ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2011
Seria: TRANSPORT z. 72 Nr kol. 1860

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RESULTS OF MEASUREMENT OF TRANSITIONAL EFFECTS AT AIR PRESSURE CHANGES IN PNEUMATIC COUPLING DURING MECHANICAL SYSTEM OPERATION

Summary. At our department we pay attention in the long term to the pneumatic flexible shaft couplings – their development, research and application to the torsionally oscillating mechanical systems (TOMS). Their main advantage is, that gaseous medium pressure change in their compression space causes a change of the dynamic torsional stiffness and thereby the natural frequency of the mechanical system. This fact we use by tuning of mechanical systems, especially during its operation and therefore is necessary to know the character of the transitional effects at pressure changes in the coupling. This paper deals with presentation and evaluation of measured processes of transitional effects at rapid and slow air pressure changes in pneumatic coupling, applied in specific TOMS.

WYNIKI POMIARÓW EFEKTÓW PRZEJŚCIOWYCH PRZY ZMIANIE CIŚNIENIA POWIETRZA W PNEUMATYCZNYM SPRZĘGLE PODCZAS DZIAŁANIA SYSTEMU MECHANICZNEGO

Streszczenie. Od dłuższego czasu, na naszym Wydziale szczególnie skupiamy się na elastycznych sprzęgłach pneumatycznych – interesuje nas ich rozwój, badania z nimi związane oraz ich zastosowanie w drgających skrętnie systemach mechanicznych (TOMS). Ich podstawową zaletą jest fakt, iż zmiana ciśnienia czynnika gazowego w przestrzeni kompresji powoduje zmianę dynamicznej sztywności skrętnej i w rezultacie zmianę częstotliwości własnej systemu mechanicznego. Fakt ten jest wykorzystywany w tuningu systemów mechanicznych, szczególnie podczas pracy urządzenia, a zatem istotna jest wiedza dotycząca charakteru efektów przejściowych przy zmianach ciśnienia w sprzęgle. Niniejszy artykuł stanowi prezentację i ocenę zmierzonych procesów efektów przejściowych w przypadku szybkiej i wolnej zmiany ciśnienia powietrza w pneumatycznym sprzęgle, zastosowanym szczególnie w TOMS.

1. INTRODUCTION

The by us developed pneumatic couplings can very well fulfill the standards, which are currently imposed on the flexible shaft couplings (stability of properties, high-flexibility, transmission of high load torques, compensating of shaft misalignments etc.) [1, 2, 6].

The main advantage of pneumatic couplings over conventional flexible couplings results from their constructional principle. Flexible transfer of the load torque from the driving to the driven part is ensured by compression of the gaseous medium, concluded in an impermeable covering. Gaseous medium change in this compression space causes a change of the strength and *running* properties of pneumatic coupling, that including the dynamic torsional stiffness too. The value of the dynamic torsional stiffness of flexible coupling has a direct impact on the natural resonance frequency (frequencies) of torsionally oscillating system, in which the given coupling is applied.

By the suitable change of gaseous medium pressure in compression space of pneumatic coupling we can change – suitably adapt the system dynamics with regard to existing sources of torsional oscillation excitation. Resonances can be ejected in consideration of operation speed range (OSR) of mechanical system by the suitable value of torsional stiffness k (fig. 1) [3, 4, 5, 6]. Therefore we use the pneumatic flexible coupling as a means for active tuning of torsionally oscillating mechanical systems (TOMS) during their operation [3, 4, 5].

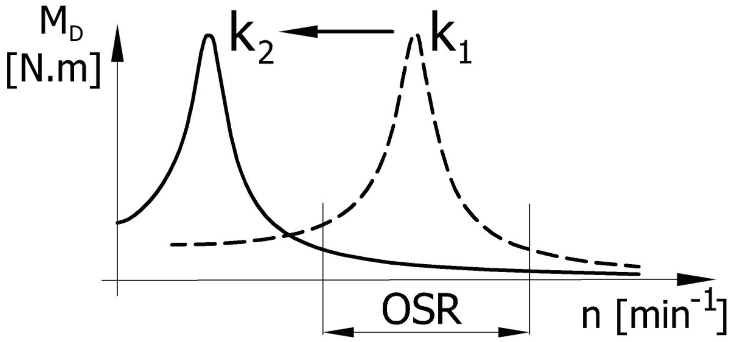

Fig. 1. Principle of mechanical systems tuning
Rys. 1. Zasada tuningu mechanicznych systemów

In consideration of this issue realized by us is necessary to know the character of the transitional effects at gaseous medium pressure change in the pneumatic coupling during operation of the system, and that in order to pneumatic flexible coupling was really the tuner and don't the torsional oscillation exciter.

The objective of this paper is therefore presentation and evaluation of measured processes of transitional effects at air pressure changes in compression space of pneumatic coupling, applied in concrete TOMS (fig. 2), under the following conditions during mechanical system operation:

- at transition across the resonance region at rapid and slow pressure increase,
- at transition across the resonance region at rapid and slow pressure decrease,
- at transition from the resonance region at rapid pressure increase,
- at transition from the resonance region at rapid pressure decrease.

