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Design and Research on High-performance Opening Mechanism of Sideward Opening Aircraft Door for Large Civil Aircraft

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ABSTRACT
At present, the sideward opening aircraft door adopts manual opening method, in order to reduce the frequency of contact between personnel and the door under the Covid-19, this paper designed an electric opening and closing mechanism. The sideward opening aircraft door is divided into lifting process and rotation process. The door is designed with an electric lifting branch chain driven by shock absorber spring and gear rack. The upper and lower rocker arms of the hinge arm are lifted to lift the sideward opening aircraft door. The top of the door is designed with new spherical gears as a turnout mechanism, the lifting process spherical gear adaptive rotation to the parallel position of the parallel link; after the completion of the door lifting, the rack drive spherical gears along the horizontal direction to achieve door rotation, so as to smoothly achieve the smooth operation of the door. The three-dimensional modeling using Solidworks software realizes the electric opening of the side-open boarding door, which provides a certain reference for the electric opening mechanism of the civil aircraft door.

***Keywords*-**Sideward opening aircraft door, Electric opening, Raising mechanism, Spherical gears

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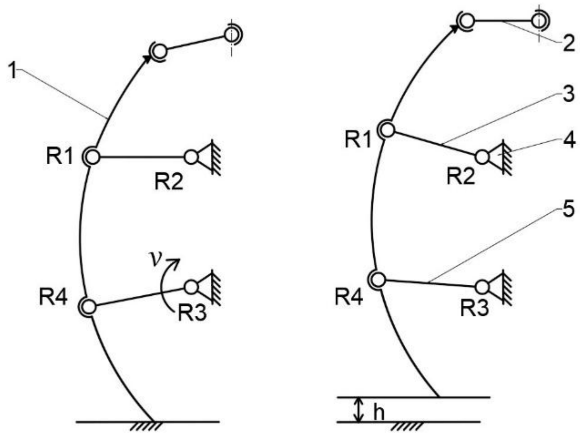
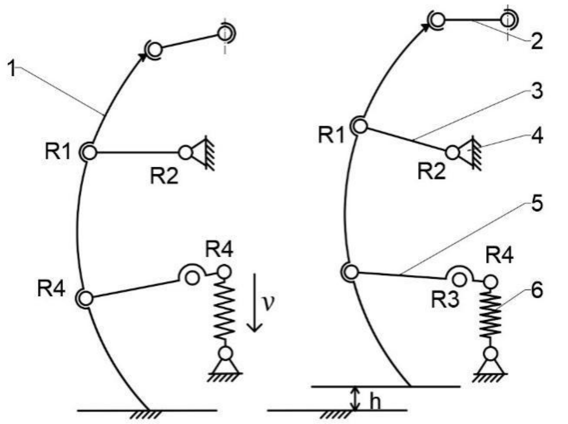
I. INTRODUCTION

With the rapid development of science and technology, the electric opening gradually replaces the manual opening. At present, most aircraft door opening process uses the link mechanism such as Fig.1 [1], which drives a series of links under the condition of manual opening. The structure is more complex, and the operation is more laborious. In the manual opening condition, the door is lifted by about 50 mm, and then the parallel link is used to open the door. The opening stage has a spring assisted mechanism, as shown in Figure 2 [2]. The lifting stage of the aircraft door is completed through the contraction and relaxation of the two springs.The device is simple, but it cannot guarantee the stability of the door. At present, when the Covid-19 is rampant, unnecessary contact should be minimized and the risk of cross-infection should be reduced. Under the premise of ensuring the tightness and reliability of the door, this paper puts forward the scheme of opening the aircraft door under the condition of effectively reducing contact and manual opening. At the same time, to further ensure the safety of personnel, an electric opening mechanism is designed.



