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NEW MECHANICAL MODEL FOR THE SCROLL MECHANISM AND ITS MECHANICAL ANALYSIS

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ABSTRACT

As a new approach and a replenishment of the lack of useful and suitable mechanical model in the past, the authors for the first time employed a pair of one crank — two sliders mechanism as a general mechanical model for all kinds of driving arrangement system of scroll compressor. These work revealed some general requirement and working conditions for all kinds of structures of scroll mechanism and provided a theoretical and proper understanding of some working principle specially the working conditions of radial compliant mechanism.

INTRODUCTION

Scroll compressors are quickly gaining popularity in many applications, and the fixed-orbiting driving arrangement scroll system is very common in commercial production today[1],[2].This arrangement has the advantage of being mechanically simple, but it generally requires higher machining precision in order to obtain good performance. Radial compliant design is a good approach to solve this problem. Unfortunately, the radial compliant design in the current applications, which is mainly effected by means of a flexible link between the main crank shaft and the orbiting scroll, also has the disadvantage of generating large variation in inertial force carried by the flank in variable speed or large capacity applications. A big activity in recent years has addressed co-orbiting and co-rotating driving arrangement scroll compressor. But many people are perplexed by these driving arrangement and indeed no any useful and perfect mechanical model for scroll compressors was in use in the past, so much more work has to be done to get proper cognition on this subject. A new mechanical model built by the authors is presented in this paper. It is pursued to lead people to get a good understanding of all kinds of structure of scroll compressor.

MECHANICAL MODEL

The mechanical model built by the authors for orbiting scroll in a fixed-orbiting arrangement scroll compressor employs one crank and two sliders and is composed of three parts except frame and four lower pairings as shown in Fig.1. According to the principle of kinematics of machinery, we can easily know it is a constrained kinematics chain with one degree of freedom.This mechanism restricts the orbiting scroll,which is rigidly fixed to the slider-1,in a curvilineal translation manner. It is quite evident that the radius of the circular curvilineal translation path is definite by the crank,which represents the crank shaft of scroll mechanism.

A complete set of fixed-orbiting arrangement scroll compressor is diagrammed in Fig.2. Comparing it with the model of orbiting scroll shown in Fig.1, the difference is that it contains a fixed scroll, which is rigidly connected to the frame and has a inner surface identified with the envelope of the locus generated by the outer surface of orbiting scroll when it orbits in a restricted curvilineal translation manner. It is of importance to note that the point B, at which the fixed scroll and orbiting scroll contact each other, provides a void restraint, this can not change either the degree of freedom of original mechanism or the circular curvilineal translation manner of the orbiting scroll.

A conventional radial compliant mechanism developed from the fixed-orbiting construction is described by means of the model as shown in Fig.3. It has a flexible link between the main crank shaft and the orbiting scroll and this construction provides a radial compliant effect at the meshing point B between two scroll members by means of adjusting the radius of crank shaft.

The co-orbiting driving arrangement of scroll mechanism in which both scrolls are allowed to orbit with independent radial constraints is shown in Fig.4. One of the scroll members, named driving scroll, is moved by the crank-1 while the other, named free scroll, is driven by the driving scroll and its motion is determined by geometry of this mechanism and gas force. Therefore a pair of mechanical model as shown in Fig.1 are involved in this system.

MECHANICAL ANALYSIS OF CO-ORBITING ARRANGEMENT OF SCROLL MECHANISM

The mechanical system shown in Fig.4 is composed of six parts except a frame and eight lower pairings. If the contact at point B between two meshing profiles is always keeping in a higher pairing manner, this construction is also a constrained kinematics chain with one degree of freedom. Let us go to a complex case and proceed an analysis to a pair of practice scrolls with an involute profile in order to confirm that the link of high pairing exists at point B. As shown in Fig.5, a driving scroll, which is rigidly connected to slider-1 and is driven by the crank-1, has an involute profile generated by a circle O_1, while a free scroll, which is rigidly connected to slider-4 and is driven by the driving scroll, has an involute profile generated by a circle O_2. The both circles O_1 and O_2 have equal radii, a. According to the method of analysis of direct-contact mechanisms[3], the problem needed to be solved here is to validate the conjugate relation between the two profiles.

