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THEORETIC AND EXPERIMENTAL DETERMINATION OF THE FLOW RESISTANCE COEFFICIENT AT GASEOUS MEDIUM FLOW INTO AND OUT OF THE PNEUMATIC COUPLING

Summary. In order to continuous tuning of the torsional oscillating mechanical system during its operation, we are making use of application of the pneumatic flexible shaft couplings, developed by us. By the gaseous medium pressure change in pneumatic couplings we can change its torsional stiffness and thereby the dynamics of whole system too. In term of dynamics is necessary to know the transitional effects of mechanical system, which are arising at its continuous tuning. For the numerical computation of these transitional effects it is necessary to know the values of flow resistance coefficients at gaseous medium flow into the compression space of pneumatic coupling from the pressure tank and out of compression space into the atmosphere. For that reason presents this paper theoretic and experimental procedure of given coefficients determination.

Keywords: continuous tuning of mechanical system, pneumatic flexible shaft coupling, gaseous medium pressure change, transitional effect of the system, gaseous medium flow, flow resistance coefficient

TEORETYCZNO-EKSPERYMENTALNE WYZNACZANIE WSPÓŁCZYNNIKÓW OPORU PRZEPŁYWU PRZY PRZEPŁYWIE MEDIUM GAZOWEGO DO I ZE SPRZĘGŁA PNEUMATYCZNEGO

Streszczenie. W celu ciągłego dostrajania podczas pracy drgającego skrętnie mechanicznego układu napędowego używa się podatnych sprzęgieł pneumatycznych, które zostały opracowane w miejscu pracy autora niniejszego referatu. Zmiana ciśnienia medium gazowego znajdującego się w sprzęgle pneumatycznym wpływa na zmianę sztywności skrętnej, a tym samym na dynamikę całego układu. Z punktu widzenia dynamiki istotne jest poznanie stanów przejściowych układu mechanicznego występujących przy jego dostrajaniu w sposób ciągły. Do obliczeń numerycznych tych zdarzeń przejściowych niezbędna jest znajomość wartości współczynników oporu przepływu strumienia gazu płynącego ze zbiornika ciśnieniowego do przestrzeni ściskania sprzęgła pneumatycznego oraz z przestrzeni ściskania do atmosfery. Z tego powodu w niniejszym artykule przedstawiono teoretyczno-eksperymentalną procedurę określania wartości tych współczynników.

Słowa kluczowe: dostrajanie mechanicznego układu napędowego w sposób ciągły, pneumatyczne sprzęgło podatne, zmiana ciśnienia medium gazowego, stan przejściowy układu, przepływ medium gazowego, współczynnik oporu przepływu

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1. INTRODUCTION

Gaseous medium pressure value in compression space of pneumatic coupling has direct influence on its torsional stiffness value. Dynamic torsional stiffness value of flexible coupling has direct influence on natural frequency (frequencies) of torsional oscillating system, wherein is given coupling applied. By suitable pressure change in pneumatic coupling we can therefore change – suitably adapt dynamics of the system in regard to existing sources of torsional oscillation excitation. This fact we are using with advantage at continuous tuning of torsional oscillating mechanical system (Fig. 1) during its operation [3]. By suitable value of torsional stiffness k it is possible to bring out the resonances from individual harmonic components of excitation in regard to operation speed range (OSR) of the system [2], [7].

At application of continuous tuning of mechanical system occurs in the pneumatic coupling various gaseous medium pressure changes (in term of their time dependence and size) during operation of mechanical system. In order to pneumatic flexible coupling really would be a tuner and not an exciter of torsional oscillation, it is necessary to know the character of transitional effects of mechanical system at these pressure changes. To be possible to determine given transitional effects under various conditions by the computation, it is necessary to describe the gaseous medium flow into and out of the pneumatic coupling. Therefore the objective of paper will be the presentation of theoretic and experimental procedure of important parameter for gaseous medium flow determination – flow resistance coefficient.

