Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 13 (22): 5192-5197, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.5192.5197

Study about the New Mechanism Crank-group Driving Mechanism

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Abstract: Crank-group driving mechanism is a new type of transmission mechanism it belongs to the elastic mechanism with clearance. It has many advantages and its application prospect in the light machinery industry is very wide. This study introuduced the mechanism's origin and movement form, the existence conditions of crank-group, the structure and configuration of the mechanism its function and characteristics the influence of clearance between kinematic pairs and the methods of decreasing the influence of clearance.

Key words: New transmission mechanism, existence conditions of crank-group, configuration, clearance, decreasing the influence

INTRODUCTION

Origin of the mechanism: In some special light industrial machinery, such as packaging machinery, tobacco machinery, special drill press and printing machinery, there's a need to realize the parallel output and make multiple parallel-axis rotate synchronously, while the transmission torque is not big. If using gear, tooth belt or chain to transmit power, generally it has to increase some sizes of mechanism's structure to avoid the interference in space. But this way will make the machinery immense in sight. In order to solve the above problems, we put forward a kind of new transmission mechanism which is called crank-group driving mechanism.

Crank-group driving mechanism (Fig. 2) is evolved from the double crank driving mechanism (Fig. 1). In the new mechanism, there's one (or two) crank is taken as the active crank it drives the plane truss to do the translation and the plane truss drive other cranks to move. The movement rules of crank-group driving mechanism and the double crank driving mechanism are the same and the plane truss can be regarded as the connecting rod of double crank driving mechanism. When the connecting rods are in translation, all the cranks rotate in uniform motion at the same speed. The motion states of any two cranks in mechanism are the same and synchronized in time.

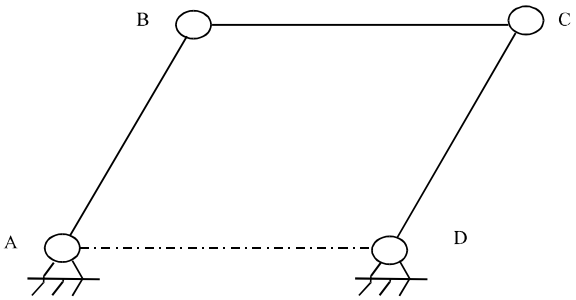

Fig. 1: Schematic diagram of double crank driving mechanism

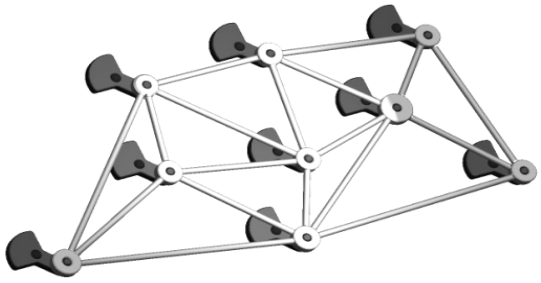

Fig. 2: The general form of the crank-group driving mechanism

The movement form of new mechanism: To tell from the aspect on form of movement, crank-group driving mechanism is a kind of uniform mechanism that rotates continuously. Its transmission ratio is constant and it belongs to a "mechanism of constant speed ".To tell from the relative position of the input and output shaft it can realize the relative motion of "parallel axis". Therefore, the crank-group driving mechanism can be called a link mechanism of parallel axis with fixed speed.

Explanation: The concept of uniform mechanism that turns continuously is as follows. The instantaneous speed ratio between the driving link and the driven link is a constant or approximate constant value. When the

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driving link rotates uniformly, the driven link also rotates uniformly or approximately rotates uniformly. The general movement geometric feature of it is that the position of instantaneous center of relative velocity between the driving link and the driven link won't change.

The existence conditions of crank-group: There're two conditions that must be satisfied for the existence of the crank-group: (1) It meets the existence conditions of double crank in the parallelogram mechanism between any two crank in the mechanism, that is to satisfy the length conditions for parallelogram mechanism: The equivalent two sides are parallel and equal; (2)When a driven crank and active crank formed a parallelogram mechanism, the rest of all the driven cranks become "virtual constraints" and they won't produce real constraint to the mechanism. In the design process of the crank-group driving mechanism it has already strictly met the first requirement. At the same time, in order to realize the generalization and standardization of the new mechanism, we adopt the idea of assembling and put forward the discretization structure of truss. Then eliminated the necessity to set clearence and ensure the manufacturing error of node position for truss. Through the adjustability of assembly, the redundant cranks naturally became the "virtual constraints".

