the drive [3]. It was determined that after the frequency of excitation changes, the sound pressure also changes in the environment of the belt. In case of constant force of initial tension and when the eccentricity increases, the amplitude of the sound pressure also increases.

Fig. 1 and 2 presents the speed values of air particles that surround the belt in case of different excitation frequencies.

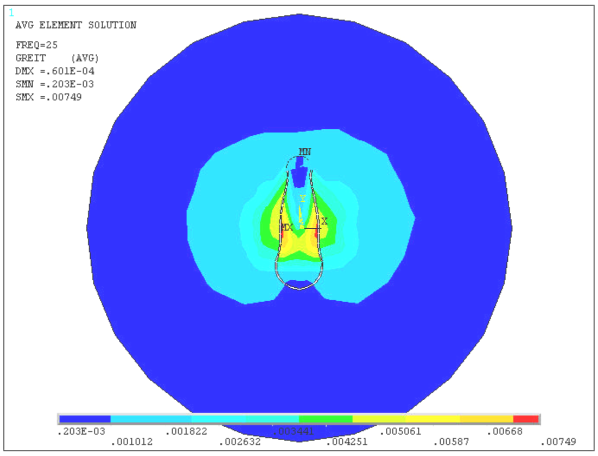

Fig. 1. **The distribution of element fluid velocity in belt environment, when the excitation frequency *f*=25 Hz and the initial tension force F_0=400 N**

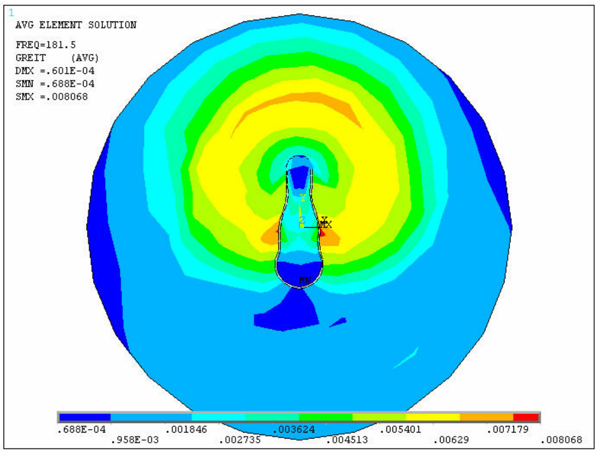

Fig. 2. **The distribution of element fluid velocity in belt environment, when the excitation frequency *f*=181.5 Hz and the initial tension force F_0=400 N**

The distribution of sound pressure in the belt environment when the frequency of excitation is 181.5 and 250 Hz, is presented in Fig. 3 and 4.

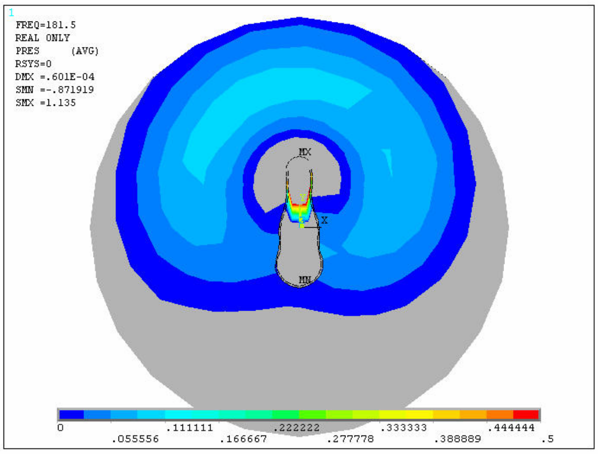

Fig. 3. **The distribution of sound pressure amplitude real part in belt environment, when the excitation frequency *f*=181.5 Hz and the initial tension force F_0=400 N**

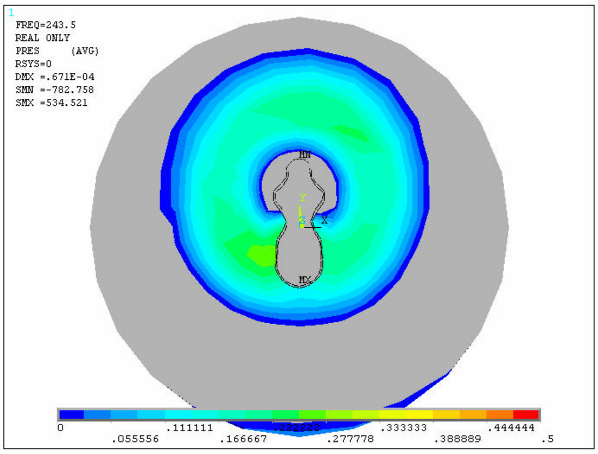

Fig. 4. **The distribution of sound pressure amplitude real part in belt environment, when the excitation frequency *f*=250 Hz and the initial tension force F_0=400 N**

Fig. 5 presents the dependency of the amplitude of a sound pressure on the frequency of excitation in different points of a belt environment.

