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Proceeding Paper

A Study of the Dynamic Stiffness of Flexible Couplings with a Rubber–Metal Element Type SEGME †

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Abstract: The dynamic characteristics of flexible couplings with a rubber–metal element type SEGME have been studied. The hardness of the rubber element of the SEGME 25 coupling is 53 Shore A, and that the SEGME 63 coupling is 73 Shore A, respectively. The experimental study was carried out in conditions of alignment of the connected shafts, and also at different levels of radial misalignment. The influence of an additional angular misalignment was investigated. The results show that, for this coupling type, the radial misalignments induce a downward nonlinear dependence on the dynamic stiffness. The presence of a small angular displacement in the shafts causes significant radial deformations. The sensitivity of the coupling decreases with the high hardness of the rubber element.

Keywords: rubber; flexible coupling; misalignments; dynamic stiffness

1. Introduction

The couplings [1] are used to connect shafts in different transmission systems for propellers [2], car engines, cranes, and many more. In some flexible coupling constructions, the presence of radial misalignment creates angular misalignment, which, in turn, affects the performance of the transmission [3]. Other researchers focused their efforts on the effect of the vibration spectra of rotating machinery depending on imbalance and parallel or angular misalignment [4]. They suggested a model for the simulation of the dynamic behaviors and vibration characteristics of a rotating system. A modified model of Davidenkov's hysteresis equation of state was synthesized in [5]. On this basis, analytical solutions have been obtained for the intensity of the amplitude of internal friction in solid bodies, as well as in polycrystalline metals with imperfect elasticity.

The material of most working parts of flexible couplings is rubber. It is characterized by nonlinear behavior according to load, misalignment, thermal conditions [6], and more. This is why studies are made to describe the best coupling selection for shaft system connections.

The object of this research are flexible couplings of the SEGME type, which are designed to transmit a nominal torque of T_n = 25 Nm and T_n = 63 Nm, respectively. Couplings are made according to [7]. The main dimensions of the semi-coupling with the flexible element are shown in Figure 1. The coupling consists of a metal flange with a hub (4), connected by means of bolts (5) to an outer ring (1), and a rubber flexible element (2) is vulcanized to it, which, in turn, is also vulcanized to the hub (3) for joining the shaft. The rubber element of the SEGME 25 coupling has a hardness of 53° Shore A, and, for SEGME, of 63–73° Shore A. Since couplings of this type were developed according to their role in creating a type order of the Bulgarian state standard, conclusions about the nature of the behavior of each of them under the same load conditions may apply to the entire group. This study was carried out in order to analyze the behavior of the coupling [8] under conditions of extreme misalignment. For a SEGME 25 coupling [7], there is an allowable radial misalignment of 0.3 mm and an allowable axial misalignment of 0.5 mm, and for

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SEGME 63, the same misalignments are provided, respectively, at 0.5 and 0.6 mm [9]. For both couplings, the allowable angular misalignment is 2°. For both couplings, the allowable angular misalignment is 2°. It is also accepted to investigate a coupling with a real greater stiffness [10,11] in the rubber element, since, for some mechanisms, a more accurate positioning of the driven shaft is important. Regardless of the fact that bellows couplings have a sufficiently high resistance to torque and bending, research [5] has been carried out on the appearance of additional load in the presence of eccentricity between the shafts being joined. Small radial deviations have been found to induce additional radial forces that can reach base load levels.

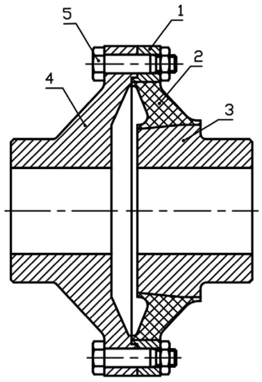


Figure 1. Basic construction of the coupling SEGME type.

The coupling consists of a metal ring (1), a vulcanized rubber element (2) to it and to metal hub (3). The metal disc (4) is connected with a ring (1) with bolts (5).

On a coupling-test stand [12], the general appearance of which is shown in Figure 2, measurements were carried out to experimentally determine the characteristic $T = T(\varphi)$ of the couplings.