Meanwhile by using lightweight materials, can fully guarantee the stiffness of mechanism and control the elastic deformation in a small range. Thus, the existence conditions of the crank-group are clear and can be realized relatively easy.

CONFIGURATION AND CHARACTERISTICS OF MECHANISM

Structure and configuration: From the structure's point of view, crank-group driving mechanism belongs to a kind of elastic mechanism with clearance. Breaking through the rigid assumption about constructional elements in the classical mechanism, we regard it as an elastic mechanism with clearance and assume that clearance , error and elastic deformation are all in the range of control. When the distribution of cranks and motion coupling meet some kind of conditions, the redundant crank pair can be regarded as virtual constraints and the mechanism can be released from the state of indeterminate. Then it can be regarded as a mechanism with established trajectory. Generally speaking, the existence of clearance has very big effect on the dynamic response of the mechanism. However, the flexibility of the connecting rod in the mechanism can play a role delaying for the clearance.

The rod pieces of crank-group driving mechanism is made from light materials and there may appear tiny deformation in movements. When the external force vanished, each component would recover back to the state before deformation. So it can be taken as a kind of elastic mechanism. It has the advantages of elastic mechanism: Can emerge elastic deformation, can absorb vibration and there's quantitative relationship between force and deformation, etc.

Crank-group driving mechanism is composed by lower pair and a number of components and it belongs to a kind of lower pair structure. Each of its components forms a closed chain and it is a closed chain mechanism. Compared to the widely used open chain mechanism it has many advantages, such as compact structure, great rigidity, high precision, fast response speed and so on. What's more, the movements of all components are in parallel planes. Therefore, the crank-group driving mechanism is a kind of planar mechanism with multiple closed loops. In addition, the number of public constraints of each ring is the same, we don't need to calculate each ring respectively. So the freedom of mechanism can be calculated in accordance with the freedom formula of single closed loop plane mechanism and the freedom of mechanism is one. Choose a crank arbitrarily and provide it with power and take it as the driving link, then the movement of other components is certain, too.

Speaking from the aspect of configuration method, crank-group driving mechanism is a kind of combination mechanism. Its combination way is diverse and we can choose different combination ways according to actual needs, such as series type (Fig. 3) and parallel type (Fig. 4) and so on.

Function and characteristics of mechanism: Crank-group driving mechanism can drive multiple parallel axis to rotate synchronously, i.e to realize the movement of parallel output. Compared with the traditional driving mechanism, crank-group driving mechanism has the following advantages:

- The structure is simple and compact and it's easy to manufacture with low cost
- The design and manufacture of the components of mechanism realize seriation, standardization
- It has high driving accuracy and shortens the transmission chain greatly
- The repetition rate of using is high and it will improve the production efficiency
- The power consumption of machine tool is small and with little mechanical noise in the working process
- The movement in work is stable and reliable and its moving range is very wide

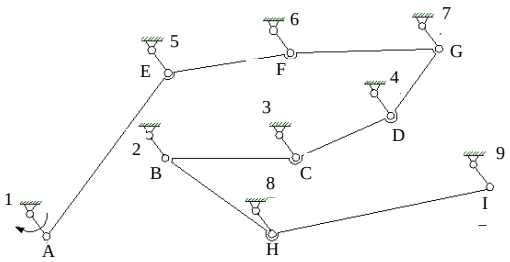

Fig. 3: Series type of the mechanism

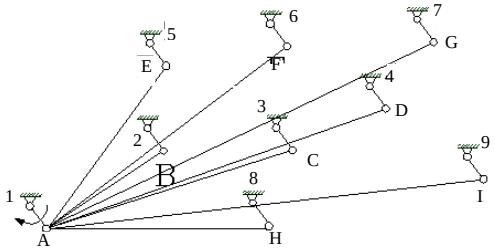

Fig. 4: Parallel type of the mechanism

What's more, the mechanism adopts the concept of separation and we can combine, install and remove components of mechanism according to the needs in actual production. It meets the requirements in various kinds of occasions and saves material and environmentally friendly.

