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INVESTIGATION OF VARIOUS FACTORS INFLUENCE ON DYNAMIC LOAD OF MECHANICAL SYSTEM BY PNEUMATIC COUPLING APPLICATION

Summary. In order to tuning or continuous tuning of torsional oscillating mechanical systems (TOMS) during their operation we apply the pneumatic flexible shaft couplings in these systems. By appropriate gaseous medium pressure change in given couplings we change their torsional stiffness and thus the dynamics of the whole system too. Rapid gas pressure increase in the pneumatic coupling during system operation can under certain conditions excite additional dynamic load, what we in final consequence understand as an external faulty event of the system. Therefore, the objective of this paper will be the investigation of various factors influence (viscous damping coefficient, inflation time, twist angle of the coupling and mass moment of inertia of the load) on given faulty event of the system, based on measurements and mathematical modeling.
Key words. Pneumatic flexible coupling, rapid pressure increase, faulty event.

BADANIE WPŁYWU RÓŻNYCH CZYNNIKÓW NA OBCIĄŻENIE DYNAMICZNE UKŁADU PRZY ZASTOSOWANIU SPRZĘGŁA PNEUMATYCZNEGO

Streszczenie. W celu dostrojenia lub płynnego strojenia układów mechanicznych drgających skrętnie podczas ich pracy stosujemy w nich pneumatyczne elastyczne sprzęgła łączące wały. Dzięki właściwej zmianie ciśnienia medium gazowego we wspomnianych sprzęgłach, zmieniamy ich sztywność skrętną, a dzięki temu również dynamikę całego układu. Szybki wzrost ciśnienia medium gazowego w sprzęgle pneumatycznym podczas pracy układu może w określonych warunkach wywołać dodatkowe obciążenie dynamiczne, co w ostatecznym efekcie jest traktowane jako zewnętrzne zjawisko uszkadzające układ. Z tego powodu celem artykułu jest badanie wpływu różnych czynników (współczynnik tłumienia lepkiego, czasu napełniania, kąta skrętu sprzęgła oraz masowego momentu bezwładności obciążenia) na dane zjawisko uszkadzające układ, co zostało przeprowadzone na podstawie pomiarów oraz modelowania matematycznego.
Słowa kluczowe. Pneumatyczne sprzęgło elastyczne, szybki wzrost ciśnienia, zjawisko uszkodzenia.

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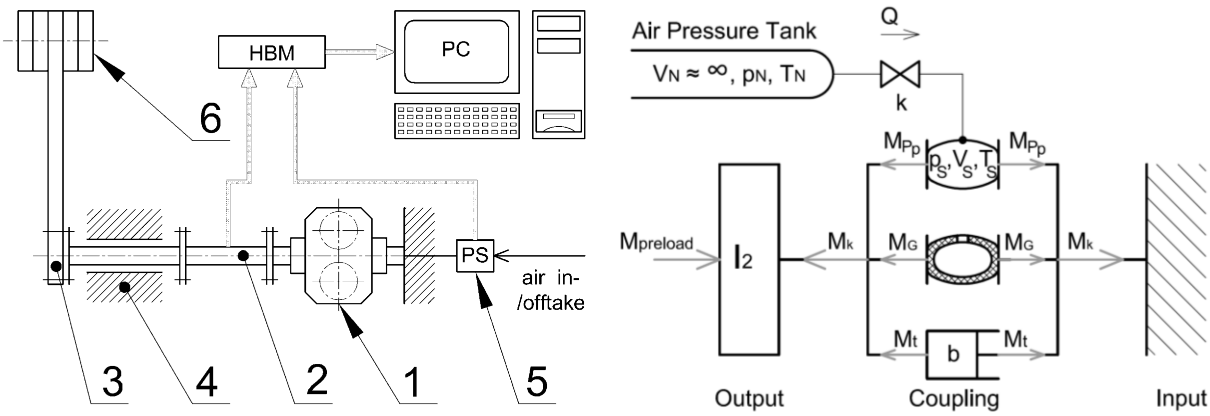
1. INTRODUCTION

Faulty event could be characterized as a primary failure cause. The consequence of faulty event inception can be directly a failure inception, or a damage inception.