We set up the coordinate systems: S_1 (X_1, O_1, Y_1) and S_2 (X_2, O_2, Y_2), rigidly connected to the driving and free scrolls respectively. According to the properties of parallel-crank four-bar linkage, we can find that the driving scroll and the free scroll share a common rotational center O. Now we set the third coordinate system S (X, O, Y) rigidly connected to the frame.

Equations of the involute profile of the driving scroll in S_1 are given as follows,

$$X_1 = a(\cos\phi + \phi\sin\phi) \tag{1}$$

$$Y_1 = a(\sin\phi - \phi\cos\phi) \tag{2}$$

where, ϕ is the involute angle.

Equations of the involute profile of the free scroll in S_2 are also given as follows,

$$X_2 = a[\cos\phi + (\phi + \pi)\sin\phi] \tag{3}$$

$$Y_2 = a[\sin\phi - (\phi + \pi)\cos\phi] \tag{4}$$

By transferring Eqs.(1) and (2) from S_1 to S, then from S to S_2, we get equations of the driving scroll in S_2 as follows,

$$X_1' = a(\cos\phi + \phi\sin\phi) + R_{ord}\cos\alpha - R_{orf}\cos(\alpha + \gamma) \tag{5}$$

$$Y_1' = a(\sin\phi - \phi\cos\phi) + R_{ord}\sin\alpha - R_{orf}\sin(\alpha + \gamma) \tag{6}$$

Where R_{ord} and α represent the length and the rotational angle of the crank-1, R_{orf} and β represent the length and the rotational angle of the crank-2 respectively, and γ represents the difference between the rotational angles of the two cranks. The parametric Eqs.(5) and (6) represent a family of planar curve locus, which is generated by the involute profile of the driving scroll in the coordinate system S_2 when the mechanism is driven by the crank-1. If its envelope exists, it must satisfy the following equations,[3]

$$\frac{\partial Y_1'}{\partial \phi}\frac{\partial X_1'}{\partial \alpha} - \frac{\partial Y_1'}{\partial \alpha}\frac{\partial X_1'}{\partial \phi} = 0 \tag{7}$$

By solving the Eq.(7) we can get,

$$\alpha = \phi - \tan^{-1}\frac{R_{ord} - R_{orf}\cos\gamma}{R_{orf}\sin\gamma} \tag{8}$$

Let the angle $\theta_0 = \tan^{-1} \dfrac{R_{ord} - R_{orf}\cos\gamma}{R_{orf}\sin\gamma}$. As shown in Fig.5, through point O_2 we draw a normal line of line segment OO_1 and it intersects OO_1 at point G, then through point O, we draw another normal line of line segment O_1O_2 and it meets the extension of line segment O_1O_2 at point M. Certainly,angle θ_0 represents $\angle O_1O_2G$ and $\angle O_1OM$. Now we can write Eq.(10) as following,

$$\alpha = \phi - \theta_0 \tag{9}$$

Substitution of Eq.(9) into Eqs.(5) and (6) yields the following equations,

$$X = \left[a + R_{ord}\cos\theta_0 - R_{orf}\cos(\theta_0 - \gamma)\right]\cos\phi + \left[R_{ord}\sin\theta_0 - R_{orf}\sin(\theta_0 - \gamma) + a\phi\right]\sin\phi \tag{10}$$

$$Y = \left[a + R_{ord}\cos\theta_0 - R_{orf}\cos(\theta_0 - \gamma)\right]\sin\phi - \left[R_{ord}\sin\theta_0 - R_{orf}\sin(\theta_0 - \gamma) + a\phi\right]\cos\phi \tag{11}$$

