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Proposal of Methodology and Calibration of Dynamometers for Quantification of Forces in Anchor Bolts

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Abstract: Anchor bolts in heavy machines of metallurgical plants are often, from the point of view of their carrying capacity, limiting factor in increasing productivity. This paper presents some possibilities of increasing strength of anchor bolts using numerical and experimental methods of mechanics. Proposed and verified procedures allow determining the actual stress states during tightening the anchor bolts and nuts and reduce dynamic loads in bolts as well as in operating machines.

Keywords: Anchor bolts, numerical and experimental methods of mechanics, dynamometer.

1. Introduction

Heavy equipment's of metallurgical plants (converters, casting pedestal, fans, etc.) are exposed during their operation to intensive dynamic loading. Pedestals of these devices are most often fastened with anchor bolts through which the dynamic loading is transmitted to the ground. On the workplace of authors has been solved several tasks associated with increasing of carrying capacity of anchor bolts in heavy equipment of metallurgical plants [1-4].

In the paper is described methodology and realization of dynamometer calibration used for regulation of forces in anchor bolts of casting pedestal.

2. Force states in anchor bolts

In the analysis of stress relations in the anchor bolts is necessary to know the size of the prestress, as well as the size of the static and dynamic load in different working regimes of metallurgical equipment's. Distribution of forces in pre-stressed bolted connections with vanishing variable load, which occurred most frequently in the analyzed cases are shown in Fig. 1.

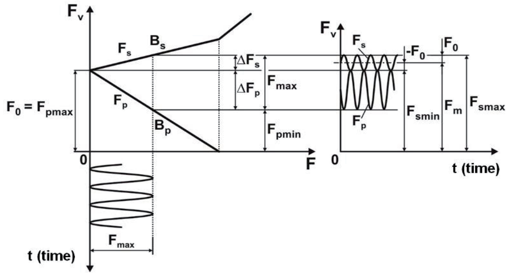

Fig. 1: *Vanishing load in bolt connection with prestress.*

During loading of bolt connection according to Fig. 1 the maximum force in a bolt is

$$F_{s\max} = F_0 + \Delta F_s = F_0 + \frac{k_s}{k_s + k_p} \cdot F_{\max}$$

and force amplitude $\Delta F_s/2$ in bolt depends on bolt stiffness k_s and stiffness of flange k_s.

Increasing ratio k_p/k_s reduces the force amplitude in the bolt while bigger force F_0 in pre-stress is needed to ensure contact of connected parts. However, from the point of view of bolt fatigue safety this change has a positive effect [5-7]. Force F_0 in pre-stress of a bolt is caused by torque moment M_u. In case that after long-term working is necessary to tight anchor bolts or if modernization of equipments is connected with necessity to tighten bolts due to possible change on bolts (rust, plastic deformation, lack of drawings of bolts in concrete foundations, etc.) it is difficult to determine dependency $F_0 = F_0(M_u)$ or $F_0 = F_0(p)$, where p is pressure in corresponding tightening equipment producing tightening torque M_u [8-10].

In the paper is proposed methodology of determination of axial force in bolts of casting pedestal by using of strain-gages that are applied on deformation body of the dynamometer. Axial forces in anchor bolts of carrying elements can reach high levels. Proposed dynamometers are used for determination of axial forces in anchor bolts with diameters 52 mm and 56 mm, respectively, loaded by normal force reaching almost 350 kN. The magnitude of loading force was determined by superposition of forces resulting from pre-stress and increments of axial forces due to operation of casting pedestal (including dynamic forces). The dynamometer has to be able to measure such forces.

Deformation body of dynamometer for measurement of axial forces was proposed and optimized by the finite element method and its drawing is given in Fig. 2. The dimensions of dynamometer has to fulfill technical demands for its using in operation conditions, e.g. its height is defined by the space between anchor bolt and carrying part of casting pedestal that cannot be disassembled (operation measurement is realized in the time of capital repair of casting pedestal). The shape of deformation body was proposed to allow preservation of strain-gages against mechanical damage.

