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Possibility of Carrying Capacity Increasing of Anchor Bolts in Heavy Equipments of Metallurgical Plants

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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, dynamic loading, numerical and experimental methods of mechanics*

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1. Introduction

Heavy equipments 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 equipments of metallurgical plants [1,2,3]. In the article are given examples of some possibilities of increasing of the anchor bolts strength for the selected metallurgical equipments.

2. Force States in Anchor Bolts

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

During loading of bolt connection according to Figure 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 [4,5]. 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 $F_0 = F_0(M_u)$.

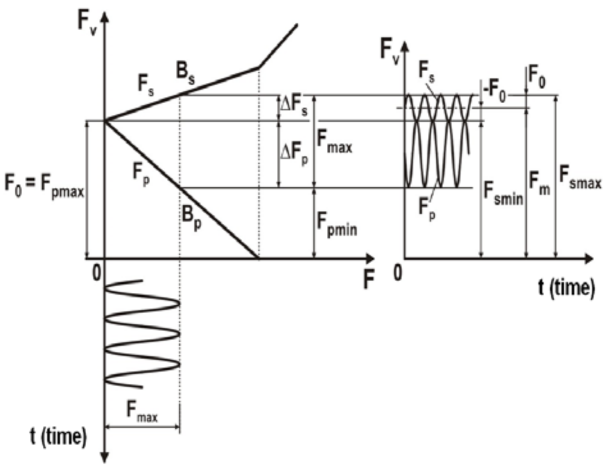

Figure 1. Vanishing load in bolt connection with prestress

Tightening of nuts is often accomplished by hydraulic torque wrench and the torque is limited by the oil pressure. Due to the physical conditions of tightening (the friction coefficient, the state of threads) the forces in bolts differ. There are plastic deformations in some screws and on first screws on nuts and bolts that are in contact are inelastic deformations, too. The problem was solved by modification of nut design that results to more uniform loading of screws and on the other side allows experimental investigation of dependence between the force and torque on bolts under conditions achievable in practice. For that purpose new nut has been designed, associated with the force-measuring element (see Figure 2) with applied sensors T1 to T4, in the arrangement appropriate for the torque measurement [6,7].

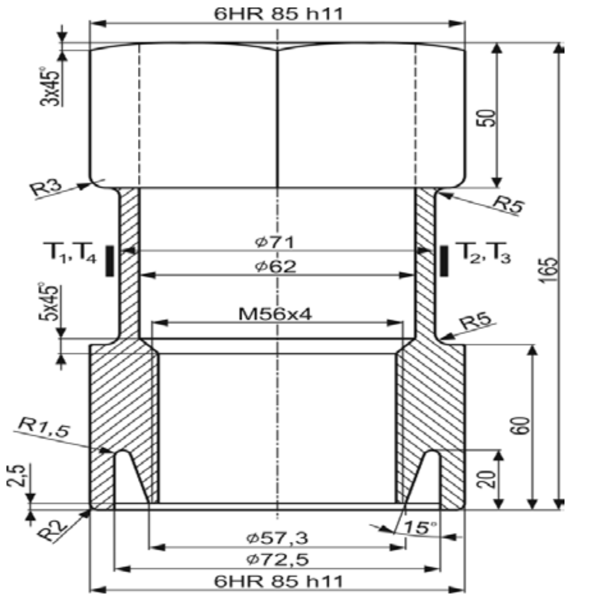

Figure 2. Body of dynamometer with a nut with strain-gages T_1 to T_4 for determination of tightening moment

To determine the forces in the bolts in operating conditions was proposed experimental facility containing additional deformation elements on which it was possible to invoke in the bolt required axial force and to measure its change during operation Figure 3.

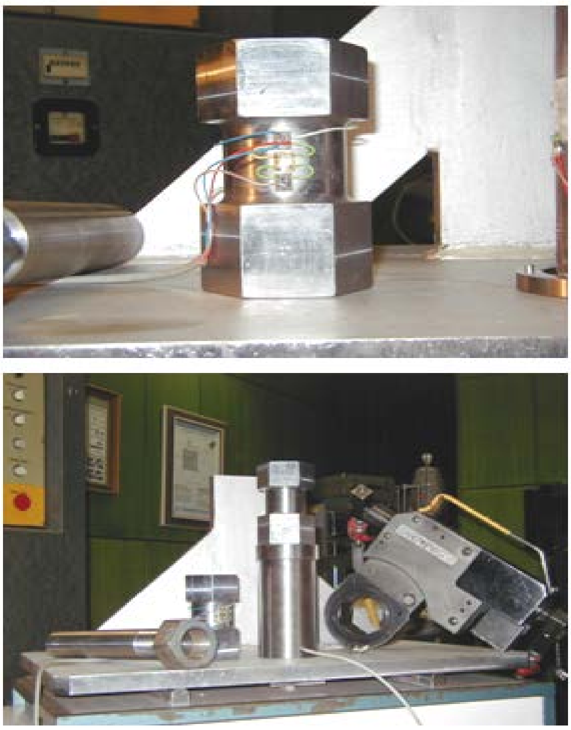

Figure 3. Equipment for experimental determination of prestress in bolt

For illustration, Figure 4 shows the time-dependent charts of measured forces in bolt and in dynamometer for experimental verification of laboratory equipment. In Figure 5 are given time-dependent charts of force in a bolt during verification of interaction of anchor bolt and foundation in operation conditions.

