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Steel compliant Cardan universal joint

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ABSTRACT

In this paper, a compliant Cardan universal joint made of steel is introduced. This is the first steel compliant universal joint that is reported in the literature. The mechanism is produced from two different sheet metals; thus, it has the advantage of easiness in manufacturing. Many mechanisms with different dimensions are designed. Resultant stresses at flexural hinges are determined via analytical and finite element analysis method. Torque transmission capacities of these mechanisms are determined. Guidelines, trends, and parameter trade-offs for the design of such mechanisms are presented. Fatigue life of these mechanisms is estimated theoretically. Further, one of these mechanisms is manufactured and tested for fatigue strength. It is verified that results of experiments are consistent with theoretical predictions. It is strongly believed that the steel version of compliant Cardan joint has a great potential to be used in industry.

1. Introduction

In this paper an original design for a compliant Cardan universal joint is introduced by using the fundamentals of the previous study [1]. The mechanism is produced from steel plates where compliant hinges are made of blue polished spring steel. The spring steel plate is sandwiched between external steel plates to form one part of the compliant Cardan universal joint. The other part is identical and when these parts are assembled at right angles, they form the compliant Cardan universal joint (Fig. 1.).

The previous compliant Cardan universal joint also consists of only two identical parts assembled at a right angle with respect to each other as seen in Fig. 2 [1]. The design has the advantages of minimum number of parts, compactness, easiness in manufacturing and assembly. It was verified that the single axis flexural hinges are predominantly subjected to normal stresses due to bending, thus torsional stresses can be neglected [1]. In the previous study, the mathematical model of the complaint universal joint is constructed by using its PRBM (pseudo-rigid body model). The purpose of PRBM is to provide a simple method of analyzing systems that undergo large, nonlinear deflections. PRBM is accurate even for large deflections for many cases. If bending is the dominant loading in a flexural hinge, PRBM is more accurate [2].

Mathematical model of the motion of the PRBM, deflection of hinges, and torque transmission of the compliant Cardan universal joint made of polypropylene were derived and verified in the previous study [1]. PRBM of the previous design and the new original design is the same, thus kinematic design stage will not be presented in this study. Successful implementation of a compliant universal joint in real life applications depends not only on its kinematic design but its mechanical design as well. Therefore, in this study static and fatigue strength of the "steel" compliant Cardan universal joint is analyzed. There is no study that addresses strength issues of compliant Cardan universal joints in the literature. After the design procedure, a set of steel compliant universal joints are manufactured and a fatigue test setup is built. The test setup is capable of testing mechanisms for various output torque and bend angle values. Finally, the theoretical results are compared with experimental results of the manufactured prototypes.

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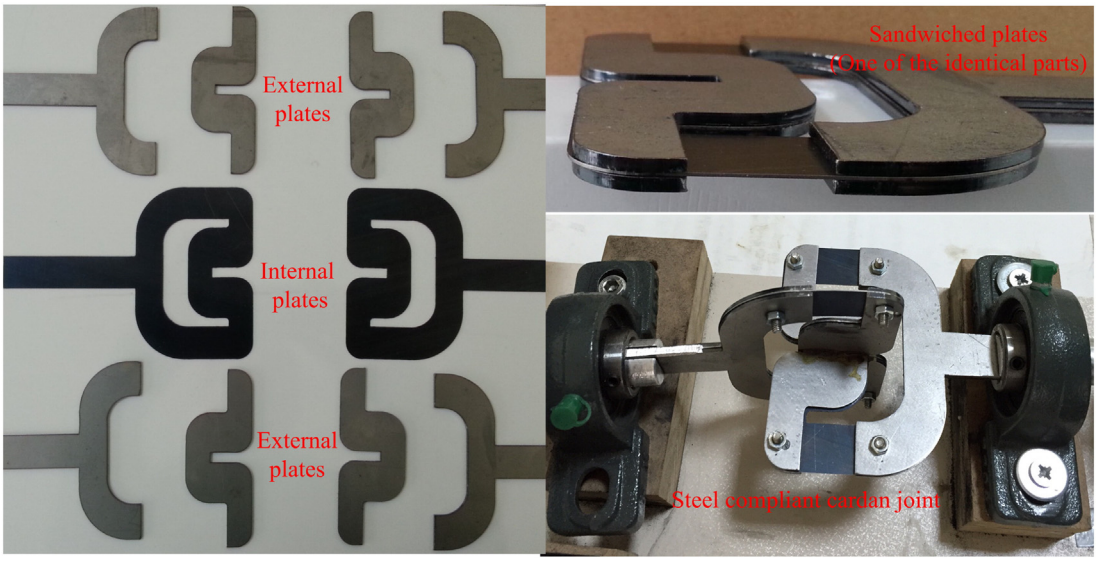

Fig. 1. Steel compliant Cardan universal joint.

2. Background

Cardan joints are common devices for transmitting motion between misaligned intersecting axes. Their capability of easy mounting, resisting high loads, and commercial availability makes them an attractive problem [3–9]. The Cardan universal joint is a spherical four-bar linkage in which the arc lengths of the moving links are exact right angles and the connected shafts intersect at an angle. The existing literature about spherical four-bar linkage considers its analysis, synthesis, applications, and type determination [10–17]. Spherical four-bar mechanism is a special case of spatial four-bar mechanism. The first compliant spatial four-bar mechanism that possesses out of plane motions was studied by Tanık and Parlaktaş [18]. Studies about spatial compliant mechanisms are limited in the literature [19–23]. Trease, et al. [24] and Rubbert et al. [25] proposed designs for compliant universal joint. Finally, flexible-ring joints should also be mentioned as compliant universal joints [26]. Although rubberized fabric is the more common ring material, a number of thin metal discs could also be used instead of fabric rings.

The dimensions of the compliant Cardan universal joint are presented in Fig. 3 [1]. There are three constraint equations (Eqs. (1)–(3)) which must be satisfied.

$$b = a + l/2 \tag{1}$$

$$d = t_p \tag{2}$$

$$c \approx 0.5t_p(\tan\zeta) + b(\tan\zeta \sin\zeta - \cos\zeta + 1) \tag{3}$$

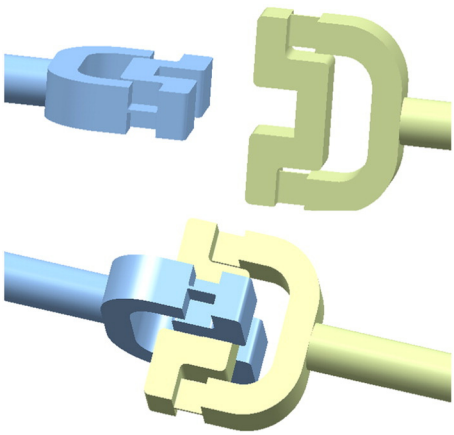

Fig. 2. The previous compliant Cardan universal joint [1].