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Variation of static parameters of cooperation in axisymmetric connection

Marian Dudziak[a], Grzegorz Domek[b], Andrzej Kołodziej[a,]*

[a]Technical Institute, Higher Vocational State School in Kalisz, Kalisz, 62-800, Poland
[b]Faculty of Mathematics, Physics&Technical Sciences, Kazimierz Wielki University in Bydgoszcz, Bydgoszcz, 85-092 Poland

Abstract

During designing the profiles of construction elements are defined as a perfect shape of line, circle or cylinder etc. Due to the production process the elements macrogeometry can be distorted in many ways. The direct measure of deviation of the real shape of a part from its nominal shape (the designed one) is a form deviation. If any additional restrictions concerning form deviations are not given in a production drawing, then the influence of these form deviations should be taken into account in allowable area of dimensions variation which is defined with tolerance zone. High values of rectilinearity deviations of a generating line, roundness deviations and cylindricity deviations can be a reason of changes of the assumed functional requirements. On the basis of saddleback shafts with oval cross-sections manufactured in three accuracy classes, i.e. IT4, IT6 and IT9, the authors have presented the variation of static parameters of cooperation. The shafts were coupled with sleeves (with a nominal circular cross-section) on experimental test stand. The obtained values of friction forces and moments of friction which are necessary to disassemble the connection were compared with the results of FEM numerical analyses. The applied method also allowed to determine the values of contact pressures in a connection.

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Keywords: form deviations; static analysis with the FEM; axisymmetrical connections

* Corresponding author. Tel.: +48 62-767-9685; fax: +48 62-767-9581.
E-mail address: a.kolodziej@ip.pwsz.kalisz.pl

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1. Introduction

During designing and preparing of technical documentation the profiles of construction elements are defined as a perfect geometrical profiles of e.g. straight line, circle or cylinder. As a result of production process one can get the elements with distorted macrogeometry in a different ways [1–3]. The selected types of deformation of the profile are presented for the cylindrical element. Rectilinearity of the generating line of the cylinder (Fig. 1 – concavity, convexity, uniformity), cross-section profile (Fig. 2 – oval, three-angular, multi-angular) and the entire profile of the cylinder (Fig. 3) were distorted. The real number of permutations of geometrical forms of distortions is unlimited.

Direct size of real deviation of the element profile from its nominal shape (the designed one) is form deviation. For each case this deviation should be kept in the area limited by two ideal lines or surfaces defined by the tolerance.

The division and graphical denotation of the tolerance of the cylindrical elements are defined in standard PN-EN ISO 1101:2006.

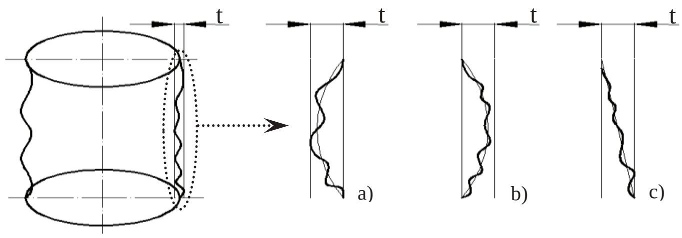

Fig. 1. Form tolerance – rectilinearity of the generating line, t – tolerance: a) concavity, b) convexity, c) uniformity.

Construction elements are usually applied for assembling together. Hence, the designer defines the application and character of cooperation by the allowable area of variation of the dimensions, i.e. grade of tolerance. If any additional restrictions for form deviations are not defined in technical documentation, then these form deviations should be kept in the allowable area of dimensions variation which is defined by the tolerance zone. However, for many cases this approach is wrong. High values of deviations of rectilinearity of the generating line, roundness and cylindricity can be a reason of default of assumed functional requirements. These deviations have a special influence on the operation parameters during high speeds and powers. For constructional elements in engines and power transmission systems these deviations are the reason of fast wear, seizing the cylinder bearing surfaces, excessive consumption of oil and fuel or excessive exhaust gas emission. Therefore, the authors are interested in the influence of variable values of form deviations on the static and dynamic properties of the connection.

