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Development of Special Metrological Devices

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Abstract: . The paper is focused on the complex design of metrological equipment for the verification and calibration of torque sensors. It describes the specifics of the design of such a device from the origin of the idea for its creation and the entire process of construction including the methodology of creating a complete product. Describes the function of the measuring device. It describes its individual structural parts. It points to the specifics of the structural design with regard to metrological requirements. It solves the issue of measurement uncertainty and the effect of the required accuracy on the construction of a special measuring arm made of carbon material. It presents the results of the FEM analyzes of the carbon arm and compares them with the required accuracies given by the metrological requirements. It also points out the different properties of the different carbon structures of the Pre-preg materials used to design of the measuring arm. It also presents the results of measurements of such carbon materials.

Keywords: Metrological Equipment, Torque, Design, Composite Material, FEM.

1. Introduction

The use of torque sensors nowadays finds application in various industries and various products. All sensors used in products are always calibrated before use. The calibration system is based on another torque sensor called an etalon. It is the standards that need to be calibrated regularly. The goal is to create a document that guarantees its accuracy and purpose of use. Special metrological devices are used for such purposes. In calibration laboratories, these are usually constructed using basic physical principles. Devices are usually created using metal components from special steel or carbon materials [1-7]. The new proposed device will use not only a change in the weight of the weights but also a change in the arm of the force and the construction of the arm of the device from carbon composite materials to create a moment of force. Regarding the design of the device, it is important to realize that, in addition to the traditional design activity, it is necessary to pay attention to metrological aspects, measurements of various characters in order to obtain data for FEM analyzes [8, 9].

2. Subject & Methods

A. *Design of new measuring system*

To create a moment (Moment Direction +), the arm is in a vertical position and a weight with a known mass generates zero moment (fig.1). By moving the arm in the direction of the arrow, the position of the weight in the IV quadrant is changed and a force moment corresponding to the angle of rotation of the arm is generated. When the horizontal position of the arm is reached, the maximum moment is generated. If the weight is placed on the other side of the arm and the arm is in a vertical position (the weight is in quadrants I, and II), the weight again generates zero moment. By passing the arm through quadrant II in the direction of the arrow, the moment of force is again generated depending on the rotation of the arm, (with the value of the moment -) and the maximum moment is reached when the arm with the weight is on the left side in a horizontal position. The fig. 1 represents a changing the angle of the arm with a constant loading weigh. Derivation of the required torque is also possible in another way, in such a way that the arm is constantly in a horizontal position and the weights change from the minimum weight to the maximum. Such a principle is used by default. It follows from the above that the method of deriving the required torque is possible in three ways. The first is by changing the angle of rotation of the arm, the second is by changing the weight of the weights, and the third method is a combination of changing the angle and at the same time changing the weight of the weights. This is a common design task. Due to

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the required measurement accuracy and the fact that torque derivation with an accuracy of at least the maximum torque value is required up to 2000 ± 0.04 N.m; it is a complex problem in terms of requirements for the design of the device as a whole and for the measurement systems used.

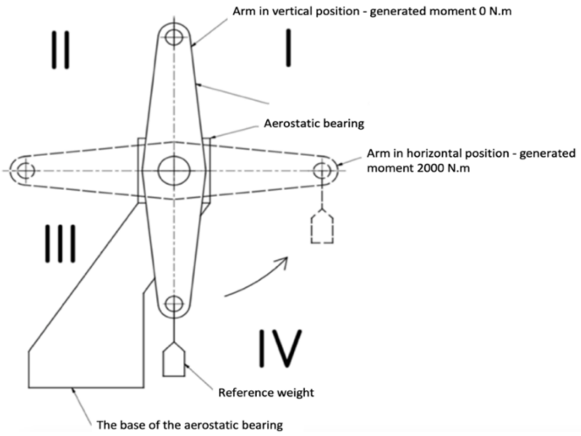

Fig. 1, The principle of torque generation by changing the position of the measuring arm

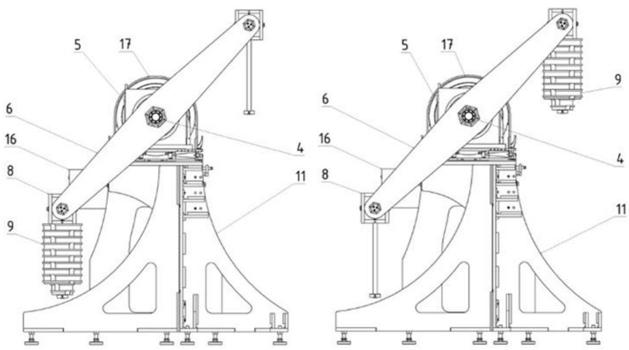

Fig. 2, View of the method of torque generation by changing the position of the measuring arm: left - using of quadrant IV, right - using of quadrant II.

