Kinematic Analysis of Universal Joint using Catia V5

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***Abstract*—A universal Joint also known as the Cardan joint, U-joint or universal coupling is a joint in a rigid rod that allows the rod to 'bend' in any direction, and is commonly used in shafts that transmit rotary motion. The purpose of this research is to study the kinematic analysis of universal joint's revolute bearings and to design a compliant universal joint. The common design consist of two yokes, having a single bend angle, arranged with a pinion at right angles. Compliant version enables the joint with two bend angles, in two different planes. To achieve the compliance over the universal joint, kinematic analysis of common universal joint is conducted and the results are generalized. For a common U- joint, pinion- yoke revolute have angular motion specifically for every bend angles. It is an important aspect of these bearings that while in action they never go through complete cycles. In other words, each of these bearings revolves only within a range of angles with respect to its axis. This angular motion is well studied for different bend angle combination up to 30 degree in two different planes. Based on the results, revolutes' angular motions are generalized, and evaluated.**

***Keywords*— Compliant Universal Joint, Yokes, Pinion, Revolutes.**

1. INTRODUCTION

A U-joint (universal joint) is basically a flexible pivot point that transmits power through rotational motion between two shafts not in a straight line. It is a connection between two intersecting rotating shafts which are coplanar and are inclined at an angle with respect to each other. They are used to transmit motion, power, or both. U-joints are used to absorb vibrations and shock in the drive line; they are also used to allow the rear/front to travel up and down.

Universal joints go by a lot of different names - U joint, Cardan or Hooke's joint and the simplest and most common type is the Cardan joint or Hooke joint shown in Fig.1. It consists of two yokes, one on each shaft, connected by a cross-shaped intermediate member called the pinion. The angle between the two shafts is called the operating angle or bend angle (ξ). It is generally, but not necessarily, constant during operation.

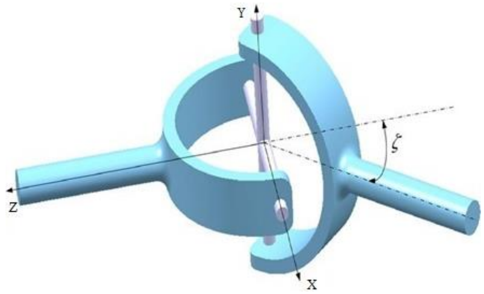

Fig.1 Cardan universal joint

The original compliant joint proposed in this study consist of two operating angles or bend angles, that exist between input and output yoke in X-Z and Y-Z planes. Enabling compliance, transforms spherical four bar universal joint in to spatial four bar linkage mechanism. In this study, classical kinematic analysis of compliant universal joint is done using Catia V5R18 software package. Angular motion between pinion and input-output yokes, with respect to input yoke rotation are analyzed in detail so as to achieve compliance over the bend angles. Through kinematic analysis, revolutes' angular motion can be predict for required output yoke positions. Traditional universal joints, are employed to transfer torque from one shaft to another, apart from power transmission this compliant mechanism can be used for spatial motion arrangements. Typical applications of compliant universal joints includes, as tool holder and guiding mechanism in a machining, drilling and cutting process etc.

2. UNIVERSAL JOINT MECHANISM

The original Universal joint was developed in the sixteenth century by a French mathematician named Cardan. In the seventeenth century, Robert Hooke developed a cross-type Universal joint, based on the Cardan design. Then in 1902, Clarence Spicer modified Cardan and Hooke's inventions for the purpose of transmitting engine torque to an automobile's rear wheels. By joining two shafts with Y-shaped forks to a pivoting cruciform member, the problem of torque transfer through a connection that also needed to compensate for slight angular variations was eliminated. Both names, Spicer and Hooke, are at times used to describe a Cardan U-joint.

The Hooke coupling is commonly called a universal joint because of its ability to transmit motion between two intersecting but non collinear shafts. It should be remarked that there are a number of universal joints and that the Hooke type is but one of the lot. In continental Europe it is known as the Cardan (also Kardan) joint. As it happens, neither cardan nor hook invented it; Hooke's name is associated with it since he put it to use in the seventeenth century.