From measurements at TOMS with applied pneumatic flexible shaft couplings it was find out, that under certain conditions can come to exciting of additional dynamic load by impact of rapid gaseous media pressure change in compression space of pneumatic coupling. At work of us-practiced regulations the most dangerous fall occurs, when it come to rapid pressure increase in compression space of coupling during operation of mechanical system.

Loaded and twisted pneumatic coupling opens at pressure increase wherein, whereby great torque arises. Size of this overpressure torque M_{Pp} depend on product of the static moment of coupling compression space effective surface (product of effective surface and distance of centre of gravity of this surface from coupling rotation axis) and overpressure in coupling. By coupling opening occurs acceleration of rotational masses, connected to coupling and thereby mechanical system wobble.

2. USED EXPERIMENTAL DEVICE



a) b)

Fig. 1. Used experimental device: a) schematic representation, b) dynamic model
Rys. 1. Zastosowane urządzenie próbne: a) schematyczne przedstawienie, b) model dynamiczny

In Fig. 1a is schematic displayed used experimental device. Free mass on the output of mechanical system is connected to one flange of pneumatic flexible shaft coupling (1). Second coupling flange is fixed. Free mass on the output of given mechanical system with mass moment of inertia I_2 is created above all by load arm (3) and weights (6), that together creates by self-weight necessary preload torque $M_{preload}$ (static torque). Torque, by whose is coupling loaded, is scanned through torque sensor (2). Gaseous medium pressure in compression space of pneumatic coupling is scanned through pressure sensor (5). Measuring equipment MX840 from HBM Company subsequently synchronizes signals from both sensors in time and sends data to PC. Bearings of the system (4) were modified so that rolling-resistance in them was minimal (using special lubricant and suitable fittings).

In Fig. 1b is dynamic model of the system, displayed in Fig. 1a. At this dynamic model it is assumed that gaseous media pressure p_S in compression space of coupling with volume V_S changes equally. Next it is assumed that pressure tank volume V_N is infinite. So theoretical and practical results can be comparable, we must use in praxis the pressure tank big enough, in this case $V_N = 300\,l$. Gaseous medium flow from pressure tank to coupling is described with mass flow Q and k is flow resistance coefficient. The total load torque M_k, transmitted by pneumatic coupling is sum of gaseous media overpressure torque M_{Pp}, rubber-cord covering of pneumatic flexible elements torque M_G and damping torque M_t. In dynamic model we consider, that character of pneumatic coupling damping is viscous, with viscous damping coefficient b. Detailed mathematical description of given dynamic model is mentioned in the work [8]. At measurements, described in the next chapter, was as gaseous medium used air.

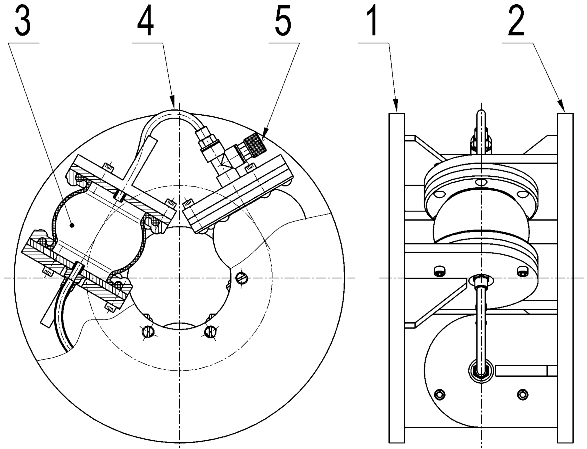


Fig. 2. Pneumatic coupling type 3-1/110-T-C
Rys. 2. Sprzęgło pneumatyczne typ 3-1/110-T-C

The coupling in Fig. 2 was made within the frame of cooperation of our department with Polish firm FENA in Katowice. Coupling is created by *2* equal flanges (1,2), which are coupled with *3* on the circumference tangential arranged pneumatic flexible elements (PFE) (3). Complete mutual cross connection of PFE is realized by hoses (4), herewith is created the compression space of coupling. Pressure in coupling can be changed by inflation of PFE to required pressure through pneumatic glad-hand (5). Coupling serves for transmission of load torque in terms of PPE compression.

