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Research applying Spherical Gear and Ring – Rack Mechanism to Rotary Work Table

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Abstract: A novel rotary table based on the spherical gear and ring involute rack is presented in this paper. Firstly, the generating spherical gear is analyzed and when the teeth of the spherical reach the extremely large value, this spherical transform to the ring rack. And then, the position of the work table is determined by analyzing kinematics of the mechanism based on spherical gear and ring-rack.

Keywords: Rotary table, Spherical gear, Ring-rack, Mechanism, Involute

I. INTRODUCTION

The machine tool industry has undergone enough changes as the requirement of user engineering systems changed. It started with the manufacture of basic general-purpose machine tools. Although these machines offered higher flexibility, they were not suitable for mass production. With growing need of fast production, mass production machines are conceived. These machines were highly specialized but inflexible [2, 8]. Thus, great need is felt for tools that could bridge the gap between highly flexible general-purpose machine tools and highly specialized, but inflexible mass production machines. Numerical control machine tools with proper fixture set up must take up this role very well. And this has excited this research work on design and development of rotary work table for CNC machine [8]. However, most rotary tables were designed with the traditional gears (spur, helical or bevel gears) that have one freedom of movement, so they are not flexible. The rotary work tables proposed in this article uses the spherical gear mechanism which can simultaneously control two angles in the space.

II. GENERATED THE SPHERICAL GEARS

The tooth surface of the spherical gear are generated by rotating a convolute curve around an axis [1][3]. The spherical gear with the ring-involute teeth was shown in figure 1. O_1O_2 is the linking line passing the teeth top midpoint of one gear and the teeth midpoint of the other. Then all circles on the surface gear become the corresponding ball, as teeth top ball, teeth football, dividing ball and so on. If we mount gear 1 and gear 2 on a pair of universal frames that have two freedoms of movement, gear 1 and gear 2 will keep moving around the ball center O_1 and O_2. When two gears are moving, the pair node balls will make a pure rolling-movement, and then achieve fixed transmission ratio spherical surface moving. The generating principle of the ring involute teeth were shown in figure 2. C is the basic circle, K—K is the generator, N&S are two intersections of basic ball and gyratory axis, K—K and gyratory axis are in the basic circle surface P. When generator K—K makes a pure roll- movement on the basic circle and gyrate with basic circle surface P around the gyratory axis, the locus of any point on generator K—K will form the teeth profile camber of the spherical gear. The basic ball is the set of the locus, which are all points on the basic circle. Obviously, the teeth profile curve across the gyratory axis on any section surface is involute, and the set of all involute constitutes a ring camber. Therefore, the teeth profiles camber is a ring involute camber.

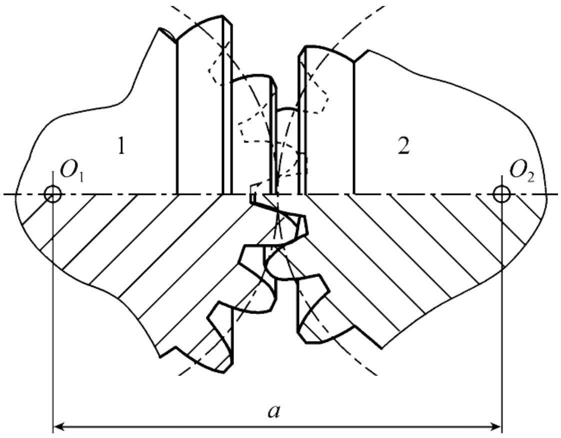

Figure 1. The generating spherical gear[4][5]

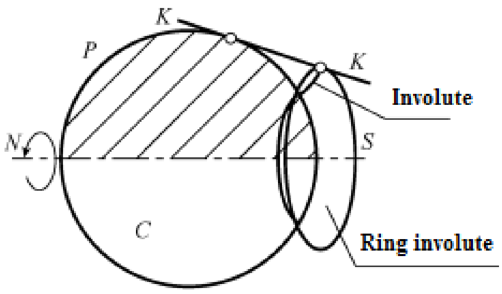

Figure 2. The ring involute teeth surface[6][7]

III. TRANSMISSION BETWEEN THE SPHERICAL GEAR AND RING - RACK

The transmission using the spherical gears has the high kinematic accuracy and flexible motion in the work area. When the teeth of the spherical reach the extremely large value, this spherical transform to the ring rack with ring involute teeth. And then, there is the transmission using spherical gear and ring rack, shown in figure 3.