2. EXAMINED TORSIONAL OSCILLATING MECHANICAL SYSTEM

Given torsional oscillating mechanical system (fig. 2) consists of the driving electromotor (*1*) with continual rotation speed regulation, which is driving the four-joint mechanism (*2*). This mechanism transform rotary motion to swinging, sinus-variable movement (at neglect of harmonic components of higher orders, those amplitudes are small in comparison with first order harmonic component) [1, 2]. The mechanism is then working as a kinematical exciter of torsional oscillations and oscillate with a free mass on output of the mechanical system, which is coupled with the oscillate-working arm – primary, through the pneumatic flexible shaft coupling type *4-2/70-T-C* (*3*). The free mass on the output of given mechanical system consist above all of the load arm – secondary (*4*) and weights (*5*), that created together by a self-weight the needed static preload. Accelerations of both arms (primary and secondary) in time are sensed with the piezoelectric sensors of acceleration (*6*), that are placed on equal radius.

Signals from the sensors (*6*) are transmitted through the amplifier and integrator in one (*8*) and scope (*7*) in the computer (*9*), where are recorded as circular path deflections dependent on time and postprocessed as an-gular deflections dependent on time. Air reservoir, from which compression space of the pneu-matic coupling (*3*) is filled, is a part of the compressor (*10*). Precise value of air overpressure in compression space of pneumatic coupling is possible to set up by the manometer (*11*). By the throttle-valves (*12*) and (*13*) it's possible to regulate the pressure change speed in compression space of coupling at saturation and release of air. Overpressure in compression space of coupling dependent on time is sensed with the pressure sensor (*14*) and next processed through measure equipment from the firm HBM.

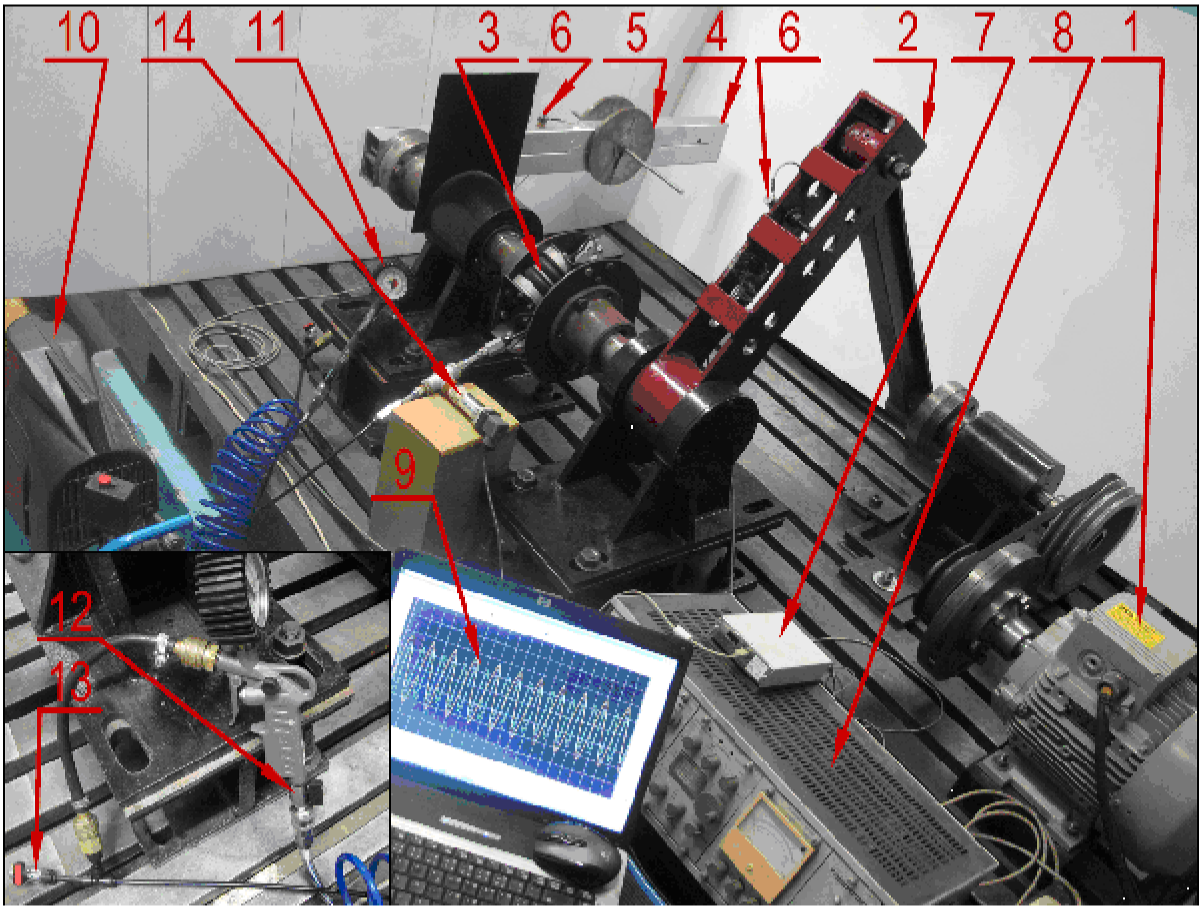

Fig. 2. Examined torsional oscillating mechanical system
Rys. 2. Zbadany drgający skrętnie układ mechaniczny

Pneumatic flexible coupling type *4-2/70-T-C* (fig. 3) is tangential-type coupling. Its compression space consists of 4 pneumatic flexible elements (*3*), that are tangential placed on its perimeter. Compression space is situated between the driving (*1*) and driven (*2*) flange. Such a construction insured a possibility of torque transmission in both directions, because at coupling-twisting are 2 bellows extended and 2 compressed. Through the hose (*6*) and distributor (*5*) is realized the filling of compression space with gaseous medium.