(a) closed state (b) opened state
1-door 2-the parallel link 3-Upper rocker arm 4-fuselage 5-lower rocker arm
Fig.1 schematic diagram of existing linkage mechanism



(a)closed state (b) opening state
1-door 2-the parallel link 3-Upper rocker arm 4-fuselage 5-lower rocker arm 6-spring character
Fig.2 schematic diagram of existing spring assist mechanism

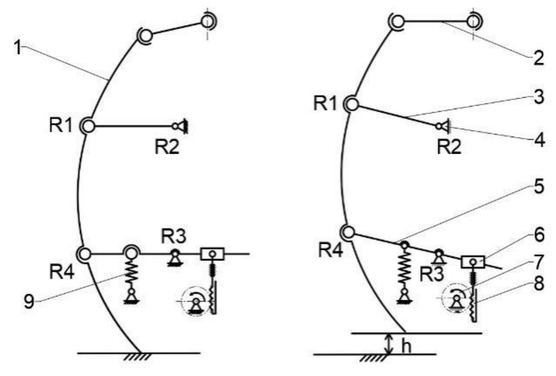
With the development of intelligent aircraft door, it is necessary to design a simple and reliable electric opening system with low installation difficulty. At the same time, to effectively enhance the reliability of the system, an electric opening branch chain is designed by taking mechanical transmission as the main transmission mode. The opening of the sideward aircraft door is divided into lifting process and rotating process. The electric lifting branch of the door with shock absorber spring and gear rack transmission is designed, and the upper and lower rockers of the lifting hinge arm are used to realize the lifting of the door. A new spherical gear is designed at the top of the door as a rotating mechanism, and the spherical gear is adaptively rotated to the parallel position of the parallel link during the lifting process. After the door lift is completed, the spherical gear is driven by rack to rotate along the tangent direction, to realize the door smoothly, in order to reduce contact and reduce manual force. In addition, this paper also conducts a series of analysis on the spherical gear. In this paper, the traditional cylindrical gear is used to design a new type of spherical gear composed of arc tooth and ring tooth. Therefore, the spherical gear has multiple degrees of freedom to realize the multi-directional movement, and the feasibility of the spherical gear and rack matching as a transmission mechanism is verified. The spherical gear is used in the door scheme to realize the spherical gear rotation and no interference with other mechanisms when it is in the lifting stage. When in the rotation stage, as the main transmission mechanism, to achieve the purpose of opening the door smoothly.

II. THE DESIGN OF THE AIRCRAFT DOORMECHANISM

2.1 Design of lifting mechanism

Most of the existing doors adopt the design scheme that the center of gravity of the mechanism does not coincide with the geometric center, to achieve the effect of labor saving. The center of gravity is outside the fuselage. After the lifting stage is completed, the door will move outside the fuselage due to gravity and complete the rotation and opening stage of the aircraft along the established trajectory, to realize the whole opening process. For example, for the A320 boarding gate, to meet the motion timing of the door mechanism, two sets of parallel links with different gravity centers and geometric centers are designed at the lifting mechanism. The above mechanisms can also play the transformation function of the transmission force direction of the linkage mechanism [3]. However, in the lifting stage, it still needs artificial force to lift the door to the established track, and the parallel link is used to make the door turn out of the fuselage.

