PRECISION AND STABILITY OF MAXWELL-TYPE KINEMATIC MOUNTS

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1. Introduction

Kinematic mounts (KMs) are often used in high-precision applications since they are self-locating and free from backlash, allow sub-micrometric re-positioning, can accommodate differential thermal expansions and their behaviour can be represented in closed form (Slocum, 1992). Their main drawback is constituted by the high contact stresses that are to be analysed via the nonlinear Hertz theory (Hertz, 1895). The most common KM design configuration is the Maxwell-type KM constituted by 3 V-grooves on one end (typically the support) and 3 balls on the other end of the mount (typically the supported piece) so as to achieve an exact constraint of all 6 spatial degrees of freedom (Figure 1).

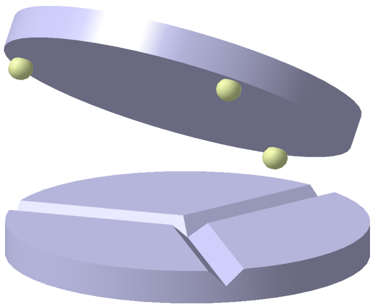

Figure 1. Maxwell type 3-V groove KM.

The aim of this work is to analyse the influence of mechanical parameters on KMs' behaviour and especially on their positioning precision and stability. An example of a KM used to support a large structure is considered.

2. Analysis of KM precision and stability

The analysis of the considered KMs comprises force and moment balance equations, expressions for the calculation of stresses and deflections at the contact points and error motion calculation. Knowing the external loads and the geometry, the loads at each groove-ball interface and the respective contact point reactions can be computed from the overall force and moment balances. The nonlinear behaviour of point contacts between elastic isotropic solids, where the contact area is small compared to the radii of curvature and the dimensions of the involved bodies, encompasses then the calculation of the equivalent Young's modulus and contact radius. The elliptical contact area, the interpenetration distances and the contact stresses can hence be obtained.

It was shown that the approximate methods of calculation of the characteristic KM parameters are appropriate for most high-precision applications (Zelenika, 2004). By performing experimental measurements (Figure 2), it is thus proven that in the whole elastic deformations range the correspondence of the theoretical values with the experimental ones is within the intervals of uncertainty of the latter. The KMs' precision is shown to be comparable to the surface finish (100nm range).

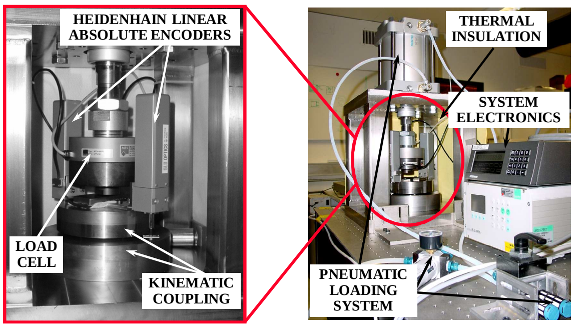

Figure 2. Used experimental set-up.

The calculated stresses and strains allow next, under the assumptions that the change of the distances between the KM supports is small, to calculate the couplings' error motions about its centroid (Slocum, 1992) –Figure 3.

3. Design example

The calculation procedure is hence implemented in structured software algorithms and used to assess the characteristics of a KM aimed at supporting a large vacuum chamber of a particle accelerator facility. The input data define the maximal support area diameter of 1 m and the load to be supported as 5 kN with an additional 300 N lateral load. The KM elements are chosen having silicon nitride balls and tungsten carbide grooves.

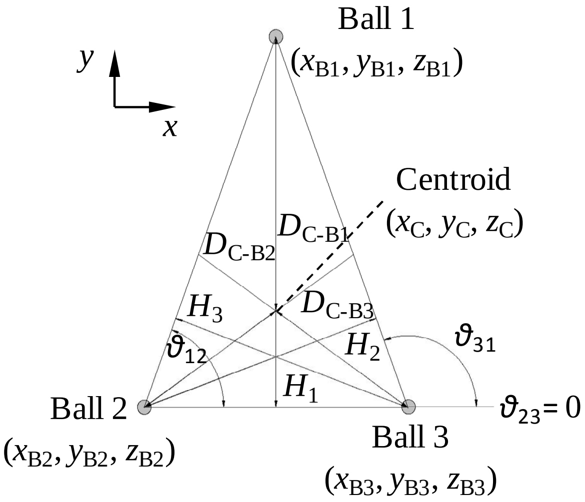

Figure 3. Top view of KM's geometry.

The stress calculations allow establishing that, for a certain coupling radius R_C and a maximal allowable stress q_{all} (Esk; Gimex), suitable ball radii are R_b = 18 mm (Figure 4) and V-groove arch radii are R_g = -21.6 mm.

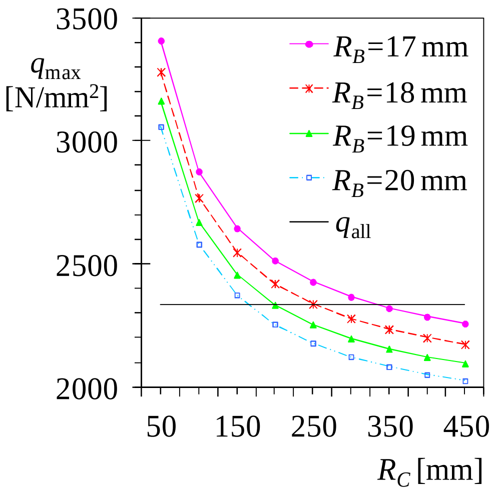

Figure 4. Dimensioning of the KM elements.

In terms of KM's stability, two design configurations are considered, i.e. one where the normals to the planes containing the contact forces are directed towards the centroid of the coupling (case A) and the other (case B) where the normals bisect the angles between the balls (Slocum, 1992). Obviously, the KM will lose its stability when one of the contact forces becomes negative. The stability conditions could thus be determined for different KM geometries and lateral load orientations. In Figure 5, as an example, are shown the stability regions when the lateral load is directed as the positive KM x-axis and passes through the KM centroid. In could hence be shown that, when the length of the KM is extended with respect to its width, the configuration of case B is generally better from the stability point of view.

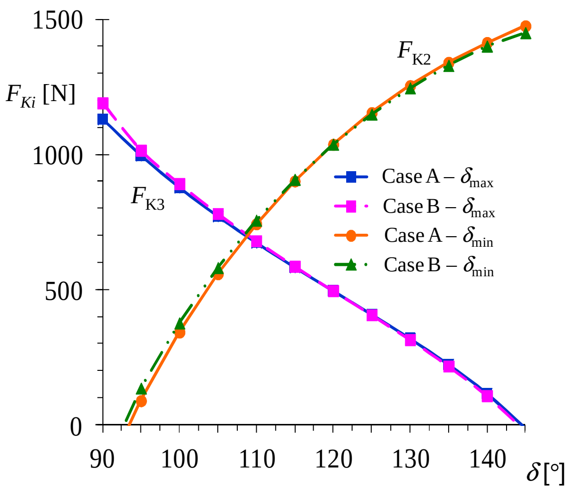

Figure 5. Stability region of various KM configurations.

4. Conclusions

A thorough analysis of the precision and stability of Maxwell-type KMs is performed. Suitable algorithms are implemented and applied to a design example, allowing the stability regions for different designs to be established.

Acknowledgements

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5. References

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