OTPI521 Synopsis of

"Tolerancing kinematic couplings"

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Distance Learning
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1.) Abstract

This report is a synopsis of a technical paper "Tolerancing kinematic couplings". In this paper, the relationships between manufacturing cost and tolerances of the kinematic couplings are described. The position and orientation of kinematic mount are derived using parametric expression of positions of each contact points. It contains the manufacturing errors, and solved using iterative process of multivariate analysis.

The manufacturing cost is described as a function of manufacturing process, nominal dimensions of the parts of kinematic mounts and tolerances of dimensions. The tolerances of the dimensions are allocated using an optimization algorithm for minimizing the manufacturing cost.

2.) Introduction

Kinematic couplings are used for precision positioning of one rigid body, and its application and usefulness are well known. Many kinematic mounts now are used for precision machines such as optical systems. Resting position and orientation accuracy is important, but the precision of the kinematic mount is due to tolerance or adjusting which both increase total costs.

In this paper, a method for allocation tolerances to the dimensions of the kinematic mount with minimized manufacturing cost is introduced. The calculated kinematic mount is shown in Figure. 2.1.

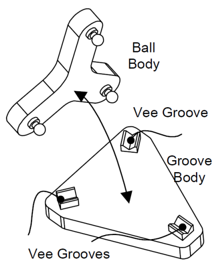


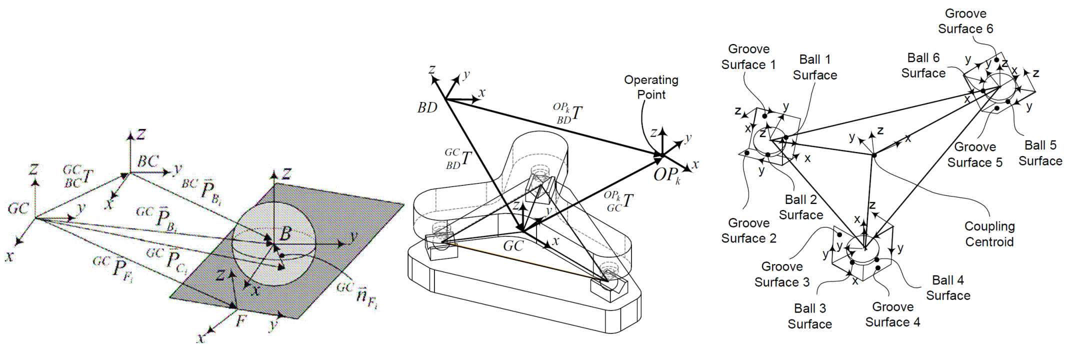
Figure.2.1 Kinematic mount with balls and grooves

3.) Tolerance allocation of kinematic mount

Tolerance allocation is operated with the following 4 aspects.

(1) Describe the geometry and dimensional variation in a mathematical form
(2) Combine dimensional variation in the ball body and groove body to estimate variation in the resting position and orientation of the ball body
(3) Relate assembly variation to the performance requirements of the kinematic coupling
(4) Relate dimensional tolerances to manufacturing costs

Resting position of kinematic mount is represented in parametric expression, shown in Figure.3.1. The position is described as a position vector expressed in coordinate system located at the centroid of a triangle defined by the centers of the three ball or grooves' coupling centroid. And the each vectors are transformed by the homogeneous transformation matrices (HTMs). The position error includes the manufacturing error.



(a) (b) (c)

Figure.3.1 Parametric expressions of kinematic mount

4.) Multivariate error analysis

Variation at operating point is also described in matrices form derived from Taylor expansion. Multivariate error analysis uses the linear approximation. This can describe the deviation in the matrices form. The algorithm uses this matrices expression, solving the equation iteratively.

5.) Tolerance optimization

The cost of the ball and groove bodies depends on the manufacturing process and dimensional tolerances. The total cost depends on the dimension (tj), range (Rj), and the three constants (aj, bj, cj), given as Eq.1. The three constants are given in Tabe.5.1, given by Chase[2]. These constants can be used for exemplary kinematic coupling.

Optimal tolerances for the dimensions are determined using nonlinear constrained optimization. We can solve the problem with Eq.2.

$$C_{\text{total}} = \sum_{j=1}^{l} \left(\frac{c_j R_j^{a_j}}{t_j} \right)^{1/b_j} \quad \cdots\cdots \text{Eq.1}$$

$$\text{minimize} \left(\sum_{j=1}^{l} \left(\frac{c_j R_j^{a_j}}{t_j} \right)^{1/b_j} \right) \text{such that} \quad \cdots\cdots \text{Eq.2}$$

$$0 \le \sigma_{x_r} \le \sigma_{x_r}^{\max},\ 0 \le \sigma_{y_r} \le \sigma_{y_r}^{\max}, 0 \le \sigma_{z_r} \le \sigma_{z_r}^{\max}, 0 \le \sigma_{\alpha_r} \le \sigma_{\alpha_r}^{\max},\ 0 \le \sigma_{\beta_r} \le \sigma_{\beta_r}^{\max},\ 0 \le \sigma_{\gamma_r} \le \sigma_{\gamma_r}^{\max}$$

Table.5.1 Constants for relationship between cost and dimension

Dimension	Process	a_j	b_j	c_j
Thickness of the plate	Milling	0.4431	2.348	0.0355
Length of a leg	Grinding	0.4323	1.385	0.0217
Diameter of a ball	Lapping	0.3862	1.052	0.0130
Location of a hole	Milling	0.4431	2.257	0.0255
Height of a vee-groove	Grinding	0.4323	1.421	0.0228

6.) Conclusion

This paper gives the tolerance optimization method using parametric expression of resting position and orientation. The deviation at operating point also derived in matrices expression and used for multivariable error analysis. The algorithm solves the equations, which describe manufacturing costs and dimension tolerance iteratively, and gives the optimized allocation of tolerance for each dimension of kinematic mount.

7.) Comparison with other papers

This paper describes the cost of kinematic mount, but many other papers describe the design of kinematic mount[(3)-(8)]. This paper is useful for optical system designers in terms of total designing considering manufacturing cost. We can calculate the estimate of cost considering tolerance of each dimension with systematic calculation. If we have to estimate manufacturing cost of kinematic mount, this paper gives us a lot of useful knowledge, and we should read the other technical reports listed in this paper.

8.) Bibliography

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