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CONSIDERATIONS REGARDING LINKAGES USED FOR SHAFTS COUPLING

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ABSTRACT

The problem of shafts coupling having crossed axes using linkages is treated in the present work. The degree of freedom of the coupling link is found and the conclusion drawn is that a correct coupling can be structurally achieved using a bicardanic telescopic linkage.

The practical solution for the coupling link encounters problems concerning the prismatic joints of the linkage. In this joint, the self-locking may occur as a result of the end effects phenomena. Several practical solutions are considered and the optimum solution is found to be given by the shaft and splined bushes assembly. The main advantage of the transmission consists in the fact that for the given data for the axes position and an imposed input motion, the output motion can be precisely found.

Keywords: shafts coupling, bicardanic linkage, end effects

1. INTRODUCTION

In technical applications, the problem of coupling a mechanism and a rotation motor in assembling a machine is seldom met [1]. In theory, the relative position of the two axes can be a random one as these axes crosse, their relative position being characterized by the angle between axes and the length of common normal between them [2]. In the situations when the angle and/or the common normal have reduced values, the axes being in the domain when the co-axial constraint is applied, one of the technical coupling methods consists in using elastic coupling elements. In theory, these elements have an infinity of degrees of freedom and, therefore, they present the advantage of solving the misalignment between the two shafts and can transmit the torque from the motor element to the driven element [3]. The disadvantage of this technical solution consists in strictly constraining the coaxial deviation of the two shafts.

A general solution that will be subsequently presented consists in using a kinematical chain completed by rigid elements amongst cylindrical lower pairs ensue – including the particular situations of the prismatic pairs or the rotation pairs.

The coupling using gears for transmitting the relative motion between the two elements ensures a very good quality of the motion transmission between the axes, but it requires strict tolerances of the deviations from the nominal position of the axes. In addition, the gears are very expensive machine parts and, as they transmit the motion via high pairs, in which the contact pressures are considerable. In conclusion, in the case when the relative position between the axes transmitting the motion presents considerable deviations from the nominal position and a rigorously constant transmission ratio is not essential, one of the enhanced solutions is using the kinematic chains with lower pairs.

2. ACTUAL PROBLEM AND PROPOSED SOLUTION

Fig. 1. GUNT WP300 universal material tester [4]

Furthermore, a genuine example is presented. The universal material tester machine GUNT WP 300, [4] (Fig. 1), is a didactical machine and is provided with a hand operated loading system that presents the disadvantage that the load is not continuously increasing, as it can be seen in Fig. 2, where such a loading diagram is presented. The saw-tooth pattern is caused by the impossibility of ensuring the continuity by a manual action of the handle that, rotating the screw, acts upon the hydraulic system. To avoid this inconvenience, the replacement of the manual operating system by an electrical one was proposed, specifically, the driving screw to be operated by a direct current motor. The coupling may be made using rigid elements [5-7] when the alignment of the shafts is well acquired.