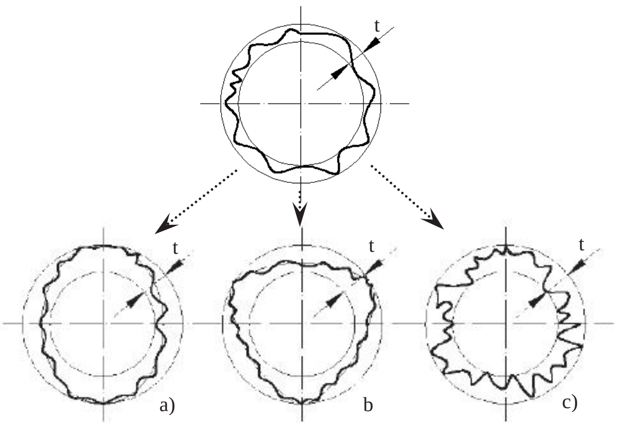

Fig. 2. Form tolerance – cross-section profile, t – tolerance: a) oval, b) three-angular, c) multi-angular.

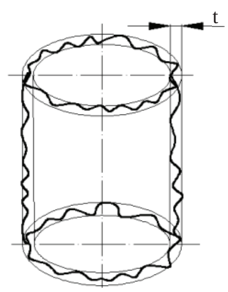

Fig. 3. Form tolerance – cylindricity, t – tolerance.

2. Experimental investigations

Experimental investigations have been conducted for special cylinders with the variable profile geometry in longitudinal and transverse sections. The details concerning the examined elements and methodology of investigations are presented in works [4–6].

3. Numerical investigations

The hole in the hub has been assumed as nominally round with diameter ø19 mm (Fig. 4). The shafts with oval cross-sections and tolerances $T_w = 6$ μm (Fig. 4a), $T_w = 13$ μm (Fig. 4b) and $T_w = 52$ μm (Fig. 4c) have been analysed. The aim of the investigations was the determination of the required value of force which allows to disassemble the connection (friction force – F_{fr}). To realize this aim, it was necessary to calculate the values of reactions at contact points between the shafts and hub and value of coefficient of friction (it was experimentally calculated $\mu = 0.12$). The values of friction force and geometrical features of connection allowed to determine the value of moment of friction which is required to disassemble the connection (T_{fr} – moment of friction).

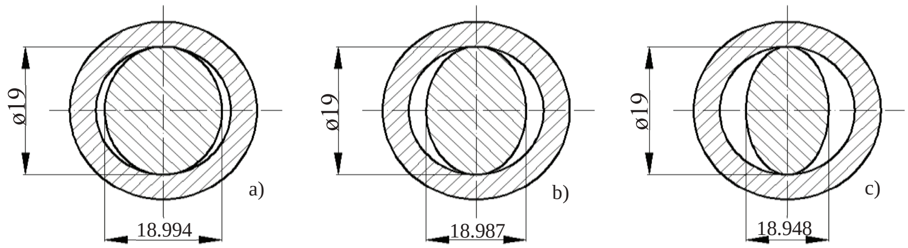

Fig. 4. Analysed cases of axisymmetric connection: a) $T_w = 6$ μm, b) $T_w = 13$ μm, $T_w = 52$ μm.

4. Numerical model

Numerical model was built in analogical way as in works [4–6]. Fig. 5 presents the numerical model with the generated mesh (2D elements – CPS4R). The shaft is placed in the hub hole which was modelled as a rigid surface. Fine mesh was generated at contact points (Fig. 5). Contact between the shaft and hole was defined with the value of coefficient of friction $\mu = 0.12$. The connection was loaded with the gravitational force for the half of the shaft weight [4–6]. The surface of the hub hole has not got any degrees of freedom [7–9].