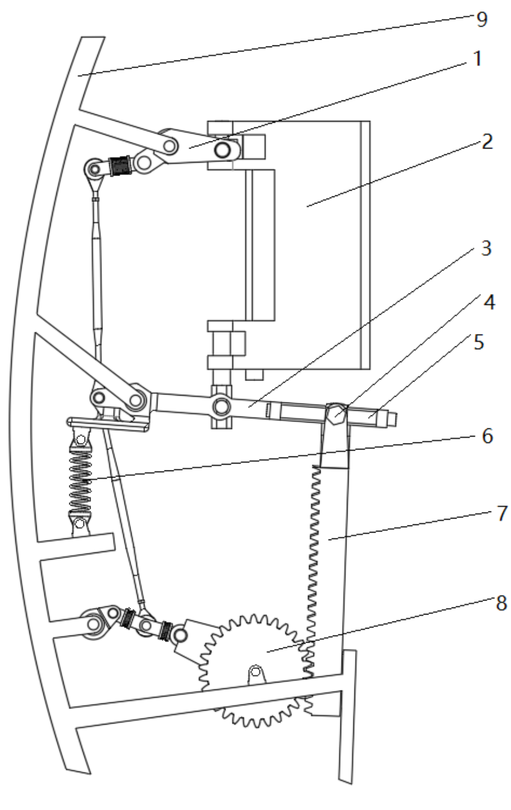
The lifting mechanism is improved on the previous mechanism. The motor is used to drive the gear, and the gear rack is used to drive the aircraft door to complete the lifting stage. The gear and rack can be designed according to the height required for lifting, as shown in Fig. 4. The mechanism takes gear 1 as the prime mover to drive the rack 2 to move in the vertical direction. At the same time, the trajectory of rack 2 is determined by the guide groove. The slider 3 is connected above the rack 2, and the rack 2 and the slider 3 can rotate relatively. The slider 3 can move on the fine link 4. The rotation of the lower rocker arm 5 is realized by combining the mutual rotation between the slider 3 and the rack 2 and the mutual movement between the slider 3 and the fine link 4. At the same time, the upper rocker arm 7 and the lower rocker arm 5 are always parallel to constrain the cabin door to rise along the arc along the fixed trajectory. The rising height of the cabin door is determined by the rising height of rack 2, to realize the lifting stage of the cabin door. The door is equipped with a spring 8, which can achieve two assist effects by controlling the length and state of the spring: the spring is compressed when the cabin door is closed, and further protection is provided by elastic force when the cabin door is closed; the spring is stretched in the closed state, and the lifting mechanism is assisted by the elastic force during the opening of the door. At the same time, the door can be opened faster in emergency situations to reduce losses.



(a) closed state (b) opening state

1 - door 2 - parallel link 3 - upper rocker arm 4 - hinge 5 -lower rocker arm 6 - slider 7 - gear 8 - rack 9- assist spring

Fig. 3 schematic diagram of aircraft door opening mechanism

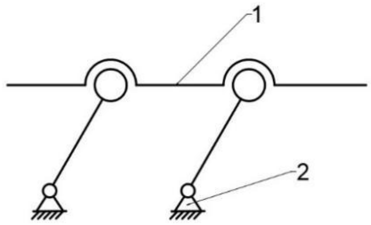


1- upper rocker arm 2- hinge 3- lower rocker arm 4- slider 5-slider link 6- assist spring 7- rack 8- gear 9- door

Fig. 4 lifting mechanism

2.2 Design of rotating opening mechanism

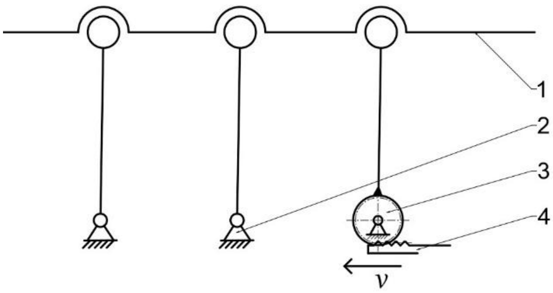
To ensure the safety of the door and avoid the accidental opening of the door, the lifting assist mechanism should not provide the load to make the door open when the door is completely closed. The rotation and opening stage of the existing sideward aircraft door is mainly due to gravity, that is, the center of gravity of the cabin door is outside the fuselage [1]. The parallel link is used to constrain its trajectory, as shown in Fig.5, to achieve the predetermined opening effect. At the same time, the door is fixed through gust lock after opening, to avoid the loss caused by the door shaking [4]. It is precisely because the center of gravity is outside the fuselage that additional force is required during the closure phase to enable it to close. However, during the flight, the door still has the trend of opening outward, coupled with the pressure difference inside and outside the door, so that it still exists in the risk of opening during the flight.



