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COMPARATION OF SELECTED PNEUMATIC FLEXIBLE SHAFT COUPLINGS

Summary. At our Department we deal with the development of pneumatic flexible shaft couplings, which in addition to other flexible couplings are able to change their torsional stiffness by adjusting the air pressure in their flexible elements. This article deals with comparison of two selected pneumatic flexible shaft coupling. The first coupling is a newly developed pneumatic flexible shaft coupling with wedge elements. Pneumatic flexible shaft coupling with wedge elements was developed to improve the properties of pneumatic flexible couplings, especially the nominal and maximal torque and maximum angle of distortion. Due to the reason that coupling with wedge elements isn't manufactured yet, we will use only a mathematic model of this coupling. The second coupling is a tangential pneumatic flexible shaft coupling manufactured by FENA company.

PORÓWNANIE WYBRANYCH ELASTYCZNYCH SPRZĘGIEŁ PNEUMATYCZNYCH

Streszczenie. Nasz Wydział zajmuje się rozwojem elastycznych sprzęgieł pneumatycznych, które jako dodatkową funkcję posiadają możliwość zmiany sztywności skrętnej przez dostosowanie ciśnienia powietrza do ich elastycznych elementów. Niniejszy artykuł prezentuje porównanie dwóch wybranych elastycznych sprzęgieł pneumatycznych. Pierwsze sprzęgło to nowo stworzone elastyczne sprzęgło pneumatyczne z elementami klinowymi. Takie sprzęgło został stworzony, aby ulepszyć właściwości sprzęgła szczególnie przy nominalnym i maksymalnym momencie obrotowym i maksymalnym kącie odkształcenia. Ze względu na fakt, że sprzęgło z elementami klinowymi nie zostało jeszcze wyprodukowane użyjemy jedynie matematycznego modelu takiego sprzęgła. Drugie sprzęgło to elastyczne sprzęgło pneumatyczne wyprodukowany przez firmę FENA.

1. INTRODUCTION

Previously known flexible shaft couplings are manufactured with metal, rubber or plastic flexible elements. The most widely used flexible couplings in engineering are flexible shaft couplings with rubber flexible elements. In addition that they compensate radial or axial displacement, they are characterized by a non-linear Coupling torque transmission characteristics. There are also known their initial dynamic properties, ie. dynamic torsional stiffness and damping coefficient. Durability and hence the life-time of rubber flexible element is closely connected with the heating of the coupling and hence the heating of its flexible elements. Permanent heat causes progressive fatigue of flexible elements. With fatigue rubber materials lose its original dynamic properties. In this case, positive non-linear characteristics of the original shaft coupling changes to (unknown) characteristics with completely different dynamic properties. Consequently, the currently used flexible shaft couplings are losing their basic mission – appropriate tuning of mechanical systems ensuring the flexible load transfer torque in these systems [3, 4].

The above disadvantages of the current flexible shaft couplings are removed and the requirement demanded for new types of couplings are fulfilled with pneumatic flexible shaft couplings with wedge flexible elements, namely pneumatic tuner of torsional vibration with wedge flexible elements, developed at our department [8, 9]. This type of flexible shaft couplings in addition to other flexible couplings are able to change their torsional stiffness and hence the the dynamic properties of mechanical systems using this type of flexible couplings. This is able by adjusting the air pressure in their flexible elements. But compared to traditional flexible couplings these couplings have some disadvantage because that by given outer dimension they have lover nominal torque [2].

Efforts to eliminate this disadvantage led us to develop a new type of pneumatic flexible shaft couplings with special wedge elements. Currently manufactured pneumatic flexible elements are designed for linear deformation. Wedge elements have a shell shape designed for use in pneumatic flexible coupling and the deformation on a circular arc trajectory. This allows us to to use more flexible elements in pneumatic flexible coupling and achieve a greater twist angle..

The aim of the paper is to determine the static load characteristics by calculation, the nominal and maximum torque of pneumatic flexible coupling with wedge elements, and then compare these characteristics with the characteristics of currently manufactured pneumatic flexible shaft couplings with the same outer diameter.

2. PROPERTIES OF NEWLY DEVELOPED PNEUMATIC SHAFT COUPLING WITH WEDGE FLEXIBLE ELEMENTS

Pneumatic torsional oscillations tuner with wedge elastic elements (fig. 1) consists of driving hub *(1)* and driven hub *(2)* with the supporting surface *(3)* and *(4)*, among which are air-spring units.

