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Gear Joint for Aerial Manipulators

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ABSTRACT

This paper briefly presents a gear joint with two degrees of freedom and describes possibility of use for manipulators and unmanned flying manipulators. A kinematic scheme for a gear joint is developed with its kinematic characterizations. Its kinematic characterization is expressed as function of parameters of external applied torques and input speeds on the shaft. General schemes are considered for a manipulator design with gear joint and for operation analysis of a gear joint.

Keywords: Joint, Gear, Manipulator, Design, Kinematic Scheme.

1. INTRODUCTION

Gears are used in different kind of applications, such as manipulators, elevators, heavy machines, bridges, drives of vehicles, final drives and other machineries mainly as a reducer. The high efficiency of gears depends on different factors, for example, types and profiles of teeth, contact point stresses, number of teeth and bearings. The basic theory of gears, computational design, development, backlash simulation, and the analysis of stress of gears have been pointed out in [1, 4,5]. Gears and gearboxes can be built as planetary gearboxes with a continuously variable transmission (CVT). This type of mechanism is able to change the gear ratio thanks to the applied load through 2DOF as presented in [2]. With high efficiency planetary gear drive has been described in [3], which has a power transmitting efficiency of 0.996. This gear drive is single stage planetary gear set. The mechanism consists of a sun gear, an input and output carrier, satellites, a ring gear and a support. This gear drive was designed to apply for turbo motors.

Gear drives also can be used in robotics and different types manipulators as a speed reducer in R joints. In many research works for example, [6,9,10] the dexterity, workspace and singularity of new developments of the 3 revolute (R) parallel manipulators were presented with the effect of the adjustable links dimension in to the manipulator performance. Another case a new planar 5 revolute parallel mechanism, having 9 actuation modes has been described in [7]. In [8] presented a gearbox joint with 2 DOF and its possibility of use for manipulators.

Open problems may be identified in the high efficiency, considering smooth change reduction ratio, efficiency, mobile gear joint in space, smooth motion. This paper presents a design of a novel gear joint for different manipulators. The main focus of the gear joint is in features that are suitable for use the proposed mechanism in applications, where an applied load power can generate critical situations.

2. KINEMATIC CHARACTERIZATION AND REQUIREMENTS

In this research work the proposed novel gear joint is presented as a gear drive with a planetary gearing. Mainly the proposed mechanism consists of 2 mobile planetary gear sets. Main requirements for a novel design can be as light structure with a few components, low energy consumption, high ratio, smooth motion, high efficiency, adapting to applied external load and flexible joint in space. These described requirements superimpose needed operation features to proposed gear joint.

The novel gear joint is compact structure with 2 DOF with a compact gear mechanism consisting of an input carrier (arm) C1, an output carrier (arm) C2, input and output sun gears 1 and 4, which are mounted on a shaft by key, input and output satellites 2 and 5, input and output ring internal gears 3 and 6 which are fixed together as rigid body, Kinematic scheme is presented in Figure1. Following gears 2 – 3 – 6 – 5 – 4 – 1 created a closed mechanical chain with an operation as differential.

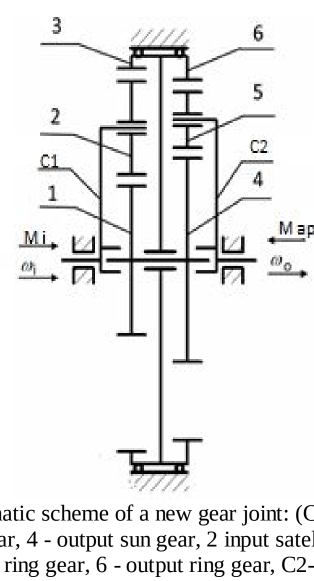

Figure 1: Kinematic scheme of a new gear joint: (C1-input carrier, 1- input sun gear, 4 - output sun gear, 2 input satellite, 5- output satellite, 3- input ring gear, 6 - output ring gear, C2- output carrier).