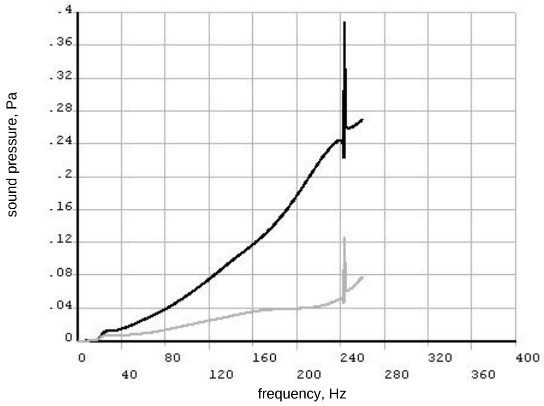

Fig. 5. **Dependency of sound pressure on the frequency of excitation at different measurement points: ▬ 1 measurement point; ▬ 6 measurement point (The positions of measurement points are indicated in Fig. 6)**

According to the results of the numerical experimental model, when the initial tension force of the belt and eccentricity are constant and the frequency of excitation is changing, the character of the acoustic pressure and speed of air particles in the belt environment is also changing. When the excitation frequency is increasing the acoustic pressure in the air medium surrounding the belt is also increasing. The value of the acoustic pressure in the area of the 89-456+1excitation frequencies at 243 Hz increases almost twice. It may be explained by the fact that the resonance of drive's belt is excited. Also Fig. 5 shows that the value of the acoustic pressure is bigger at points of surrounding medium, which are closer to the excitation place. The created FEM model reflects the real situation, which could have been confirmed just by the experimental research of the levels of a sound pressure in a real acoustic field.

Results of the experimental research

In order to check the obtained results of the theoretical model, the experimental research of acoustic emission of belt-drive at Machine Vibrations and Acoustic Noise Levels Testing Laboratory was done. To make the experiment the belt-drive of two pulleys with a constant axial distance and the measurement equipment of vibrations and noise "Pulse" of Bruel&Kjaer Company were used. During the research the sound pressure at separate points of the environment of the belt-drive was measured. The positions of measurement points are indicated in Fig. 6.

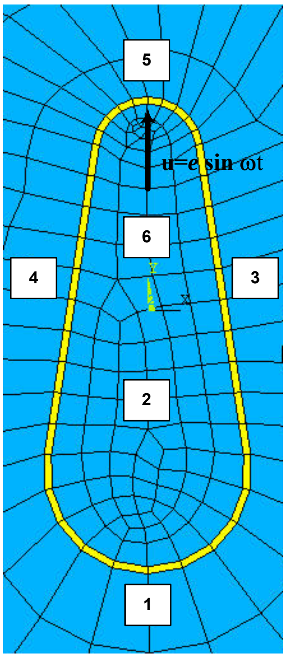

Fig.6. **Scheme of positioning of measurement points of acoustic intensity of belt-drive and the place of parametrical excitation**

When the intensity of the acoustic field at different points was measured, the revolutions of driving axis of belt-drive were changed and in such a way the frequency of parametrical excitation of the belt-drive's belt was also changed. The results are presented below in the form of diagrams.

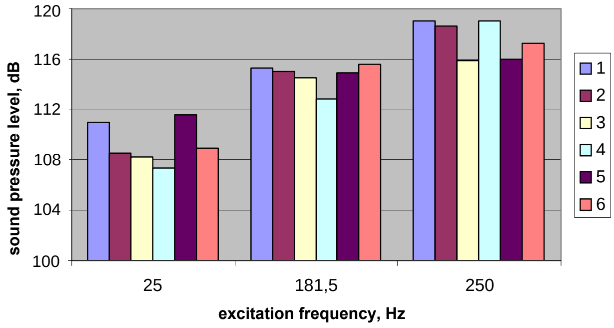

Fig. 7. **Level of sound pressure at different points of belt-drive in case of different frequencies of revolutions of driven pulley**

Experimental and theoretical dependencies of levels of sound pressure at different drive points on the frequency of excitation are presented in Fig. 8 – 10.

According to the results of experimental research, the character of changing acoustic pressure's level when the excitation frequency is changing is analogous to the result

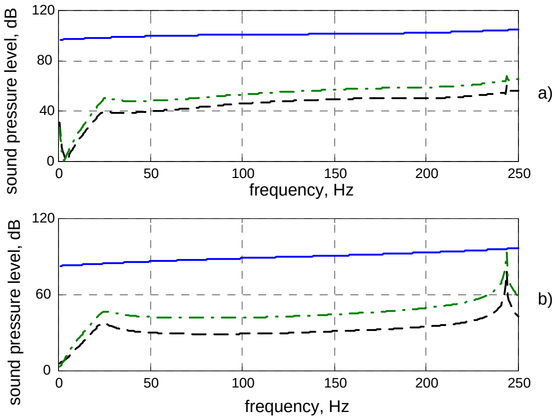

Fig. 8. Dependency of sound pressure's level on the excitation frequency: a – 1 measurement point; b – 2 measurement point. Experiment ▬▬ ; model F_0=400 N ▬ ▬ ; model F_0=800 N ▬ · ▬