Each pneumatic flexible unit comprises of two flexible elements, namely a compressed flexible wedge element *(5)* and also extended wedge flexible element *(6)* Interconnection between wedge flexible elements *(5)* and *(6)* and thus between the compression spaces are provided by throttle openings *(7)*. If compression space of coupling is filled with gaseous medium through valve *(8)* to a predetermined pressure, this keeps the driving hub *(1)* against the driven hub *(2)* in the basic position. Transmitted oscillating load torque causes deflection of the driving body *(1)* against the driven body *(2)*. As a result, creates, as already mentioned, the compression of gaseous medium in compression chambers of wedge flexible elements *(5)* and *(6)* proportional to the load. Simultaneously the oscillating component of the torque load causes pulsing of the gaseous medium in the compression chamber of coupling, which forces a flow of medium through interconnecting throttle openings *(7)* proportional to oscillation.

The basic nature of pneumatic tuner's design is that the loading torque is transferred from the driving hub to the driven hub by compression space, which consists of air-filled flexible pneumatic units [4, 5].

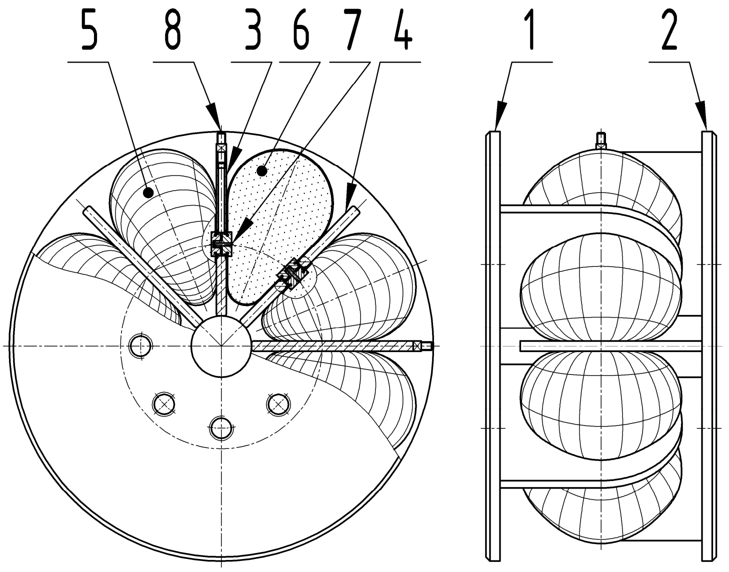

Fig. 1. Pneumatic tuner of torsional vibration with wedge flexible elements type 8 – 1/110 – T – C
Rys. 1. Tuner pneumatyczny drgań skrętnych z klinowymi elementami elastycznymi typ 8 – 1/110 – T – C

3. MATHEMATICAL MODEL OF PNEUMATIC COUPLING WITH WEDGE FLEXIBLE ELEMENTS

Pneumatic flexible shaft coupling with wedge elements shown on fig. 2 has been designed to have the same outer diameter as tangential coupling shown on fig. 7.