Carrier C1 transmits applied driving force to the closed mechanical chain (2 – 3 – 6 – 5 – 4 – 1) then carrier C2 transmits output resistance forces. Movement can start at fixed output carrier C1 with one DOF. In order to transmit movement from the input carrier C1 to the output carrier C2 satellite 5 should be locked so, this moment be reached also by friction at gear contacts. This is one of the peculiarities of the system. The input carrier C1 pushes input satellite 2 that moves both input sun gear 1 and 3 input ring gear that transfers different forces to output ring gear 6 and 4output sun gear correspondingly. Thereby, satellite 5 pushes with different forces transmitted from its contacts with output ring gear 6 and 4 output sun gear, and therefore carrier C2 moves. In addition, the system will be able to work with 2 DOF because of a possibility of activating a second DOF, when gear 5 will be unlocked by overcoming frictions at gear teeth contacts and internal forces of gear mechanism. It gives a possibility overcoming critical conditions with overloading in the output preserving both the gearbox structure and functioning [8].

Main characteristics of the proposed mechanism are in two input mobile links, efficiency, high reduction ratio, low energy loss, mobile joint, 2DOF, smoothly changing reduction ratio. The proposed mechanism may be a suitable gear joint solution for many non-constant operation, since it is able to adapt its operation to variable applied loads.

Characterization of the proposed mechanism as a kinematic characteristic may expressed as function of parameters of external moments on the carriers M_{C1}, M_{C2} and input angular velocity ω_{C1}. If referring to Figure 1, the relations among the angular speeds of the gears with z_1, z_2, z_3, z_4, z_5, z_6 teeth may be expressed in next the form

$$\frac{\omega_1 - \omega_{C1}}{\omega_3 - \omega_{c1}} = u_{13}^{(C1)} \quad (1)$$

$$\frac{\omega_1 - \omega_{C2}}{\omega_3 - \omega_{C2}} = u_{46}^{(C2)} \quad (2)$$

where

$$u_{13}^{(C1)} = -\frac{z_3}{z_1}$$

$$u_{46}^{(C2)} = -\frac{z_6}{z_4} \quad (3)$$

$$\omega_{C2} = M_{C1}\omega_{C1} / M_{C2} \quad (4)$$

When z_i - number of teeth in gears (i =1,.,6). From equations (1) and (2) angular speeds ω_3, ω_1 of gears 3 and 1 will be obtained as

$$\omega_3 = \frac{(u_{13}^{(C1)} - 1)\omega_{C1} - (u_{46}^{(C2)} - 1)\omega_{C2}}{u_{13}^{(C1)} - u_{46}^{(C2)}} \quad (5)$$

$$\omega_1 = u_{13}^{(C1)}(\omega_3 - \omega_{C1}) + \omega_{C1} \quad (6)$$

Thereby, given an input movement with ω_{C1} and M_{C1} the output motion obtained with ω and M.

3. A VIRTUAL DESIGN OF A GEAR JOINT

A virtual computer design of a gear joint with planetary gear set was worked out using CAD systems in Solid Works software. A 3D model of the proposed mechanism of the gear joint with the main components is shown in Figure-2, referring to Figure1. As can be observed in Figure2 C1-input, 1-input sun gear, 2-input satellite, 3-input ring gear, 4- output sun gear, 5-output satellite, 6-output ring gear, C2- output carrier is demonstrated. Parameters of gears, module of gears and number of teeth are shown in Table 1.

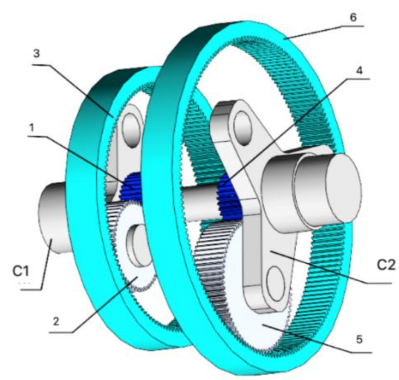

Figure 2: A 3D model of a planetary gears for the new gear joint in Figure1.

