Analysis of the impact of the central connecting element stiffness on the accuracy characteristics of micro-positioning elastic module with "Butterfly" flexures

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***Abstract*— Angular orientation and micro-positioning systems with elastic monolithic flexures are one of the preferred in precision mechanical engineering, especially in cases where high accuracy and minimal deviation of the axis of rotation or low to no maintenance and operation in adverse/contaminated environment are required. These advantages are related to the fact that the module is monolithic, which practically means that there are no assembled elements and there is no friction between the various components of the system. This paper presents the results of the study of the stiffness of the central element that is connecting the elastic flexures and its impact on the deviation of the center of rotation and transfer curve of the micro-positioning elastic module.**

Keywords*— *accuracy characteristics, positioning, angular orientation, elastic guides, measuring module, flexures, axis of rotation

I. INTRODUCTION

Micro-positioning systems with elastic modules find application in the orientation and positioning of various optical and laser systems, as well as in various types of analysis or measurements, where high accuracy and stable axis of rotation is required.

Main aspect of the design of a micro-positioning elastic module is definitely the elastic flexures, and their geometry is a major factor affecting its accuracy and operational characteristics. A major disadvantage of this type of mechanisms is their small range in case minimal deviation of the axis of rotation is required. The working range is often within 2-4º. There are also elastic systems that provide a large range, but the main challenge is the deviation of the axis of rotation, which is also the main accuracy parameter. One of the widely used elastic guides that provide a relatively large working range and relatively small deviation of the axis of rotation are "butterfly" type flexures or designs based on it. The developed micro-positioning measuring module with elastic flexures is based on a „butterfly" flexure but with optimized geometry (Fig. 1) that is reaching operational range of ±22.5º. Position 1 indicates the elastic flexures, position 2 is the central connecting element that provides the internal connection between the elastic flexures, and position 3 and 4 are the outer rings - lower fixed and upper movable respectively. The design consists two coupled rotary modules of butterfly type with a common central axis and depend on the operational needs, it is possible to choose which of the two outer rings is movable or fixed.

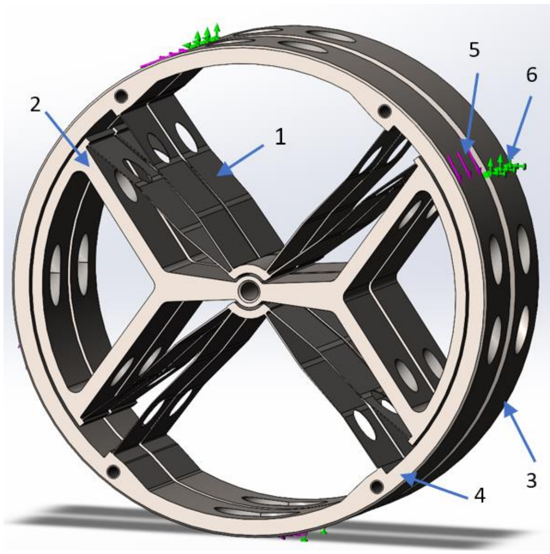

Fig. 1. Micro-positioning elastic module with monolithic design - scheme

The nonlinear elastic mathematical model for finite element analysis is used for the purpose of the study, with the assumption that the material is isotropic. Simulations were made using CAD/CAM software. The scheme of the study shown on fig. 1 is as follows: one of the two outer rings pos. 3 (in this case the lower one) is fixed (marking shown on pos. 6), and on the other ring pos. 4 (upper) torque is applied, and direction of the torque is indicated by pos. 5. The movement or in this case the rotation obtained depending on the value of the applied torque shows the transfer curve of the elastic

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module, i.e. the angular motion depending on the applied moment. Based on this curve, the rotation value at a certain torque can be determined. In order to be able to compare the different flexure's geometry, the same dimensions (nominal) of the module are used, i.e. all dimensions except the shape of the guides shall be the same. The focus of this study is the behavior of the elastic module with a change of the stiffness of the central connecting element, which plays an important role connecting all the elastic guides and distributing the forces after their deformation.