The new driving mechanism has a lot of advantages and its application prospect in the light machinery industry is very wide. It is a kind of planar closed chain mechanism with good rigidity. But in planar closed chain mechanism, the widely existence of virtual constraints led to the result that the mechanical system is rather sensitive to the errors An and Ren (2002), so it's a necessary to control the manufacturing error and assembly error. Originally, according to the transmission principle to analysis the mechanism, there is no geometry motion error and assembly error, but the fact is not the case. In the mechanism, the kinematic pair is the link to connect two components and allow relative motion between two components. In addition, there are manufacturing error, assembly error and wear, so the existence of clearance in kinematic pair is inevitable An and Huang (2002). Therefore, crank-group driving mechanism belongs to a kind of elastic mechanism with clearance. Elasticity refers to that it's made of lightweight materials and has tiny ability of elastic deformation, when the external forces vanished, the mechanism can restore the initial state. The clearance means that there a certain clearance between each kinematic pair. The purpose of setting aside a certain clearance in each kinematic pair is to guarantee the machining precision of the mechanism, enable the mechanism operate normally, prevent the stress in assembly. But at the same time, the existence of clearance also led to some unfavorable impact on mechanism.

THE INFLUENCE OF CLEARANCE ON THE MECHANISM

The existence of clearance will lead to the following results: (1) The motion of actual mechanism deviate from the ideal mechanism's, motion accuracy and function of the mechanism decline, or even become invalid; (2) Elements of each kinematic pair may produce collision which easily cause the impact dynamic load, increase dynamic stress and dynamic strain of components and then affect the load transmission of system, lead to the vibration and noise and fault hidden trouble; (3) Lead to the damage and failure of kinematic pair, reduce the efficiency and aggravate wear. Wear is not only a main kind of failure forms for mechanical parts but also the first reason which cause other subs equent failure (Bai *et al*., 2011).

Generally, the clearance won't cause big influence on the mechanism's static precision: It almost has no impact on the mechanism's angular displacement and the impact on the angular velocity of the mechanism is also rather small. However, the existence of the clearance between kinematic pairs changes the dynamic characteristics of the mechanism and it has great influence on the mechanism's angular acceleration. It makes the mechanism appear fluctuation, reduce the movement stability, increase the collision force in hinge joints and present the characteristics of high frequency oscillation.

Meanwhile, too tiny clearance would make the operation of the mechanism not flexible, cause severe friction, accelerate the wear of the component; while, too large clearance will lead to many other adverse effects. The bigger the clearance is, the greater the speed is, the larger the collision power between the components is, the bigger the influence on the dynamic characteristics of the mechanism is, the greater the dynamic performance of mechanism deviate from the ideal's, the worse the kinematic precision and stability is, the bigger the damage to the mechanism is, the reliability and service life of mechanism would reduce Bai (2011). Therefore, clearance in kinematic pair is one of the important factors that influence the dynamic characteristics of the mechanism and its effects on the mechanism's dynamic performance can not be ignored.

METHODS OF DECREASING THE INFLUENCE OF CLEARANCE

The existence of clearance Guo and Yue (2012) seriously affects the dynamic performance and reliability of the mechanism. Therefore, to ensure the mechanism's good dynamic performance and its reliability, measures must be taken to minimize the bad effects of clearance. So the study on kinematics and dynamics problems of mechanism with clearance has important theoretical significance and practical value. And the study about dynamics problems of mechanism with clearance has become one of the key problems to solve urgently in mechanical engineering both at home and abroad. At present, there're mainly two basic methods to solve the above problem: (1) Improve processing and manufacturing precision of the mechanism and eliminate the clearance. Because, reducing kinematic pair clearance and preventing the wear of kinematic pair in working process are effective measures to improve or ensure the motion accuracy of the planar linkage mechanism Jia *et al.* (2012) (but from the point of view of manufacturing cost it is not realistic if you want to eliminate the clearance completely); (2) Adopt reasonable design, so as to reduce the effect of kinematic pair clearance as far as possible Jin *et al.* (2001) (this method is feasible, so it has great practical significance).

Design and configuration of kinematic pair: The reasonable design of mechanism includes various factors but in terms of the crank-group driving mechanism, one of the key points is that the reasonable design and configuration of kinematic pair. For unreasonable design and configuration of kinematic pair will produce virtual constraints. If we want to realize the movement of the crank-group driving mechanism, the influence of virtual constraints in the mechanism must be eliminated. And in most cases, virtual constraints will show the influence on \the mechanical properties through the geometrical error of kinematic pair. If the specific geometrical conditions that virtual constraints exist can't be met, the virtual constraints will become actual effective constraints which affect the movement of mechanism.

Planar linkage mechanism is based on the plane constraint structure, to ensure the realization of planar motion (Li *et al.*, 2005). When planar constraints in theory due to various errors, especially the existence of geometrical errors of kinematic pair elements, destroyed the plane constraints and lead to the uncertainty of constraint it will cause a series of harmful effects to the mechanical properties of mechanism. This kind of forced plane constraint cause the result that there're widespread virtual constraints in the planar mechanism. In the crank-group driving mechanism as Fig. 5 shows, when the mechanism operates without load, 8 driven cranks are all virtual constraints. Then, if we want to make the mechanism achieve the desired law of motion, the rational design and configuration of kinematic pair it's very important.