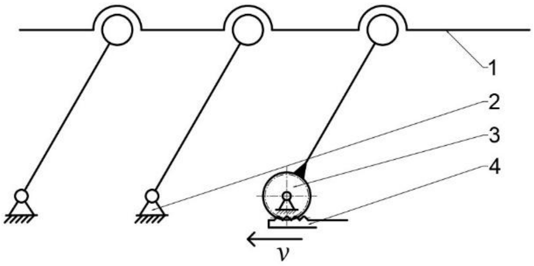
1-door 2- fuselage

Fig.5 schematic diagram of existing rotary open mechanism

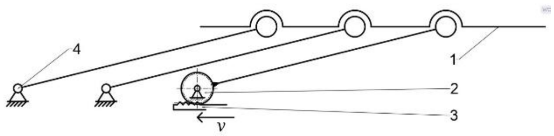
The rotary mechanism is improved on the original parallel link, and the gear rack is used to realize the rotation and opening of the door. As shown in Fig. 5, the mechanism takes the rack as the prime mover to drive the rotation of the spherical gear (the center of the spherical gear is fixed), to drive the rotation of the parallel bars and realize the opening and closing of the door. The multi-degree-of-freedom spherical gear and rack are used as the outgoing mechanism scheme, as shown in Fig.6 [5]. Through the movement of the lifting mechanism, when the door is lifted, the spherical gear rotates normally to the parallel position of the parallel four-bar mechanism, and the spherical gear and the transferred rack reach the established matching position. In this process, the meshing state of the spherical gear and the rack does not affect the motion of the rack. In this process, the bars of the parallel four-bar mechanism are always parallel, and the angular displacement, angular velocity, and angular acceleration of the three connecting rods are also always equal, which can fully ensure the stability of the motion attitude of the door at the exit stage and ensure that the door is parallel to the fuselage after lifting along the shape curve and the cabin door opens along the fuselage.



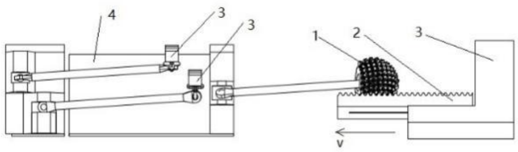
(a)closed state



(b) opening process



(c) opening state
1-door 2-spherical gear 3-rack 4-fuselage
Fig.5 schematic diagram of rotating opening mechanism



1-spherical gear 2-rack 3-fuselage 4-door
Fig.6 Rotating open mechanism

III. DESIGN ANALYSIS AND APPLICATION OF SPHERICAL GEAR

Compared with the two existing spherical gear formation methods, the spherical gear designed by Zhang Litong et al. is shown in Fig. 7(a)[5], and the spherical gear designed by Professor Pan Cunyun is shown in Fig. 7(b)， we take a different design approach [6].

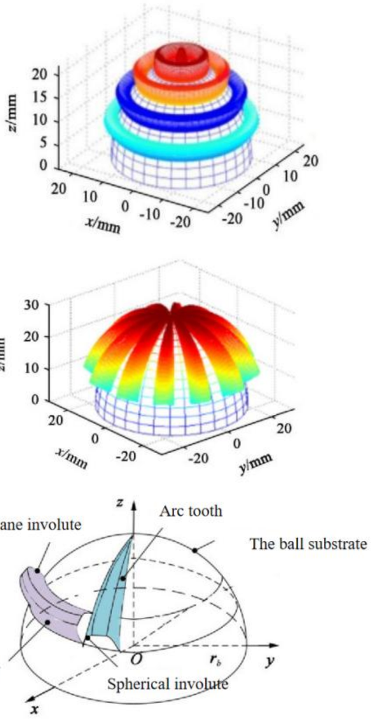


Fig7(a). Zhang Litong's spherical gear model

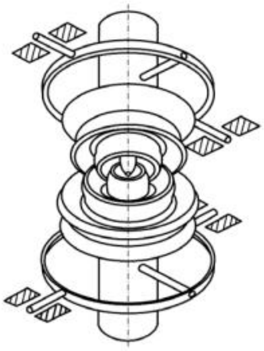


Fig7(b) Pan Cunyun's spherical gear model

The new spherical gear design is derived from an involute cylindrical gear. Firstly, the involute equation of the cylindrical gear is derived using Fig. 8.