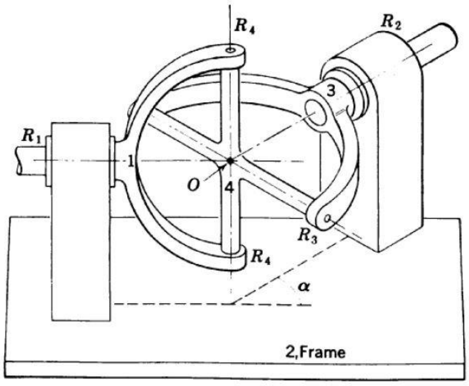

Fig.2 Hooke Joint

A recognizable Hooke joint is shown in Fig. 2 [3]. The two shafts misaligned by an angle α are represented by the revolutes R1 and R2. The central cross 4 carries the revolutes R4 and R3, whose axes are at right angles. Furthermore, the axis of R1 is perpendicular to that of R4, and the axes of R3 and R2 are also perpendicular and all four revolute axes intersect at a common and fixed point O.

Table-1

Nomenclature	
R1	Revolute joint between input yoke (link 1) and frame (link 2).
R2	Revolute joint between output yoke (link 3) and frame (link 2).
R3	Revolute joint between output yoke (link 3) and pinion (link 4).
R4	Revolute joint between input yoke (link 1) and pinion (link 4).

III. KINEMATIC ANALYSIS OF UNIVERSAL JOINT

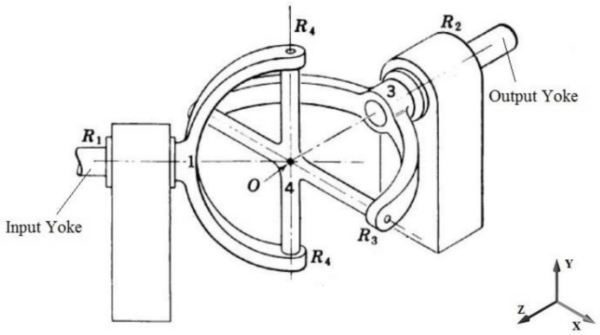

Fig.3 Hooke Joint

The Hooke joint is shown in one schematic form in Fig. 3 [3]. All particles of link 4 (no matter what its physical shape might be) move on spherical surfaces centered at the fixed point O, that is all particles of link4 move on concentric spheres whose center is the fixed point O. Such a motion is specifically called spherical, to distinguish it from led well regulated spatial motions that would occur if revolute axes did not intersect at a common point. Links 1 and 3, considered individually in a plane perpendicular to the particle's axis of rotation. However, since the axes of R1 and R2 possess a common point at O, we can also imagine the particles of links 1 and 3 to move on spheres centered at O.

Common cardan universal joint consist of four revolute joints, R1, R2, R3 and R4. The input yoke and output yoke are fixed to base using revolute joints, R1 and R2 and they are connected with pinion using revolutes R3 and R4. In common universal joints, misalignment of yokes is mainly on single plane causing bend angle on X-Z plane. When yokes rotate, the revolutes R3 and R4 have specific angular motion so as to transfer rotary motion from input to output yoke. For every bend angle R3 and R4's angular motion will be of different manner.

Angles between R4 - R1 and R4 - R3 will be 90 degrees always. When output yoke become compliant and spatially moved, it create misalignment in two planes, X-Z and Y-Z. Therefore compliant mechanism will be operated on two bend angles, along two different planes. Even though output yoke can move spatially, mutual intersection of all revolute axes at a fixed point O, declares that this spatial mechanism to be also a spherical mechanism.

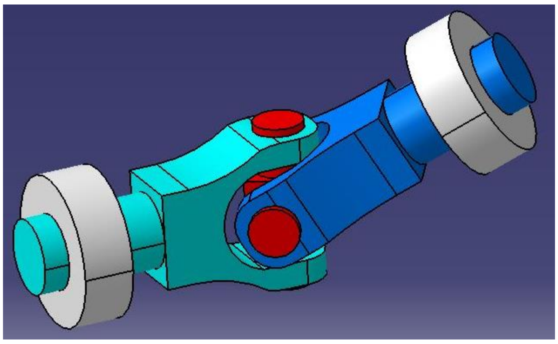
Fig.4 Universal joint modelled in Catia v5r18