The rational design of kinematic pair means that ensure the kinematic pair have good mechanical properties and working reliability and reduce the number of virtual constraints in the structure of kinematic pair. The kinematic pairs in crank-group driving mechanism are all turning vices, so the key to the problem is the rational design and configuration of turning vices.

Design and configuration of turning vices: Turning vices is one of the most common kinematic pairs, shaft parts usually need to be supportinged by turning vices. Generally speaking, one shaft needs two fulcrum, the main task of turning vices' design is to determine the type of two fulcrum kinematic pair. Reasonable combination of the two supportings has important influence on the following parts, the geometrical precision of the bearing, shaft assembly, running sensitivity and deformation coordination properties Pu and Ji, 2006. Fig. 6 shows the

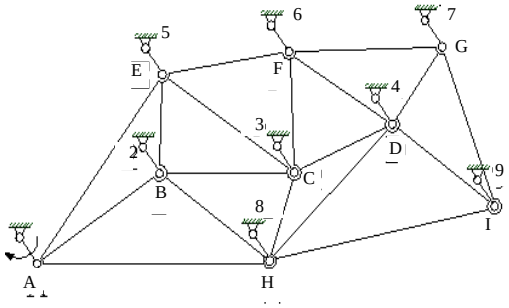

Fig. 5: Schematic diagram of crank-group driving mechanism

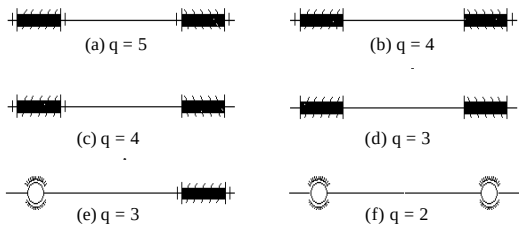

Fig. 6: Supporting combination type of shaft that are commonly used

commonly used supporting combination type of shaft and the number of virtual constraints for each combination type. Then introduce the characteristics and applications of each combination type, therefore we can know how to choose the suitable supporting combination type.

Generally, the structure shown in Fig. 6a is a kind of bidirectional fixed structure for the two fulcrums. It is difficult to assembly and the structure is very sensitive to temperature deformation, so it is used very rare. As shown in Fig. 6b, the structure is generally suitable for short axis whose span is small it's fixed by one-way for each fulcrum. This structure is relatively easy to assembly but can't guarantee accurate axial positioning for shaft parts. As shown in Fig. 6c, the structure is suitable for long axis whose span is large. It adopts the structure that the fulcrum is bidirectional fixed at one end and the other end mobile. If the axial movement of freedom for shaft parts has been bound in the loop, the structure whose two sides are both mobile as shown in Fig. 6d can be used, compared with the structure in Fig. 6c it can reduce a virtual constraint. If the axis coaxial tolerance of the bearing for two fulcrums has great error, the stiffness of shaft at work is low, or have big bend or tilt, we can use spherical vices' combination structure with the role of adjusting the center, as shown in Fig. 6e and f.

Generally speaking, the number of virtual constraints for turning vices is large, the rotation accuracy is high, the stiffness is big but the moving sensitivity is low and the adaptability for temperature is bad, the manufacturing cost for bearing Sun *et al*., 2012 is high and the assembly is hard. In practical application, we can have a comprehensive consideration of various factors and choose the appropriate supporting combination type according to the requirements.

Improve the conditions of friction and lubrication: In addition, if you want to reduce the influence of clearance, the function of lubricant is also cannot be ignored. Because adding lubricant between the friction surfaces can reduce friction and wear effectively, protect the parts from rust and have the effect of cooling temperature, buffering and vibration (Wang and Liu, 2001).

So, we can fill the wedge clearance between shaft pin and bushing with lubricating oil to form extrusion hinge with oil film, in order to decrease the large deformation of elastic rods caused by the shock of kinematic pair and make the deformation response of the elastic rods show steady state changes and weaken the wave phenomenon, so as to improve the steady state performance of mechanism in operation Yang (2001). We can also take the following measures to improve the conditions of friction and lubrication, such as installing elastic components and wear bushing between bent pin and its hole. Meanwhile, in order to offset the parallelism error between the driving crankshaft and each driven crankshaft caused by the processing and assembling error, we can install spherical bearing between the bent pin on the spindle and the inner hole on rods.