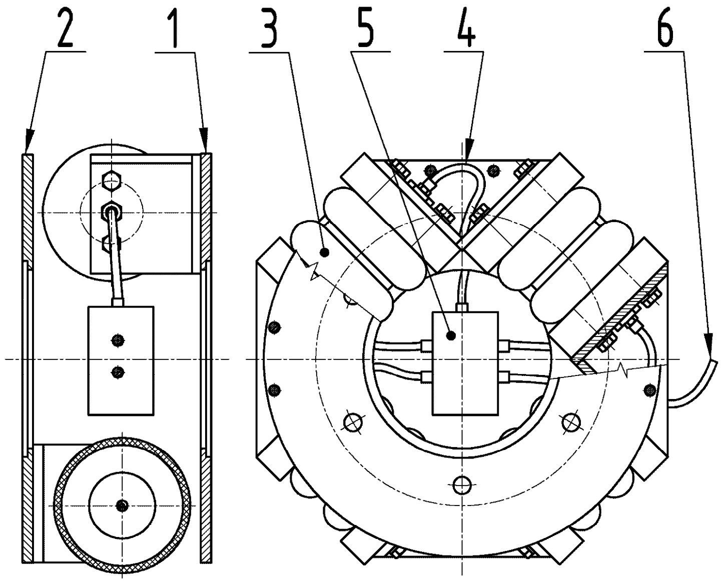

Fig. 3. Pneumatic flexible coupling type 4-2/70-T-C
Rys. 3. Elastyczne sprzęgło pneumatyczne typ 4-2/70-T-C

3. DEFINITION OF INPUT PARAMETERS

Exciting amplitude selection – amplitude of angular deflection of the primary oscillate working arm was chosen $\varphi_{1A} = 1{,}25^{\circ}$. It is the smallest value, which can be chosen at current type of mechanism construction and is the best in term of measuring conditions and demonstration of presented results.

Selection of suitable static preload – that is created by the free mass on the output – given preload must be suitable selected in consideration of transmission ability of the applied pneumatic coupling. It must be satisfied a condition, that during operation of the mechanical system the allowed maximal twist angle of given pneumatic coupling $\varphi_{max} = 11{,}5^{\circ}$ can't be exceed, that its damage not occurs. Coupling twisting during operation of given mechanical system is induced by as static overload, as dynamic inertial effects of free mass on the output.

Outgoing of above listed conditions and before realized static and dynamic measurements of given pneumatic coupling was selected static overload torque, which is created by the free mass on the output of given mechanical system of value $M_{ST} = 61{,}5 N.m$.

Determination of excitation frequency – for selected gaseous media in compression space of the pneumatic coupling overpressure range $p = 100 - 700\ kPa$ was measured and calculated a dependence of natural oscillation frequency of the mechanical system Ω (fig. 4) by the free oscillation method according [8]. On *fig. 4* we can see, that the natural oscillation frequency of given mechanical system is changing smoothly nonlinear in range of *2,26 – 3,69 Hz* by overpressure change in range of *100 – 700 kPa*, what correspond with dynamic torsional stiffness of given coupling change in range of $807 - 2147\ N.m.rad^{-1}$.

The resonance was thereafter adjusted at overpressure *400 kPa* in the middle of overpressure range. Excitation frequency, which correspond with natural oscillation frequency of mechanical system at given overpressure is *2,94 Hz*. Thereafter measured resonance curve of dynamic twist angle of the coupling φ_A dependent on overpressure p in its compression space at above listed conditions we can see on fig. 5.

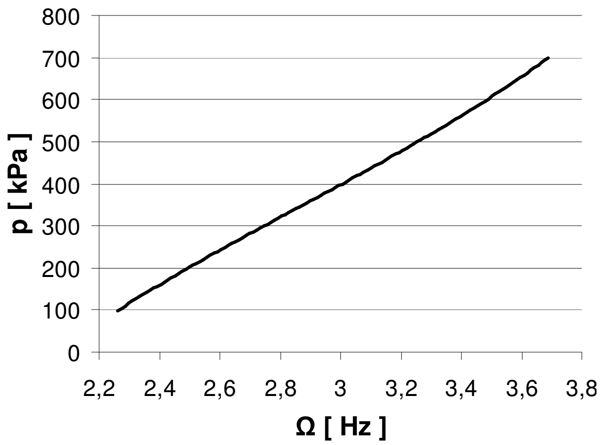

Fig. 4. Natural oscillation frequency of the mechanical system Ω dependent on air overpressure p in compression space of the pneumatic coupling

Rys. 4. Częstotliwość drgań własnych w mechanicznym systemie Ω zależna od nadciśnienia powietrza p w przestrzeni sprężania sprzęgła pneumatycznego