If the conjugate relation between the two scroll profiles involved in this mechanism exists, the Eqs.(10) and (11) must be equivalent to Eqs.(3) and (4) respectively. Comparison of these two group equations yields,

$$R_{ord}\cos\theta_0 = R_{orf}\cos(\theta_0 - \gamma) \tag{12}$$

$$R_{ord}\sin\theta_0 = R_{orf}\sin(\theta_0 - \gamma) + a\pi \tag{13}$$

$$\theta_0 = \tan^{-1}\frac{R_{ord} - R_{orf}\cos\gamma}{R_{orf}\sin\gamma} \tag{14}$$

Based on Eqs.(12)、(13) and (14), we can obtain following results:

1.When all of these parameters involved in the Eqs.(12)、(13) and (14), including a 、R_{ord}、R_{orf}、θ_0 and γ are satisfying the Eqs.(12)、(13) and (14), the Eqs.(10) and (11) are equivalent to the Eqs.(3) and (4) respectively, then the conjugate relation between the profiles of the driving and the free scroll in this mechanism exists. Certainly the contact between them is in a higher pairing manner over the whole round and this construction is a constrained chain with one degree of freedom.

2. In Fig.5, the triangle OO_2O_1 is referred to a driving triangle. Two sides of this triangle, R_{ord} and R_{orf} , are constant once the compressor is assembled. Another side of this triangle, O_2O_1, which is symbolized as R_{or}, indicates the distance between the centers of the two scroll. Actually it is a radius of the rotation of driving scroll about the center of the free scroll and usually we name it orbiting radius of scroll geometry. In general, R_{or} remains constant, and also the angle γ is constant. In this case, the transmission ratio between driving and free

scroll is uniform. The variation of R_{or} will occur with the results of the change of the shape of the driving triangle and the phase angle γ due to partial tolerance of scroll profiles 、 liquid 、 or debris. At this moment the rotating speed of the free scroll varies and soon it returns to normal speed. This case represents the effect of radial compliance of co-orbiting arrangement mechanical system.

3. Also in the driving triangle we can find out the requirement for a pair of meshing scrolls as $R_{orf} + R_{or} \geq R_{ord}$. This is a general requirement for the co-orbiting arrangement. When the radius, R_{orf} decreases to 0, the angles γ and θ_0 become 0 and $\pi/2$ respectively, then $R_{or} = R_{ord}$. In this limiting case, the free scroll center O_2 and the common curvilineal translation center O are coincident,and the free scroll becomes stationary. The co-orbiting arrangement system becomes the fixed-orbiting arrangement system. In this case, the scroll geometry orbiting radius, R_{or}, is equal to the radius of the driving crank, and it can not be changed to adapt to any disturbance. So the radial compliant behavior disappears.

CONCLUSION

1. The orbiting scroll in a scroll mechanism can be modeled by a mechanism composed of one crank and double sliders. A co-orbiting arrangement scroll mechanism can be described by a pair of the mechanisms of one crank and double sliders.

2. The co-orbiting arrangement system is the general case of the scroll mechanism. The general requirement for this arrangement is, $R_{orf} + R_{or} \geq R_{ord}$. The limiting case $R_{or} = R_{ord}$, represents the fixed-orbiting arrangement scroll mechanism.

3. The variation of scroll geometry orbiting radius caused by the partial tolerance 、 liquid 、 or debris can not interrupt the operating of the co-orbiting system, so it is a radially compliant driving system.