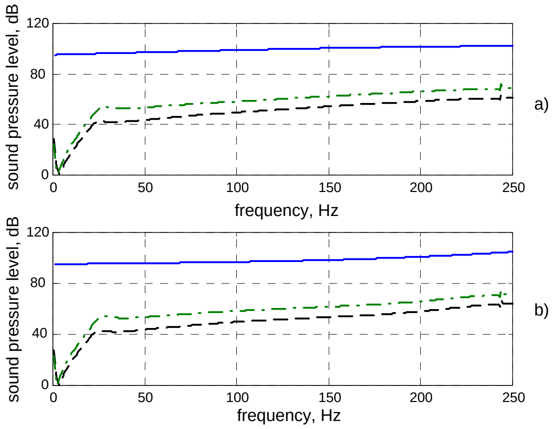

Fig. 9. Dependency of sound pressure's level on the excitation frequency: a – 3 measurement point; b – 4 measurement point. Experiment ▬▬ ; model F_0=400 N ▬ ▬ ; model F_0=800 N ▬ · ▬

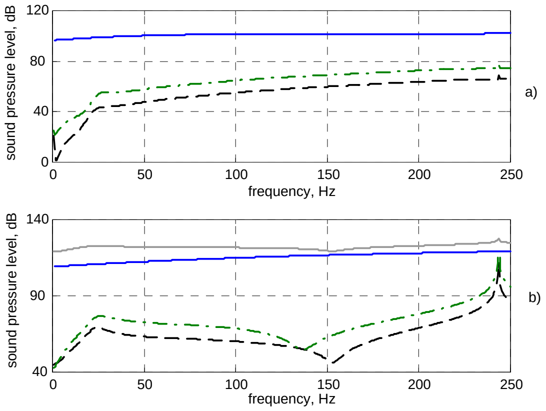

Fig. 10. Dependency of sound pressure's level on the excitation frequency: a – 5 measurement point; b – 6 measurement point. Experiment ▬▬ ; model F_0=400 N ▬ ▬ ; model F_0=800 N ▬ · ▬ ; calibrated mathematical model F_0=800 N ▬▬

of mathematical modeling using theoretical model: when the excitation frequency is increasing, the level of sound pressure in all measurement points is also increasing (Fig. 7-10). However the numerical values of the sound pressure's level received during experiment and calculated with the help of the model are different. The measurement points 2 and 6 at 245 Hz may serve as an exception, where the values determined by experiment and model differ least. Such a result may be explained by the fact that when the acoustic field generated by a belt-drive is modeled, the model is quite simplified: the model was two-dimensional, other excitations in the belt-drive were not taken into account, as well as contact interaction of pulleys and belt, etc. The fact that tendencies of the results of the mathematical model and the experimental research completely coincide allows calibration of the mathematical model using the results of experiments, i.e. the excitation is such as to make the modeled level of a sound pressure fit the level determined by the experiment. The calibrated model (Fig.10, b) may be further used to determine the correlation of defects of belt and the received level of a sound pressure.

Conclusions

- The character of changing level of a sound pressure generated in the environment of belt-drive calculated by the theoretical model is similar to the experimental results at the measurement points quantitatively.
- The values of a sound pressure received by the model and experiment are significantly different due to the simplified model.
- In the further research of acoustic fields generated by a belt-drive it is purposeful to improve the model taking into account the additional excitations in the belt-drive and to evaluate the contact interaction of pulleys and belt.

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Diržinės perdavos generuojamo akustinio lauko garso slėgio modelio tyrimas

Reziumė

Tarp įvairių vibrodiagnostikos metodų yra nedaug tokių, kurie galėtų būti taikomi diržinėms perdavoms, nors jos technikoje seniai ir labai plačiai vartojamos. Tai siejasi su tuo, kad diržams, kaip pagrindiniams perdavų elementams, būdingas mažas standumas, masė (palyginti su kitais elementais), nedidelis atsparumas veikiamoms dinaminėms jėgoms, temperatūrai, trinčiai ir kitiems poveikiams. Be to, diržinės perdavos eksploatavimo sąlygos nuolatos kinta, todėl jų elgsena dažnai nenuspėjama.

Ši aktuali problema nagrinėjama daugelyje literatūros šaltinių. Tuo tarpu diržinės perdavos akustinė spinduliuotė, plačiai nagrinėjama projektavimo ir gamybos metu, retai taikoma diržinių perdavų diagnostikos uždaviniams spręsti. Nagrinėjant diržinės perdavos diržo būklės kontrolės klausimą, buvo ištirtas akustinis laukas, generuojamas perdavos skaitmeniniu modeliu, sudarytu BEM pagrindu, ir gautieji rezultatai palyginti su eksperimentiniais duomenimis. Tai leido sukalibruoti generuojamo akustinio lauko modelį, panaudoti jį pažeistų diržų akustiniams laukams modeliuoti ir kurti akustinės diagnostikos metodus, neturinčius daugumos žinomų vibrodiagnostikos metodų trūkumų.

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