II. Butterfly Flexures Design

One of the main components of the elastic system is the central connecting element, which is the connection between the individual pairs of flexures (Fig. 2).

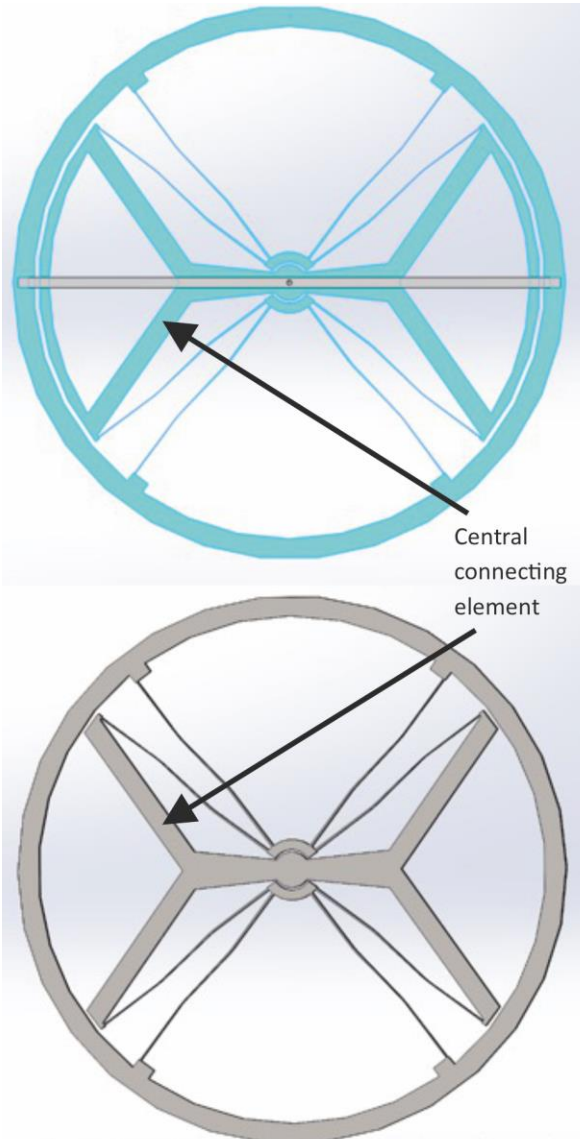

Fig. 2. Central connecting element of micro-positioning elastic module with "butterfly" design

It is also the element that transfers the resulting forces between the different elastic flexures and balancing these forces between the flexures. Therefore, its geometry can have a direct influence on the accuracy parameters of the elastic micro-positioning module, and here its weight and stiffness would play an important role. As weight could have a negative effect on module performance, the stiffness could have a positive effect on characteristics i.e. the greater the stiffness, the less the impact on accuracy performance would be.

The impact of the connecting element stiffness on the accuracy characteristics can be observed because under loading it is deformed excessively, leading to an undesirable effect on the elastic module's performance. This study was performed taking into account two variants of the connecting element - with a support/reinforcement between the two ends, as shown in fig. 2 (up) and without such a support as shown in fig. 2 (down). The research done in this way shows the importance of the stiffness of the element, as in the first case the weight increases, but the stiffness also increases, while in the other case, the weight is reduced but the stiffness is also reduced. The scheme of the study is the same as explained in Fig.1. The load is torque only, with no additional forces in order to study the ideal case and exclude any other additional factors i.e. to focus on the central connecting element geometry only.

The results are shown on Fig. 3, where the transfer curve using center element without reinforcement is compared to the nominal design with reinforcement of the connecting element.