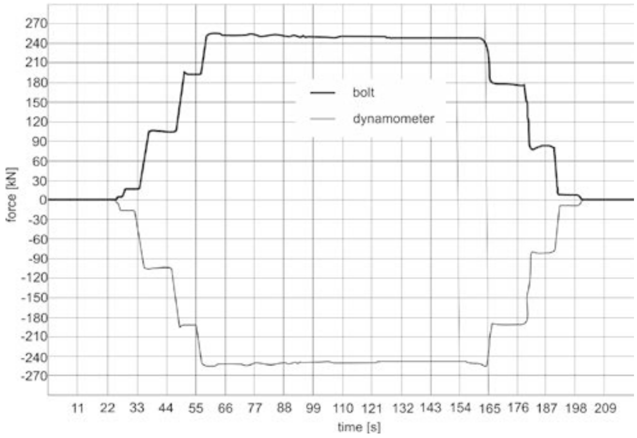

Figure 4. Time-dependent charts from test of dynamometer

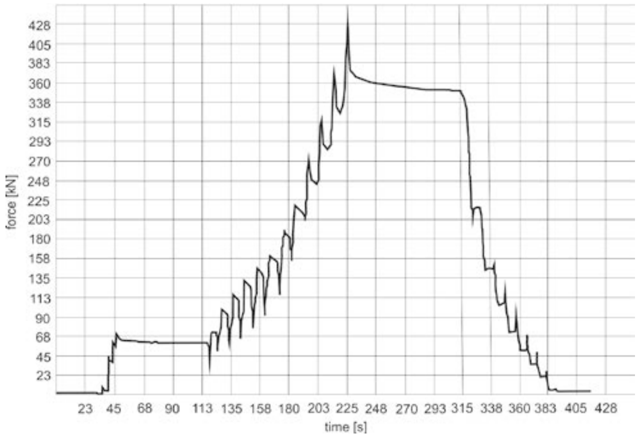

Figure 5. Time-dependent charts of force from test of anchor bolt and foundation interaction

The presented experimental device was used for set-up of required preload forces in anchor bolts for several pedestals of heavy equipments of metallurgical plants.

3. Possibilities of Increasing Carrying Capacity of Anchor Bolts

As mentioned above, from the point of view of fatigue safety of anchor bolts, it is advantageous to reduce the amplitude of the dynamic force components in the bolts during operation by increasing the ratio of flange k_p and k_s stiffness. Application of this procedure is presented in anchoring stand of converter. In Figure 6 are shown the vertical fields of displacements in bottom part of pedestal determined by the finite element method for loading of pedestal by preload forces in the anchor bolts.

As results from Figure 6, the prestressing forces in the anchor bolts significantly deform upper flange of the box structure of pedestal in the location of their action. For this reason was the flange stiffness k_p small and only slightly higher than the stiffness of the bolt k_s. This caused an increase in the amplitude of the dynamic component of axial forces in bolts, enlarge their deformations, thus causing excessive vibration of pedestal during operation of converter.

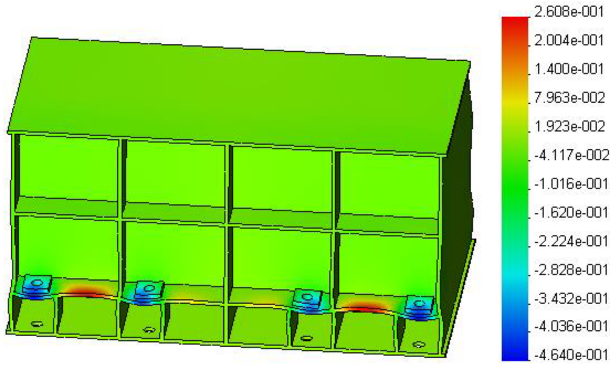

Figure 6. Vertical displacements in bottom part of pedestal caused by prestress in anchor bolts

Increasing the stiffness of the flange was ensured by using reinforcing tubes connected to each anchor bolts according to Figure 7.