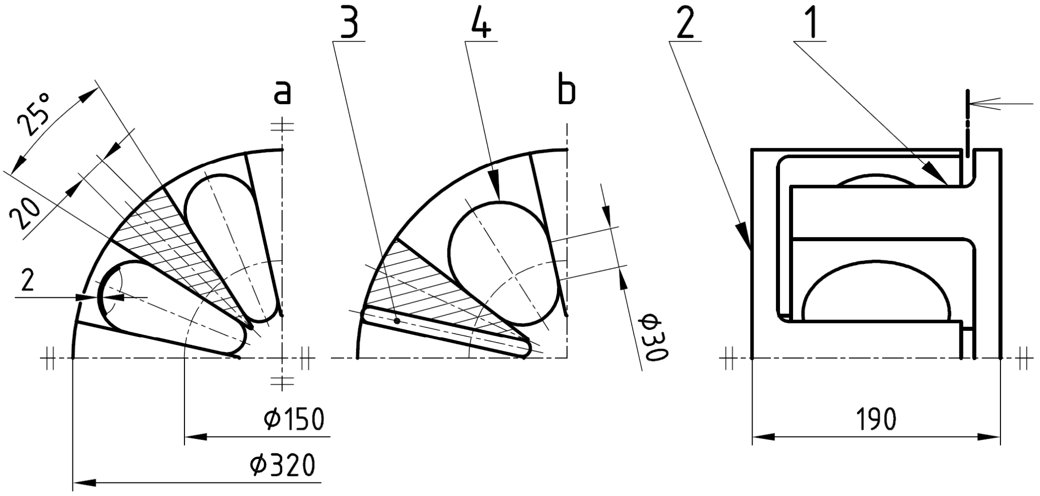

Fig. 2. Flexible shaft couplings with pneumatic wedge elements type 8 – 1/110 – T – C in neutral position (a) and by maximum twist angle (b)
Rys. 2. Elastyczne sprzęgło z elementami klinowymi typ 8 – 1/110 – T – C w pozycji neutralnej (a) oraz przy maksymalnym kącie skręcenia (b)

Since that this type of flexible tuner isn't currently manufactured, it was necessary to determine its basic characteristics theoretically based on a mathematical model. All dimensions necessary to calculate the static load characteristics are shown on fig. 2.

For static load characteristics computations the following conditions were considered:

- volume of the interconnecting and filling lines are neglected, as well as reduction of the tire volume by the flange of element,
- we considered only the gas volume enclosed inside the tire of element,
- compression volumes of wedge elements are interconnected,
- neutral surface of the tire lies in the middle of the tire‘s thickness,
- the length of meridial fibres of neutral surface was considered constant [5],
- the contact surface between elements and hubs is planar,
- in the part where flexible elements do not touch the supporting surfaces, meridial fibres of neutral surface are circular arcs [5], touching the equidistants of supporting surfaces,
- wedge elements has been designed so that contact surface between hub and maximally stretched element forms a circle with a diameter of *30 mm*,
- under static loading, the gas compresses and expands isothermally [5]
- equal absolute values of loading torque work and mechanical work of compressing air.

Static load characteristics of the flexible coupling determined from the mathematical model of flexible couplings is shown on fig. 3. From the static load characteristics then we determined the maximum torque of coupling M_M and then nominal torque M_N as third of maximum torque.

The courses of the nominal and maximum torque of coupling according to the initial pressure of gaseous medium in flexible elements are shown on fig. 4.

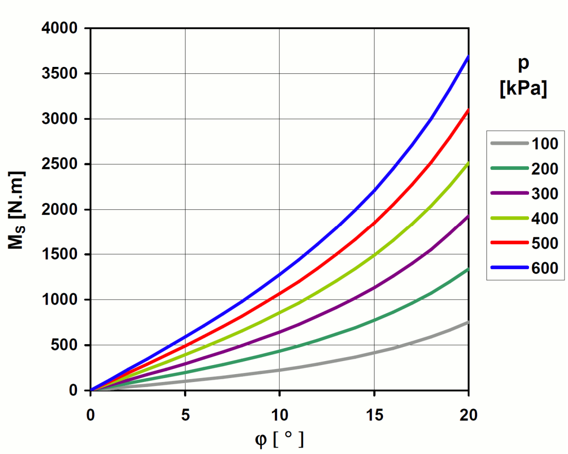

Fig. 3. Static load characteristics
Rys. 3. Charakterystyka obciążenia statycznego

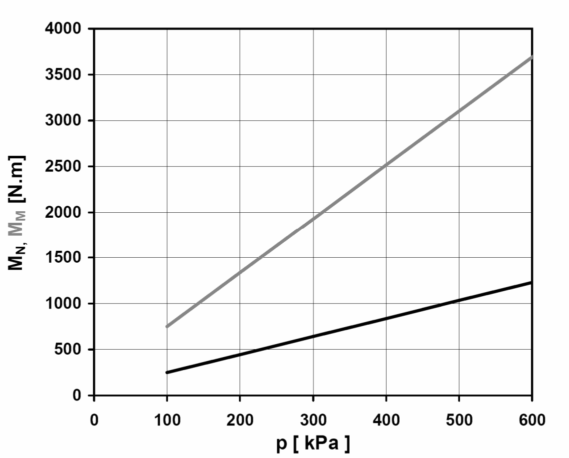

Fig. 4. Maximum torque and nominal torque curves dependent on initial pressure
Rys. 4. Maksymalny moment obrotowy i nominalna krzywa momentu obrotowego zależna od ciśnienia wyjściowego