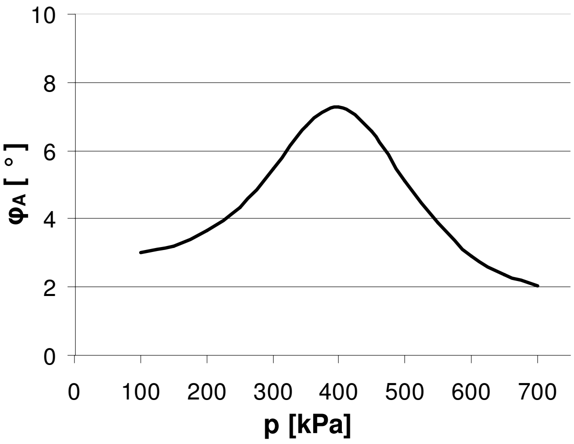

Fig. 5. Resonance curve of dynamic twist angle of the coupling φ_A dependent on overpressure p in its compression space

Rys. 5. Krzywa rezonansu w kącie dynamicznego skrętu sprzęgła φ_A w zależności od nadciśnienia p w jego przestrzeni sprężania

4. RESULTS OF MEASURING

At transitional effects was observed dynamic twist angle of the pneumatic coupling φ dependent on time t, complemented with air overpressure p changes in compression space of coupling at time dependences – blue curves (fig. 6 – 11). From followed figures it can be seen, that time duration of transitional effects is consistent with duration of air pressure change in compression space of coupling.

Transitional effect can be in this case characterized as section of unsteady time dependence of dynamic twist angle of pneumatic coupling φ. The durations of transitional effects we can see in tab. 1.

It is also necessary to say, that the sections of dependence of pneumatic coupling dynamic twist angle φ of stabilized magnitude on the fig. 6, 10 and 11 after transitional effects subsidence at rapid pressure changes are caused by imperfection of amplifier integration. Duration of these sections therefore weren't included in time duration of transitional effects.

Table 1

Durations of transitional effects

No. of figure	Start overpressure [*kPa*]	Final overpressure [*kPa*]	Duration of transitional effect [*s*]
6	100	708	2.1
7	100	700	14.87
8	700	100	2.74
9	700	100	17.37
10	405	708	1.97
11	400	80	2.3

As we can see from tab. 1, achievement of accurate start and final air overpressure in compression space of coupling values at measuring was very difficult, especially at rapid overpressure changes, because these changes were realized without using of electronic control.

On following pictures we can also observe air overpressure changes *p* in compression space of coupling dependent on time *t*. These curves haven't smooth character, because during operation of this mechanical system there are relative large coupling twistings, mainly in the resonance region, and therefore pressure values oscillations in compression space of the coupling. These oscillations are god visible mainly at transitional effects at slow pressure change, but also at stabilized oscillating process, especially in the resonance region.

