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PARTIAL RESULTS OF THE GRANT PROJECT: „RESEARCH AND APPLICATION OF UNIVERSAL REGULATION SYSTEM IN ORDER TO MASTER THE SOURCE OF MECHANICAL SYSTEMS EXCITATION”

Summary. In general terms the mechanical systems (MS) means the system of driving and driven machines arranged to perform the required work. We divide them into MS operating with constant speed and MS working with a range of speed. In terms of dynamics we understand MS as a system of masses connected with flexible links, it means systems that are able to oscillate. Especially piston machines bring heavy torsional excitation into the system, which causes oscillation, vibration, and hence their noise. Governing of the torsional vibration, as a source of MS excitation, on a basis of results of our research, can be achieved by applying a pneumatic coupling tuned by the proposed universal control system. On this basis, it can be concluded that with given connection a new continuous tuning method in steady state a connection of MS is created.

Keywords: mechanical system, vibration and noise of mechanical systems, governing the source of mechanical systems excitation, control system, continuous tuning (tuning during the operation) of mechanical systems

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1. INTRODUCTION

Any MS in terms of how we understand the dynamics of the system means masses connected with flexible links between them, it means systems that are able to oscillate. Piston machines, which are classified as either MS drivers or driven units, bring to those systems extensive torsional vibration. This means that MS with internal combustion engines, compressors and pumps can be characterized as torsional oscillating mechanical systems (TOMS). In the range of operating speed it can occur a very intensive resonance between the excitation frequencies (reciprocating machines) and the natural frequency of the system. Consequently, there comes to vibration and related over-stress in the whole MS. Excessive dynamic stress often causes malfunction of various parts of the system, such as:

- shaft fatigue fractures,
- gear-box failure,
- deformation and failure of flexible couplings etc.

Therefore, applies the rightful need to control their dangerous torsional vibration.

2. SCIENTIFIC GOALS OF THE PROJECT

The overall objective of the presented project will be the research, application and analysis of the universal control system function to ensure the governing of the source of excitation in a different types of MS. Among the primary source of MS excitation belongs torsional vibration. Governing the source of MS excitation will be provided by a new way, which consists of continuous tuning, it means tuning during operation in steady state conditions, by patents [1], [2]. The essence of a patent [2] is that each MS must contain a pneumatic coupling (2) controlled by control system (5) (Fig. 1). The pneumatic couplings control with universal control system implemented by us, whose principle of operation result from patents [11], [12], [13], will be provided on the basis of closed-loop control (Fig. 2). Implementation of MS continuous tuning can continuously adjust the properties of pneumatic coupling to the systems dynamics so that torsional vibration doesn't occur during its operation.