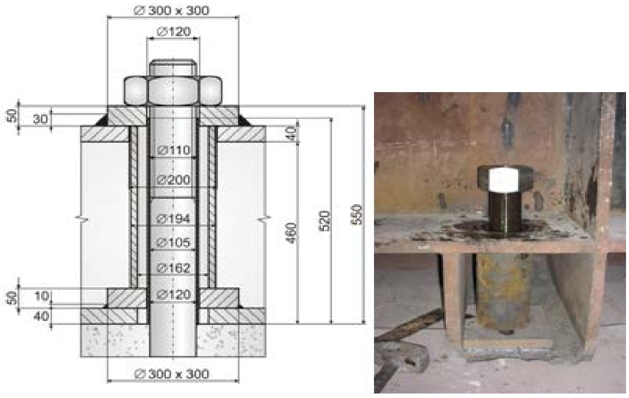

Figure 7. Reinforcing pipe of anchor bolt a) schema, b) practical realization

Increasing the stiffness of the flanges on the one hand, reduces the amplitude of the dynamic component of force in the anchor bolts. On the other hand, it is necessary to increase preload force in a bolt. On the basis of assessment of the strength of anchor bolts under static and dynamic loading, taking into account their mechanical properties, it was necessary, in addition to reducing the levels of dynamic loading of bolts, to achieve a reduction of stresses in location of stress concentrators.

According to [4,8,9] the greatest concentration of stress in the bolt occurs in the place of the first thread of nut. Change of stress distribution is caused by the unproportional distribution of force to single screw threads Figure 8 due to different deformation of bolts and nuts. The most loaded is the first thread of nut and corresponding part of bolt. Consequence of this is that the first thread manifests the biggest notch effect which is due to load from the force flow in the shaft, but also due to local maximum of the bending stress of the most loaded thread.

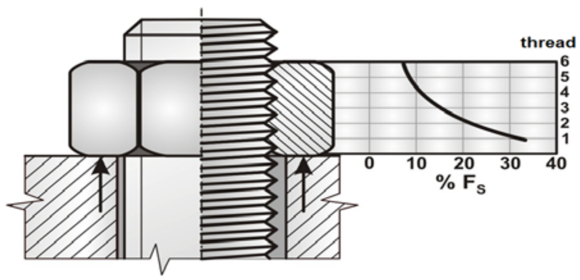

Figure 8. Irregular force distribution in thread of nut

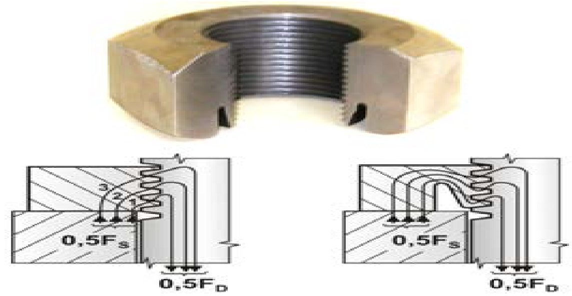

Figure 9. Modification of nut for decreasing of stress concentration

In order to decrease large notch effect in the standardized thread, it is necessary to ensure the best quality of its surface at the root of profile and reduce the relative loading of the first and second thread. This second method of increasing the fatigue strength of bolted joint can be realized by design modifications that are based on the idea to change the nut stiffness near first thread by decreasing its cross-sectional area. This creates conditions for opening of nut due to bending Figure 9. This modification has the effect of reducing loading of the first thread and increasing loading of other less loaded threads.

In Figure 10 are shown equivalent von Mises stresses for the modified nut, documenting decreased loading of first thread.

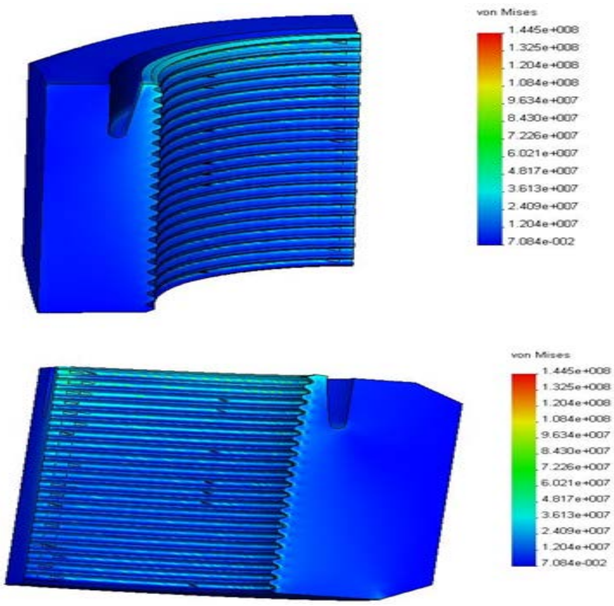

Figure 10. Fields of equivalent von Mises stresses in modified nut

Before implementation of the proposed modifications, stiffness analysis of reinforced flange of anchor bolts was accomplished. In Figure 11 are shown fields of vertical displacements of modified flange and anchor bolt for small part of structure computed by the finite element method.

