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INCREASING OF RELIABILITY OF CONVERTER

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The innovative activities in steel production invoke exploitation of new machines with the higher production capacity and productivity of labor. The paper deals with deformation and stress analysis of carrying parts of converter pedestal on the base of which the proposals and supporting measures were made that had the aim to increase reliability of the converter during steel production. This was achieved by lifespan prolongation of anchor and connecting bolts of converter pedestal, by change of stiffness of connected elements as well as by correction of nuts of bolted connections. The realization of structural changes decreased loading amplitudes and consequently the vibrations of pedestal. Solution was verified by numerical and experimental procedures of mechanics.

Key words: *steel production, converter, pedestal, bolt connection, stiffness*

Povećanje pouzdanosti konvertora. Inovacijske aktivnosti u proizvodnji čelika dovode do primjena novih strojeva s većim kapacitetom proizvodnosti i radne produktivnosti. Ovaj rad se bavi analizom deformacija i naprezanja nosivih dijelova konvertorskog postolja te su na temelju toga, napravljeni prijedlozi i potporna mjerenja s ciljem da se poveća pouzdanost konvertora tijekom proizvodnje čelika. To se postiglo tako što se promjenom krutosti spojnih elemenata produljila dužina sidrenih i spojnih svornjaka postolja konvertora ali i korekcijom matica na mjestima povezanim svornjacima. Provođenjem strukturalnih promjena smanjile su se amplitude opterećenja a shodno tome i vibracije postolja. Rješenje je verificirano numeričkim i eksperimentalnim mehaničkim postupcima.

Ključne riječi: *proizvodnja čelika, konvertor, postolje, spoj sa svornjakom, krutost*

INTRODUCTION

During the last century the steel industry was influenced by several crises which invoked strong innovation activities in development of new classes of steels. Innovation was based on the statement of representative of automotive industry Bernhard Rolinson who said: “Steel has a long tradition but despite of this its potential from the point of view of material properties is exploited only to 20%” [1].

Importance of the steel as a material results from the following factors [2]:

- Earth’s crust contains approximately 5,6% of iron, which ensures base material for its production,
- in comparison to other materials, the steel can be produced with lower energetic requirements,
- various steel classes can be produced effectively under constant level of quality,
- required properties of products made of steel can be reliable ensured by the technique of steel alloying and further processing (precise production),
- processing of steel made products (forming, welding, machining) is without any problems.

During the last twenty years there were developed many new steel classes which fulfill special requirements from various areas of industry. The motivating force in these innovative activities is the automotive industry which participates on several projects (ULSAB - Ultra Light Steel Auto Body, ULSAC - Ultra Light Steel Auto Closures, ULSAS - Ultra Light Steel Auto Suspensions and ULSAB - AVC - Ultra Light Steel Auto Body - Advanced Vehicle Concept) oriented on the production of new steels for the production of car bodies [3, 4].

The main aim of the innovation activities is to increase the attractiveness of the steel in comparison to competing materials (aluminium, special alloys, composities and the like) [5, 6] and to exploit positive qualitative and price parameters of steel.

Increasing of steel quality, production of new classes with a smaller range of chemical composition, smaller influence of steel production on ecology is attained by new technological equipment in production. Steel indus-

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try invests huge amount of money in reconstruction and renewal of out of date equipments as well as in building of new, modern and ecologically not so harmful technological complexes.

For the modernization of steel production the new oxygen converters are mostly used by which the mass of pig iron is increased (from common 140 to 160 ton to 180 to 220 ton), the processing time with improved steel quality is decreased, the safety of workers is increased by computer controlled production and the environment protection is better.