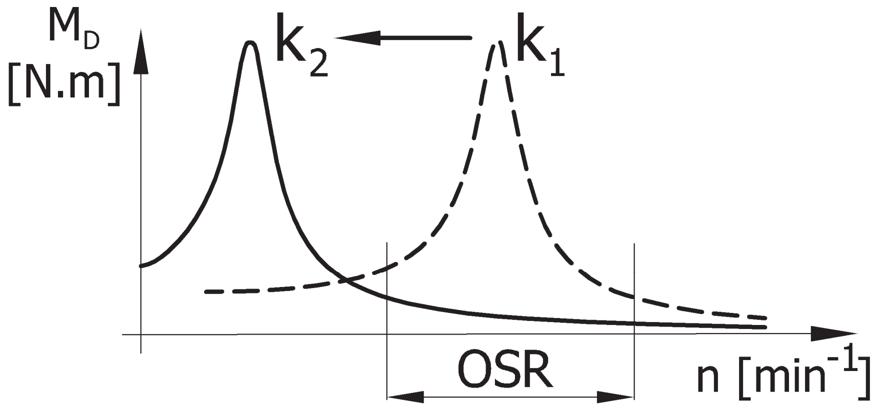

Fig. 1. Mechanical systems tuning principle
Rys. 1. Zasada strojenia układów mechanicznych

2. MATHEMATICAL MODELLING OF PNEUMATIC COUPLING COMPRESSION SPACE INFLATION AND DEFLATION

At inflation and deflation of compression space of pneumatic couplings is outgoing from assumption that gaseous medium pressure is going to keep changing equally in whole compression space. Gaseous medium is flowing from pressure tank, which volume is theoretically infinite, to the pneumatic coupling compression space after a pattern in Fig. 2, where:

T_N – is temperature of gaseous medium in the pressure tank [K],
T_S – is temperature of gaseous medium in compression space of the coupling [K],
p_N – is absolute gaseous medium pressure in pressure tank [Pa],
p_S – is absolute gaseous medium pressure in compression space of the coupling [Pa],
V_S – is pneumatic coupling compression space volume [m^3],

Q – is mass flow between pressure tank and compression space of pneumatic coupling [kg.s^{1}],
K – is flow resistance coefficient [Pa.kg^{-3}.s].

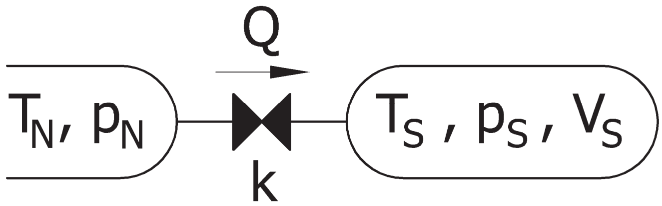

Fig. 2. Scheme of compression space of pneumatic coupling inflation from pressure tank
Rys. 2. Schemat napuszczania komory sprężaniowej sprzęgła pneumatycznego z pojemnika ciśnieniowego

So that it could come about gaseous medium flow from pressure tank to the coupling or from coupling to environment, pressure differential $\Delta p = p_N - p_S$ [Pa] has exist. For turbulent flow in the piping at flow throttling hold [5]:

$$\Delta p = k.Q^2 \Rightarrow Q = \sqrt{\frac{\Delta p}{k}} . \tag{1}$$

Following differential equation needs to be solved in time:

$$dm_S = Q.dt , \tag{2}$$

where m_S [kg] is gaseous medium weight in compression space of pneumatic coupling. For fluctuant gaseous medium are following formulas (3), (4) considered.

Temperature of fluctuant gaseous medium T_p [K] will be:

$$T_p = -\mu.\Delta p + T_N , \tag{3}$$

where μ [K.Pa^{-1}] is Joule-Thompson's coefficient for gaseous medium
(air: μ = 0,0000024 [1]).