From the static load characteristics then we have determined the maximum torque of coupling M_M and the nominal torque M_N. The courses of the nominal and maximum torque of coupling according to the initial pressure of gaseous medium in flexible elements are shown on fig. 4. The static torsional stiffness k_s by different initial pressures p were determined from tangents to static load characteristics. Consequently we determined the size of the dynamic torsional stiffness k_d (fig. 5) according to: $k_d=(1,05 + 4,14\cdot10^4)\cdot p$ [3]. Then we determined the size of nominal dynamic torsional stiffness k_{dN} depending on the initial pressure of the gaseous medium in the compression volume of pneumatic flexible elements (fig. 6). As the nominal stiffness value, we considered the stiffness for the coupling loaded with nominal torque. Finally, we determined the dependence of the relative torsional stiffness

$k_0 = k_{dN} / M_N$ on the initial pressure p, which characterizes the degree of "high-flexibility" of the given shaft coupling. As highly-flexible we consider the couplings which have the relative torsional stiffness value $k_0 < 10$ [3].

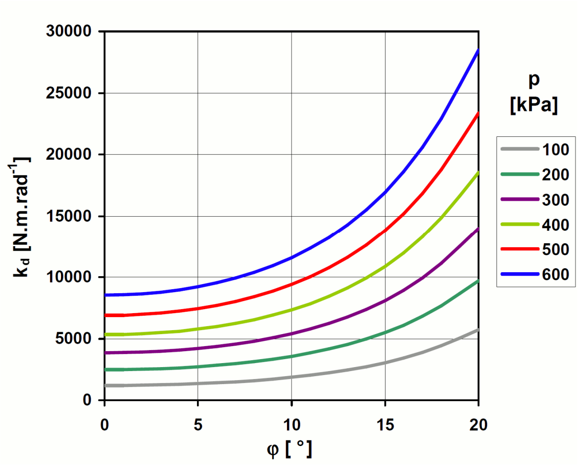

Fig. 5. Dynamic torsional stiffness curve dependent on twist angle
Rys. 5. Krzywa dynamicznej sztywności skrętnej zależna od ciśnienia

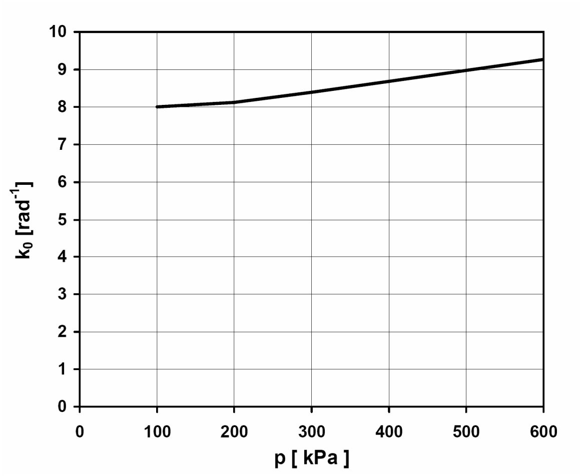

Fig. 6. Relative torsional stiffness curve dependent on pressure
Rys. 6. Względna krzywa sztywności skrętnej zależna od ciśnienia

4. PROPERTIES OF TANGENTIAL PNEUMATIC FLEXIBLE SHAFT COUPLING

It is a pneumatic flexible shaft couplings type *3 – 1/110 – T – C* produced by *FENA* company. For our contribution this coupling was chosen because of all currently produced of flexible pneumatic couplings types it can transfer the largest torque by the given external dimensions [2].This pneumatic flexible coupling shown on fig. 7 consists of driving hub *(1)* and driven hub *(2)*, connected with three pneumatic flexible elements *(4)*. Compression volumes of pneumatic flexible elements are interconnected with hoses *(3)*. Since the flexible elements of this coupling are always all pressed, or expanded so this pneumatic flexible coupling can transfer the loading torque only in one sense, in the direction of compression of flexible elements.

Properties of this flexible coupling have been experimentally determined at our department [13]. The measured static load characteristics of the flexible coupling is shown on fig. 8. From the static load characteristics then we have determined the maximum torque of coupling M_M and the nominal torque M_N. The courses of the nominal and maximum torque of coupling according to the initial pressure of gaseous medium in flexible elements are shown on fig. 9.