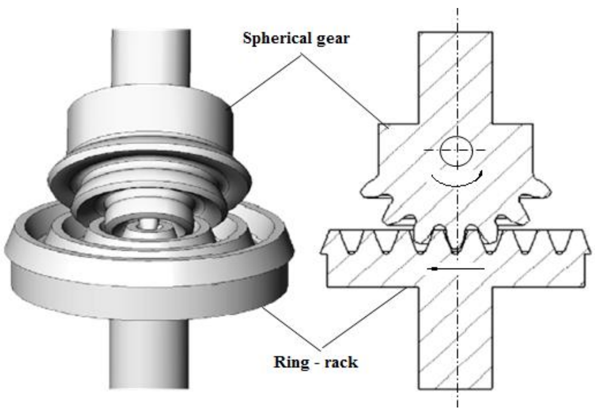

Figure 3. The mechanism based on the spherical gear and Ring- Rack

With this structure, the rotational motion of the spherical gear can transform into the linear motion of the ring-rack. Otherwise, if the ring-rack is seen as a driving mechanism, the motion of the ring-rack along the direction x-z is transformed into the two-dimensional rotation of the spherical gear. Thus, the transform between the two-dimensional rotation and linear motion can be performed by the spherical gear mechanism. This can be applied to control the aerial executive mechanism.

To determine the position of the spherical gear, the systems of coordinates are selected as figure 4:

- The fixed coordinate:

$C_{10} = [O_{10}, x_{10}, y_{10}, z_{10}]$, $C_{20} = [O_{20}, x_{20}, y_{20}, z_{20}]$

- The moving coordinate system, which is the body coordinate system on gear 1;

$C_1 = [O_1, x_1, y_1, z_1]$

- The moving coordinate system, which is the body coordinate system on gear 2:

$C_2 = [O_2, x_2, y_2, z_2]$

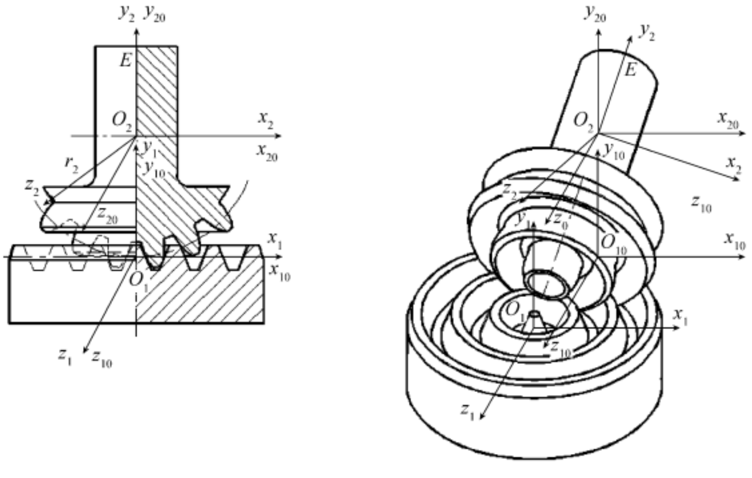

Figure 4. The coordinates of mechanism based on the spherical gear and Ring- Rack