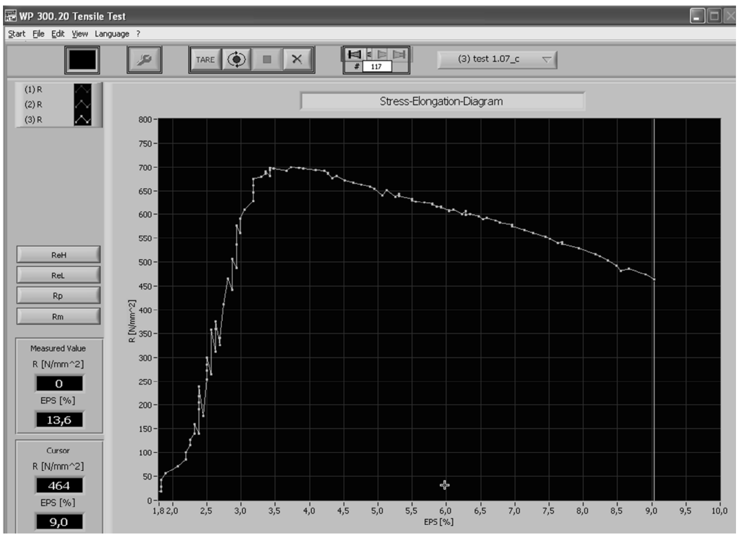

Fig. 2. Traction stress-strain diagram obtained on GUNT WP300 machine

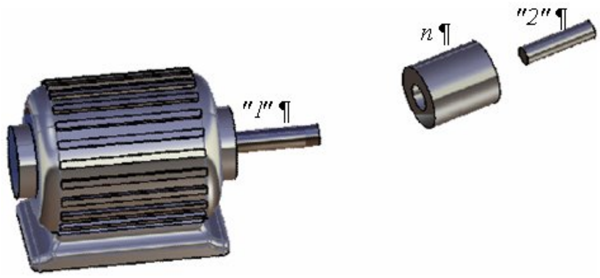

Fig. 3. The d.c. motor, coupling shaft and a generic element of the coupling chain

3. THEORETICAL CONSIDERATIONS

It is assumed that for coupling the two shafts, a kinematic chain consisting of rigid elements jointed by kinematic pairs of 5-th class (revolute or prismatic pair) is used. It is considered that to the driving shaft denoted "1" is attached an open kinematic chain made of n elements and p lower pairs, the first element of the chain being linked to the blocked driving element. For a most general coupling case, the final element of the coupling chain must have 6 degrees of freedom:

$$L = 6 \cdot n - 5 \cdot p = 6 . \tag{1}$$

The equation (1) is an equation in integer numbers, having the simplest non-banal solution:

$$n = 6,\ p = 6 . \tag{2}$$

If the structural condition (2) is fulfilled, the last element from the coupling chain has six degrees of freedom and, consequently, it can take any spatial orientation. Therefore, the bushing "n" can be attached to the shaft "2" at any point and randomly oriented with respect to it, allowing for correct coupling of the two shafts. The actual solution for coupling the two shafts is based on connecting two cardanic couplings into a bicardanic telescopic coupling [8, 9], as shown in Fig. 4.

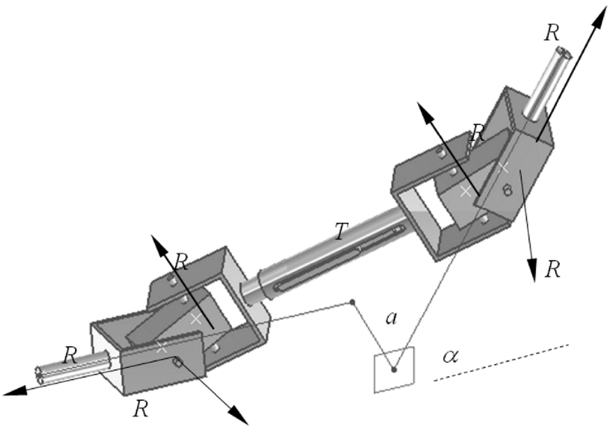

Fig. 4. Kinematic coupling chain

Among the pairs of the kinematic chain, the sliding pair is the most complicated. In this pair, the emergence of self-locking is rather possible [10]. It is interesting to notice that in living organisms, sliding couplings are hardly ever met. As an example, Figure 6 presents a model of the human body, where only spherical and revolute pairs were used, as the self-locking risk is very reduced in these pairs.