Volume of fluctuant gaseous medium V_p [m^3] will be:

$$V_p = \frac{dm_S}{\rho_p} , \tag{4}$$

where ρ_p [kg.m^{-3}] is density of fluctuant gaseous medium, which we calculate from state equation:

$$\rho_p = \frac{m_p}{V_p} = \frac{p_S}{R_m.T_p} , \tag{5}$$

where m_p [kg] is weight of fluctuant gaseous medium and R_m [J.kg^{-1}.K^{-1}] is gaseous medium specific gas constant, for air R_m = 287,1.

Consider we next the total volume V_{pc} [m^3] after elementary quantities of gaseous medium reflowing at constant pressure:

$$V_{pc} = V_S + V_p , \tag{6}$$

and the total temperature T_{pc} [K] after elementary quantities of gaseous medium reflowing at constant pressure, computed from calorimetric equation:

$$T_{pc} = \frac{dm_S.T_p + m_S.T_S}{dm_S + m_S}. \tag{7}$$

To computation of temperature T_S [K] and pressure p_S [Pa] values of gaseous medium in compression space of coupling in computation step k at polytrophic change of state consideration following formulas were used:

$$T_{S(k)} = T_{pc(k-1)} \cdot \left(\frac{V_{pc(k-1)}}{V_{S0}} \right)^{n-1}, \qquad p_{S(k)} = T_{pc(k-1)} \cdot \left(\frac{V_{pc(k-1)}}{V_{S0}} \right)^{n}, \tag{8}$$

where n is polytrophic exponent, $n \in \langle 1;1,4 \rangle$ for air.

At deflation of pneumatic coupling compression space into the atmosphere we appoint to absolute gaseous medium pressure p_N in pressure tank the atmospheric pressure. Program for compression space of pneumatic couplings inflation and deflation was created in MS Excel.

3. EXPERIMENTAL MEASUREMENT OF AIR PRESSURE CHANGE IN TIME AT PNEUMATIC COUPLING COMPRESSION SPACE INFLATION

Flow resistance coefficient value at gaseous medium flow depends above all on shape and dimensions of the piping, through which come about the flow. In following experimental part will be presented the determination of air flow resistance coefficient at air flowing from pressure tank to pneumatic coupling according to Fig.3, thus at inflation of its compression space.

In order to determination of flow resistance coefficients the compression space of pneumatic coupling volume should be constant. Therefore both flanges of the pneumatic coupling type 3-1/110-T-C (Fig.3.c) were fixed, so that its twisting (and thereby even its volume change) at in/deflation not occurs. Exact value of given pneumatic coupling compression space volume (V_S = 0,001414898 m^3) was determined by the SolidWorks model.

At realization of experimental measurements was used for compression space of pneumatic coupling inflation pressure tank with volume of 300 l (Fig. 3a). If we connect a closed volume with zero overpressure toward pressure tank with overpressure, pressures will be equalized. So that after pressure equalizing occur the deflation of the pressure tank overpressure by 1 % over the original value, the value of connected volume must have been approximately 2 l. Compression space volume value of the pneumatic coupling used by experimental measurements was less than 2 l, therefore it was able to considering the pressure tank as infinite.