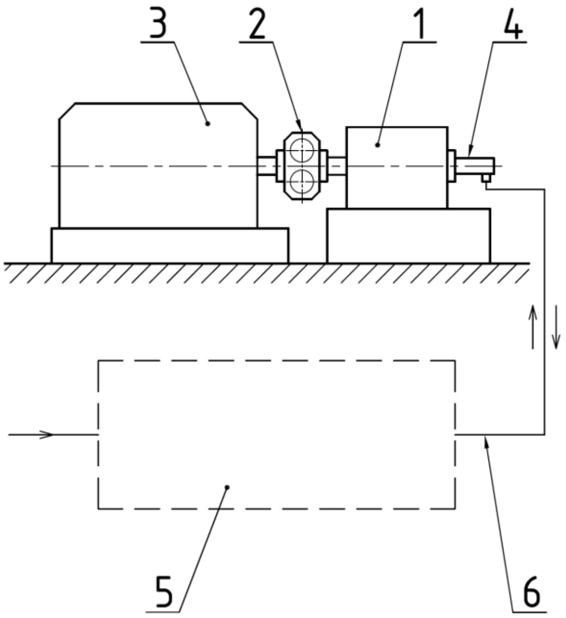


Fig. 1. Principle of continuous tuning in MS

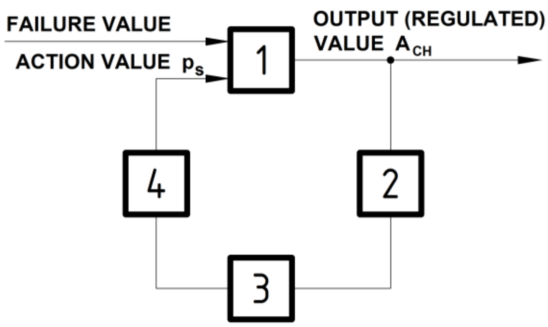


Fig. 2. Regulation circuit for continuous tuning of MS

On a basis of patents fundamental, the MS will be presented by a laboratory mechanical system (LMS) by Fig. 3 and pneumatic connection will be realised by pneumatic coupling developed by us. [3], [4], [5] (Fig. 4 and 5).

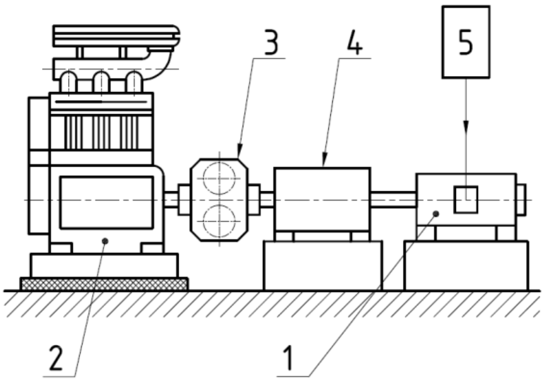


Fig. 3. Laboratory mechanical system

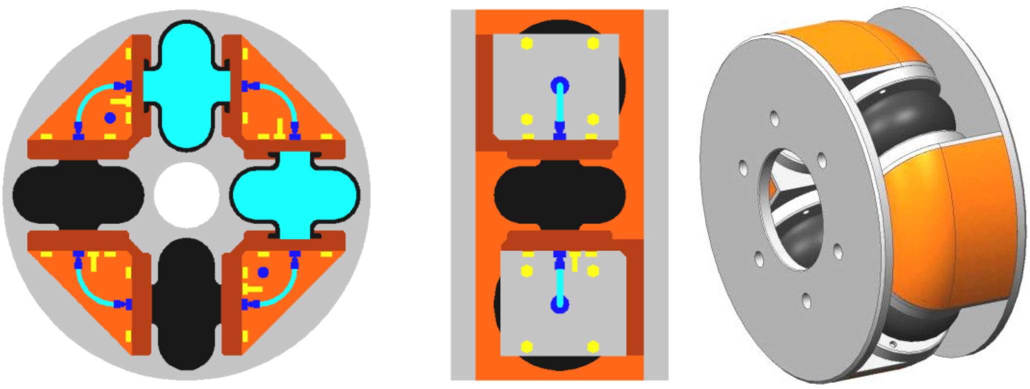


Fig. 4. Tangential pneumatic tuner of torsional oscillations of type 4–1/–T–C

To reach the stated objective, it is necessary to focus on the resolution of the following partial objectives:

1. Realization of the LMS for the possibility to provide two operating modes, namely work at constant speed and work with a range of speed;
2. Research and realization of an universal control system to ensure the governing of the LMS excitation source in its various working conditions;
3. Development of a control algorithm to ensure the governing of the LMS excitation source with its continuous tuning;
4. Realization of experimental measurements on the LMS focused onto governing the LMS excitation source for following cases:

4.1. fault-free operation of piston device of the LMS running in its various working modes,
4.2. case of an accidental failure of piston device in various working modes of the LMS.