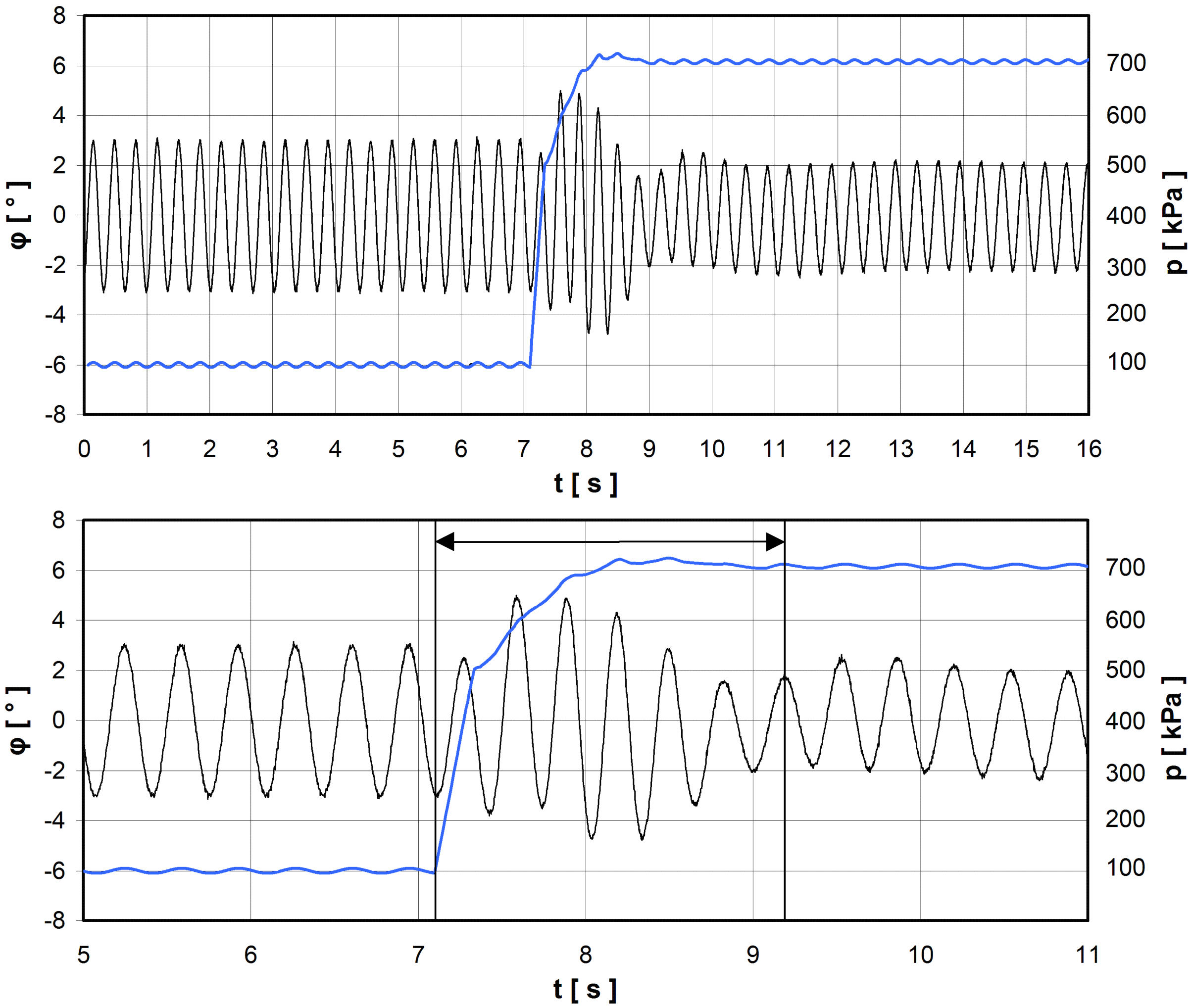

Fig. 6. Transitional effect across the resonance region at rapid air overpressure increase
Rys. 6. Efekt przejściowy wzdłuż obszaru rezonansu przy szybkim wzroście nadciśnienia powietrza

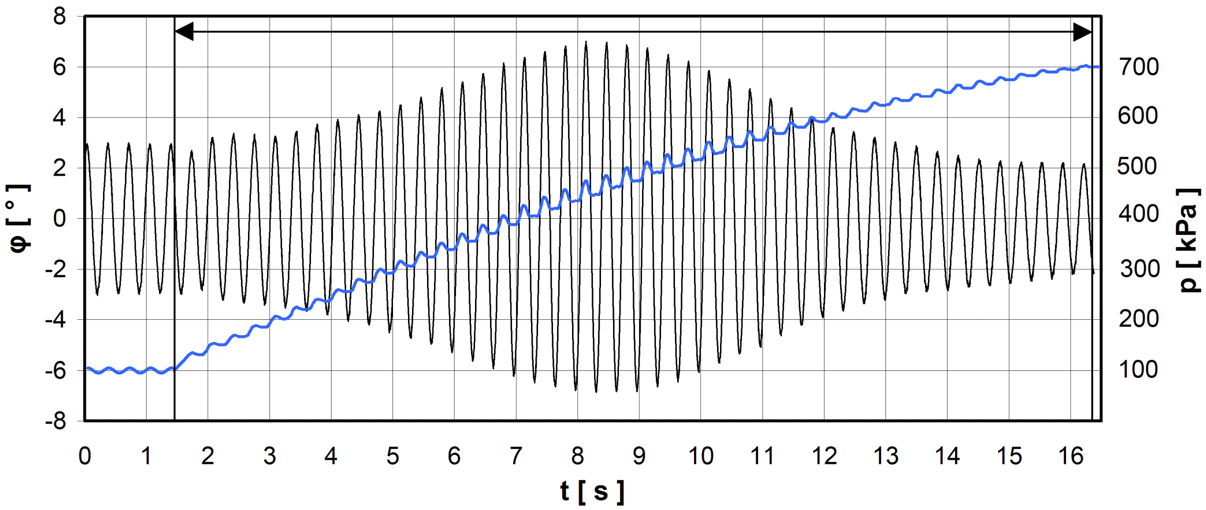

Fig. 7. Transitional effect across the resonance region at slow air overpressure increase
Rys. 7. Efekt przejściowy wzdłuż obszaru rezonansu przy wolnym wzroście nadciśnienia powietrza