B. The principle of the devices and description

The device (Fig. 3) for calibrating force moment sensors consists of a supporting two-part frame (11) with a device for adjusting the position of an aerostatic bearing (5), where the control unit (16) is located on the frame, a drive (14) on a linear guide (12), on which gearbox (13) with drive (14), connected by means of a shaft with connecting accessories (2), with a calibrated torque sensor (1), with a shaft (4) supported in a central aerostatic bearing (5) and with a test arm (6)), at the end of which there is a test arm pin (10), a secondary bearing (7) with a hinge (8), on which weights (9) hang, while a mechanical brake (17) and a test arm rotation angle gauge (15) are placed on shafts (3). The method of calibrating force moment sensors is carried out by first hanging weights (9) on the test arm (6), stabilizing the vertical position of the test arm (6) with suspended weights (9), ensuring zero force moment, force moment sensor (1) is clamped between the connecting accessories (2), the indication of the torque sensor (1) and the test arm tilt angle gauge (3) is reset, then the tilt angle of the torque sensor (1) is changed using the electric drive (14)). In this way, the test arm (6) with the weights (9) generates a load on the moment of force sensor (1) when the angle is changed. The value indicated by the moment of force sensor (1) is com-pared with the conventional value of the moment of force calculated from the exact length of the test arm (6), the measured value of the angle of rotation (17) the value of the force caused by the weight of the weights (9). To change the direction of the moment of force, the position of the weight (9) on the arm (6) is changed to its right or left side. To change the magnitude of the moment, the angle of rotation of the arm, or the weight of the weights, or both parameters are changed simultaneously. In this way, it is possible to generate the required torque continuously in a certain measurement range.

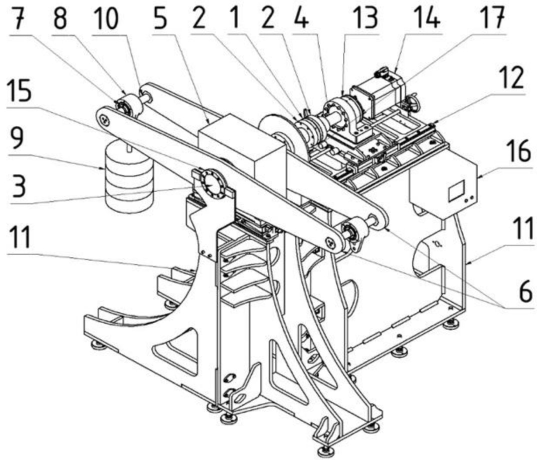

Fig. 3, The basic elements of the equipment: 1 - force sensor; 2 - connecting accessories; 3, 4 - shaft; 5 - aerostatic bearing; 6 - test arm; 7 - secondary bearing; 8 – hinge; 9 - hanging weights; 10 - test arm pin; 11 - supporting two-part frame; 12 - linear guide; 13 – gearbox; 14 – drive; 15 - test arm rotation angle gauge; 16 - control unit.

C. Procedure for developing a meassuremen system

In order to create the device, it was necessary to create a procedure starting from the application of the correct physical principle to the final metrological control of the device. The following structural system design was created for the proposed device.

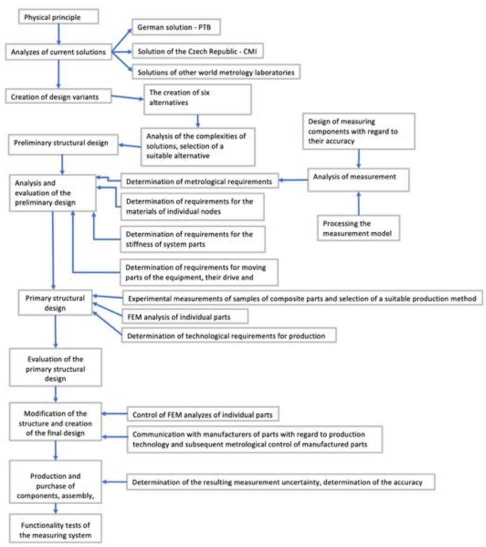

Fig. 4, Development procedure in the creation of new metrological equipment

D. Influence of Metrological Requirements on the Design of the Device

In order to determine the requirements for stiffness and maximum deformations of individual nodes of the structure before the creation of the primary structural design, metrological requirements enter the design process. Since the concept of the device is known and all purchased parts are typed and their accuracy values are known, and we know the required accuracy class of the device, we will create a measurement model. The measurement model is described in [10] and its result is the determination of the requirements for the construction of the measuring arm and other parts of the structure so that the deformations of the structural nodes have the specified maximum permissible values to meet the condition of the required overall measurement uncertainty. The Equation 1 describes the proposed model of static force moment generation.