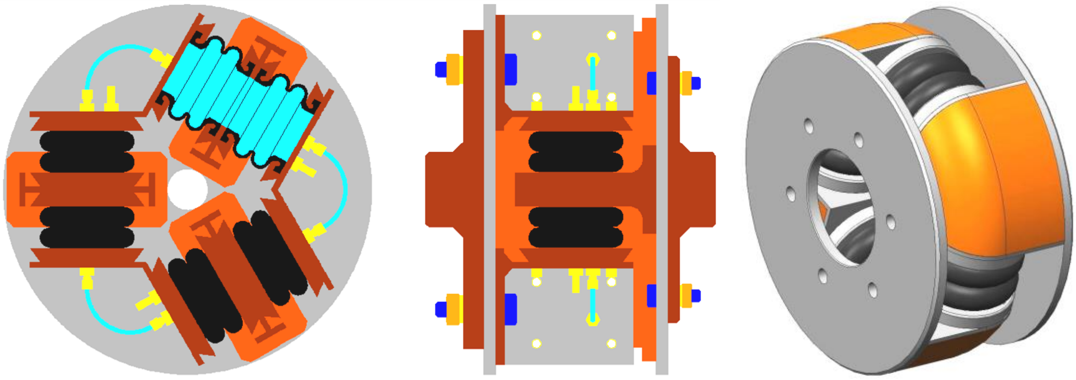


Fig. 5. Differential pneumatic tuner of torsional oscillations of type 3–2/–D–C

Research in field of the governing of dangerous torsional vibration as a source of MS excitation, has high economic benefits, because its primary function is to extend the life and performance of the different parts of the system, and thereby ensuring their smooth operation without vibration and noise.

It must be noted that the proposed project solves the control of dangerous torsional vibration with direct optimization of MS, which is characterized by continuous tuning of the system during their operation in steady state. Therefore, the proposed method should be seen as a way of governing the excitation source of MS, thereby governing the vibration and noise of the entire plant themselves. In view of the scientific field Elements of machines and mechanisms, we understand the proposed control method as a new and very promising contribution to the area of the current methods for solving the size of the torsional vibration of given systems. The basic principle of the proposed control method consists in the continuous tuning of MS with pneumatic couplings - pneumatic tuners of torsional vibration regulated by the proposed universal control system [9], [10]. Continuous tuning of MS during operation in steady state is characterized by an appropriate adaptation of the basic dynamical properties, particularly the dynamic torsional stiffness of pneumatic tuner to the dynamics of the system. Adaptation will be provided by the proposed universal control system that forms a closed-loop feedback control system (on Fig. 2).

Thereby we can continuously change, thus adjust the dynamic properties of pneumatic tuner to the dynamics of MS, so that dangerous torsional vibration doesn't occur during the working mode. Control circuit according to Fig. 2 consists of regulated MS (1–LMS characterized on Fig. 3) and piezoelectric mechanical vibration sensor (2), which transfers the electrical signal to the controller-microprocessor (3), proportional to the size of the mechanical vibration A_{CH}. Microprocessor (3) based on embedded control algorithm will process the electrical signal, with the intention of seeking the minimum A_{CHmin}, and control the actuator (4 – as an pneumatic distributor). Controlling the actuator we regulate an Action variable p_S, i.e. by the intake or discharge of gaseous media we will increase or decrease the pressure in the pneumatic tuner.

Construction and operation of the universal control system providing smooth changes of the basic characteristics of pneumatic tuners will result from granted patents [11], [12], [13].

Another benefit of the proposed project for the economy, and for the scientific field Elements of machines and mechanisms as well, is the application of new elements for the proposed way of governing the MS. These new elements are the different types of air tuners of torsional oscillations [3], [4], [5] (Fig. 4 and 5) developed and examined by us.

3. THE CONDITIONS FOR REALIZATING THE CONTINUOUS TUNING OF TORSIONALLY OSCILLATING MECHANICAL SYSTEMS DURING OPERATION IN STEADY STATE

Continuous tuning of TOMS during steady state operation is currently not implemented in practice. This is mainly because of its possible implementation have not been created the basic conditions. Presence of pneumatic couplings, i.e. an element which during operation is able to change its basic characteristic properties, especially dynamic torsional stiffness, enabling the practical realization of continuous tuning of the given systems.