The oxygen steelmaking process rapidly refines a charge of molten pig iron and ambient scrap into steel of a desired carbon and temperature using high purity oxygen. The furnace or converter is a barrel shaped, open topped, refractory lined vessel that can rotate on a horizontal axis. The overall purpose of this process is to reduce the carbon from about 4 % to less than 1 % (usually less than 0,1 %), to reduce or control the sulfur and phosphorus, and finally, to raise the temperature of the liquid steel made from scrap and liquid hot metal to approximately 1635 °C. A typical configuration is to produce a 220 tons of heat about every 45 minutes, the range is approximately 30 to 65 minutes. The event times, temperatures, and chemistries vary considerably by both chance and intent. The required quantities of hot metal, scrap, oxygen, and fluxes vary according to their chemical compositions and temperatures, and to the desired chemistry and temperature of the steel to be tapped. Fluxes are minerals added early in the oxygen blow, to control sulfur and phosphorous and to control erosion of the furnace refractory lining. Input process variations such as analytical (hot metal, scrap, flux and alloy) and measurement (weighing and temperature) errors contribute to the chemical, thermal and time variations of the process. The energy required to raise the fluxes, scrap and hot metal to steelmaking temperatures is provided by oxidation of various elements in the charge materials. The principal elements are iron, silicon, carbon, manganese and phosphorous. The liquid pig iron or hot metal provides almost all of the silicon, carbon, manganese and phosphorous, with lesser amounts coming from the scrap. Both the high temperatures of the liquid pig iron and the intense stirring provided when the oxygen jet is introduced, contribute to the fast oxidation (burning or combustion) of these elements and a resultant rapid, large energy release. Silicon, manganese, iron and phosphorous form oxides which in combination with the fluxes, create a liquid slag. The vigorous stirring fosters a speedy reaction and enables the transfer of energy to the slag and steel bath. Carbon, when oxidized, leaves the process in gaseous form, principally as carbon monoxide. During the blow, the slag, reaction gases and steel (as tiny droplets) make up a foamy emulsion. The large surface area of the steel droplets, in contact with the slag, at high temperatures and vigorous stirring, allow quick reactions and rapid mass transfer of elements from metal and gas phases to the slag. When the blow is finished the slag floats on top of the steel bath. Controlling sulfur is an important goal of the steelmaking process. This is accomplished by first removing most of it from the liquid hot metal before charging and later, inside the furnace, by controlling the chemical composition of the slag with flux additions.

New converters are often built on the locations of original (old) converters and they are placed on the original pedestals (Figure 1.). Increasing of mass of heats, decreasing of time for processing of scrap and pig iron, changes of power and control of drives result to changes in parameters of dynamic loading of converter pedestals.

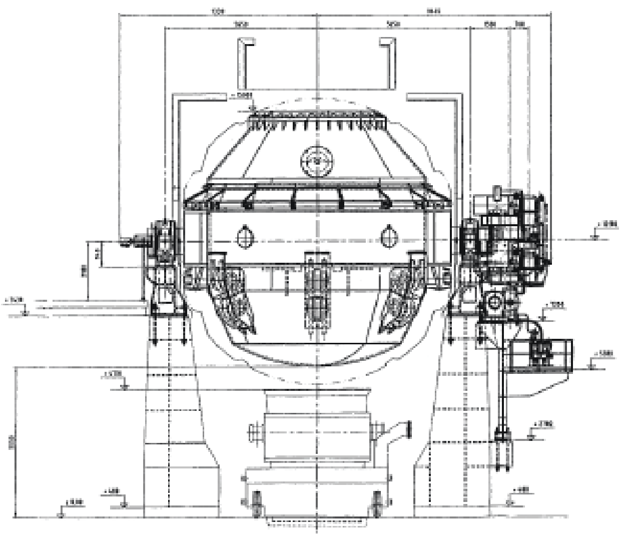

Figure 1. **Schema of converter with pedestals and bases**
Slika 1. **Shema konvertora s postoljem i temeljem**

For the reliable operation of dynamic loaded machines and equipments it is necessary to ensure appropriate rates of stiffnesses of flanges and bolts in bolt connections in order to ensure their expected lifetime by fluctuating loading.

The aim of the paper is to assess the lifetime period of bolt connections of anchor and connecting bolts, to make proposals and supporting measures for reduction of load amplitudes. By optimization of stiffness rates of bolts and flanges as well as by changes in prestress is achieved that the stresses in pedestals of converter during operation and consequently their vibrations are decreased. Accordingly the operational reliability of converter is increased.