CALCULATION METHOD OF REASONABLE MOVING CLEARANCE

In practical applications, the proper selection of kinematic pairs is also very important. The calculation method of reasonable moving clearance is described as follows. By reference Zhou (2006), we can see that the moving clearanceäand eccentricity and radius of the pin hole, radius of the crank shaft γ and are relevant to the relative rotation angleθ, the relationship between them is show in Fig. 7. When R andãare determined, δ is only the cosine function of the θ (Fig. 8). The value of the eccentricity will be affected by the rotation angle and also

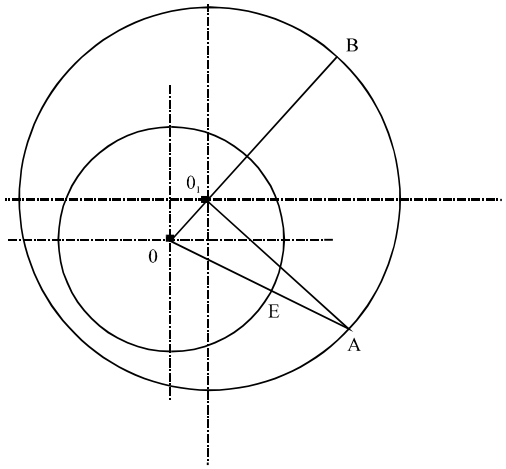

Fig. 7: Diagram of clearance

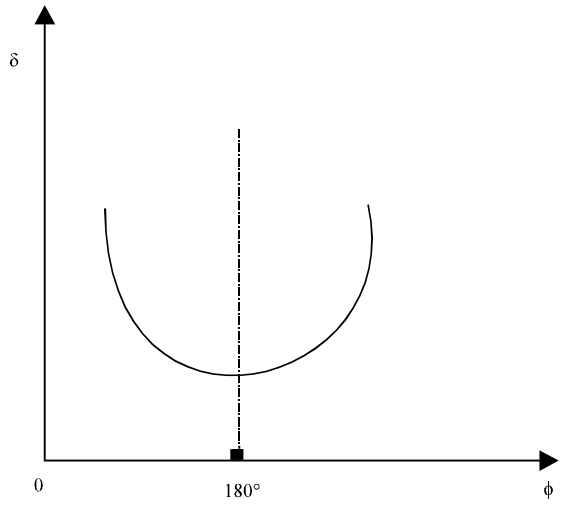

Fig. 8: Relationship between δ and φ

will be affected by the roughness between crank shaft and the pin hole at the same time.

Explanation: In Fig. 7, $OO_{1=e}$, $O_1A = R$, $OE = \gamma$, $EA = \delta$, $<OO_1A = \theta$, $<BO_1A = \varphi$.

The steps to choose reasonable moving clearance are as following:

- According to the value of h to select the cooperation relationship between shaft and hole and satisfy the condition that $\delta_{min} \geq$ the maximum deviation between crank shaft and pin hole shaft
- Work out $\delta_{1min} = h(1-\alpha)$ ① (In the formula , $h = R-\gamma$, $\alpha = e/h$, δ_1 is the most ideal moving clearance, h is the radius of the clearance, α is the relative eccentricity) According to experience, generally when $0.6 \leq \alpha \leq 0.9$, the moving clearance is relatively reasonable
- $\delta = (2.5 \sim 3)\ \delta_{1min}$

Generally speaking, in actual application, we can select the value of formula ②, or take a bit larger value according to the formula ①, both of them can meet the requirements.

CONCLUSIONS

Through the following measures, such as selecting reasonable clearance and supporting combination type, the suitable design and configuration of turning vices and improving the conditions of friction and lubrication, can reduce the various adverse effects of clearance in mechanical system at a low level of manufacture precision and production cost. Meanwhile, they can make the mechanism automatically adapt to the random variation of external working conditions and environment, make the static and dynamic work stable and reliable and reflect the features of low noise, long life, high efficiency and energy saving. At the same time, realize the compliance of manufacturing and assembly and meet the needs of the technology development for the modern mechanical product. By all the ways above, the precision of the crank-group driving mechanism and the quality of the whole mechanical system are improved and they lay the foundation for its engineering application in light industry machinery. There is no doubt that it plays an important role in the development of mechanical industry. The essay only qualitatively puts forward the point of view on the influence of clearance and the ways to decrease its bad effects, there are not enough perfect in some degree. Therefore, the quantitative study of the influence that kinematic pair's clearance have on the crank-group driving mechanism and find out a set of feasible methods of controlling the precision of clearance will also be a key point in further research.

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