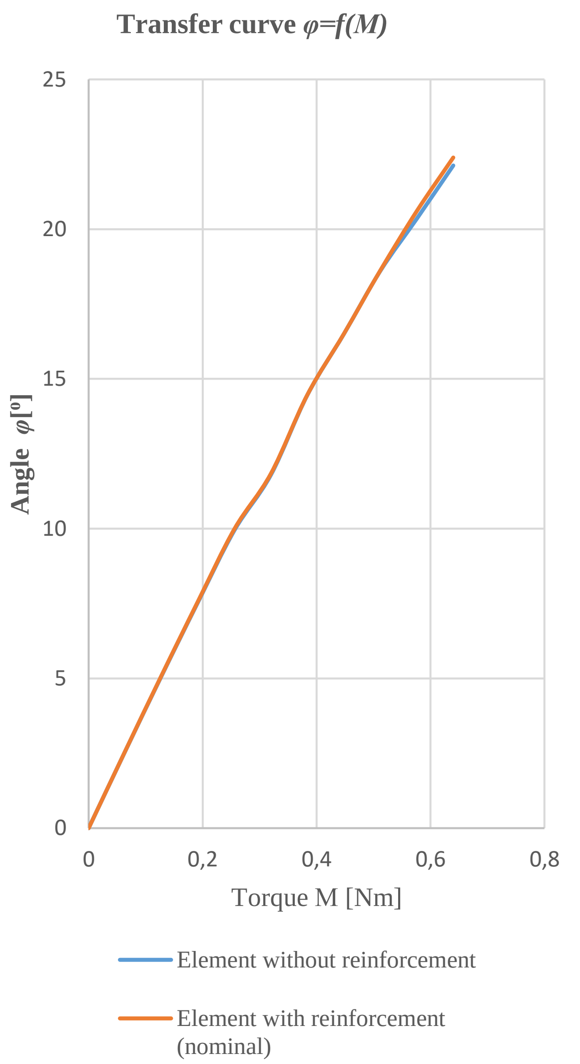

Fig. 3. Transfer curve in case central element with reinforcement (nominal design) and without reinforcement is used

The graph shows that there is almost no impact on the transfer curve, which indicates that the impact of the central link, as long as it is stiffer than the flexures, does not directly affect the operational range. Nevertheless, that there is almost no impact on the transfer curve it is not the same case with the deviation of the center of rotation.

On fig. 4 are show the results of the deviation of the center of rotation along X-axis.

between stiffness and weight, the issue in this case is the weight. Making the structure heavier would lead to greater stresses in the flexures and greater deformations along the Z axis, so this element should be as light as possible. Increase of the weight also lead to increase of the inertial forces during movements of the elastic module. The design that has been chosen and present in this paper is as light as possible and at the same time rigid enough in order to have minimal impact on the accuracy characteristics.

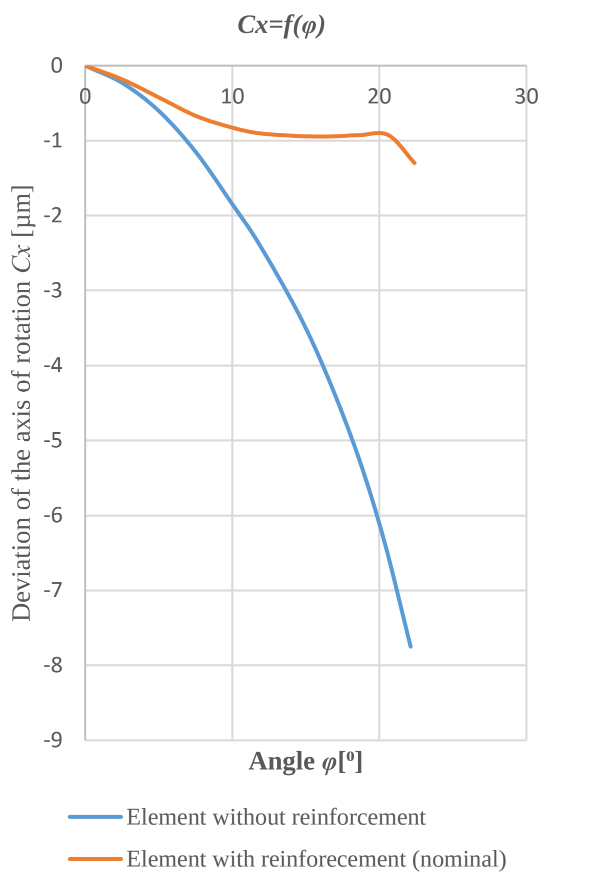

Fig. 4. Deviation of the center of rotation along X-axis in case central element with reinforcement (nominal design) and without reinforcement is used