$$M_{E,\alpha}^{(m)} = mg\left(l\cos\alpha + \Delta y_{\alpha}^{(m)}\right) + \Delta m_R\, l_{TR} g\ \cos\alpha + \delta M_{EB} + \\ +\delta M_{Emet} \qquad (1)$$

Where *m* is the weight of the standard weight in [kg], *l* is the arm length in [m], Δm_R is the weight difference (imbalance) in [kg], l_{TR} is the coordinate of the center of gravity of the loaded and unloaded part of the arms in [m], then α is the angle of the arm relative to the horizontal position in [º], δM_{EB} is the error of the moment needed to overcome the friction in the bearing in [N.m], δM_{Emet} is the error of the force moment caused by the influence of the method in [N.m]. The result of the solution is the estimation of the measurement uncertainty of the standard combined uncertainty (Fig. 5) and the determination of the maximum possible deflection of the measuring arm in the horizontal direction, i.e. in the direction that affects the calculated length of the arm depending on the angle of rotation of the arm. The limits of $\Delta yMin$ and $\Delta yMax$, i.e. $\pm\Delta y$, are determined by this calculation and the actual calculated deviation obtained by FEM analyzes of the designed measuring arm must be within these limits.

$$\Delta yMin = -\frac{lmg\cos\alpha(r.10^{-k}) - 2u\left(M_{E,\alpha}^{(m)}\right)}{mg} \\ \leq \Delta y_{\alpha}^{(m)} \leq \\ \leq \frac{lmg\cos\alpha(r.10^{-k}) - 2u\left(M_{E,\alpha}^{(m)}\right)}{mg} = \Delta yMax \qquad (2)$$

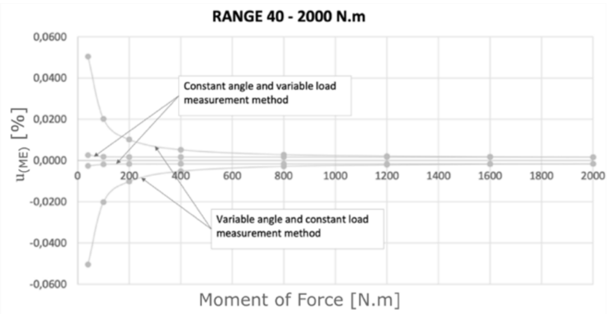

Fig. 5, Measurement uncertainty for two different measurement methods depending on the gener-ated torque.

Where m is the weight of the standard weight in [kg], l is the arm length in [m], α is the angle of the arm relative to the horizontal position v [º], r.10-k is for accuracy class CLASS 005, r = 1 and k = 5, u is the required measurement uncertainty in [%].

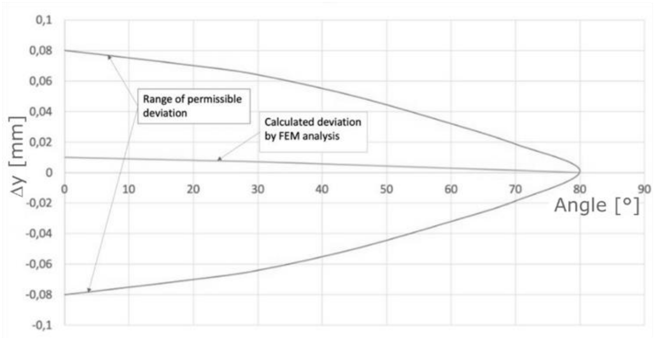

Fig. 6, The course of the permitted deviation and the course of the calculated deviation of the measuring arm made of carbon composite

The Fig. 6 shows the field obtained by calculation from the measurement model in which the calculated deformation for the proposed arm structure must be located. It is clear from the figure that the maximum deformation of the arm at a generated torque of 2000 N.m, when it is in a horizontal position and in the horizontal direction, is 0.01 mm and meets the criterion of being smaller than the possible calculation al-lowed, which in this state is obtained by calculation according to of the measurement model is 0.08 mm and gradually decreases to zero value at an angle of inclination of the arm of 80°. The Fig. 6 also shows how the deformation of the arm in the horizontal direction depends on the angle of rotation of the arm from 0.01 mm to 0 mm at an angle of inclination of the arm of 80°.