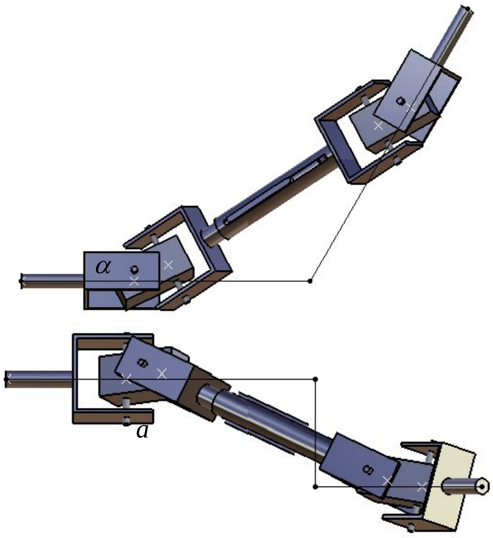

Fig. 5. The crossing angle and common normal of coupling chain at actual size

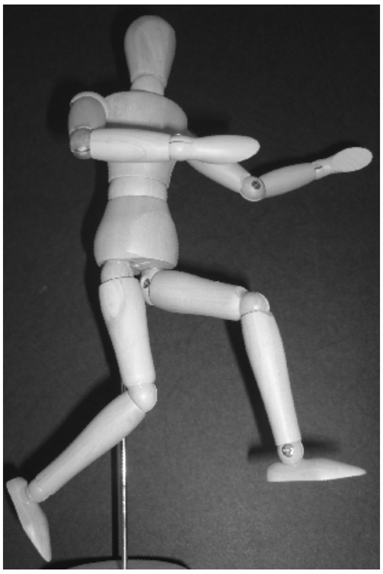

Fig. 6. Model of the human body with spherical and revolute pairs

4. ANALYSIS OF PROPOSED SOLUTION

Furthermore, three variants of the sliding pairs are next analyzed, in order to choose the most adequate one. The prismatic pair with square cross-section is modelled by FEA and the displacements are presented in Figure 7a while the stresses are shown in Figure 7b.

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The analysis for the hexagonal cross section is presented in Figures 8-9 and the symmetrical wedging assembly is analyzed and presented in Figures 10-12.

As it can be seen (Fig. 9a), in the section where the contact shaft-bushing is initiated, the stresses present maximum values in the region of hexagonal shaft edges while in section $"B"$, at the end of the contact (fig. 9.b), the equivalent stress maxima are considerably smaller and occur on shaft faces. Therefore, the self-locking is expected to occur in $"A"$ section.