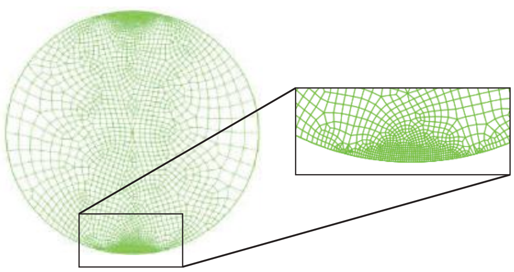

Fig. 5. Numerical model with mesh.

Three angular positions of the shaft in the hole have been investigated for every case of tolerance. First position was defined as position 0°. It corresponds to support of the shaft on the hole at the bottom point (Fig. 5). Material properties: Young's modulus $E = 210$ GPa, Poisson ration $\nu = 0.3$, steel density 7830 kg.m^{-3}.

5. Results of numerical investigations

Numerical investigations allowed to determine the state of reduces stresses (Mises stresses) and values of contact pressures at the contact points. Additionally, it was possible to determine the values of reaction forces and friction forces and moments of frictions required to disassemble the connection.

5.1. Position 0°

Fig. 6 presents the results of calculation for angular position 0° for the tolerance IT9. It also shows the values of reaction forces at contact zones between the shaft and hub. Fig. 7 presents the values of contact pressures. Table 1 presents the values of reactions in contact zones for the other tolerances.

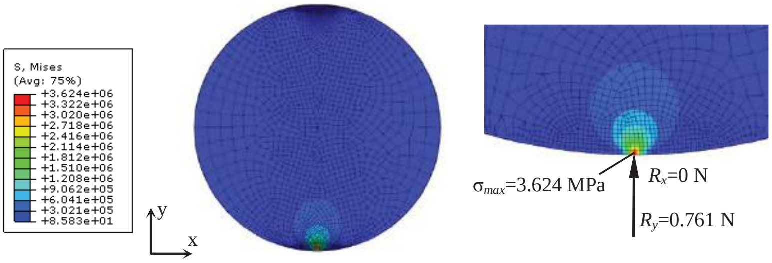

Fig. 6. Spots of the concentration of the reduced stresses (Mises stresses) and reaction components at the supports of the shaft for the angular position 0°.

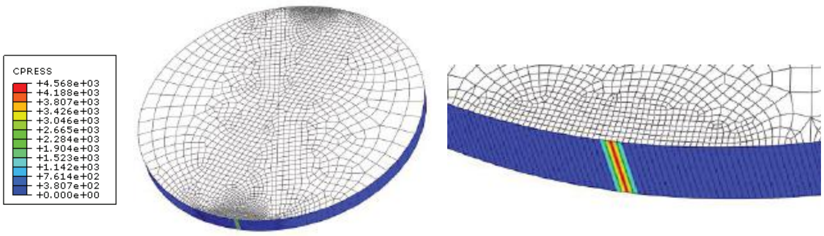

Fig. 7. The values and spots of the concentration of contact pressures for the angular position 0°.

5.2. Position 45°

Fig. 8 presents the results of calculation for angular position 45° for the tolerance IT9. It also shows the values of reaction forces at contact zones between the shaft and hub. Fig. 9 presents the values of contact pressures.

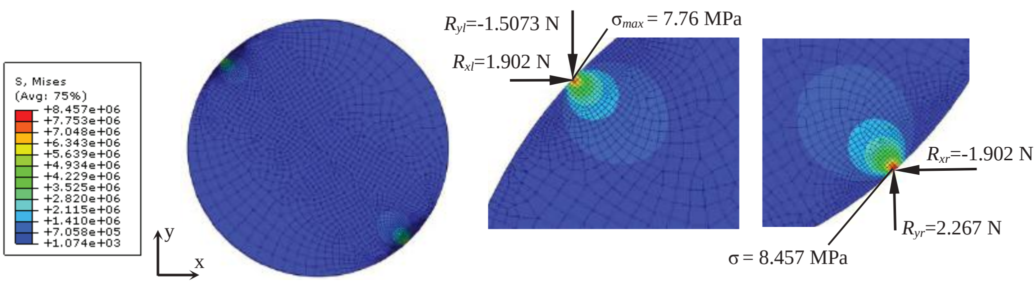

Fig. 8. Spots of the concentration of the reduced stresses (Mises stresses) and reaction components at the supports of the shaft for the angular position 45°.