Realization of TOMS continuous tuning requires to satisfy the following conditions:

- TOMS must meet the basic requirements of realization continuous tuning [15], i.e. tuning the system during its operation in steady state,
- by the realization of TOMS continuous tuning it is not necessary to know in advance its regulatory mathematical model, but it is necessary to know whether the system objective function (a function of input and output variables) has an extreme [10], [16], [17].

3.1. Continuous tuning characteristics of torsionally oscillating mechanical systems

Based on the nature of the patent [15] follows that the system (fig. 6) must contain a pneumatic flexible shaft coupling [18] controlled by the regulatory system [11], [19].

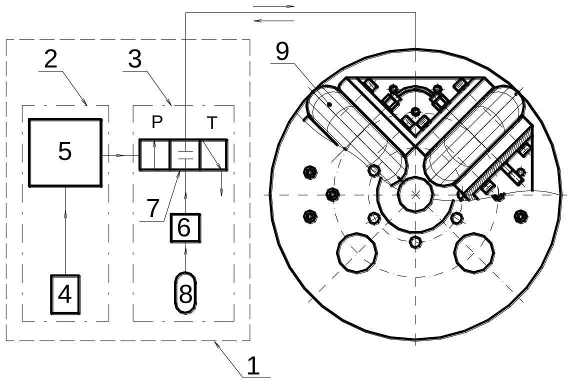


Fig. 6. Schematic representation of the torsionally oscillating mechanical systems continuous tuning operation

Result of the activities of the regulatory system is the fact that due to continuous pressure changes of the gaseous medium in pneumatic couplings intends the change of its basic dynamic properties, i.e. dynamic torsional stiffness. Changing the dynamic torsional stiffness we are changing the frequency of natural the system Ω_0, i.e. adapting it to the frequency of the *i*-th harmonic component of load torque ω so that the system is within the range of operating mode working not in resonance with any harmonic of exciting torque, therefore, applied to the condition

$$\Omega_0 \neq i.\omega. \qquad (1)$$

3.2. Construction and nature of torsionally oscillating mechanical systems continuous tuning

Fig. 6 schematically shows a control system and a schematic view of the TOMS continuous tuning operation, according to the patent [11], [19].

Control system (*1*) consists of a control (*2*) and actuating subsystem (*3*). Control subsystem (*2*) is characterized by a microprocessor (*5*), which is built into the electronic system ESLER under position *6* on fig. 7 and the piezoelectric sensor of mechanical vibration acceleration (*4*) built-in the electronic system ESLER under the position *9* on fig. 7. Sensor *(4)*, which is located on the mechanical system sends an electrical signal to the microprocessor (*5*) proportional to the mechanical vibrations of the system. Actuating subsystem (*3*) consists of an electromagnetic distributor (*7* – presented with position *7* on Fig. 7), which is through the control valve (*6*) connected to the gaseous medium container (*8* – presented with position *8* on Fig. 7). Microprocessor (*5*), which forms the basic control component of the whole regulatory system (*1*), by closing the electromagnetic two-position distributor (*7*) causes its shift, so the inlet branch *P* or the outlet branch *T* will increase or decrease the pressure of gaseous medium in the compression volume of pneumatic flexible shaft coupling.