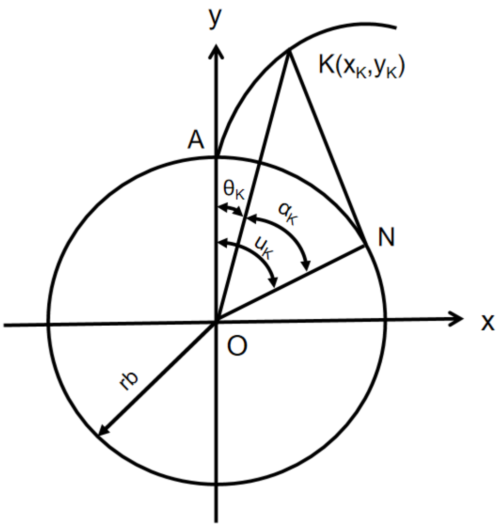


Fig.8 Cylindrical gear involute Cartesian coordinates

According to the generation principle of plane involute, the coordinate system of the involute line is established. r_k is the radial direction of point k, and α_k is called the pressure angle of point k on the involute. r_b is the radius of the base circle, where $u = \theta_k + \alpha_k$ is the rolling angle of the involute, the expansion angle θ_k, and the pressure angle α_k.

The roll angle of the involute line is:

$$cos\alpha_k = r_b \,/\, r_k \qquad (1)$$

$$tan\alpha_k = (\alpha_k + \theta_k)/r_b = \alpha_k + \theta_k (2)$$

Therefore :

$$\theta_k = tan\alpha_k - \alpha_k (3)$$

From the above equation, it can be seen that the expanded angle θ_k is a function of the pressure angleα_k, so it is called the involute function. It is denoted by $inv\alpha_k$:

$$inv\alpha_k - \theta_b = tan\alpha_k - \alpha_k (4)$$

The polar coordinate equation for involute lines can be obtained from the above two equations [8]:

$$\begin{cases} r_k = r_b/cos\alpha_k \\ \theta_b = inv\alpha_k = tan\alpha_k - \alpha_k \end{cases} (5)$$

When involute is represented in Cartesian coordinates, its equations can be obtained from the Fig.8:

$$\begin{cases} x_k = r_b sinu_k - r_b u_k cosu_k \\ y_k = r_b cosu_k + r_b u_k sinu_k \end{cases} (6)$$

The involute equation (6) can provide a certain basis for the modeling of the spherical gear. In this scheme, two involute cylindrical gears are respectively rotated 360° along the normal direction of the section, i.e., Fig. 9(a), and radial direction, i.e., Fig. 9(b), and then intersect, and the new cylindrical gear is obtained by taking the common part after the intersection. The designed new involute spherical gear has several ring gears distributed according to the latitude and longitude on the spherical surface. The number of gear teeth on the weft at different heights of the spherical crown decreases from low latitude to high latitude, and the design can ensure that the size of each gear tooth is similar.