In order to analysis the angular motion in revolutes, R1, R3 and R4, a universal joint (fig.4) has been modeled in Catia V5R18. Kinematic analysis is done using Digital Mockup-DMU Kinematics. Angular motion has been studied for bend angle combination of 42 sets, starting from 0 to 30 degree on planes X-Z and Y-Z. Results are plotted between angular motion of revolutes, R1- R4 and R4-R3. Output yoke's movement is not parallel to X-Y plane in actual case. For the purpose of analysis and positioning of output yoke, certain assumptions are applied over the mechanism.

A. Assumptions

1. Angular motion from Input yoke is successfully transferred to output yoke.
2. Bend angle changes in two planes, X-Z and Y-Z cause output shaft's displacement in X-Y plane.
3. For every bend angle variation, output shaft varies correspondingly in X-Y plane.

B. Angular Motion between Revolute, R1 and R4.

Here, angular motion between input yoke-frame and input yoke-pinion, are plotted for two bend angles (in planes X-Z and Y-Z) 0 to 30 degree, with 5 degree interval. Kinematic analysis has been done by fixing one bend angle in plane X-Z constant, and varying other bend angle of plane Y-Z respectively from 0 to 30 degree.

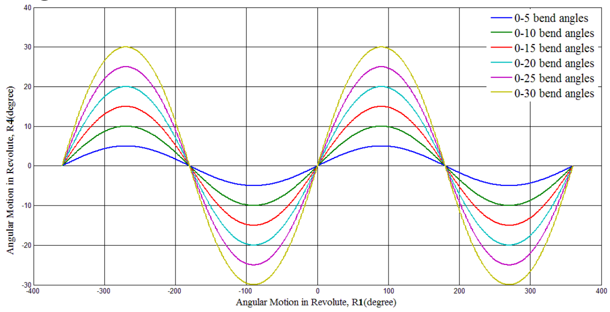

Fig.5 Plot between angular motion of revolute, R1 and R4 of 0-5, 0-10, 0-15, 0-20, 0-25, and 0-30 bend angles

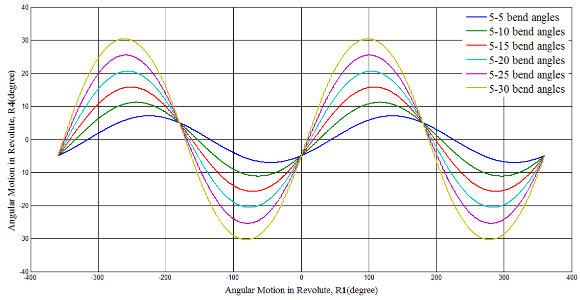

Fig.6 Plot between angular motion of revolute, R1 and R4 of 5-5, 5-10, 5-15, 5-20, 5-25, and 5-30 bend angles

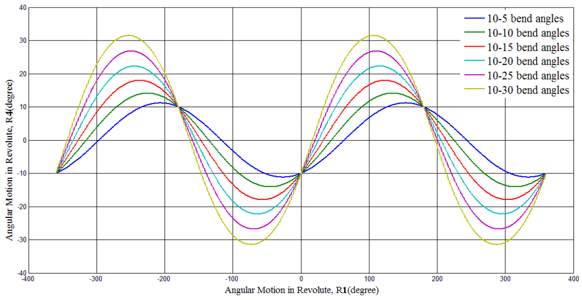

Fig.7 Plot between angular motion of revolute, R1 and R4 of 10-5, 10-10, 10-15, 10-20, 10-25, and 10-30 bend angles

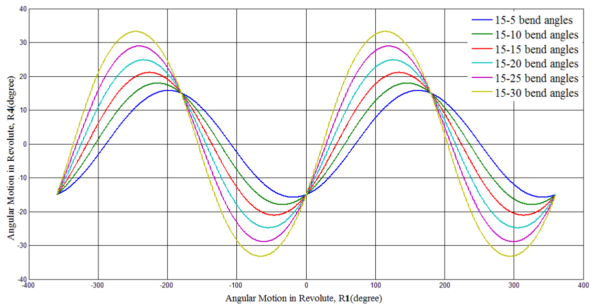

Fig.8 Plot between angular motion of revolute, R1 and R4 of 15-5, 15-10, 15-15, 15-20, 15-25, and 15-30 bend angles