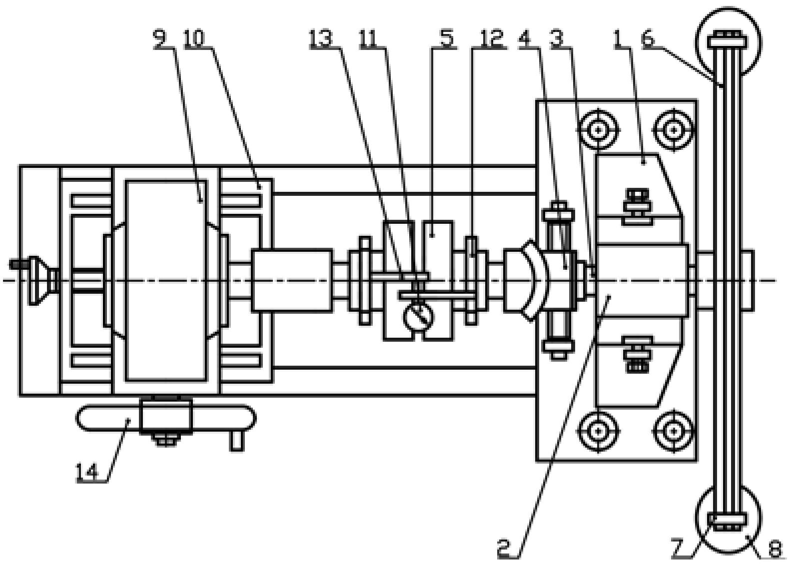


Figure 2. A flexible coupling-test stand.

A bearing box (2) is mounted on a plate (1), in which the shaft (3) rotates on rolling bearings, on one end of which, by means of a sleeve coupling (4), one half of the coupling under study (5) is mounted. On the other end of the shaft (3), a two-arm bridge (6) is fixed with the hangers (7) on which the weights (8) are placed. The other half of the coupling is connected to the output shaft of the worm gear reducer (9), which ensures its immobility. The grooved plate (10) allows axial movement of the reducer (9), and a flywheel (14) mounted on the input shaft of the reducer (9) adjusts the angular position of the contact arm (13) relative to the indicator. The linear relative displacement of the driving to the driven shaft under load is determined by an indicator clock (11) mounted on the bracket (12).

In studies of companies that produce flexible couplings, a methodology for determining the dynamic stiffness $C_{Tdyn} = \frac{T_{el}}{\varphi_w}$ (as in [6,13]) is recommended. It is recommended that the dynamic stiffness be determined according to Figure 3. T_W and φ_w denote the amplitude changes in the torque and the angular deformation of the flexible element. The dynamic stiffness is determined based on 0.8 of the variable components of the load, i.e., $T_{el} = 0.8 \times T_W$. Usually, the amplitude load is taken within the limits of 20–25% of the nominal. For the coupling with T_n = 25 Nm, variation limits of 16 to 31 Nm are accepted, and, for the coupling with T_n = 63 Nm, the limits are from 40 to 80 Nm.

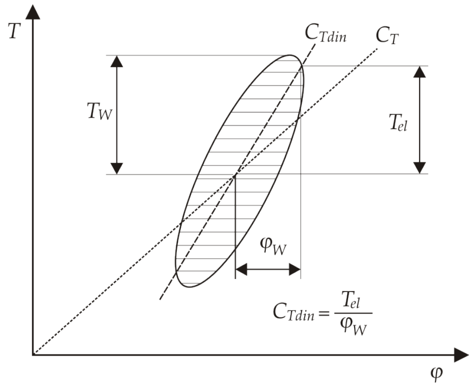
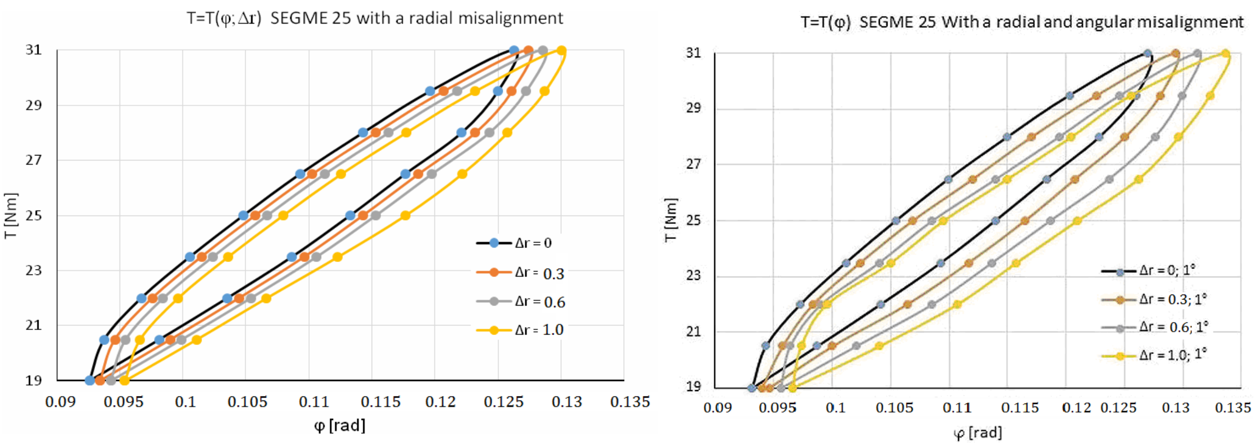