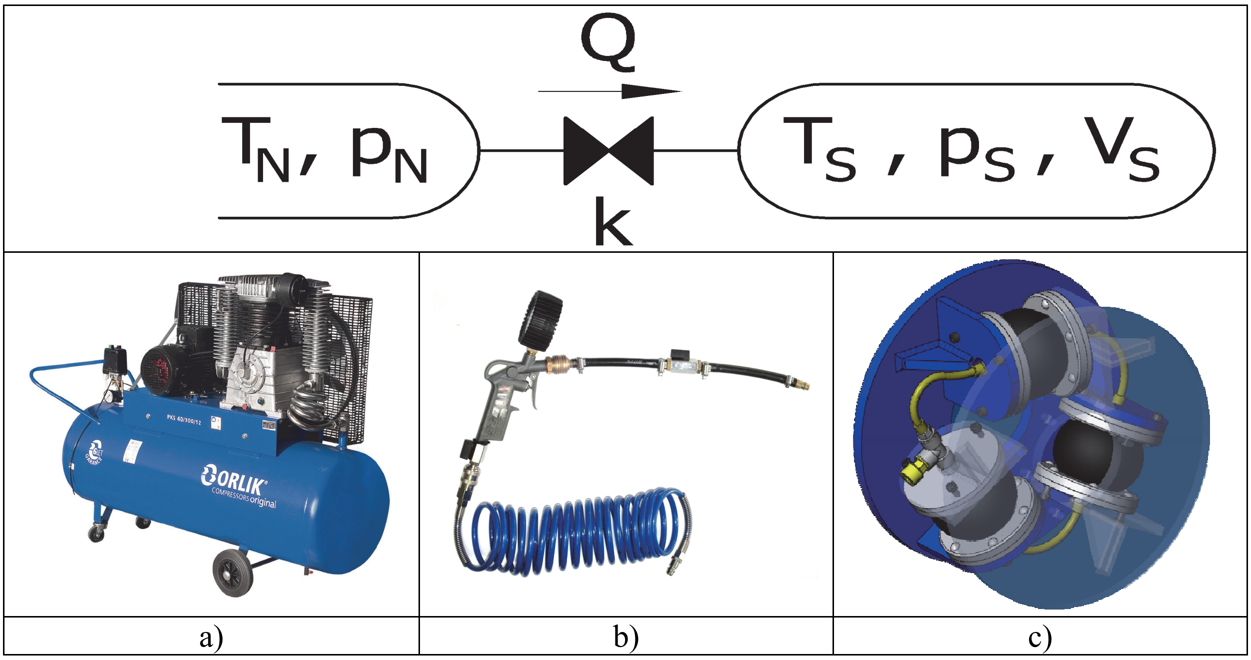

Fig. 3. Parts of system used for experimental measurement: a) compressor with pressure tank with volume of 300 l, b) pressure gun with equipment, c) pneumatic coupling type 3-1/110-T-C

Rys. 3. Części układu wykorzystywane do pomiarów eksperymentalnych: a) sprężarka ze zbiornikiem ciśnieniowym o pojemności 300 l, b) pistolet ciśnieniowy z akcesoriami, c) sprzęgło pneumatyczne typ 3-1/110-T-C

By the help of throttle valves, situated behind and in front of pressure gun (Fig. 3b) it is possible to throttling the gaseous medium flow, and thus increasing the flow resistance coefficient values. In the below presented measurement wasn't realized the flow throttling by given throttle valves.

For determination of flow resistance coefficient was following procedure used:

- The flanges of pneumatic coupling were fixed so that coupling twisting not occurs and so that the volume of its compression space V_S was constant, whereby in compression space of the coupling was zero air overpressure.
- Consequently was the compression space of pneumatic coupling inflated by air at three different values of overpressure in the pressure tank (800, 700 a 600 kPa) until full equalization of pressures in compression space and pressure tank. At the same time was scanned the time dependence of increase of absolute air pressure in compression space of given pneumatic coupling by help of pressure sensor type TSZ (manufacturer MERET) with measuring overpressure range 0 ÷ 1 MPa. Signals from the sensor were processed by measuring equipment MX840 (manufacturer HBM) [6]. Sample rate frequency of measuring was chosen 100 Hz.
- Finally were executed comparisons of measured and calculated time dependences of pressure changes by the method of deviation quadrates summation. Time dependences of calculated curves were adapted to measured dependences (by flow resistance coefficient and polytrophic exponent change), whereby it was effort to the best possible covering of curves (minimizing deviation quadrates summation). If covering of all three curves was reached (at overpressure in pressure tank 800, 700 and 600 kPa) only by polytrophic exponent modification, it was correctly chosen the flow resistance coefficient. In following figure (Fig. 4) it is possible to see the measured and computed curve dependences at specific measurement conditions that were described above.