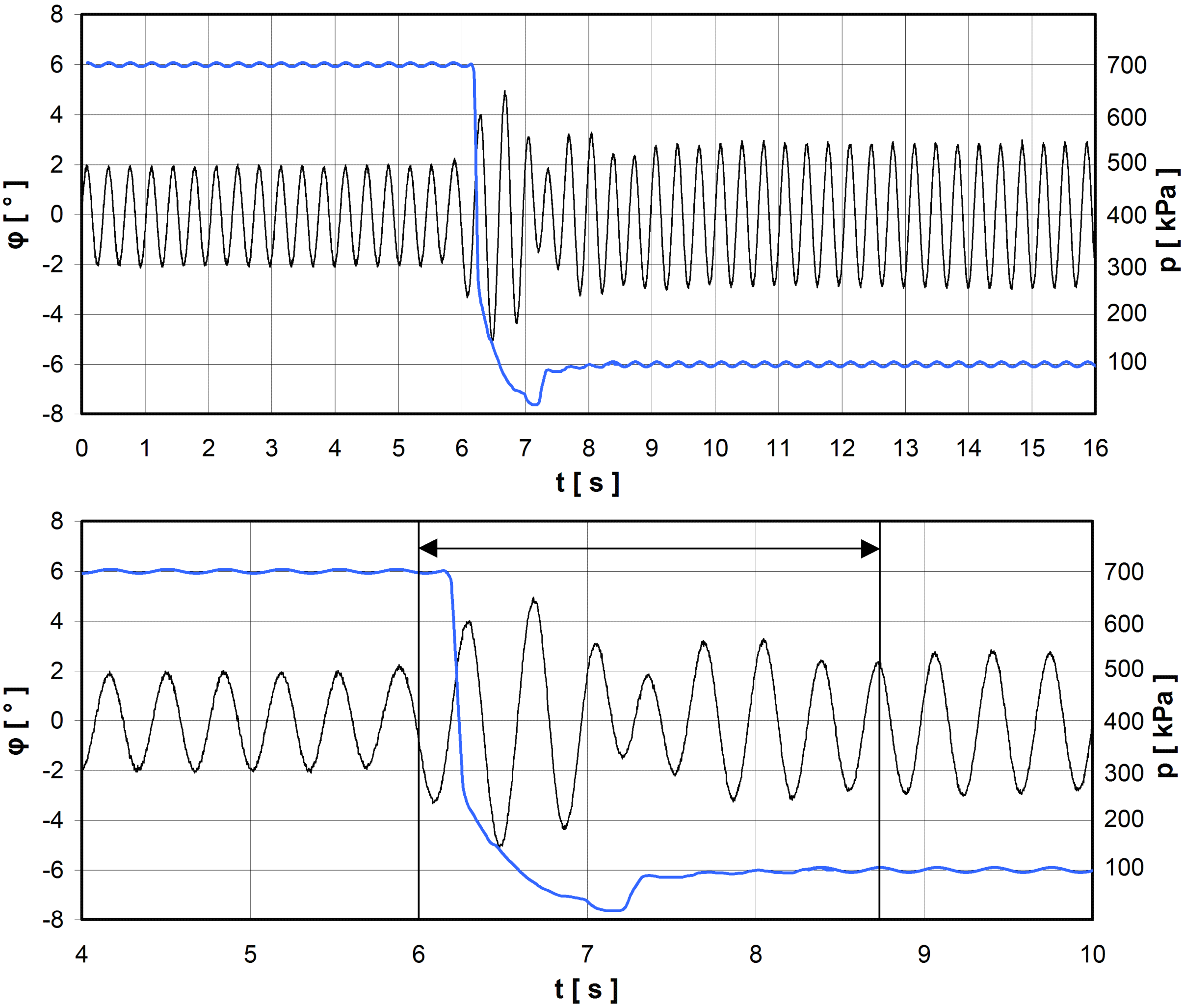

Fig. 8. Transitional effect across the resonance region at rapid air overpressure decrease
Rys. 8. Efekt przejściowy wzdłuż obszaru rezonansu przy szybkim spadku nadciśnienia powietrza

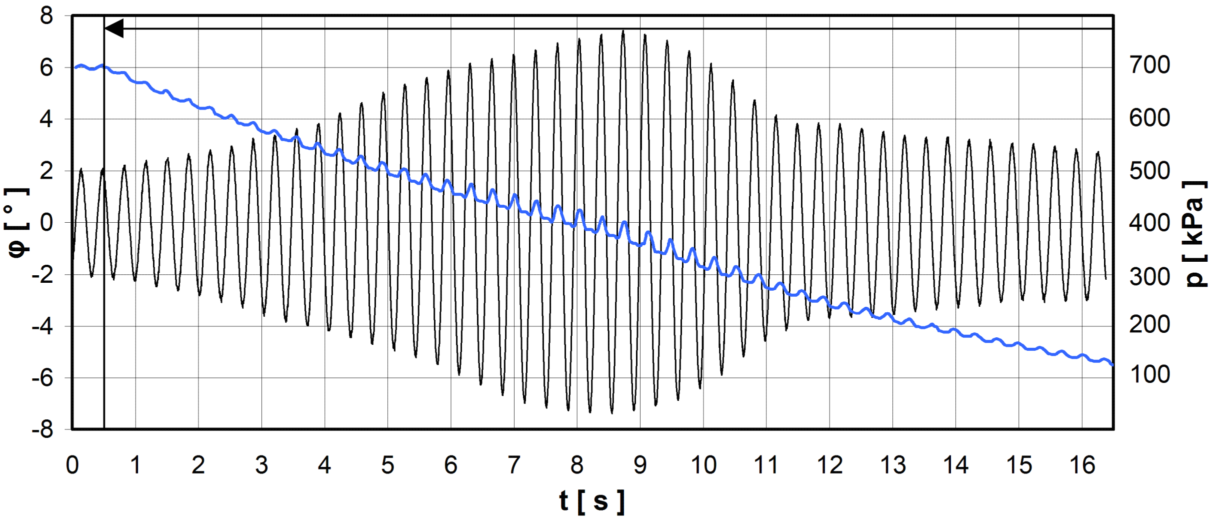

Fig. 9. Transitional effect across the resonance region at slow air overpressure decrease
Rys. 9. Efekt przejściowy wzdłuż obszaru rezonansu przy wolnym spadku nadciśnienia powietrza