3. EXPERIMENTAL MEASUREMENTS AND MATHEMATICAL MODELLING RESULTS

By following measurements (Fig. 3) are investigated dynamic effects at rapid inflation of compression space of twisted coupling (occurs pressure equalizing in pressure tank and in coupling). Rotary masses having various moment of inertia I_2 and preload torque $M_{preload}$, which is created by self-weight of arm with weights (see Tab. 1). Inflation times are always = *3 s*. Initial overpressures p_{pN} in pressure tank were *800*, *700* a *600 kPa*. Initial twist angle of pneumatic coupling was selected always $\varphi_0=15^o$, it is maximal allowable twist angle of given coupling. They are displayed measured (index „N“) a calculated (index „V“) time dependences.

Table 1

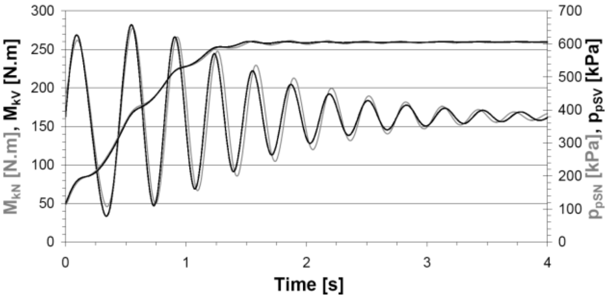
Preload moments and mass moments of inertia at measurement

Coupling 3-1/110-T-C	$M_{preload}$ **[N.m]**	I_2 **[kg.m^2]**
1 weight	163	9,801993
2 weights	297	17,792857
3 weights	425	25,483721

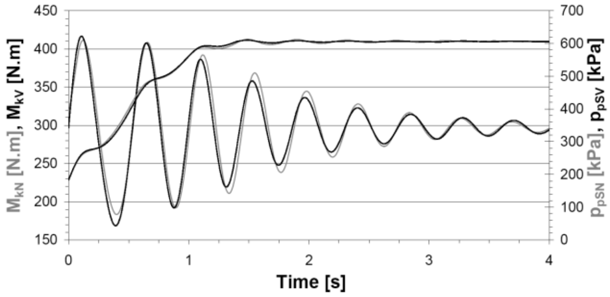
From mentioned Fig. 3 is possible to state, that computed dependences are very close to measured dependences. Given mathematical model is therefore very suitable for investigation of transitional effects at coupling inflation in this system. Final twist angle φ_1 inscribed under pictures stands for twist angle of the coupling after transitional effect subsidence. Deviations between measured and computed values can be caused by multiple factors:

- difference in computed and real values of mass moments of inertia to rotation axis of free mass, connected to coupling. Imprecision could arise for example by incorrect determination of individual parts material density and their dimensions measurement errors,
- neglect of influence of PFE-cover dynamic stiffness in computations,

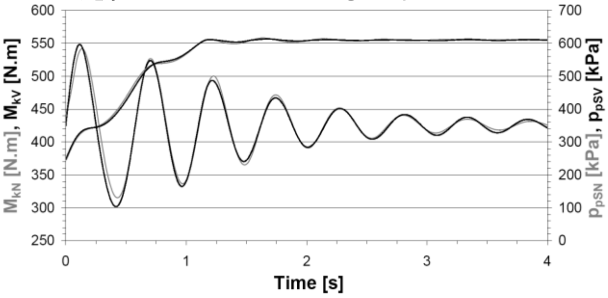
- character of damping in system is not exactly viscous,
- little unevenness of air pressure change in coupling during its inflation, etc.