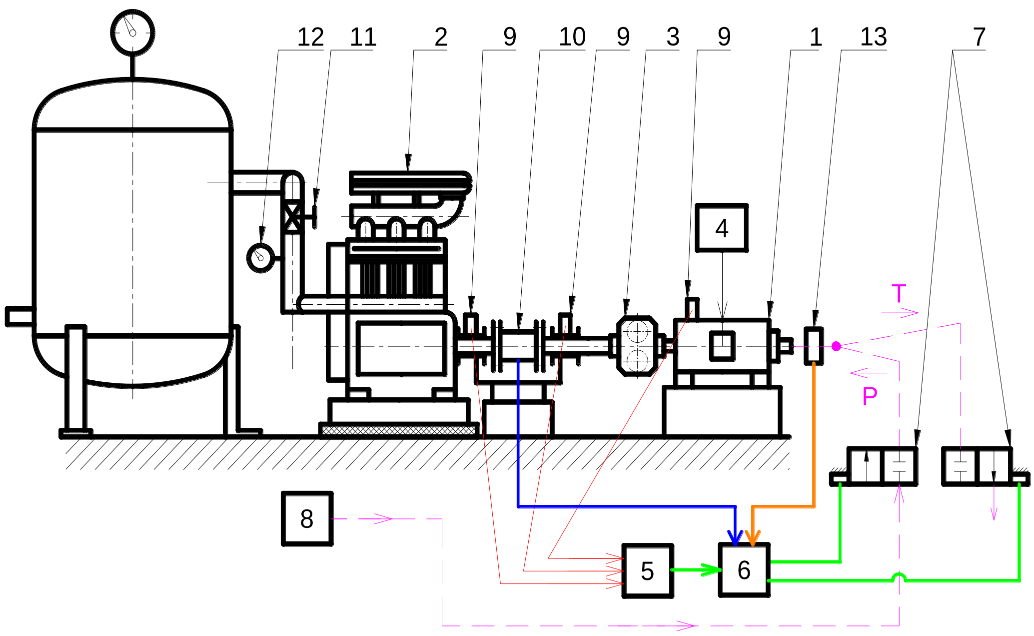


Fig. 7. Realized torsionally oscillating mechanical system

4. CHARACTERISTICS OF THE REALIZED TORSIONALLY OSCILLATING MECHANICAL SYSTEM

Realized torsionally oscillating mechanical system (Fig. 7) consists of a driving part (*1*), a pneumatic flexible shaft coupling (*3*) and the driven part (*2*). Driving part, formed by a DC electric motor type SM 160 L of the performance of 16 kW and an additional thyristor rotational frequency regulator (*4*) of IRO type with the possibility of continuous regulation from n = 0 to 2000 min^{-1}, using a pneumatic coupling drives the exciter of torsional vibrations represented by three-cylinder compressor type 3 – JSK – S. To increase the torsional impact caused by compressor into the mechanical system we use a compressor without flywheel.

TOMS load by the compressor is adjusted (regulated) by throttle valve (*11*) built into the outlet pipe from the compressor. It means that system load will be controlled and its load value will be characterized by the value of the pressure in the outlet pipe p_k obtained from the pressure gauge (*12*). In the theoretical analysis and experimental measurements, we assume pressure moving in the range $p_k = 20 \div 80$ kPa, which will respond to a minimum or maximum load torque by certain operating speeds of the system.

Measurement of the load torque were realized by the torque transducer type MOM 7934 (*10*) and simultaneously excited mechanical vibration of the system was measured by piezoelectric transducers (*9*), which are part of the vibration monitoring system ADASH 3600 (*5*).

The measured signals have been recorded and processed by the electronic system ESLER *(6)* developed by us.

Measurements were realized assuming equal excitation of the compressor cylinders at a constant predetermined speeds n = 200 to 700 min^{-1}. The gaseous medium pressure in the pneumatic tuners was continuously changed during the measurements in the range p_s = 100÷ 600 kPa.