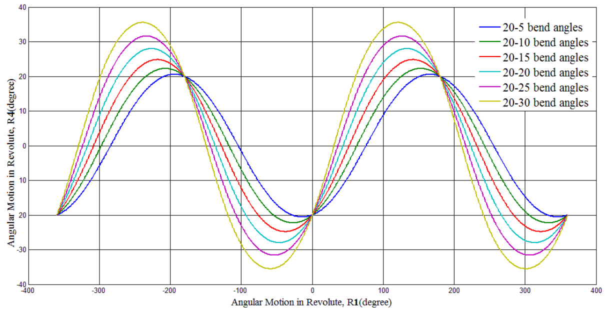

Fig.9 Plot between angular motion of revolute, R1 and R4 of 20-5, 20-10, 20-15, 20-20, 20-25, and 20-30 bend angles

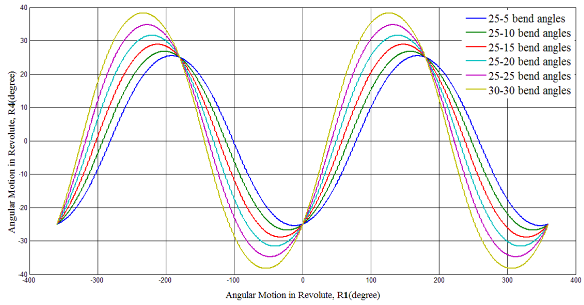

Fig.9 Plot between angular motion of revolute, R1 and R4 of 25-5, 25-10, 25-15, 25-20, 25-25, and 25-30 bend angles

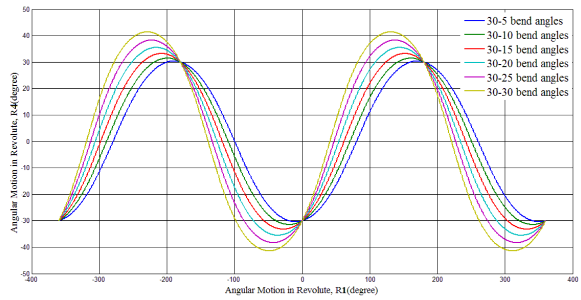

Fig.10 Plot between angular motion of revolute, R1 and R4 of 30-5, 30-10, 30-15, 30-20, 30-25, and 30-30 bend angles

C. Angular Motion between Revolute, R4 and R3.

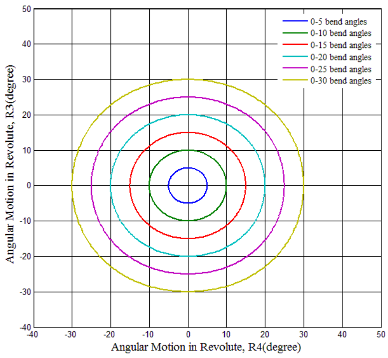

Fig.11 Plot between angular motion of revolute, R4 and R3 of 0-5, 0-10, 0-15, 0-20, 0-25, and 0-30 bend angles

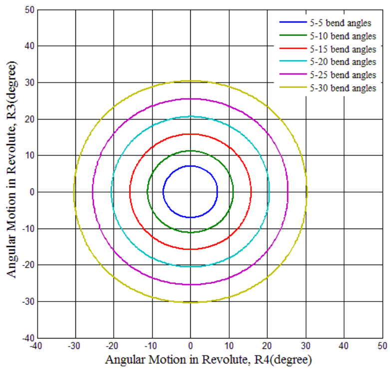

Fig.12 Plot between angular motion of revolute, R4 and R3 of 5-5, 5-10, 5-15, 5-20, 5-25, and 5-30 bend angles