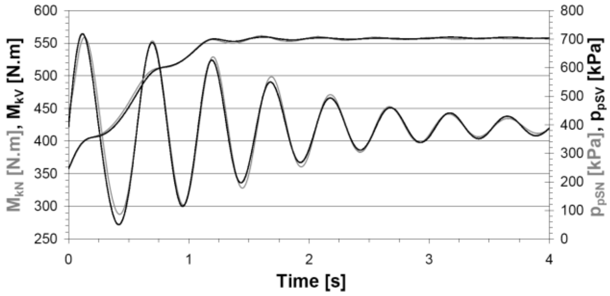
a) p_{pN} = 600 kPa, 1 weight, φ_1 = -1,992°



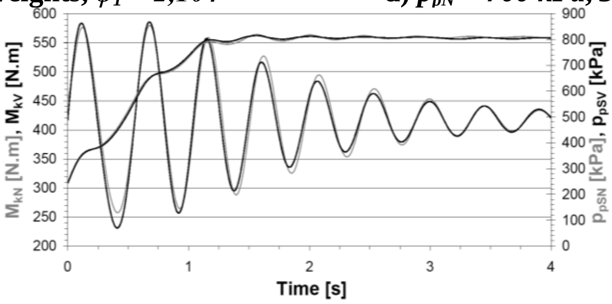
b) p_{pN} = 600 kPa, 2 weights, φ_1 = 0,084°



c) p_{pN} = 600 kPa, 3 weights, φ_1 = 2,104°



d) p_{pN} = 700 kPa, 3 weights, φ_1 = 0,976°



e) p_{pN} = 800 kPa, 3 weights, φ_1 = 0,037°

Fig. 3. a) to e): time dependences of load torque M_k, transmitted by pneumatic coupling at its inflation

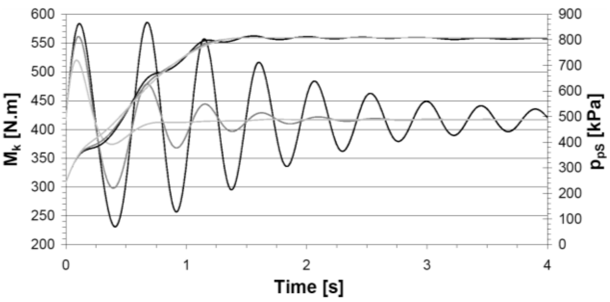
Rys. 3. a) do e): przebiegi czasowe obciążającego momentu obrotowego M_k, przenoszonego przez sprzęgło pneumatyczne podczas jego napełniania

Tab. 2

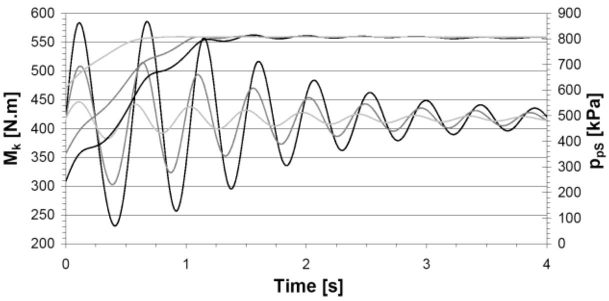
Numerical values of variable parameters at computation

	Variable parameter			
Color of curves	***b*** **[N.m.rad^{-1}.s]**	***Initial twist angle*** ***φ_0*** **[°]**	***Time of inflation*** **[s]**	***I_2*** **[kg.m^2]**
black	30	15	3	25,483721
dark grey	100	8	0,2	10
light grey	300	2	0,05	50
Color of curves	***Final twist angle φ_1*** **[°]**			
black	0,037	0,037	0,037	0,037
dark grey	0,01	0,025	8,198	0,001
light grey	0,01	0,012	12,843	0,043