E. Experimental measurement and FEM analysys

An important part of the device is the measuring arm. The weights are suspended, on measuring arm, and this system will generate torque. As part of the decision on the materials used, the research team assessed that the measuring arm will consist of two carbon arms. The maximum possible deformations of the arm in the horizontal state is shown in Fig. 6. This metrological condition must be met with sufficient safety. To be able to fulfill it, it is necessary to choose the material for the production of arms. In order to be able to choose such a material, we must do an experiment aimed at determining the modulus of elasticity for different types of materials with different laying of car-bon trains, different matrices. The next important is to create a verification FEM model from these materials, and only then to create a specific FEM model and FEM analysis based on the results of such analyzes structural element. Records of the 3-point bending tests (see Fig. 7) for obtaining the modulus of elasticity and limit values of contact pressures is presented in the graph (see Fig. 8). Graph shows the results of elastic modulus measurements for different directions of carbon fibers and different used types of Pre-preg with production technology by gradual hardening in an autoclave.

Fig.7, The 3-point bending test, composite sample with dimensions 100x10x5 mm using the test equipment LABTEST 1052

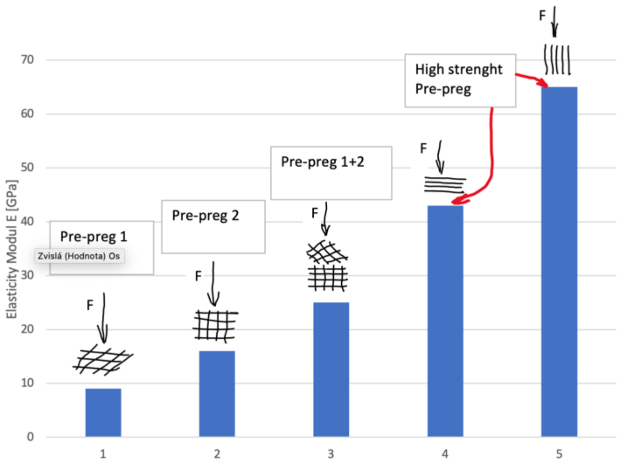

Fig.8, The elasticity modules of Pre-preg materials for FEM analyses

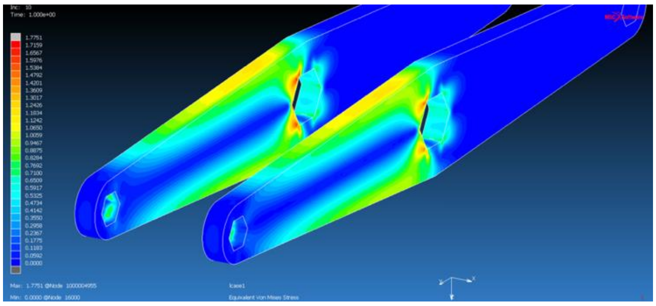

Fig. 9, FEM analysis of the measuring arm with maximum contact pressures 1.77 MPa

The FEM analysis was done with program MARC. FEM analysis of the arm for the required load 2000 N.m. The fig. 9 represents the result is the course of deviation Δy depending on the angle of rotation of the arm.

3. Discution/conclusions

The construction of metrological equipment is a very complex area, especially with regard to the required accuracies. So that the designer is able to create a complex construction system, it is necessary to choose suitable construction methods already during the design of the device. In fig. 4 shows the development procedure for solving a complex design task. Starting with the analysis of basic possible applicable physical principles and solutions to similar tasks, several possible alternatives leading to the final design solution usually arise. Meanwhile, various requirements for materials and their properties enter the development process. In the design of metrological devices, an analysis describing measurement uncertainties depending on the design itself is very important. Such an analysis is made in fig. 5, where two different design solutions of one physical principle are compared. Determining the uncertainty of the measurement determines the right way to achieve the goal. To reduce measurement uncertainty, measures are taken during the design so that the entire structural system of the device is designed not on the basis of the price of the device, but on the basis of meeting the criterion of the resulting required measurement uncertainty. This is one of the fundamental differences between the design of conventional production equipment and equipment for metrology purposes. During the design of this metrological device, it was decided that a measuring arm made of carbon material will be used in the construction of part of the device. In order to meet the minimum deformation condition of this device, a number of measurements had to be made to determine the modulus of elasticity in different directions for different internal fiber interlacing structures. When the material properties were known, FEM analyzes of individual structural nodes could be made and the possible deviations could be determined to meet the condition of the required measurement uncertainty. By performing measurements on carbon samples, a database of properties of various types of Pre-preg carbon materials was created, which can also be used in solving other design tasks associated with the design of various carbon structures. In conclusion, it is possible to state that the creation of a pair of arms is possible from carbon composite material from high-strength prepreg with modulus of elasticity from 40 to 63 MPa. With a suitable construction of metal-carbon joints, a special adjustment of the hole in the carbon arm for the metal insert is necessary so that the contact stresses do not exceed 20 MPa. It is also possible to state that the construction process for such special metrological devices is very specific and requires knowledge from several technical fields.

Acknowledgment

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