Table 1: Main characteristics of gears in Figure 2

Number of gear	**1**	**2**	**3**	**4**	**5**	**6**	**Module**
Number of teeth	35	80	185	45	55	145	0.50

The proposed gear joint mainly consists of a planetary gear set. Figure 2 presents a 3D design of a planetary gear mechanism for the novel gear joint, which is shown main functional components with no bearings, cover, housing and common commercial components. A complete mechanical design and its exploded view of the proposed mechanism is demonstrated in Figure 3.

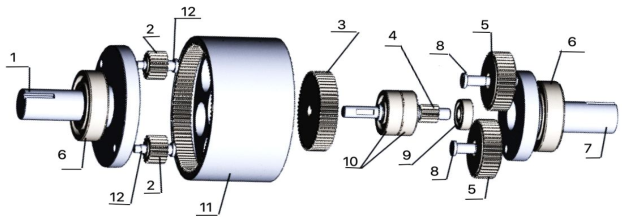

Figure 3: Assembly scheme for a gear joint in Figure-2: 1- input (shaft) carrier; 2- input satellite; 3- input sun gear; 4- shaft of output sun gear; 5output satellite; 6- bearing; 7- output (shaft) carrier; 8- spin of satellites; 9,10- bearing; 11- wheel; 12- spin

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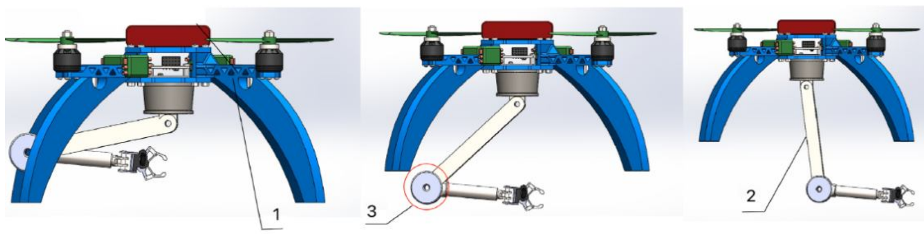

Figure 4: A scheme for a manipulator with gearbox joint: (1 and 2- links; 3- gearbox joint).

This proposed gear joint with two degrees of freedom provides a stop mode of movement when the highest value of variable resistance is reached. Herein, the moving component of the link remains motionless and the motor works at the same speed the continuously. Stop mode avoids overload and overcoming emergency situations. In manipulators with gear joints, stop mode will be overcome by moving other links, which leads to a decrease in resistance.
Common characteristics of design can refer to practical applications of the gear joint for unmanned flying manipulators as shown in Figure 4.
The main aim of the novel gear joint is related to the capability for adaptation the operation to different load conditions by preserving high efficiency and ratio for input-output loads. This proposed mechanism design solution can provide a movement of output link with a velocity which is inversely proportional to shaft loads. These described features are suitable for use the design in applications such as gear joint in for unmanned flying manipulators, where smooth control of the reduction ratio is required.

4. THE INTERACTION OF THE GEAR JOINTS OF THE MANIPULATORS

In order to develop an adjustable manipulator drive with a mechanical converter, a gearbox coupling mechanism can be used. This mechanism can ensure the movement of the moving part of the module with a speed that is reverse to the power load of the module at constant engine power. The energy circulation in a closed chain will lead to a redistribution of internal speeds in a mode with two degrees of freedom and to the formation of internal additional resistance in a mode with one degree of freedom. In figure5 a diagram of an unmanned flying manipulator with a gear joint and a translational motion module as an example of research is shown.