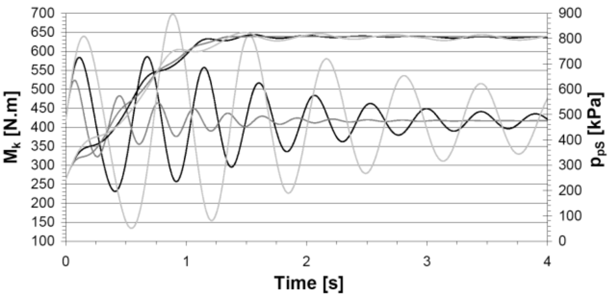
Next was investigated the influence of viscous damping coefficient b (Fig. 4a), couplings initial twist angle φ_0 (Fig. 4b), inflation time (Fig. 4d) and mass moment of inertia of the free mass I_2 (Fig. 4c) on time dependences of the load torque M_k dynamic component and overpressure in the coupling compression space p_{pS}. Computed dependences were used. As invariable base were used the computed dependences according to Fig. 3.e, displayed in each picture with black curves. If one parameter was changed, all the others were constant and their numerical values are in the row for black curve in aforementioned Tab. 2.



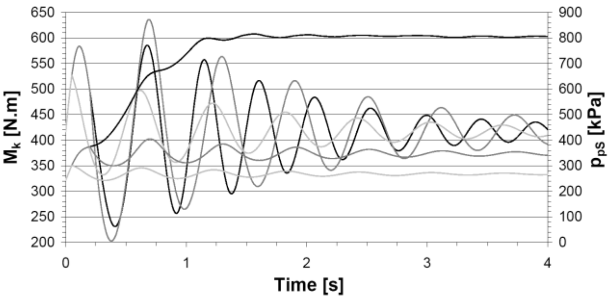
a) wpływ współczynnika tłumienia lepkiego b
a) influence of viscous damping coefficient b



b) wpływ początkowego kąta skrętu φ_0
b) influence of initial twist angle φ_0



c) wpływ masowego momentu bezwładności I_2
c) influence of mass moment of inertia I_2



d) wpływ czasu napełniania
d) influence of inflation time

Fig. 4. a) to d): influence of various parameters on time dependences of load torque M_k and overpressure in compression space of coupling p_{pS}

Rys. 4. a) do d): wpływ różnych parametrów na przebiegi czasowe obciążającego momentu obrotowego M_k oraz podciśnienia w komorze kompresyjnej sprzęgła p_{pS}

4. CONCLUSION

From measured and computed time dependences of monitored parameters in Fig. 3 and Fig. 4 we can draw a following conclusions, in respect of size of excited dynamic load (SEDL):

● With increased value of overpressure in pressure tank p_{pN} SEDL increases at invariable other parameters. It is caused by streaming speed increase, thus pressure in coupling increase and consequently by coupling twist angle change speed (angular extending). In final consequence increases the acceleration of free mass, connected to coupling and therewith coupled dynamic effects.

● With increased value of viscous damping coefficient b SEDL expectantly decreases at invariable other parameters, because the size of viscous damping is commensurable to motion speed. Likewise the duration time of transitional effect logically shortens.

● With increased value of initial twist angle of coupling φ_0 SEDL increases at invariable other parameters. It occurs by reason that with coupling twisting the static moment of compression space effective surface increases. This one increases the size of overpressure torque M_{Pp} at inflation, which accelerates the free mass, connected to coupling. We get therefore the biggest immediate accelerating overpressure torque, when the product of static moment of compression space effective surface and overpressure in pneumatic coupling will be maximal.

● With increased mass moment of inertia of free mass, connected to coupling SEDL expectantly increases at invariable other parameters. SEDL will not, of course, increase ad lib, because the coupling won't be gradually able to create such strong accelerating torque and such big acceleration.

● For achievement of considerable SEDL is enough, when the gas-intake into compression space is open for very short time. The impulse of overpressure torque M_{Pp} will be big enough to create considerable acceleration of free mass, connected to coupling.

If we would like to reduce VVDZ, increase of flow resistance coefficient k, eventually decrease of pressure in the pressure tank p_N is not very effective way in term of by us practiced regulations speed. Likewise using the oversize of pneumatic coupling is not very effective way (in order to reach of smaller twist angles of coupling in operation of mechanical system). The most effective way for us appears the application of viscous (or another) additional damper in pneumatic coupling, whereby the damping value will be dependent on specific operation terms. At this type of coupling is necessary to take care, that its twist angle don't reach the negative values, because so arises the unfavorable loading of pneumatic elements.

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