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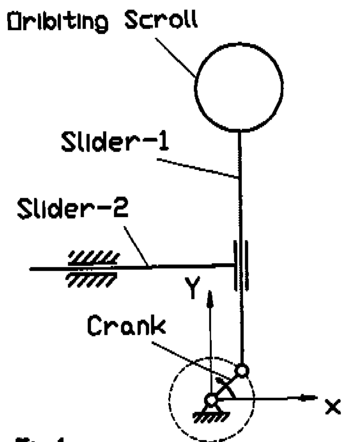

Fig.1
The mechanical model for the orbiting scroll

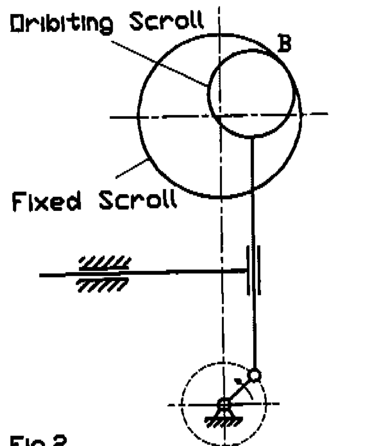

Fig.2
The mechanical model for the fixed-orbiting scroll compressor

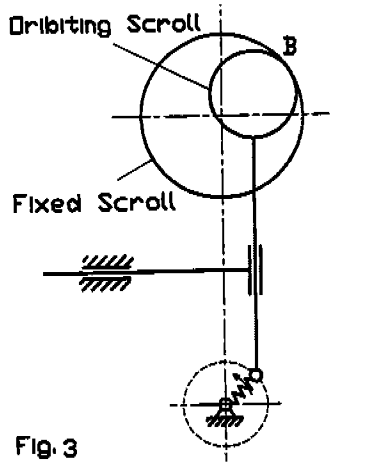

Fig.3
The mechanical model for a fixed-orbiting scroll compressor with a radial compliance

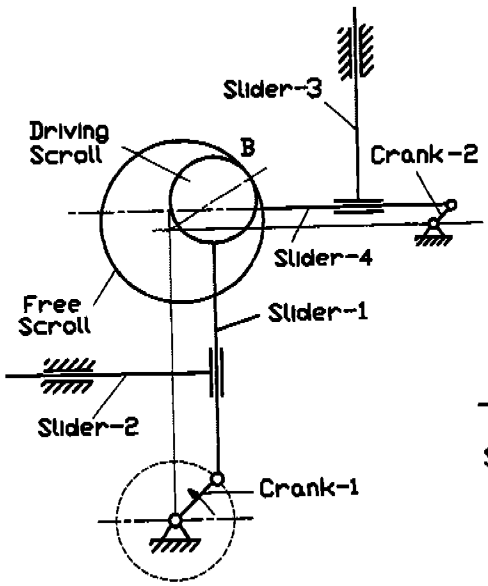

Fig.4
The mechanical model for a co-orbiting scroll compressor

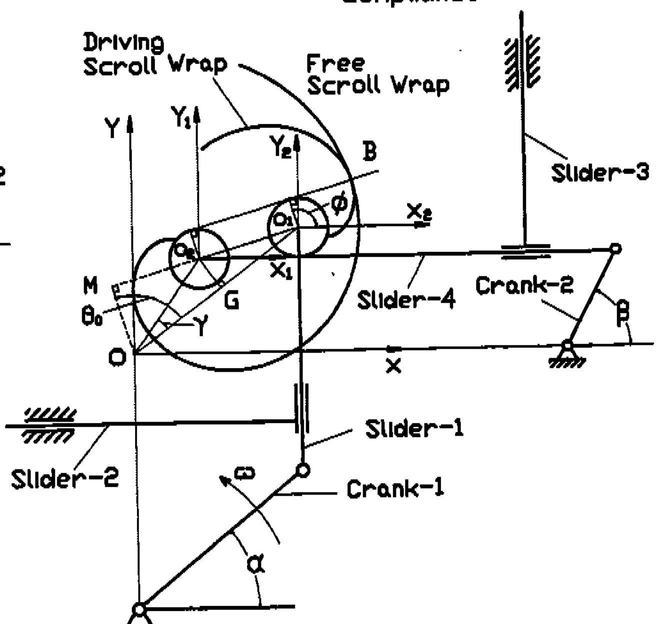

Fig.5
The illustration for the operation of a co-orbiting scroll compressor with the involute profile