FORCES IN ANCHOR AND CONNECTING BOLTS

For computation of forces in bolts, it is necessary to know prestress values as well as values of statical and dynamical loadings under various working modes (charging of iron scrap, pouring of liquid iron, turning of converter, blowing). It is also necessary to take into account the process of cleaning of internal surface of converter and its edge. The authors considered for the computations the load levels given by the producer [7]. On the base of these values the computation of forces in anchor bolts of pedestal (with prestress) and also the computation of forces in junction of pedestal and stand was provided.

With respect to the symmetry of the structure (except drive unit), and also with respect to accessibility of locations where the experimental measurement were provided, taking into account safety of measurement, the attention was focused on modelling and experimental verification of pedestal without drive.

In Figure 2. the geometrical model of pedestal and base together with bolts is shown.

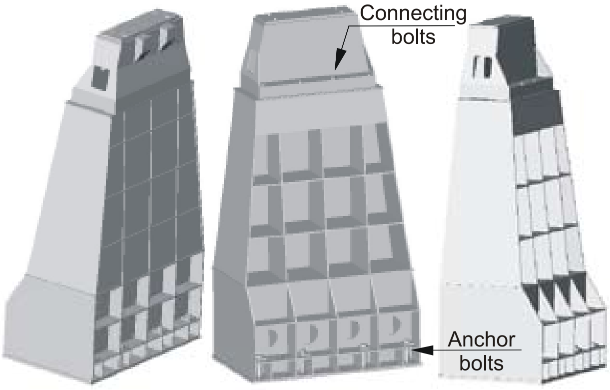

Figure 2. **Geometrical model of pedestal and base of converter**
Slika 2. **Geometrijski model postolja i temelja konvertora**

Influence of the flange stiffness of base and pedestal on stresses in connecting and anchor bolts was assessed by analytical as well as finite element method. In analytical computations were, on the base of theory of elasticity, determined the forces in connecting and anchor bolts. Of course, all important external forces were included into these computations (weight of the base, fireclay bricks and so on).

On the base of drawings, which were delivered by the customer, the computational model for the solution by the finite element method was developed. Distinctively there were created models of pedestal, base, foundations, anchor and connecting bolts. Consecutively these models were jointed into one assembly in order to have possibility to solve it as contact problem that reflects in details interactions between individual parts. On the foundations made of concrete the base jointed by eight anchor bolts was located. On this assembly the pedestal was placed and other eight connecting bolts jointed the assembly and pedestal.

Maximal forces and moments given in drawings delivered by customer loaded the model of the structure. These force quantities were recalculated for the locations where they really act in the model. Also, the self-weight of the structure was considered. Here, the weight of brickwork was added in the form of bigger value of mass density of the base.

Deformation constraints in the form of fixed nodes were applied on the bottom plane of concrete foundations.

From analytical computation as well as from computation by the finite element method results that under maximal loading the deformations at the locations of bearing houses

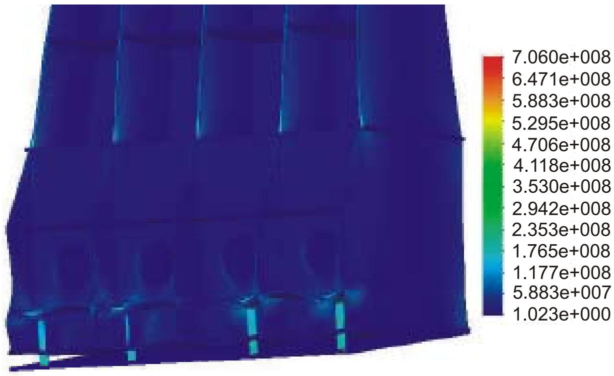

Figure 3. **Distribution of stresses in bottom part**
Slika 3. **Distribucija naprezanja u donjem dijelu**

are most of all influenced by the stiffnesses of prestressed bolt connections of connecting and anchor bolts. In Figure 3. the deformation in location of anchor bolts is shown. Figure 4. shows the deformation at the contact location between base and pedestal (magnification factor is 150).