The curve of dynamic torsional stiffness k_d (fig. 10) by different initial pressures p, and the curve relative torsional stiffness k_0 is shown on fig. 11. depending on the initial pressure of the gaseous medium in the compression volume of pneumatic flexible elements are determined as for the pneumatic flexible coupling with wedge flexible elements.

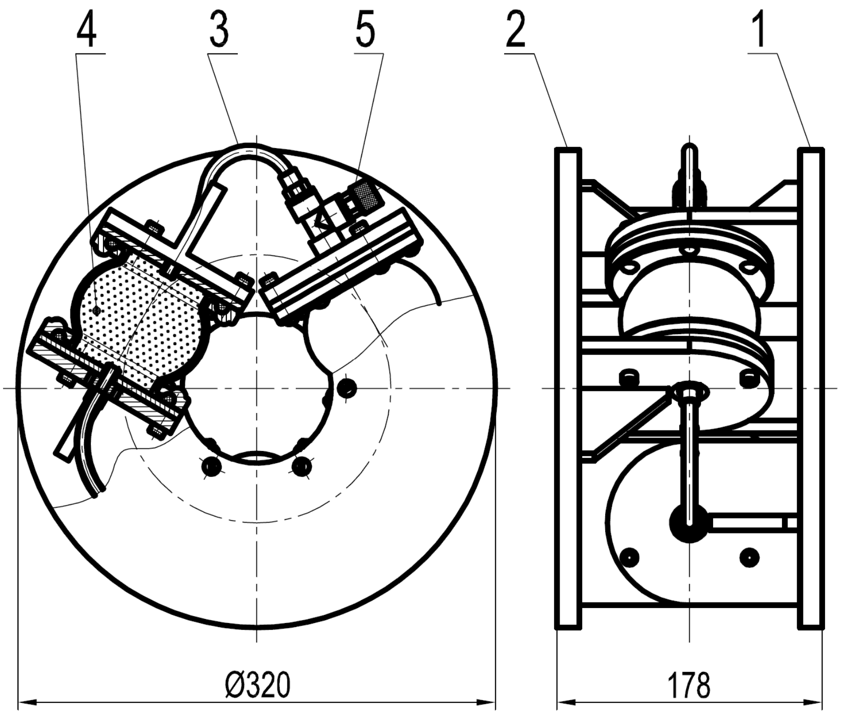

Fig. 7. Pneumatic flexible shaft couplings type 3 – 1/110 – T – C
Rys. 7. Elastyczne sprzęgło pneumatyczne typ 3 – 1/110 – T – C

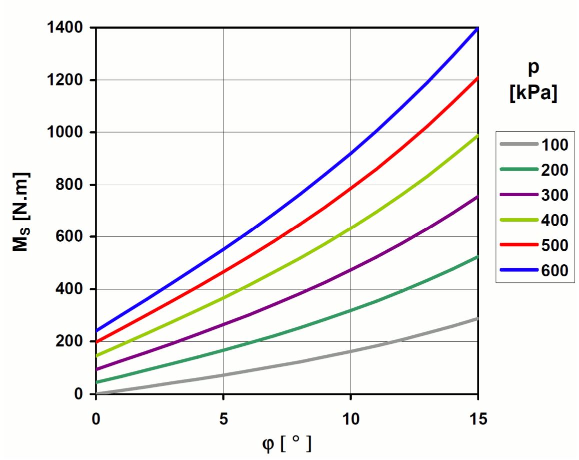

Fig. 8. Static load characteristics
Rys. 8. Charakterystyka obciążenia statycznego

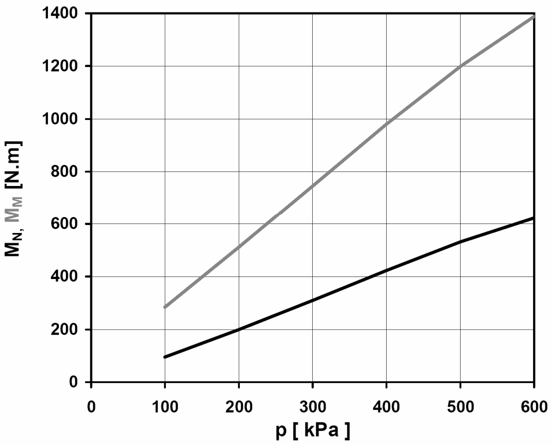

Fig. 9. Maximum torque and nominal torque curves dependent on initial pressure
Rys. 9. Maksymalny moment obrotowy i nominalna krzywa momentu obrotowego zależna od ciśnienia wyjściowego

