Reciprocating machines crosshead drive analogue

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Abstract. The possibility of developing the reciprocating machines crosshead drive analogue which main advantage is the reaction absence of the resource-defining translational pair is shown. For achieving the objective, the fundamental postulate of mechanics about the solid body movements addition is used and it is proved that when two identical in module counter rotations around the parallel axes are added, the final translational movement used for changing the power machine working cavity volume is obtained. In the proposed mechanical drive the side reaction eliminating conditions of the resource-defining translational pair are developed.

Key-words: crosshead drive, side reaction minimizing, solid body movements addition.

1. Introduction

The mechanical systems of many power machines are based on the crank-slider scheme in which the rotational movement is transformed into translational one and vice versa [1-4]. The main disadvantage of such mechanisms is the inherent side reaction of the translational pair. The reaction is formed by the main power flow, rings weight forces, rings inertial loading in motion. The side reaction modulus and nature generate the pair variable force and friction power and, as a consequence, active surfaces uneven wear and initial geometry loss, as well as the pair backlash shifting with possible impact process generation in the backlash. These phenomena have a negative impact on the movable joint performance and the mechanical system resource of the power machine as a whole.

2. Problem statement

The problem of power machine movement conversion mechanism design solution developing with minimizing the translational pair side reaction is stated and solved in the paper.

3. Theory

Numerous design solutions mechanisms of converting the rotational movement into the translational one and vice versa [5-6] are known. A successfully implemented crosshead scheme deserves attention. In the mentioned scheme the translational pair comprises two components with the crosshead component perceiving the side reaction but being structurally formed outside the operating process area, being cooled well and forcedly lubricated, and piston group is connected to the crosshead by the short intermediate ring, which points move straight with the axis coinciding with the working cylinder axis, thereby the piston group side reaction is excluded. It is evident that the crosshead scheme compared to the traditional crank-slider one is more complex in engineering implementing. The reciprocating machines crosshead drive analogue is proposed. Its kinematic scheme provides pinion cage 3 input rotational movement conversion into satellite 2 point B linear movement, and point B through ring 5 transmits the linear movement to piston 6 which is presented in figure 1.
Figure 1. The drive scheme. 1, 6 is the shaft; 2, 4 are the satellites; 3 is the pinion cage; 5 is the intermediate ring; 6 is the slider.

Figure 1 shows that the scheme includes shaft 1 implemented as the gear wheel with internal teeth engaged with the different-sized satellites based on pinion cage 3, satellite 2 kinematic radius $r$ equals to the half of the internal toothed gear wheel kinematic radius $R$. The second satellite 4 has a smaller size and serves as a counterweight producing the gearing forces symmetry. The kinematic pair center $B$ is located on the satellite circle having the kinematic radius $r$. According to figure 1 the scheme is two-dimensional, but the scheme elements and consequently the moving rings points trajectories are located in the parallel planes [7-8].

The conversion of pinion cage 3 rotational movement into slider 6 translational one and vice versa occurs by using the scheme property. The given property is that when rolling the satellite over the epicycle with this kinematic dimensions ratio, the intermediate ring 5 crank pair center $B$ installed in the kinematic radius $r$ moves along the hypocycloid degenerating into the straight line located diametrically, into the reference point $B$ trajectory. Therefore, there is no side reaction of the translational pair C.

The kinematic model of the proposed mechanical drive is based on the implementation of the mechanics fundamental postulate namely that the instantaneous translational movement is obtained when adding two solid bodies rotations with equal but oppositely directed angular velocities around the parallel axes.
In this case, when the circle inner circumference of radius \( r \) is run along the circle of radius \( R=2r \), the point \( B \) forms a hypocycloid being described by the following equation in the parametric form in the accepted coordinate system (figure 2):

\[
\begin{align*}
  x_B &= (R - r) \sin \varphi - r \sin\left(\frac{R - r}{r}\right) \varphi, \\
  y_B &= (R - r) \cos \varphi + r \cos\left(\frac{R - r}{r}\right) \varphi.
\end{align*}
\]  

(1)

Provided \( R=2r \), the following equation is derived:

\[
\begin{align*}
  x_B &= 0, \\
  y_B &= R \cos \varphi.
\end{align*}
\]  

(2)

From (4) it follows that the trajectory of point \( B \) is a straight line, which excludes the formation of the lateral reaction usually occurring in other schemes in the resource-defining translational pair \( C \). The connecting rod 5 performs the simplest straight-line movement along with the slider 6 according to the harmonic law. This favorably distinguishes the proposed drive scheme of a piston machine from the known ones.

A similar result can be obtained using the vector form of the kinematic model recording:

\[
\overrightarrow{r}_B = \overrightarrow{R} + \overrightarrow{a}.
\]  

(3)

If (3) is projected on the \( x \) and \( y \) axes, the following formulas are obtained:
The reference point B movement speed is obtained by differentiating (4) over time:

\[
\dot{y}_B = -R \sin \varphi \frac{d\varphi}{dt} = -R \omega_3 \sin \varphi.
\]

4. Results discussion

The possibility of developing the reciprocating machines crosshead drive analogue which main advantage is the resource-defining reaction absence of the translational pair is shown.

The drive, performed according to the proposed scheme, is implemented in the mechanical system of miniature gas cryogenic machines, the quality criteria of which is the exclusion of heat leakages, high mechanical efficiency and lack of lubrication in friction units.

5. Conclusions

On the basis of implementing the mechanics fundamental postulate about the solid body movements addition it is proved that when two identical in module counter rotations around the parallel axes are added, the final translational movement used for changing the power machine working cavity volume is obtained. Moreover, in the proposed mechanical drive the side reaction eliminating conditions of the resource-defining translational pair are developed.

6. References

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