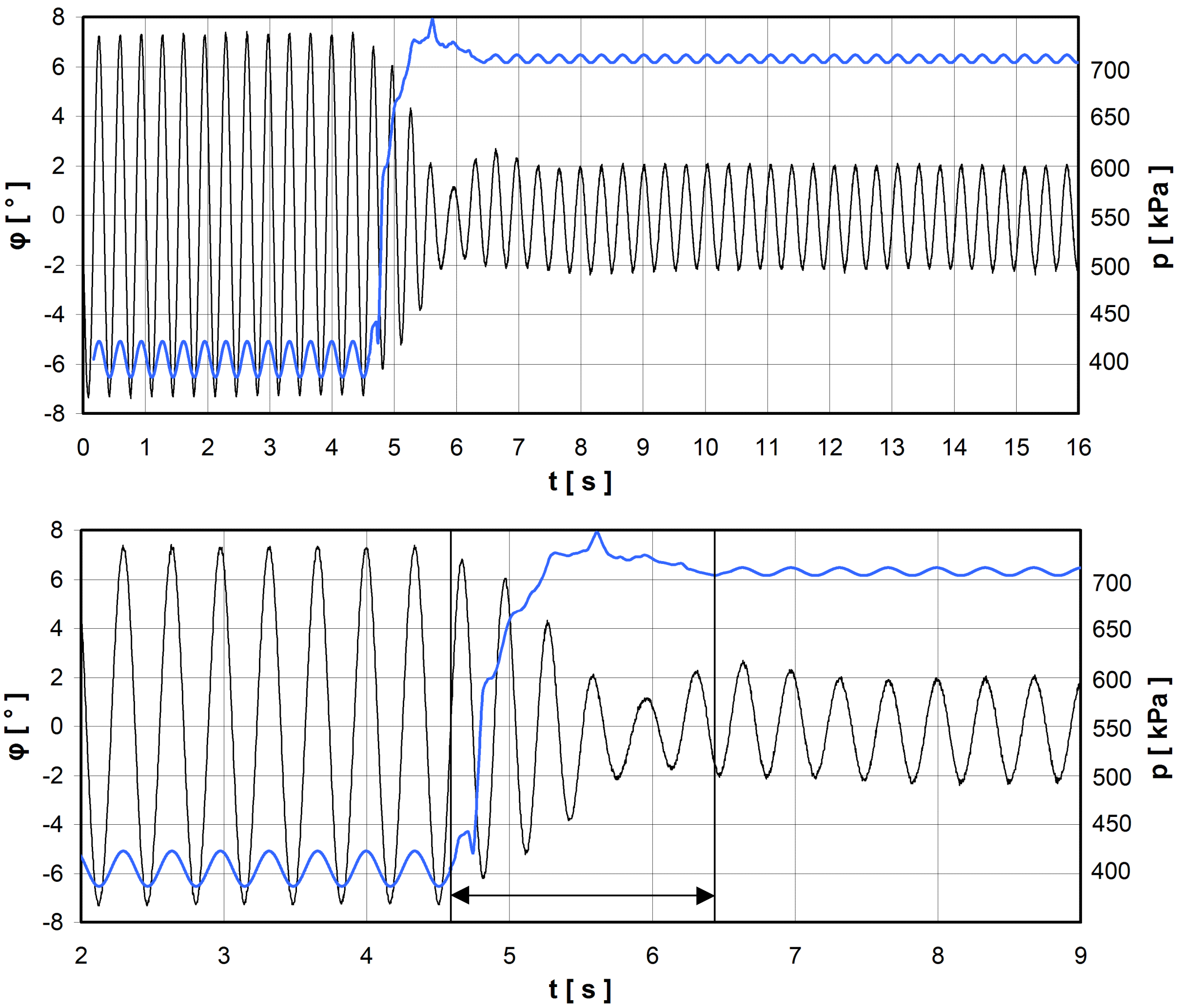

Fig. 10. Transitional effect from the resonance region at rapid air overpressure increase
Rys. 10. Efekt przejściowy pochodzący z obszaru rezonansu przy szybkim wzroście nadciśnienia powietrza