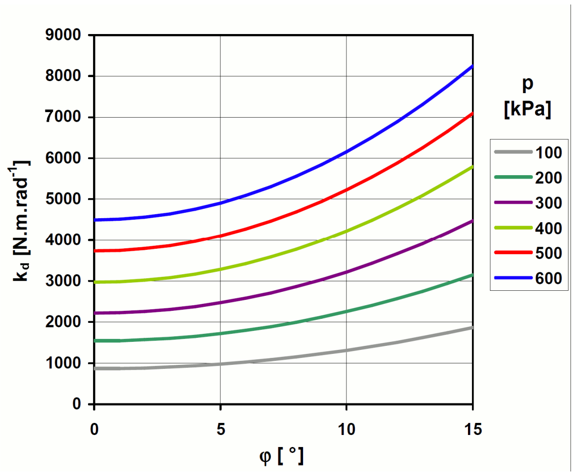

Fig. 10. Dynamic torsional stiffness curve dependent on twist angle
Rys. 10. Krzywa dynamicznej sztywności skrętnej zależna od ciśnienia

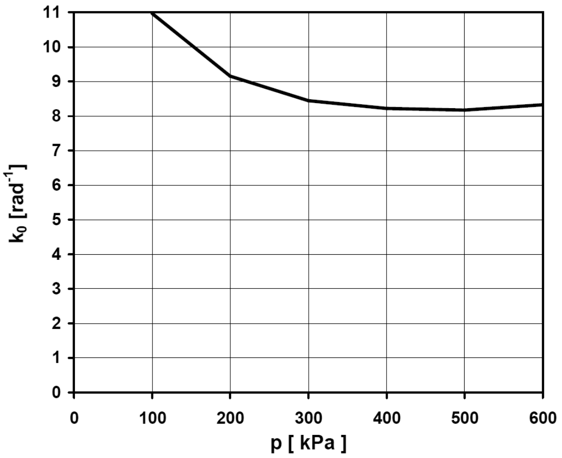

Fig. 11. Relative torsional stiffness curve dependent on pressure
Rys. 11. Względna krzywa sztywności skrętnej zależna od ciśnienia

5. CONCLUSION

With torque load transfer by pneumatic compression chamber of tuner filled with gaseous medium, we achieve compression of the medium proportional to load, by which is currently characterized the constant flexible load torque transmission in the system of driving and driven machine. Creating a throttle opening in the supporting surfaces between the compressing and simultaneously the expanding wedge flexible element, occurs the flow of gaseous medium characterized by a throttle work by oscillating torque load transmission. Throttle work arising from the flow of gaseous medium through throttle openings, is proportional to the damping work of pneumatic tuner.

The advantage of the solution is characterized by continuous flexible transmission of load torque with damping of torsional oscillations and torsional shocks in the system of driving and driven machine, and it is secured by the gaseous medium used as elastic material in the coupling. Gaseous media, throughout its lifetime isn’t subject to aging, resulting the pneumatic tuner doesn’t lose its initial positive dynamic properties, unlike the previously used flexible materials.

The new type of flexible coupling (fig. 1, fig. 2), thanks to the use of wedge flexible elements, we can use more flexible elements, and simultaneously increase the usage of space between the coupling hubs compared tangential pneumatic coupling (fig. 7).

Comparing the static load characteristics of tangential pneumatic flexible shaft couplings type *3 – 1/110 – T – C* (fig. 7) and tangential pneumatic flexible shaft coupling with wedge type elements *8 – 1/110 – T – C* (fig. 2) we can say that the coupling with wedge elements has a larger angle of twist (*20*°) than the tangential pneumatic coupling (*15*°).

The new type of pneumatic flexible coupling is also able to transfer by the same outer diameter about *2,6*-timest larger torque.

It follows that the use of wedge pneumatic flexible elements in a flexible coupling can provide great improvement in of their properties in terms of size of the transmitted torque and size reduction.

In conclusion, the design of the compression space of this air tuner ensures its inclusion to the category of highly flexible tuners, thus pneumatic tuners of torsional vibration with low torsional stiffness.

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