5. THE RESULTS OF THE CONTINUOUS TUNING OF THE TORSIONALLY OSCILLATING MECHANICAL SYSTEM REALIZATION USING THE ESLER ELECTRONIC SYSTEM

Governing torsional vibration on realized TOMS by continuous tuning using the ESLER electronic system (Fig. 8) was realized under these conditions:

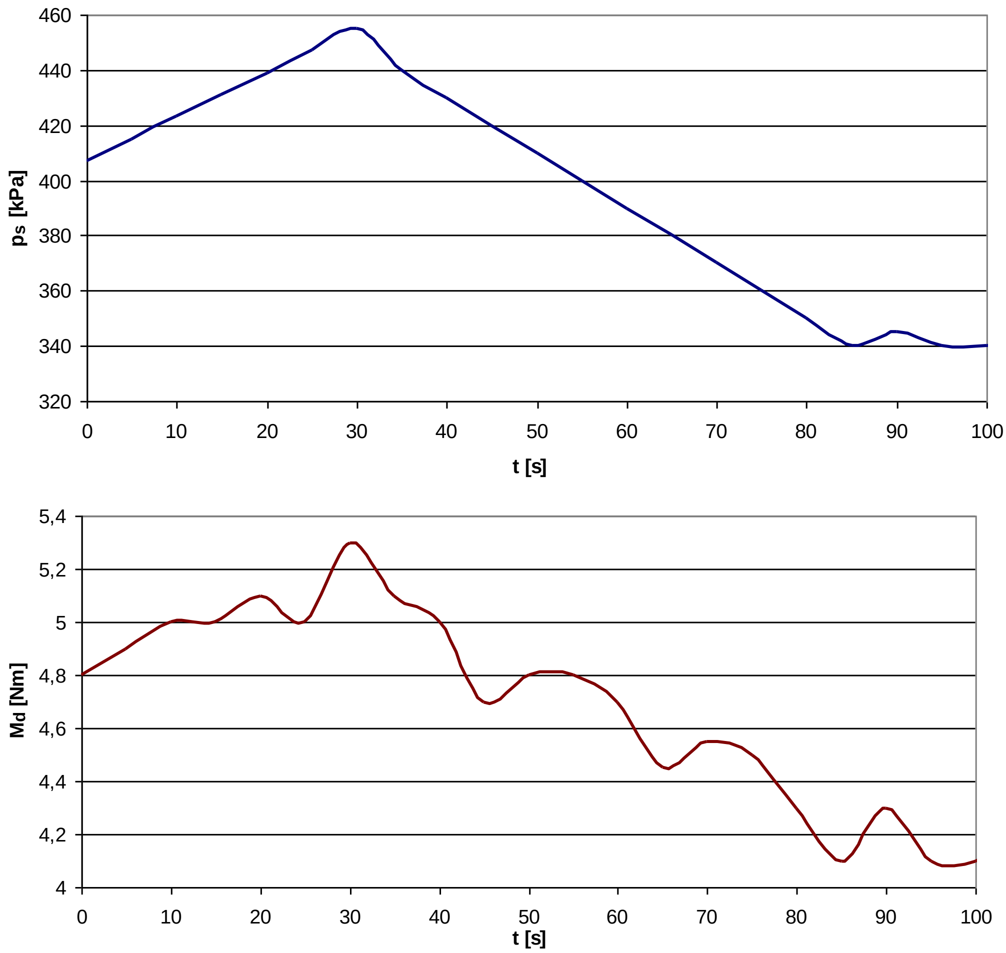
- at steady state operating mode of the given system,
- at constant operating speed n = 200 min^{-1} with characterized course of dynamic component of the torque load M_d, depending on the gaseous medium pressure in compression volume of pneumatic couplings in the range p_s = 100 ÷ 600 kPa,
- at compressor load p_k = 80 kPa,
- at the pre-defined regulating conditions:
  - the minimum working pressure of the pneumatic coupling p_{min}= 100 kPa,
  - maximum working pressure of pneumatic coupling p_{max} = 600 kPa,
  - sensitivity to changes of torque e_M = 0,3 Nm,
  - sensitivity to changes of vibratione$_V$ = 4 mm.s^{-2},
  - the number of samples to average calculation i = 10 . 10^3 samples,
  - stabilization time between the pressure changes t_s = 5s.