In the spherical disk-gear mechanism, the motion between the pitch sphere of the spherical gear and the pitch plate of the disk-gear is pure rotation. The initial position of the axis E point is (x_{10}, y_{10}, z_{10}) and the initial position of the output shaft is (0, 1, 0). The relationship between the deflection angle θ of the spherical gear and the distance of the transnational motion of the disk-gear is: $s = r_2.\theta$ or

$$\theta = \frac{s}{r_2}$$

When the disk-gear was a driving mechanism, the impute parameter is (x_1, z_1) and the output parameter is (x_e, y_e, z_e). The distance of transnational motion of the disk-gear and the orientation angle can be described as follows:

$$\begin{cases} s = \sqrt{x_1^2 + z_1^2} \\ \alpha = \arctan \dfrac{z_1}{x_1} \end{cases} \tag{1}$$

The coordinate of the tip point of the output shaft is:

$$\begin{bmatrix} x_e \\ y_e \\ z_e \end{bmatrix} = \left[C_{22_0}^{\theta}\right] \begin{bmatrix} x_{20} \\ y_{20} \\ x_{20} \end{bmatrix} = \begin{bmatrix} -\sin\alpha \sin\theta \\ \cos\theta \\ \cos\alpha \sin\theta \end{bmatrix} \tag{2}$$

where, $\theta = s / r_2 = \sqrt{x_1^2 + z_1^2} / r_2$

When the spherical gear is seen as a driving mechanism the input parameter is $(\theta_{2x}, \theta_{2z})$ and the output parameter is (x_1, z_1).

$$\begin{cases} \theta = \arccos(\cos\theta_{2x} \cos\theta_{2z}) \\ \alpha = \arcsin\left[\dfrac{-\sin\theta_{2z}}{\sqrt{1 - \cos^2\theta_{2x} \cos\theta_{2z}}} \right] \end{cases} \tag{3}$$

From that:

$$\begin{cases} x_1 = S.\cos\alpha = r_2\theta.\cos\alpha \\ z_1 = S.\sin\alpha = r_2\theta \sin\alpha \end{cases} \tag{4}$$

IV. DESIGN THE ROTARY TABLE USING THE SPHERICAL GEAR AND RING -RACK

The rotary tables using the spherical gear and ring – rack can determine any rotation angle of the table in space. This rotary table is designed with the mechanism based on the spherical gear and ring-rack, and the 2D table using the ball bearing screw, shown in Figure 5.

In order to the work table can rotate any angle in space, the ring – rack is moved straight along OX and OZ axis by the 2D table. When the ring – rack moves along in two axes, the spherical gear rotates the center O_0 on the two planes XOZ and YOZ. The motion of the 2D table are drived by two step motors and controled by using arduino main with C program, shown in figure 6.