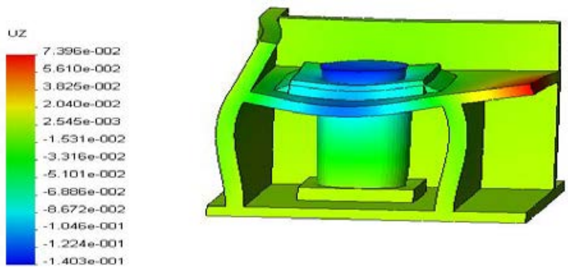

Figure 11. Vertical displacements for determination of flange stiffness

After providing structural modifications that lead to increasing of flange anchor bolts stiffness, vibration amplitudes of converter housing were reduced by approximately 30%. Displacement amplitudes measured during operation did not exceed 1.3 mm Figure 12.

Eigenfrequencies of converter pedestal were shifted to higher values and the acceleration amplitudes were decreased by 40% - 60% (see frequency-dependent amplitudes of accelerations during blowing in the converter before design modifications - Figure 13 and after structural changes - Figure 14)

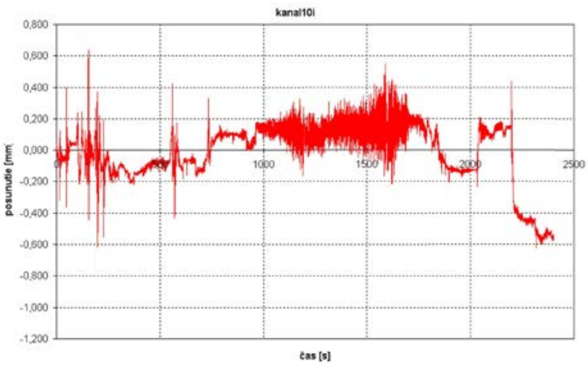

Figure 12. Time-dependent chart of displacements measured by incremental sensor during melting process

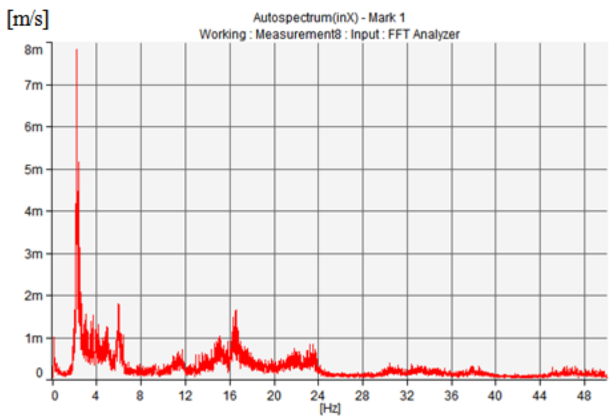

Figure 13. Dependence of acceleration amplitudes on frequencies during blowing in location of three-component sensor before modification

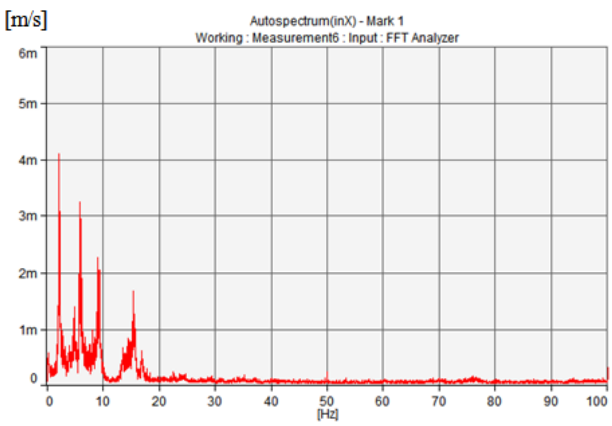

Figure 14. Dependence of acceleration amplitudes on frequencies during blowing in location of three-component sensor after modification

4. Conclusions

Lifetime of dynamically loaded machines and equipments is often limited by carrying capacity of anchor bolts. In case, in the existing structure can not be changed bolt stiffness, it is necessary to modify the flange stiffness and by appropriate choice of the prestressing force to optimize the ratio of the static and dynamic force components in the anchor bolts in operation.

On examples of anchoring of heavy equipments in metallurgical plants (converter, casting pedestal) are presented the possibilities of increasing load capacity of anchor bolts by appropriate design modifications, which ultimately lead to a reduction of the dynamic stress in anchored equipments. Increasing of lifetime of the anchor bolts can be also achieved by appropriate modification of nuts so that first bolt threads in contact with nut are loaded by smaller forces and accordingly the stress concentration in a critical location is decreased.

In order to determine dependence of actual force of prestress and tighten torque, experimental device using a dynamometer with strain gages was developed. The device allowed realizing tightening of bolts in operation for defined prestressing force.

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