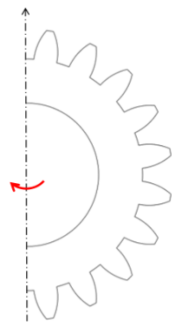


Fig. 9(a) The cylindrical gear rotates in the normal direction

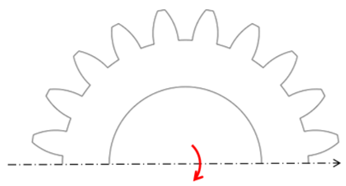


Fig. 9(b) the cylindrical gear rotates in the radial direction

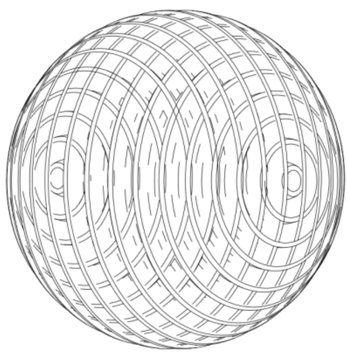


Fig.10 spherical Gear Generation Diagram

In the gear ring, two adjacent gear rings together form the outer contour of an involute gear tooth, the outside of the two adjacent gear rings is the meshing surface of the involute gear teeth, and the adjacent gear rings have different The number of teeth, the back-to-back adjacent teeth on the two adjacent toothed rings are not interfered when the two spherical gears are meshed with a tooth core to connect the adjacent teeth together，which is a new type of spherical gear[7].

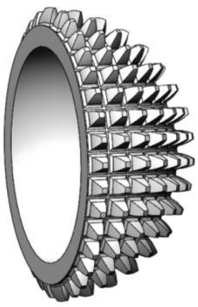


Fig.11 3D model of spherical gear

The use of an embedded concentric sphere as the motion center of the spherical gear (which is fixed to the top linkage of the door), enabling it to move radially along the rack under the drive of the rack, the model design is shown in Fig. 12. The rack and spherical pair will provide two degrees of freedom respectively a spherical gear and rack with the transmission of the moving pair and a spherical gear rotation pair.

It is worth noting that when the spherical gear during the lifting stage, the spherical gear will rotate around the center of the spherical along the weft, as shown in the Fig.13, which will not move relative to the rack, which ensures the stability of the door during the lifting stage.

And during the rotation-out phase, the spherical gear will act as the transmission mechanism.

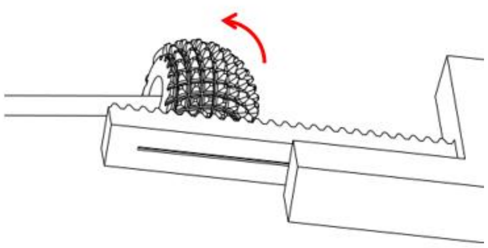


Fig.12 the state of the spherical gear in the lifting stage

In particular, the original moving part of the transmission mechanism is a rack, and the rack is pre-mounted on the fuselage and the established length of the guide groove is provided, which should be the same as the required guide for the spherical pair to rotate to the maximum angle during the transmission process (that is, the maximum angle of the door opening is less than 180°). The movement of the spherical gears drives the connecting rod to open the door smoothly outward.

The aircraft door is adjusted to the final installation position by using the electric traction spherical gear device to transport to the designated installation position, and the control system controls the rotary mechanism to drive the vertical movement of the terminal flexible gripper and rotate 180° horizontally.

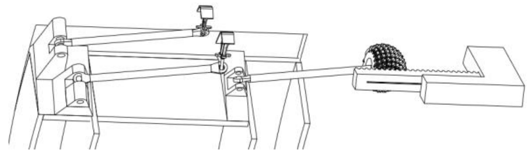


Fig.13 the rack drives the spherical gear to rotate

IV. CONCLUSION

This paper presents an electric opening branch chain of sideward opening aircraft door with spherical gear drive. The electric lifting of cabin door is realized by gear rack drive, and the electric rotation of cabin door is realized by spherical gear and rack drive. The designed new spherical gear rotates around the vertical axis of each other by the straight gear surface, and then intersects the obtained entity, namely the obtained spherical gear. The electric opening branch chain has the advantages of small starting torque, reasonable motion trajectory and high energy conversion rate. It realizes the electric opening function of the cabin door and is easy to install. It can be effectively applied to existing civil aircraft.

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