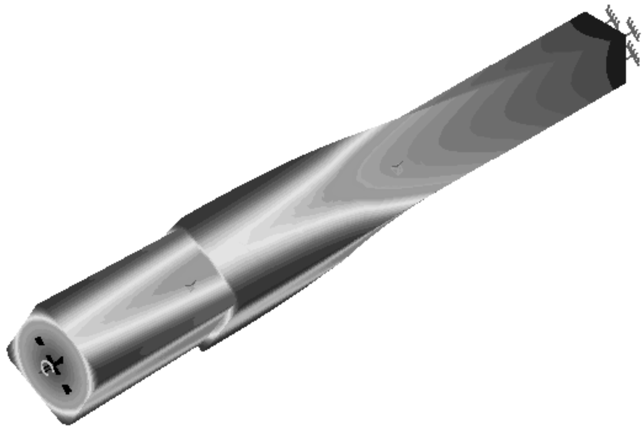

Fig. 7a. The displacements in the prismatic pair with a square cross-section

Fig. 7b. Von Mises stresses in the prismatic pair with a square cross-section

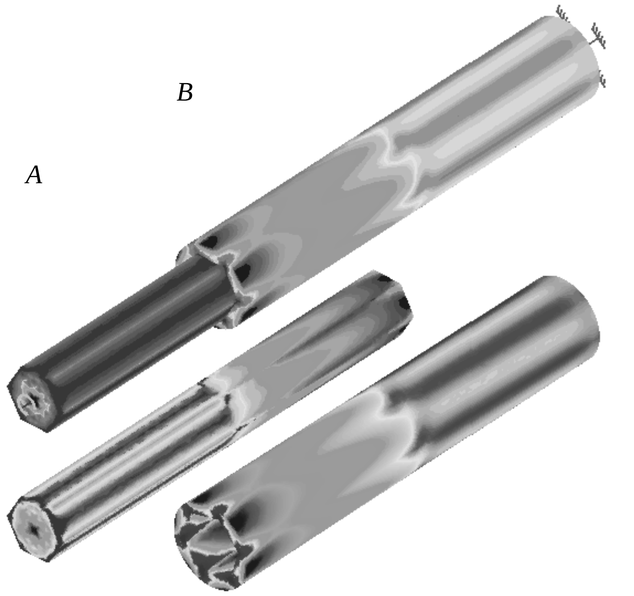

Fig. 8. The stresses in the prismatic pair with a hexagonal cross-section

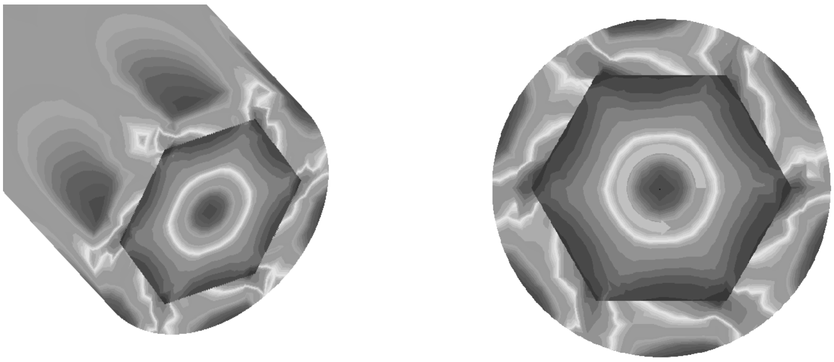

Fig. 9a. Von Mises stresses from section *A*

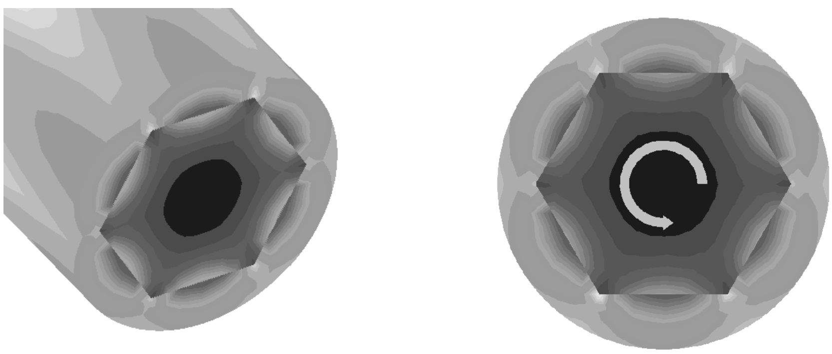

Fig. 9b. Von Mises stresses from section *B*

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All three modalities of constructing the sliding pair present the disadvantage of strong stress concentrators, the occurrence of self-locking phenomenon being, thus, very probable. Creating a sliding pair with a reduced risk of self-locking incidence requires that:

- the contact zones contributing to the torque transmission from shaft to bushing should be as distant from the pair axis as possible, to transmit the same torque at reduced force (contact pressure);
- the number of the contact regions between the shaft and the bushing must be as great as possible in order to correspondingly diminish the contact pressure.

The two above rations are fulfilled by the grooved shaft assembly. The solution proposed for the mechanism actuating is presented in Fig. 13.