Figure 3. Scheme for determining the dynamic stiffness.

2. Methodology

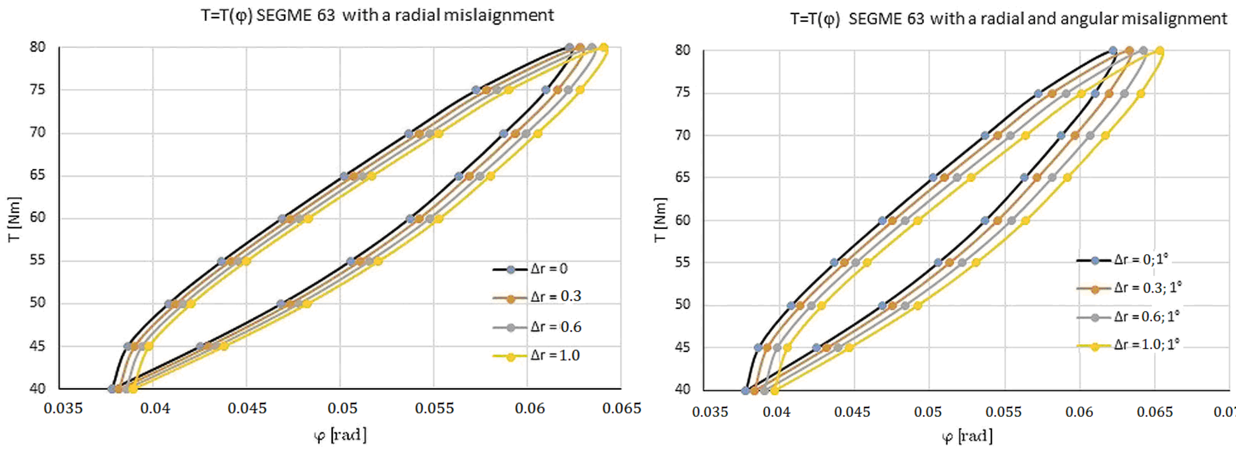
The characteristics of the SEGME 25 coupling, under conditions of shaft alignment and radial misalignment, are taken as follows: Δr = 0; Δr = 0.3; Δr = 0.6; and Δr = 1.0 mm. The characteristics are shown in Figure 4a. At the same radial misalignments, the characteristic of the coupling was taken, in the presence of an angular misalignment from the axis of 1°. The results of this study are graphically depicted in Figure 4b.



(**a**) (**b**)

Figure 4. Characteristics of SEGME 25 coupling in case of (**a**) radial misalignment and (**b**) radial and angular misalignment.

Analogous studies were also carried out for the SEGME 63 coupling. The results for the characteristics, at the same values of radial misalignment (0.3 mm; 0.6 mm; and 1 mm), are graphically shown in Figure 5a. Figure 5b shows the graph of the coupling at the above radial misalignment and an additional angular misalignment of 1°.



(**a**) (**b**)

Figure 5. Characteristics of SEGME 63 coupling in case of (**a**) radial misalignment and (**b**) radial and angular misalignment.