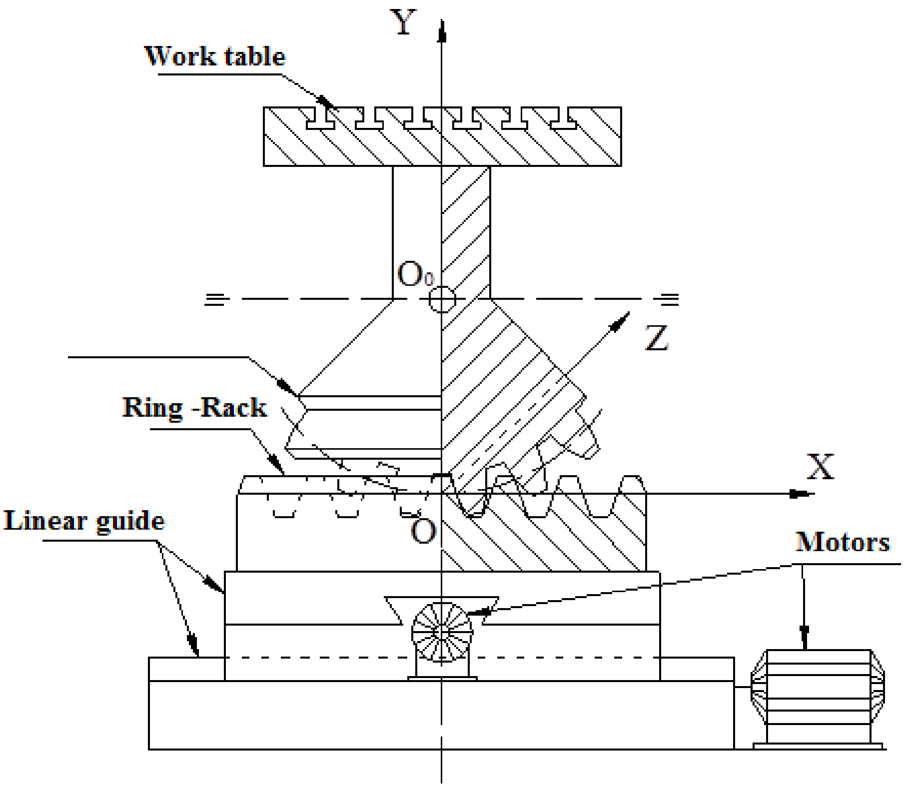

Figure 5. The structure of the rotary table based on the spherical gear and ring – rack

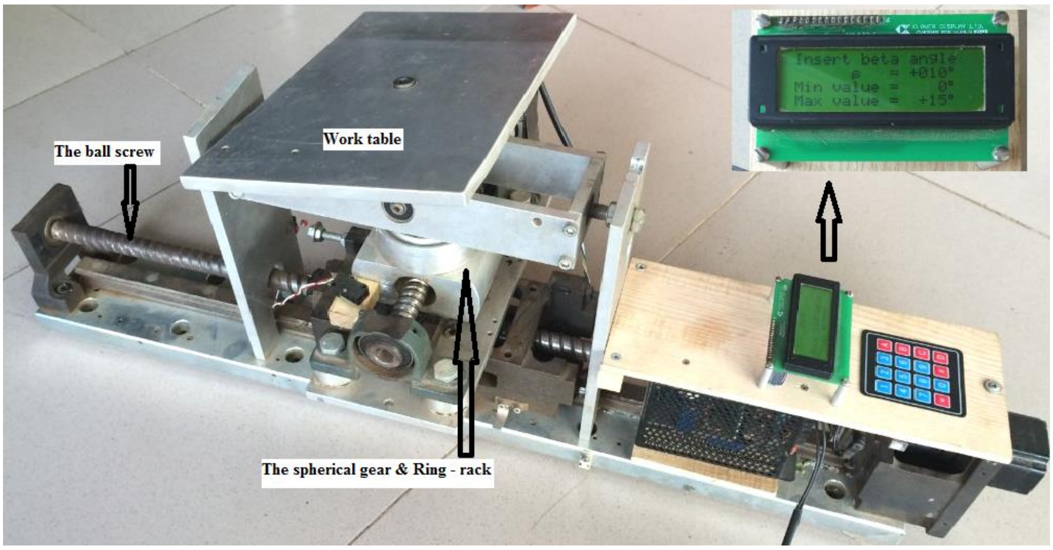

Figure 6. The model rotary table based on the spherical gear and ring – rack

V. CONCLUSION

The generating spherical gear is analyzed and when the teeth of the spherical reach the extremely large value, this spherical transform to the ring - rack. By studying the kinematics of the spherical gear and the ring – rack, the relationship between any rotation angle of the spherical gear and the linear motion of the ring – rack has been determined. Since then the novel rotary table structure has been proposed by using the new mechanism based on the spherical gear & the ring – rack, and combining the 2D table. The rotation angle of the work table has been determined by controlling the linear motion in X and Z direction of the 2D table. A rotary table model using the spherical gear & the ring – rack was also developed, using the Arduino main with the C program.

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Ethical statement: The authors declare that they have followed ethical responsibilities

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