Fig. 10. Wedging assembly scheme and the deformed FEA mesh

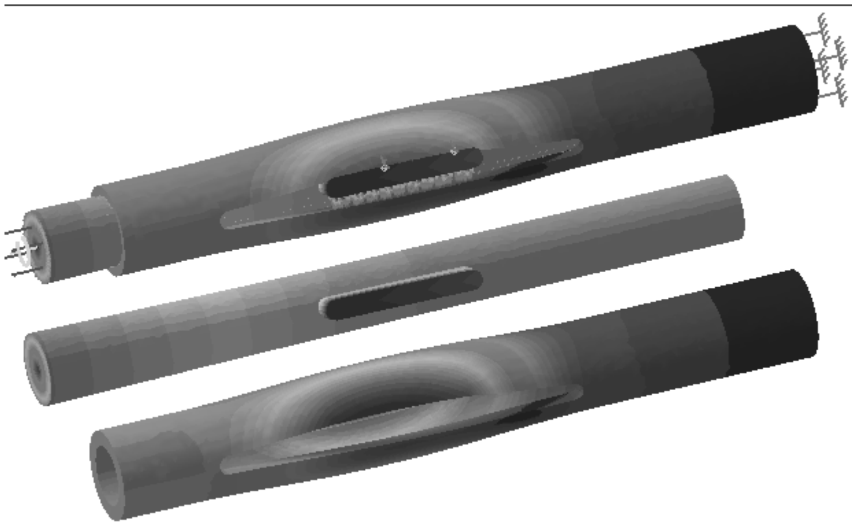

Fig. 11. Assembly and parts displacements

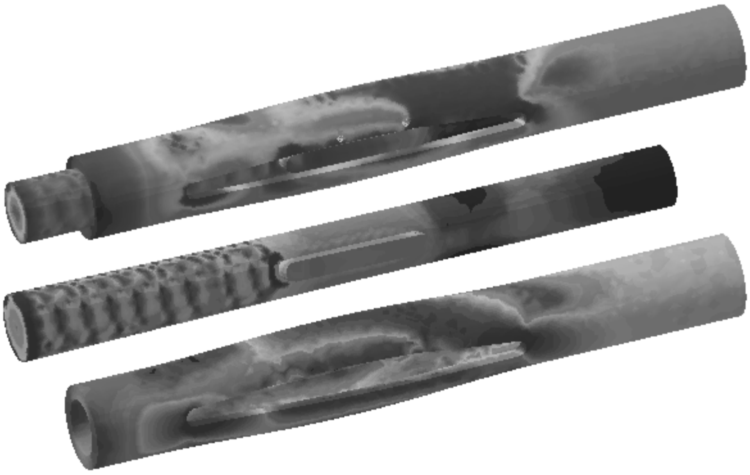

Fig. 12. Von Mises equivalent stresses from the assembly and from the component elements for wedging assembly

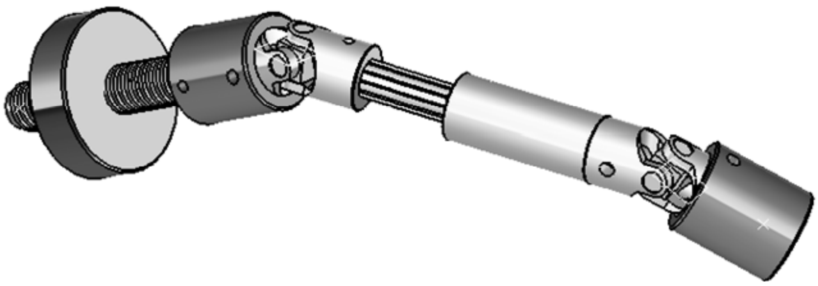

Fig. 13. Proposed actuating solution

Assuming that the kinematic coupling chain is made of the bushing "1" as the driving element, then the driven element presents a single direction of rotation motion and Figure 14 presents the variation of this motion.

The plot in Fig. 14 was obtained for the parameters $\alpha = 30^{o}$ and $a = 40\ \mathrm{mm}$. The graph shows that for the considerable values of the parameters characterizing the crossing axes of the two shafts, for a uniform variation of position angle in driving pair, the variation of the position parameter from the driven pair is quasi-uniform and, consequently, the transmission is appropriately completed.

Moreover, the coupling chain elements can be dimensionally designed in a manner that, to be considered rigid, the deformations should range within prescribed limits. Based on this hypothesis, the transfer function of the coupling chain is well-defined. If a desired motion

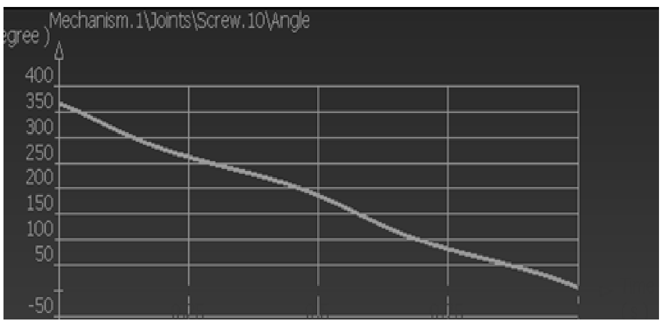

Fig. 14. The rotation motion of the driven element

is aimed at the driven element, the motion is controlled by the variation of the current of driving motor, to the mentioned function, the inverse of transfer function of kinematic chain must be considered, too.

5. CONCLUSIONS

In the case when the relative position between the axes transmitting the motion presents considerable deviations from the nominal position and it is not essential to have a rigorously constant transmission ratio, one of the improved solutions is using kinematic chains with lower pairs.

A solution for the replacement of the manual operating system of a testing machine with an electrical one was proposed, specifically, the driving screw to be operated by a direct current motor.

From theoretical considerations, the solution found for coupling the two shafts consists in connecting two cardanic couplings into a bicardanic telescopic coupling.

The sliding pair is the most complicated, the risk of self-locking is quite possible. Three modalities of constructing the sliding pair were analyzed by the finite element method and all present the disadvantage of strong stress concentrators, the occurrence of self-locking phenomenon being, thus, very probable. The grooved shaft assembly is proved to avoid this inconvenience and is proposed as solution. A more complex analysis shows that the coupling chain elements can be dimensionally designed in a manner that, to be considered rigid, the deformations should range within the prescribed limits.

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