3. Results

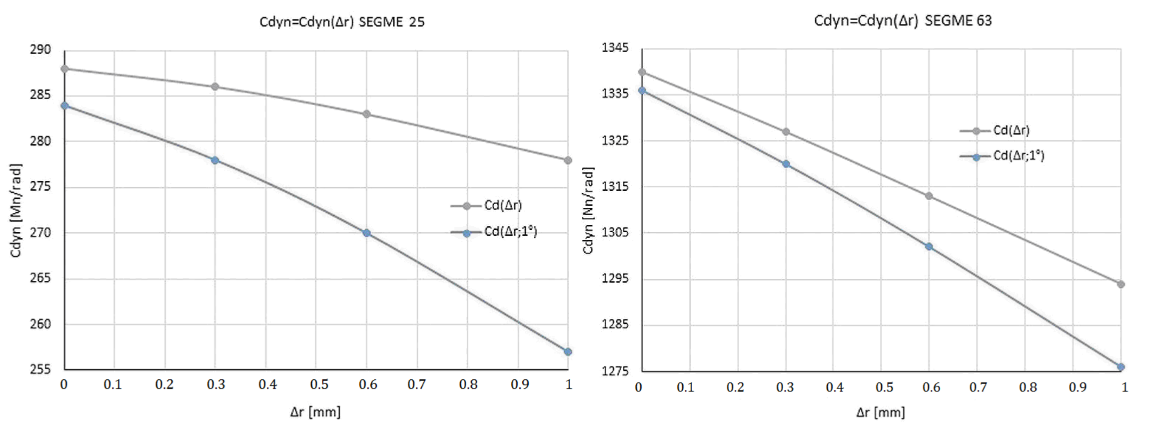
Based on the recorded dynamic characteristics, we determined the angular deformation φ_w corresponding to T_{el}. The dynamic stiffness is determined by Equation (1):

$$C_{dyn} = T_{el} / \varphi_W. \quad (1)$$

The results of the obtained values for the dynamic stiffness of the SEGME 25 coupling in the presence of only radial misalignment (0.3 mm; 0.6 mm; and 1 mm), and also with an additional angular misalignment of 1°, are shown in Table 1 and are graphically illustrated in Figure 6a.

Table 1. Dynamic stiffness of a SEGME 25 coupling with radial and angular misalignment.

Misalignments	Δr = 0	Δr = 0.3	Δr = 0.6	Δr = 1.0
T_W [Nm]	4.5	4.5	4.5	4.5
φ_w [rad]	0.015625	0.015734	0.015901	0.016187
C_{dyn} [Nm/rad]	288	286	283	278
Misalignments	Δr = 0; 1°	Δr = 0.3; 1°	Δr = 0.6; 1°	Δr = 1.0; 1°
T_W [Nm]	4.5	4.5	4.5	4.5
φ_w [rad]	0.015845	0.016187	0.016667	0.01751
C_{dyn} [Nm/rad]	284	278	270	257



(**a**) (**b**)

Figure 6. Variation in the dynamic stiffness of couplings in the presence of radial and angular misalignment as follows: (**a**) for SEGME 25 and (**b**) for SEGME 63.

The determined dynamic stiffness values for the SEGME 63 coupling in the presence of radial misalignment (0.3 mm; 0.6 mm; and 1 mm) and angular misalignment of 1° are shown in Table 2.

Table 2. Dynamic stiffness of a SEGME 63 coupling with radial and angular misalignment.

Misalignments	Δr = 0	Δr = 0.3	Δr = 0.6	Δr = 1.0
T_W [Nm]	30	30	30	30
φ_w [rad]	0.022392	0.022616	0.022848	0.023061
C_{dyn} [Nm/rad]	1340	1327	1313	1294
Misalignments	Δr = 0; 1°	Δr = 0.3; 1°	Δr = 0.6; 1°	Δr = 1.0; 1°
T_W [Nm]	30	30	30	30
φ_w [rad]	0.022455	0.022727	0.023041	0.023511
C_{dyn} [Nm/rad]	1336	1320	1302	1276

The dynamic stiffness variation in a SEGME 63 coupling with only radial misalignment, and also with radial and angular misalignment, is shown in Figure 6b.