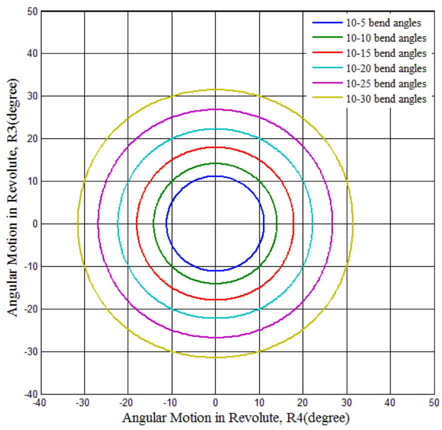

Fig.13 Plot between angular motion of revolute, R4 and R3 of 10-5, 10-10, 10-15, 10-20, 10-25, and 10-30 bend angles

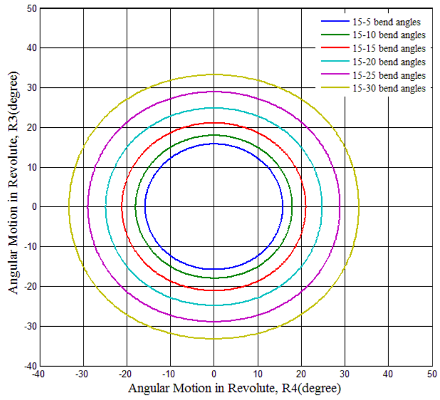

Fig.14 Plot between angular motion of revolute, R4 and R3 of 15-5, 15-10, 15-15, 15-20, 15-25, and 15-30 bend angles

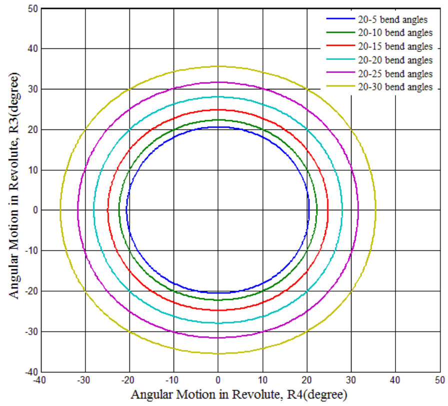

Fig.15 Plot between angular motion of revolute, R4 and R3 of 20-5, 20-10, 20-15, 20-20, 20-25, and 20-30 bend angles

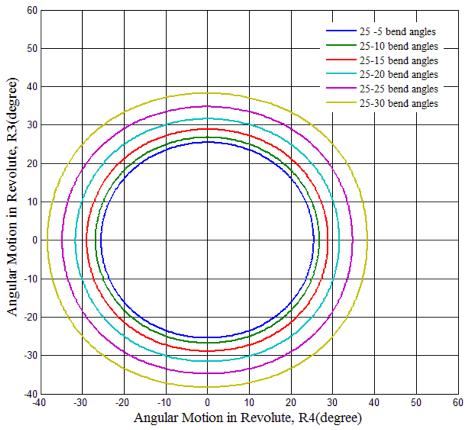

Fig.16 Plot between angular motion of revolute, R4 and R3 of 25-5, 25-10, 25-15, 25-20, 25-25, and 25-30 bend angles

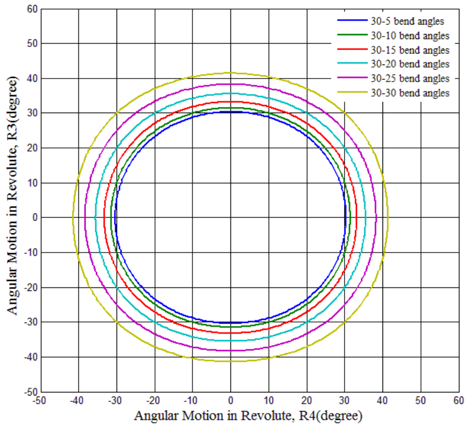

Fig.17 Plot between angular motion of revolute, R4 and R3 of 30-5, 30-10, 30-15, 30-20, 30-25, and 30-30 bend angles

Angular motion between R1 and R2 are sinusoidal in manner, where amplitude and phase shift are variables for every bend angle combination. R4 and R3 follows a circular pattern, where radius of circles changes for every bend angle combinations. Numerically, radius of R4-R3 plots are equal to amplitude of R1-R2graphs.