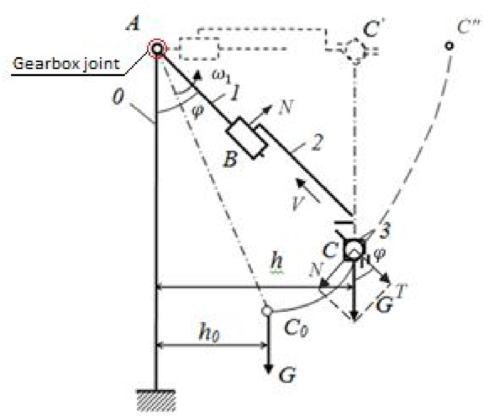

Figure 5: Interaction scheme of a gear joint with translational link

Figure-5 shows an unmanned flying manipulator consisting of an unmanned aerial vehicles (UAV), a lifting element (link) 1 with a gear joint at A point, a gripper 3 at C point, a translational drive link 2 at B point and a frame O gripper 3 at C point. Moving objects with weight G is placed on the gripper 3.
Moving objects with weight G is placed on the gripper 3. The object rises with the movement of the manipulator along the joint in A. A motor with a link 1 gear joint provides a turn in the direction of the arrow and overcomes the moment of resistance M=GL, where L - force arm. In the initial position, the rotation link 1 locates vertically and force of arm is equal to 0 (h=0). During rotation, the force L is amplified, and the moment of resistance M also increases. When the maximum resistance moment for the drive is reached ($M=M_{max}$), the module 1 stops and the gear joint comes to stop mode. The gear runs continuously and the object in grip 3 at point C remains stationary. At this point, forward movement drive unit 2 activates. Link 2 begins to move the grip 3 with the object in the direction of arrow V and the arm of force

decreases. The connection of the gear unit 1 leaves the mode of stopping the movement and ensures the lifting of the object together with link 2 of the translational movement of the lever to position C. The final position of the arm is indicated with dotted line. The manipulator continuously adapts for the conditions of motion. Manipulators, having the gear joint not require the use of motors with significantly high power. During the movement the gripper from C0 point to C′ point, both drives are switched on simultaneously.

A numerical example of calculating the power for this movement can be expressed as

$$P_{max} = P_{Amax} + P_{Bmax} \quad (7)$$

Comparison of the operation of conventional drives with gear joint drives.

Usual drives:

$$P_{A_{max}} = M_{max} \cdot \omega_1 \quad (8)$$

$$M_{max} = G \cdot L \quad (9)$$

$$P_B = G \cdot V \quad (\varphi = 0) \quad (10)$$

where ω_1 – angular velocity; V – translational velocity; φ- arm angle.

Drives with gear joint:

$$M_{max} = G \cdot L \cdot sin\varphi \quad (11)$$

$$P_{Amax} = G \cdot L \cdot sin\varphi \cdot \omega_1 \quad (12)$$

$$P_{Bmax} = G \cos\varphi \cdot V \quad (13)$$

Assuming for regular drives *ω1 = 11 rpm; L=0.7 m; G = 11 N; V=0.3 m/s and for drives with gear joint G = 11 N; L=0.7 m; ω1 = 11 rpm; V=0.3 m/s;* $\varphi=30^0$, power calculation for two cases can be computed with the model in Eqs (7) to (13). Computed results of the parameters of numerical check are presented in Table 2. As can be seen form numerical results in the table manipulators with the gear joint no require high power than manipulators with regular drives.

Table 2: Computed parameters referring to Figure 5

Drive parameter	**Regular drives**			**Drives with gear joint**		
	P_{max}	P_{Amax}	P_{Bmax}	P_{max}	P_{Amax}	P_{Bmax}
Value, W	84.91	84,7	0.21	45.22	42.35	2.87

5. CONCLUSION

In this research a gear joint with two degrees of freedom has been designed for practical applications for unmanned flying manipulators. This described gear joint is able to provide a stop mode of motion when the highest value of variable resistance is obtained to avoid the critical situation. Characterization of the gear joint and main requirements of the mechanism have been worked out. Simple kinematic scheme of an unmanned flying manipulator with the gear joint has been introduced, where interactions of the gear joint is described as interaction with regular drives of manipulators. Example is reported to present both the feasibility of the proposed gear joint in an unmanned flying manipulator and to characterize main advantages in the operation efficiency.

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