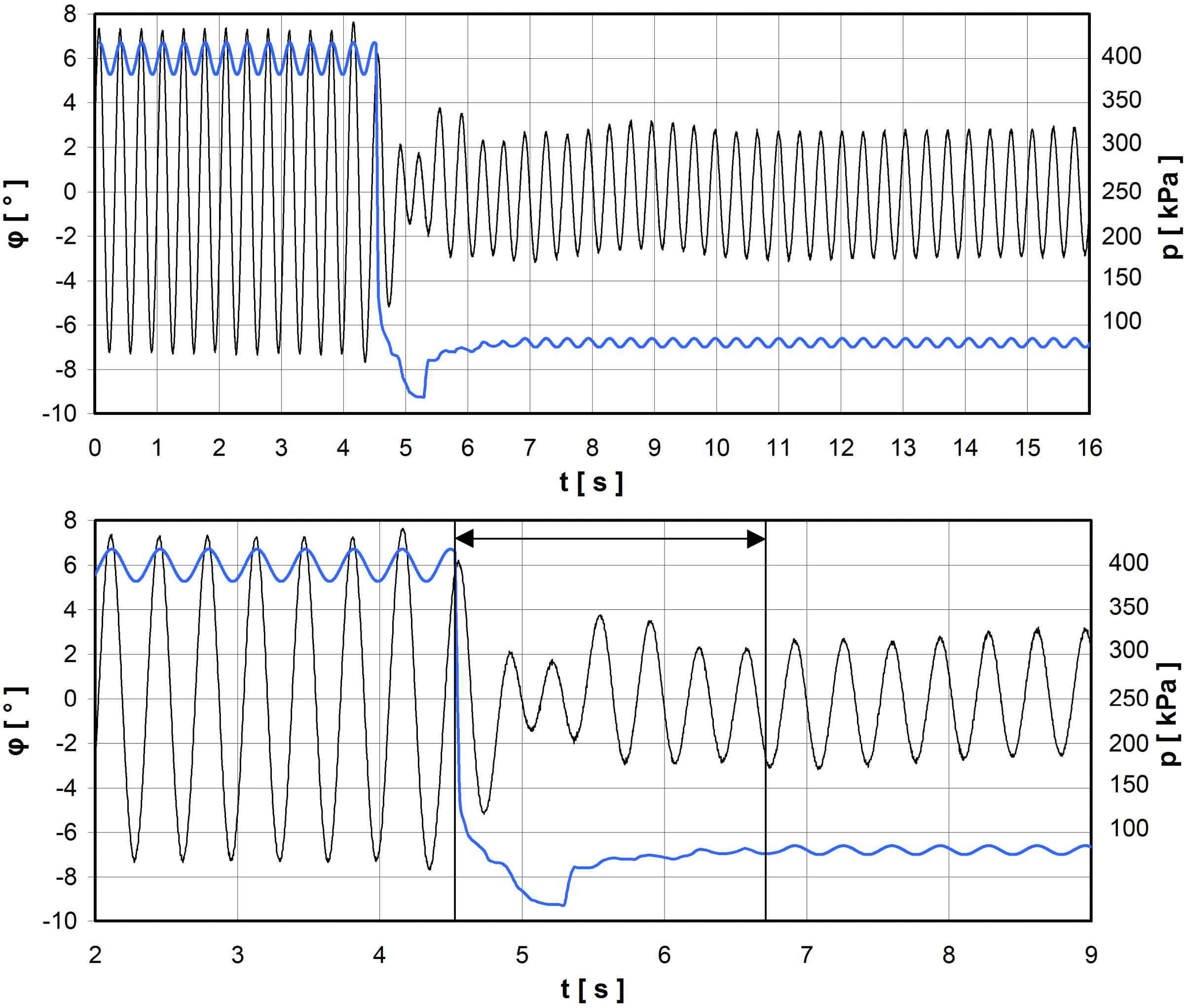

Fig. 11. Transitional effect from the resonance region at rapid air overpressure decrease
Rys. 11. Efekt przejściowy pochodzący z obszaru rezonansu przy szybkim spadku nadciśnienia powietrza

Further we can evaluate from the dependences following important facts, namely:

- ❖ by the slow continual overpressure change we can continual change the size of dynamic twist angle of pneumatic coupling amplitudes (fig. 7 and 9),
- ❖ by the rapid overpressure changes from below- and over-resonance area and backwards it is possible to prevent from dynamic twist angle of the coupling increase to the resonance amplitudes level (fig. 6 and 8),
- ❖ by the rapid overpressure changes we can very quickly take the mechanical system out of the resonant state (fig. 10 and 11).

It is also necessary to say, that form and duration of transitional effects, mainly at rapid pressure changes in compression space of coupling to a certain extent depend too on the start moment of pressure change. Its reason is, that given mechanical system oscillate at relatively big deflections, thus the dependence of pressure change in compression space of coupling is affected by dynamic impact of load inertia.

5. CONCLUSION

By gaseous media pressure change in pneumatic coupling we are thus able to effective and exactly tuning of torsional oscillating mechanical system during their operation. This fact is possible on the ground of that, that by gaseous media pressure change in compression space of pneumatic coupling we direct change torsional stiffness of coupling, and thereby a natural reso-nance frequency of the system.

In term of speed of tuning is therefore suitable to construct pneumatic couplings so that in their compression space was the pressure compensating as quick as possible at its change, be-cause only after pressure compensating reach a pneumatic coupling required properties. Thereby come to time duration of transitional effects reduction, mainly at rapid pressure changes.

It is possible to assert, that pneumatic couplings make possible a targeted exploitation of resonance phenomenon too. For this make the fact too, that by influence of large deflections in resonance do not occur to their excessive rise of temperature and thereby to their dynamic properties change, like at conventional flexible coupling types [2].

At rapid pressure changes in pneumatic coupling during mechanical system operation may be sometime needed to determinate and make provision for dynamic effects, caused by gaseous media pressure shock and consequential coupling twist angle change.

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This paper was written in the framework of grant project VEGA: „1/0304/09 – Governing of dangerous vibrations in drives of mechanical systems”.

Recenzent: Prof. Ing. Jan Gaduš, CSc.