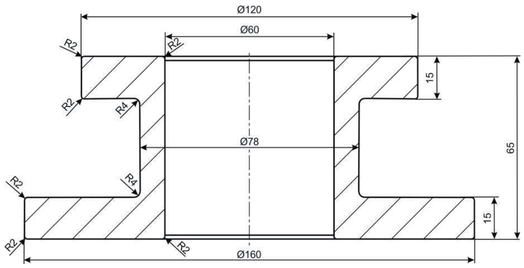

Fig. 2: *Deformation body of dynamometer.*

The boundary conditions defined for numerical analysis by the finite element method represent loading of dynamometer supported in bottom part by load created by tightening of nut.

In Fig. 3 is given the field of equivalent forces resulting from the finite element analysis of deformation body loaded by pressure which does not exceed load force 100 kN.

The magnitude of axial force 350 kN leads to

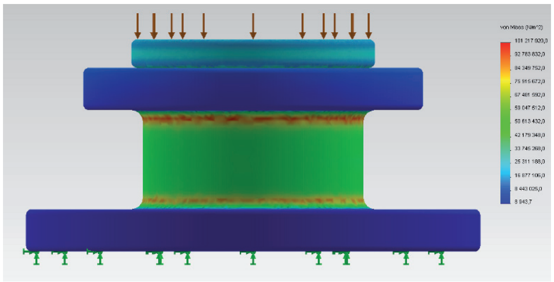

Fig. 3: *Equivalent stresses under loading 100 kN.*

the equivalent stress of magnitude approximately 210 MPa in the location of strain-gages. On the basis of analysis of results gained by numerical modeling deformation bodies of dynamometers were produced made of material 12050. In Fig. 4 is shown deformation body of dynamometer.

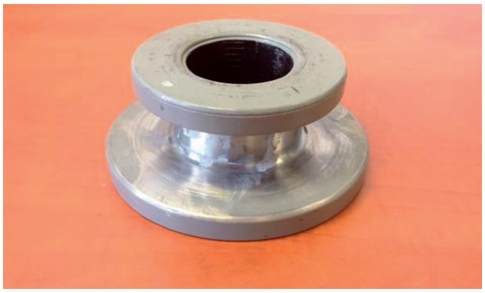

Fig. 4: *Deformation body.*

The calibration of dynamometers accomplished by strain-gages. On the deformation bodies were applied in four locations rotated by 90°, two strain-gage grids XY91-1/120 in bridge arrangement, in order to exclude influence of bending. Strain-gages and its arrangement on one deformation body of dynamometer is given on Fig. 5.

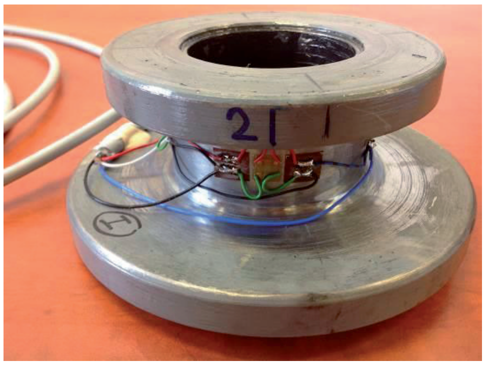

Fig. 5: *Strain-gages applied on the deformation body of dynamometer.*

The calibration of proposed dynamometers was accomplished as follows. The most accurate calibration is a calibration in laboratory by using of hydraulic loading test machine where the load forces and corresponding strains are registered on strain-gage apparatus with given bridge arrangement. In Fig. 6 is a view to measurement chain for the calibration of dynamometers. It consists of hydraulic loading machine, deformation body of dynamometer and a strain-gage P3 produced by Vishay.

Fig. 6: *Measurement chain for calibration of dynamometers.*

In Fig. 7 is given dynamometer positioned inside of grip cheeks of loading equipment.