IV.GENERALAIZATION

For every bend angle combination,amplitude and phase difference values changes, creating different angular motions. Angular motion of the input yoke is for two rotation of shaft, starting from -360 to 360 degree. Generalizing these graphs, gave common form as:

$$x = -A\times\cos((i-P)*(\pi/180)) \qquad (1)$$

Where, ‘x’ is the angular motion of revolute-R4 in degree,‘A’ is the amplitude, ‘P’ is the phase shift and ‘i’ is the input angular rotation for 2 revolutions (-360 to 360 degree).

Angular motion between revolute-R4 and revolute-R3 has been plotted. For every bend angle combination, radius of the plot is varying creating different angular motions.

$$y= (\sqrt{(A^2 - Y^2)}) \qquad (2)$$

Where, ‘y’ is the angular motion of revolute-R3 in degree. Plotting graph between ‘i’ and ‘x’ gives the angular motion between revolute, R1 and R4. Also, the ‘x’ and ‘y’ plot gives the angular motion between revolute, R4 and R3. From the equations – 1 and 2,the angular motion graphs can be plot for every bend angle combination.
Variables like amplitude and phase shift for every bend angle combination in X-Y plane of output shaft displacement is plotted below:

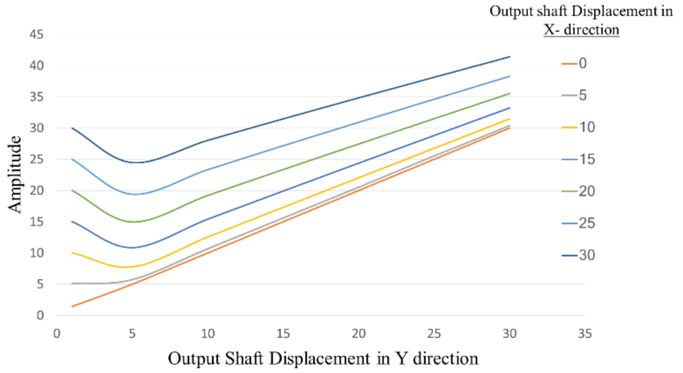

Fig.18 Plot between output shaft displacement and amplitude in X-Y plane.

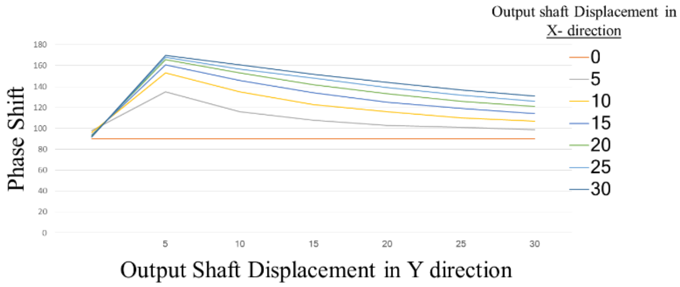

Fig.19 Plot between output shaft displacement and phase shift in X-Y plane.

IV. COMPLIANT UNIVERSAL JOINT

From the graphs above, it is possible to find out amplitude and phase shift for every bend angle combination. Therefore, angular motion of revolute- R4 and R3 can be find out for every input shaft rotation. Unlike universal joint, compliant mechanism’s output shaft is not fixed to the frame. By knowing the bend angle combination, it is possible to create a required output shaft’s position in X-Y plane. Along with the spatial motion of output shaft, it will also have the rotary motion transferred from input shaft to the output shaft. So as to achieve a particular position for output shaft, the angular motion between the revolutes-R1 and R3 can be varied according to the required bend angle combination. Angular motion between the revolutes can be controlled by using rotary voice coil actuators.

V.CONCLUSION

This paper put forward a compliant universal joint, having two bend angles. This compliant joint have 3 degrees of freedom, with output shaft’s planar displacement and its rotary motion. This mechanism can be used to machine complex geometrical shapes. By attaching this C.U.J. with cutting tools, complex shapes can be cut out from plates. In order to achieve compliance, common universal joint’s kinematic analysis has been done on revolutes using Catia v5R18. Generalization of revolutes’ angular motion propose a possibility of compliance. Revolutes’ angular motion can be varied according to the need using rotary voice coil actuators.

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