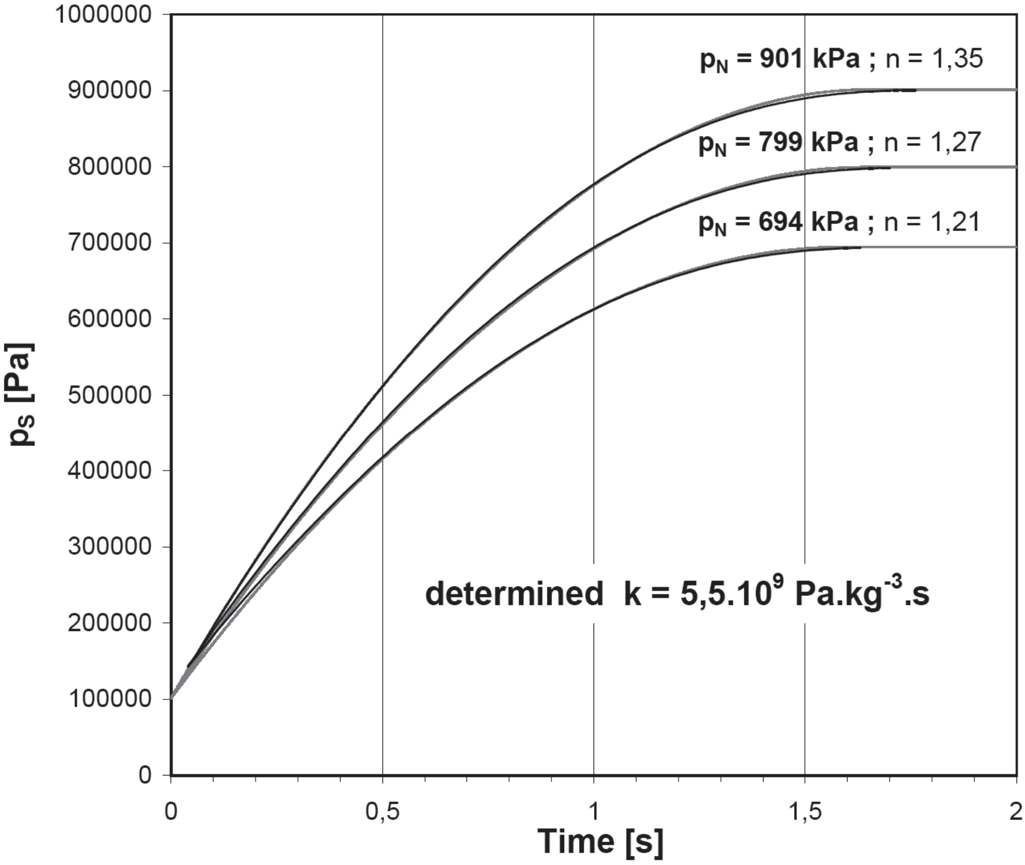

Fig. 4. Measured (black) and computed (grey) time dependences of absolute air pressure increase in compression space of the pneumatic coupling type 3-1/110-T-C

Rys. 4. Zmierzone (czarne) i obliczane (szare) czasowe cykle wzrostu ciśnienia bezwzględnego powietrza w komorę sprężania sprzęgła pneumatycznego typ 3-1/110-T-C

4. CONCLUSION

From Fig. 4 we can see that measured and computed time dependences of absolute air pressure in compression space of pneumatic coupling increase lying very closely together. It is therefore possible to assert, that the use of given mathematical model of pneumatic coupling compression space inflation is suitable. By theoretic and experimental method combination it is possible to determine the value of flow resistance coefficient very accurately with making a smaller effort such as at application of the 3D flow simulation method (which requires very detailed 3D piping modeling). As a disadvantage of theoretic-experimental advancement it is possible to mark the necessity of use of the 2-parametric optimization for flow resistance coefficient finding. This optimization can be without use of optimization software time-consuming.

Presented method of flow resistance coefficient determination was used for determination of this important input parameter at various conditions for transitional effects computations, which arose at gaseous medium pressure in pneumatic coupling during operation of the torsional oscillating mechanical system. With solution of this problem deals for example works [4], [8].

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