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A Generalized Approach for Sensitive Analysis of Four-Bar Mechanism and Identifying Sensitive Link/s Tolerances Using Relative Velocity Method

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Abstract— The performance of a mechanism is defined as ratio of difference between calculated angular velocity ratio and ideal angular velocity ratio to the ideal angular velocity ratio. The angular velocity ratio can be calculated from velocity diagram. The paper uses a crank – rocker mechanism, a type of simple four bar mechanism in which crank rotates 360° and rocker oscillates. In the presence of manufacturing errors like manufacturing tolerances, thermal deformation, deflection of links, human errors, machine defects, etc., it is impossible to maintain a constant performance of the mechanism in bulk manufacturing. There will be slight variation in the performance due to variation in one or more links. Any manufacturing process is associated with dimensional tolerances that leads to variation in part dimensions and generally cost of manufacturing increases exponentially for closer tolerances to all links of the mechanism.

The aim of the paper is to discuss an approach to determine maximum and minimum performance variation and identify links which causes maximum performance variation. The closer tolerances should be given to that link/s only which will permit to designer to give slightly loose tolerances on remaining links.

Keywords— Mechanisms, tolerances, angular velocity, performance of mechanism

I. INTRODUCTION

Mechanisms in a machine / equipment consist of number of linkages. Any mechanism is synthesized and designed to get desired performance in terms of motion, torque, force, etc. this performance accuracy of a mechanism depends on the specified input parameters. Designed performance is very important in working of a mechanism. Even with the most precise design, when it is converted into a prototype, however; unavoidable constraints such as manufacturing tolerances, joint clearances as well as deflection in links, thermal deformation of links come into play, causing inevitable deviation of prescribed position. This ultimately affects performance of the designed mechanism. In mass production, it is not possible to verify functionally all desired characteristics and if it is so, it increases cost of production. The quality of the mechanism depends upon the tolerances specified. Design engineer wants close tolerances to assure performance of a mechanism. This closer tolerances increase cost of production. On the other, manufacturing engineer prefers loose tolerances to reduce manufacturing cost. But loose tolerances affect performance of the mechanism. Main objective of this paper is to satisfy both design and manufacturing engineers. For this purpose, we will use a set of tolerance scheme which we apply on all links of the mechanism. By applying this tolerance scheme to link lengths, we will

calculate variation in the performance of the mechanism. To calculate performance variation, we are using a graphical method named 'relative velocity method', which gives accurate results and easy to apply for any configuration of mechanism. In this paper, an attempt is made to discuss an approach to identify most sensitive link/s in a mechanism which gives maximum variation in performance of the mechanism.

1.1 Previous Work

C. C. Handa and H. T. Thorat^[1] proposed a method to determine performance of mechanism. They proposed suitable scheme of tolerances which is used to keep performance within limit. They also proposed a generalized approach in identifying control link/s using instantaneous centre so that tolerances has been given only that link/s to minimize manufacturing cost.

P. L. Bhagwat and Dr. B. M. Domkundwar^[3] demonstrates the use of a graphical method for analyzing sensitivity of linkages in terms of variation of link lengths and their effect on the curvature of the coupler curve.

2. Concept

Performance of a mechanism depends on specified input parameters like link lengths. If designed mechanism is fabricated at specified accurate dimensions, performance of the mechanism is ideal and mechanism is known as ideal mechanism. Any variation in link lengths causes variation in the performance of the mechanism. Performance variation of the mechanism can be calculated using angular velocity ratio. To calculate angular velocity ratio, 'relative velocity method' is used. Performance variation of a mechanism is expressed in percentage and calculated using formula-

Performance variation =
(Calculated angular velocity ratio – ideal angular velocity ratio / ideal angular velocity ratio) * 100
..... (1)

3. Formulation

As mentioned above, angular velocity ratio can be calculated using relative velocity method, following procedure can be applicable.

a) As we are discussing about four bar mechanism, output angle varies with respect to input angle. It means, output angle is a function of input angle. Thus,

$$\theta = f(L_1, L_2, L_3, L_4, \phi)$$

Where,

L_1 – length of fixed link (link d)

L_2 – length of input link (link a)

L_3 – length of coupler link (link b)

L_4 – length of output link (link c)