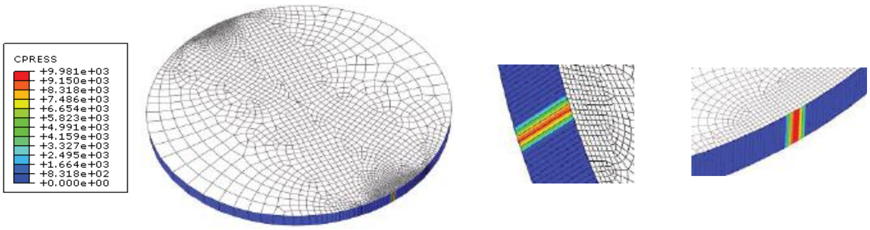

Fig. 9. The values and spots of the concentration of contact pressures for the angular position 45°.

5.3. Position 90°

Fig. 10 presents the results of calculation for angular position 90° for the tolerance IT9. It also shows the values of reaction forces at contact zones between the shaft and hub. Fig. 11 presents the values of contact pressures.

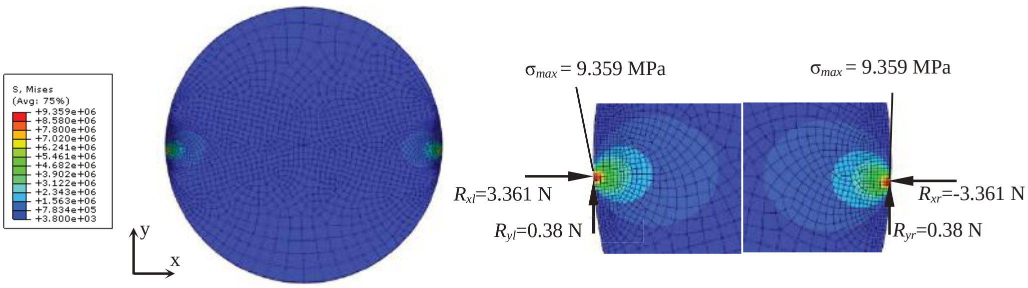

Fig. 10. Spots of the concentration of the reduced stresses (Mises stresses) and reaction components at the supports of the shaft for the angular position 90°.

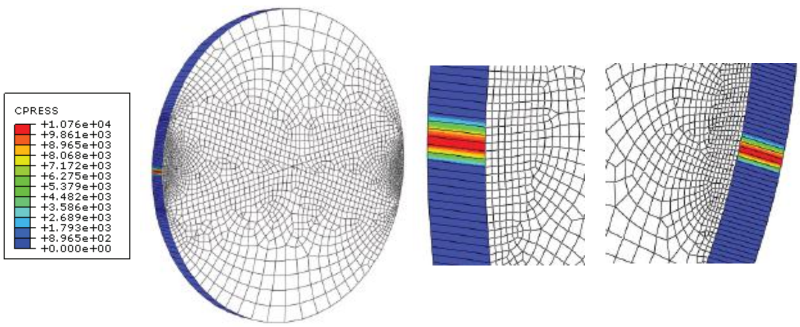

Fig. 11. The values and spots of the concentration of contact pressures for the angular position 90°.

Table 1 presents the list of component reactions, resultant reactions, forces of friction and moments of friction for three tolerances: IT4, IT6, IT9. Fig. 12 shows the graphic representation of the reduced stresses (Mises stresses) and contact pressures in the function of the angular position of the shaft for three tolerances.

Table 1. The list of the results of reactions and forces of friction and moments of friction for different angular positions of the shaft with a oval cross-section for three tolerances: IT4, IT6, IT9.