Based on fig. 4 it can be concluded that TOMS continuous tuning was started by the gaseous medium pressure in pneumatic coupling ps = 408 kPa with current dynamic component of load torque value M_d = 4,8 Nm.

Launching the continuous tuning the process of recording and processing signals from the torque sensor has begun (*10*). From the results of signal processing and results of ESLER‘s control based on the flow diagram by sensitivity to changes of torque e_M = 0,3 Nm at times t = 0 to 30s with a stabilization time t = 5s, we achieved the following results by the system monitoring:

- t=0 s, p_s=407 kPa, M_d=4,8 Nm,
- t=5 s, p_s=415 kPa, M_d=4,9 Nm,
- t=10 s, p_s=423 kPa, M_d=5,0 Nm,
- t=15 s, p_s=431 kPa, M_d=5,0 Nm,
- t=20 s, p_s=438 kPa, M_d=5,1 Nm,
- t=25 s, p_s=447 kPa, M_d=5,0 Nm,
- t=30 s, p_s=455 kPa, M_d=5,3 Nm.

From presented values it can be said that the electronic system based on specified control parameters for obvious reasons, increased the pressure in the pneumatic coupling until value p_s = 455 kPa reaching the value M_d = 5,3 Nm. By comparing the previous value of M_d = 5,0 Nm, and the next step value, ie, M_d = 5,3 Nm based on the sensitivity to the change of torque e_M = 0,3 Nm the ESLER electronic system had instructed to reduce the gaseous medium pressure in pneumatic coupling. By reducing the pressure to p_s = 440 kPa in time t = 35s the value of torsional vibration M_d = 5,1 Nm was reached. Further system monitoring of electronic system in timeframe t = 35 ÷ 100s lowered the pressure in pneumatic coupling still achieving a lower value of torsional vibration. Searched local minimum was reached by the ESLER electronic system at time t = 85s with a value of pressure in the pneumatic coupling p_s = 340 kPa and dynamic component of torque load M_d = 4,1 Nm. Value of local minimum was confirmed by further measurements when at t = 90 ÷ 100s the previously achieved values p_s = 340 kPa and M_d = 4,1 Nm have been confirmed. At time t = 100s the continuous tuning by the ESLER electronic system was stopped.



b)

Fig. 8. Graphs characterizing the continuous tuning of torsionally oscillating mechanical system by the ESLER electronic system: a) time graph of the gaseous medium pressure in pneumatic tuner; b) time graph of the torque load dynamic component

6. CONCLUSION

The sequence of steps to achieve the general objective of the present project, which is: „Research, application and analysis of the universal control system functioning for ensuring the governing the source of MS excitation, which causes vibration and noise the entire installation", apparent from the following sub-objectives of the project:

1. Realization of the MS in the laboratory with the possibility of its continuous tuning with a pneumatic tuner of torsional vibrations controlled by an universal control system and with the possibility of providing its work at constant speed and in a range of operating speeds.
2. Providing a proper air tuner of torsional vibrations for the continuous tuning of the LMS.

3. Research, construction and realization of an universal control system for ensuring the governing the excitation source of LMS in various operating modes.
4. Completion, practical modification and verification of closed-loop system for the realization of continuous tuning of the LMS in its various operating modes.
5. Realization of experimental measurements on LMS characterized by closed-loop control system at its various operating modes.
6. Evaluation of measured data from LMS characterized by closed-loop control system at its various operating modes.

Based on the presented results, it can be concluded that reducing the size of torsional vibration in any mechanical system is possible by realization of continuous tuning, thus tuning of the given system during operation in steady state. For the realization of TOMS‘s continuous tuning during operation at steady state it was developed a tuning electronic system – ESLER at our institute.

The results of experimental measurements on realized TOMS under laboratory conditions have confirmed the fact that with the continuous tuning by using the electronic system will serve to reduce dangerous torsional vibrations in any torsionally oscillating mechanical system.

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