ϕ – Input angle

θ – Output angle

b) Calculate output angle, θ using formula

$$\theta_{1,2} = 2 \tan^{-1} \{ (-B \pm \sqrt{B^2 - 4AC}) / 2A \} \dots \dots \dots (2)$$

Where,

$$A = (1 - K_2) \cos \phi - K_1 + K_3 \dots \dots \dots (3.1)$$

$$B = -2 \sin \phi \dots \dots \dots (3.2)$$

$$C = K_1 - (K_2 + 1) \cos \phi + K_3 \dots \dots \dots (3.3)$$

And,

$$K_1 = (L_1 / L_2) \dots \dots \dots (4.1)$$

$$K_2 = (L_1 / L_4) \dots \dots \dots (4.2)$$

$$K_3 = (L_2^2 - L_3^2 + L_4^2 + L_1^2) / (2 * L_2 * L_4) \dots \dots \dots (4.3)$$

Fig. Four bar chain mechanism

c) After sketching the four bar mechanism, draw velocity diagram. Points below discussed will be helpful to draw velocity diagram.

As input velocity (ω_2) is given, calculate V_2 using formula

$$V_2 = \omega_2 * L_2 \dots \dots \dots (5.1)$$

Since link L_1 is fixed, points 'a' and 'd' take as one point.

Draw a length equal to V_2 and perpendicular to link L_2 in given sense of direction from point 'a'.

Then, draw a length V_4 having unknown magnitude from point 'd' in same sense as of ω_2 perpendicular to link L_4 .

Draw another line V_3 having unknown magnitude and direction perpendicular to link L_3 .

Point of intersection of line V_3 and V_4 gives point 'c'.

Measure length V_3 and V_4 .

Calculate output angular velocity using formula

$$\omega_4 = V_4 / L_4 \dots \dots \dots (5.2)$$

3.1 Angular Velocity Ratio:

It is the ratio between output angular velocity and input angular velocity. It is given by

$$R_V = \omega_4 / \omega_2 \dots \dots \dots (6)$$

This angular velocity ratio can be used for further calculations.

4. Procedure:

Ideal performance can be calculated using specified links. This performance will change if dimensions of one or more links change. It is difficult to identify for what change in dimensions how much change in performance of the mechanism. For that purpose, a set of tolerance scheme is used. Tolerances of ± 10 mm in the interval of 0.1 mm will be given for one or more links. Procedure for calculating performance variations is as follows:

1. For specified position of the mechanism, first of all, change dimensions of link 1 in the specified interval up to specified tolerance scheme and kept remaining 3 links (L_2 , L_3 and L_4) as original. Calculate a set of performance variation for link 1 using defined formula.

2. Then, change dimensions of link 2 in same manner as discussed above and kept remaining 3 links (L_1 , L_3 and L_4) as original dimensions. Calculate a set of performance variations for link 2.

3. Then, change dimensions of link 3 in same manner as discussed above and kept remaining 3 links (L_1 , L_2 and L_4) as original dimensions. Calculate a set of performance variations for link 3.

4. Then, change dimensions of link 4 in same manner as discussed above and kept remaining 3 links (L_1 , L_2 and L_3) as original dimensions. Calculate a set of performance variations for link 4.

5. Observe all results and identify maximum and minimum values of performance variations.

6. Identify link/s which gives maximum performance variation.

Give closer tolerances to that link/s only. This will allow designer to give broader tolerances to remaining links

5. Software development and results:

Computer plays an important role in all engineering disciplines, including design synthesis and analysis. Analytical technique and graphical techniques are too cumbersome to carry out by hands. With the help of computer, it is now within grasp. For the above synthesis and analysis, we are going to develop software which will be helpful for manufacturing industries to get accurate performance in minimum manufacturing cost. Software includes:

1. Programming for sketching a mechanism.
2. Programming for calculating performance variations.
3. Programming for identifying sensitive link/s.

Quick result will be getting using this software and it will reduce time as well as manufacturing cost.

Conclusion:

The proposed method is useful in determining the tolerances required for individual links in a mechanism. Here, we are discussing about a four bar mechanism. With the same logic, we can develop software for any mechanism like six bar mechanism, slider crank mechanism, etc. and try to make any mechanism ideal.

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