Undoubtedly, for both couplings, the dynamic stiffness decreases and the nature of the curve is non-linear. For convenience, it is considered necessary to introduce relative stiffness change criteria. We introduce a criterion K_r, which shows the influence of the radial misalignment on the dynamic stiffness and is determined by Equation (2):

$$K_r = C_{dyn}(\Delta r)/C_{dyn}(\Delta r = 0), \tag{2}$$

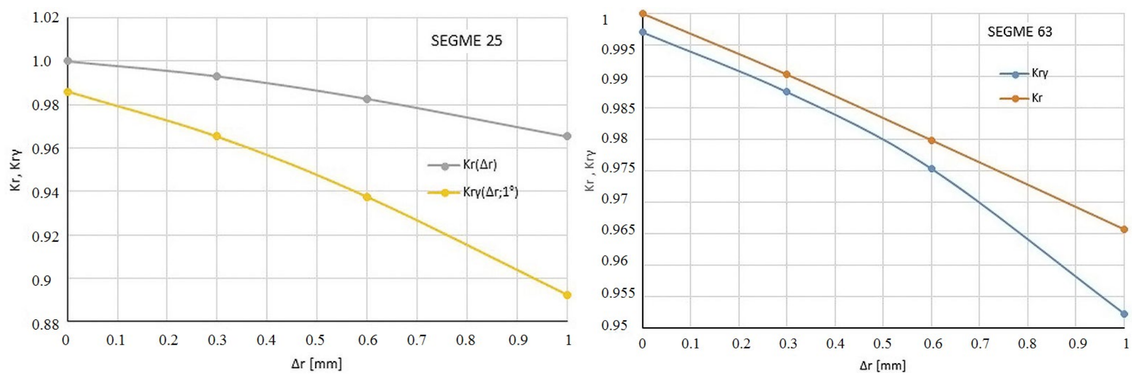
where C_{dyn}(Δr) represents the stiffness of the flexible element at the corresponding radial misalignment. C_{dyn}(Δr = 0) is the stiffness of the flexible element for the coaxial mounting of the joined shafts.

Similarly, a criterion $K_{r\gamma}$, is introduced, which is determined by Equation (3) and reflects the influence of the radial misalignment in the presence of an additional angular misalignment of 1°.

$$K_{r\gamma} = C_{dyn}(\Delta r; 1^\circ)/C_{dyn}(\Delta r = 0), \tag{3}$$

where C_{dyn}(Δr; 1°) represents the dynamic stiffness in the presence of radial and angular misalignment.

Figure 7a shows the relative change in stiffness for the SEGME 25 coupling and Figure 7b for the SEGME 63 coupling.



(**a**) (**b**)

Figure 7. Change in criteria K_r and $K_{r\gamma}$: (**a**) for a SEGME 25 coupling; (**b**) for a SEGME 63 coupling.

In this publication [14,15], a study of the dynamic stiffness of a bolted coupling and a flexible intermediate element in the presence of radial misalignment was carried out. Typical for constructions where the load induces normal stresses in the flexible element, the dynamic stiffness increases with increasing load. In the mounting with radial misalignment, an additional radial force is formed, which causes an increase in the dynamic stiffness compared to the experimental results for coaxial shafts.

4. Conclusions

With an increase in the radial misalignment up to 1 mm, which is significantly above the prescribed allowable values in the standard, the stiffness reduction is non-linear in nature; for the SEGME 25 coupling, it is 3.47% and for the SEGME 63 coupling, it is 3.19%.

For this coupling design, the large difference in rubber hardness from 53 to 73 Shore A does not have a very significant effect on the dynamic stiffness, as the difference in change at the same radial misalignment is only 0.28%.

In the presence of radial and angular misalignment, the available stiffness of the SEGME 63 coupling decreases by only 4.47%.

When making couplings of this type with a greater stiffness or when the rubber is aging, their reduced sensitivity should be taken into account compared to their dynamic stiffness.

In the presence of an angular misalignment of 1° with an increase in radial misalignment up to 1 mm, the dynamic stiffness decreases nonlinearly to 10.8%, which is an indicator of increased deformability and damping ability.

With a significant reduction in dynamic stiffness and more intense internal friction, it is desirable to analyze the heat balance of the rubber element to ensure the necessary service life.

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Mehmedov, I.; Hristov, H.; Tenev, S. Thermal Condition Modeling of a Modified Engine Mount. In Proceedings of the Technical and Scientific Conference—Transport, Ecology—Sustainable Development EKO Varna 2021, AIP Conference Proceedings, Varna, Bulgaria, 13–15 May 2021; Volume 2439, p. 6, ISBN 978-0-7354-4140-8. https://doi.org/10.1063/5.0071562.

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