Fig. 7: *Dynamometer inside of tension grips of test machine.*

In Fig. 8 is shown deformation body of dynamometer in the process of compression by loading machine. For every dynamometer was realized repeated experimental measurements for determination of dependencies between strains in deformation body and loading force. On the basis of given measurements, the calibration diagram for every deformation body was created, showing dependence of measured strain on the magnitude of force producing by loading machine, Fig.9. With respect to low sensitivity of loading machine in bottom part of measurement scale (delayed response to load force), the magnitudes were record by 50 kN. Repeated experimental measurement confirmed linear dependency of measured quantities which documents stress levels in dynamometer in elastic area.

Fig. 8: *Compression of dynamometer in test machine.*

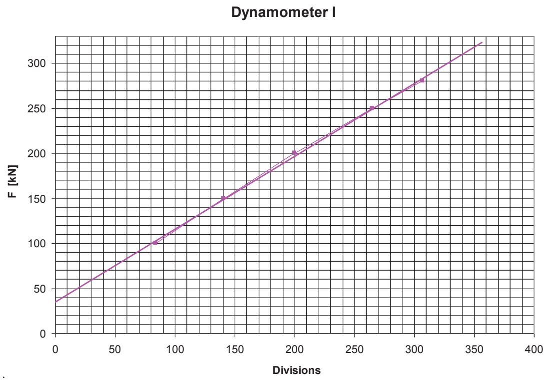

Fig. 9: *Calibration diagram of dynamometer I.*

Further calibration accomplished also in laboratories of Technical University of Košice determined dependency of compression pressure (tightening torque) adjusted on loading equipment Enerpac and produced axial force in the bolt, registered by deformation body of dynamometer. The calibration was realized by a system Enerpac which is used for tightening of anchor bolts of casting pedestal. The screws were lubricated and the type of lubrication mean is inhered in calibration diagram.

In Fig. 10 is given measurement chain for determination of dependencies between axial force registered by dynamometer and pressure in tightening equipment Enerpac.

Fig. 10: *Measurement chain.*

Measurement chain consists of tightening machine Enerpac, deformation bodies of dynamometers and strain-gage apparatus P3 produced by Vishay.

Results of the measurements are diagrams of dependencies of quantities from strain-gage apparatus P3 (number of divisions on the scale) for the dynamometer and corresponding magnitude of axial force F in the bolt or pressure p in tightening equipment. In Fig. 11 is given calibration diagram for dynamometer II.

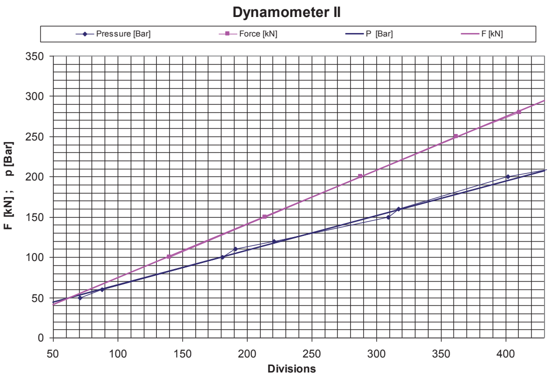

Fig. 11: *Calibration diagram of dynamometer II.*

Deformation bodies of dynamometers proposed by authors were after calibration used for determination of axial force in anchor bolts on casting pedestal (Fig. 12).

Fig. 12: *View to dynamometer installed on anchor bolt of casting pedestal.*

3. Conclusion

The results gained from the experimental measurements confirmed correctness of proposed methodology of determination of axial force in anchor bolt on the pressure invoked by tightening equipment Enerpac by using strain-gages on deformation body of dynamometer.

Because in most cases of anchor bolts, tightening was realized by dynamometers and new nuts with action of anchor bolts and foundations, for creation of necessary pre-stress was used directly determined pressure value in tightening equipment for every individual bolt. Even if there is some scattering in values of pre-stress, from calibration diagrams and verification of methodology is obvious that the differences do not reach 5 %.

4. Acknowledgments

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