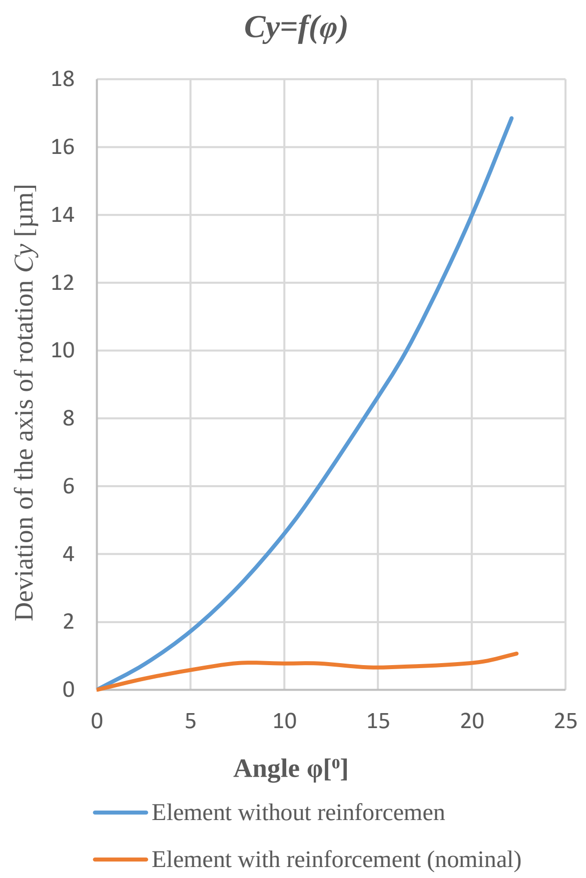

Fig. 5. Deviation of the center of rotation along Y-axis in case central element with reinforcement (nominal design) and without reinforcement is used

The deviation of position of the center of rotation reaches close to 8µm in case no reinforcement of the central connecting element is used, compared to the reinforced element where the X-axis deviation is close to 1µm, is a significant difference. Therefore, the stiffness and the geometry of the central connecting element is one of the most important parameters impacting the accuracy performance of the micro-positioning elastic module.

The deviation along the Y axis is similar, which can be seen on the graph shown on Fig. 5. The value along the Y axis reaches 17µm, which means that the stiffness of the central connecting element has even greater impact than some of the considered asymmetries resulting after manufacturing errors, i.e. the stiffness or in other words the design of the central connecting element is among the factors that most strongly affect the deviation of the center of rotation and accuracy characteristics in general. A strong dense middle connecting element would theoretically achieve the best results for accuracy, but it is not so simple as it is always a tradeoff

Conclusion

The results of the simulation analysis of the central element with optimized design show that the stiffness of the element is one of the main factors that have negative impact on the deviation of the center of rotation and the accuracy characteristics.

With insufficient stiffness, the deviations can be many times larger, reaching up to 17 µm in the case analysis and thus exceeding the deviations that can be caused by the errors during production of the elastic flexures.

Improving the strength characteristics is most often done by adding various stiffeners along the central connecting element, but this often leads to an increase in weight, which causes increase of the deviation of the center of rotation along the Z axis, so in the design of monolithic elastic angular positioning systems, it must be taken into account what is the maximum weight providing such stiffness that allows reaching the required accuracy characteristics.

During production of this central connecting element, the errors also have negative impact by introducing an additional asymmetry like the errors during production of the elastic flexures. A direct dependence between the working range of the module (±22.5º) and the stiffness of the central connecting element is not observed as long as it has a greater strength than the elastic flexures combined.

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