	The position of the shaft axis								
	IT4			IT6			IT9		
	0º	45º	90º	0º	45º	90º	0º	45º	90º
Horizontal reaction R_{xl} (N)	0	1.6518	2.9363	0	1.851	3.231	0	1.902	3.361
Horizontal reaction R_{xr} (N)	0	-1.6518	-2.9363	0	-1.851	-3.231	0	-1.902	-3.361
(R_{xl} + R_{xr}) (N)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vertical reaction R_{yl} (N)	--------	-1.3077	0.38	--------	-1.428	0.38	--------	-1.507	0.38
Vertical reaction R_{yr} (N)	--------	2.067	0.38	--------	2.193	0.38	--------	2.267	0.38
(R_{yl} + R_{yr}) (N)	0.761	0.7613	0.76	0,761	0.7649	0.76	0,761	0.7597	0.76
Resultant reaction R_l (N)	--------	2.1067	2.96079	--------	2.3378	3.2532	--------	2.4266	3.3824
Resultant reaction R_r (N)	--------	2.6459	2.96079	--------	2.8697	3.2532	--------	2.9592	3.3824
R_l + R_r (N)	0.761	4.7527	5.92157	0.761	5.2075	6.5065	0.761	5.3858	6.7648
Force of friction F_{fr} (N)	0.18264	1.1406	1.42118	0.18264	1.2498	1.5615	0.18264	1.2926	1.6235
Moment of friction T_{fr} (Nm)	0.00173	0.0108	0.0135	0.00173	0.0118	0.0148	0.00173	0.0122	0.0153

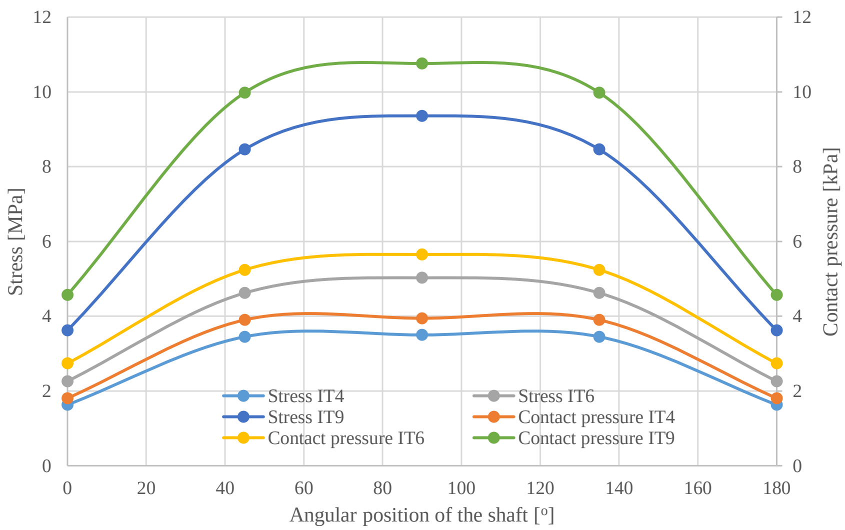

Fig. 12. Reduced stresses (Mises stresses) and contact pressures in the function of the angular position of the shaft.

6. Conclusions

The investigation results of variation of values of the friction force and moment of friction which are required to disassemble the axisymmetric connection with oval, three-angular and four-angular shafts are presented in works [4–6]. The authors have showed that if we increase the lobing, then the lower differences of values of friction force and moment of friction in function of angular position of the shaft in the hub exist. Additionally, it was proved that the odd lobing has an advantage over even lobing (oval, four-angular). In case of the examined shaft with three-angular cross-section the inequality of the value of friction force and moment of friction was definitely lower. On the basis of the analysis of the presented results in this work one can conclude that the increase of tolerance value has an unquestionable influence on the increase of the values of the cooperation parameters of the analysed connection. This fact is reflected for the values of reduced stresses (Mises stresses), contact pressures, friction forces and moments of friction.

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