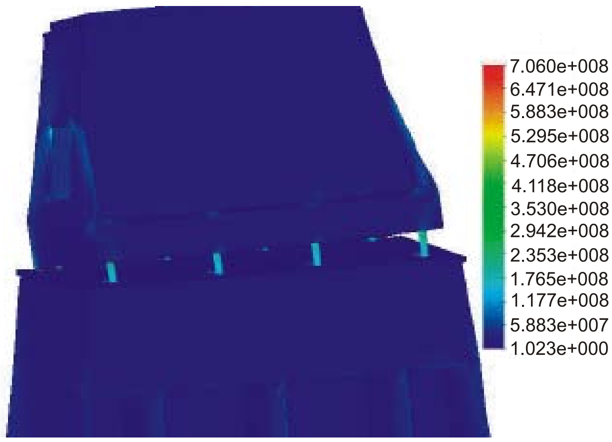

Figure 4. **Deformation in contact of pedestal - base of internal side of base**
Slika 4. **Deformacija na mjestu kontakta postolje - temelj na unutarnjoj strani osnove**

The deformation shown in Figures 3. and 4. can be decreased by increasing prestress in connecting and anchor bolts. However, the computations indicate that high prestress causes extreme deformations of connecting elements of base and pedestal.

In Figure 5. the deformation field caused by prestress in anchor bolts can be seen. Magnification factor of plotted deformations in this figure is 150.

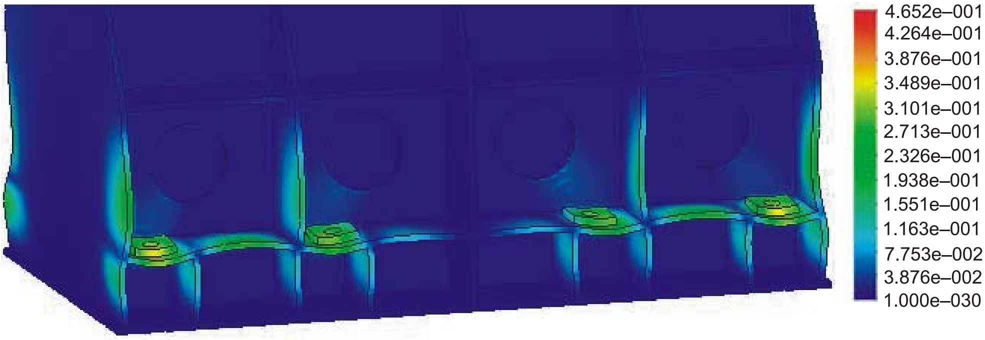

Figure 5. **Distribution of deformations invoked only by prestress in anchor bolts**
Slika 5. **Raspoređenost deformacija izazvanih prednaprezanjima u sidrenim svornjacima**

In Figure 6. are the pictures of deformed structure with prestressed connecting bolts.

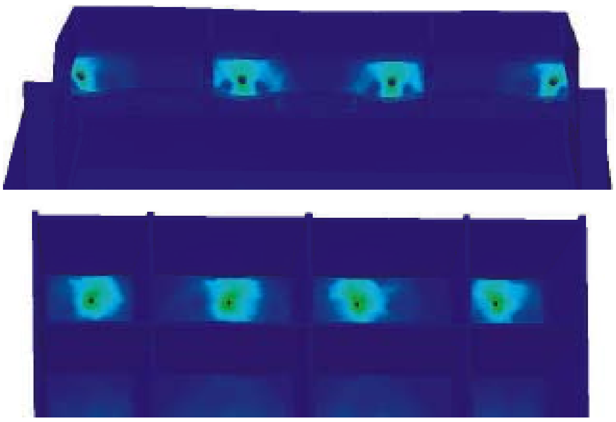

Figure 6. **Structure deformed by prestress in connecting bolts**
Slika 6. **Struktura deformiranja prednaprezanjem u spojnim svornjacima**

Anchor and connecting bolts are prestressed and loaded by alternate loading. Figure 7. illustrates relationships for the forces in bolt connection loaded by vanishing load.

According to Figure 7., the maximal force in loaded bolt is:

$$F_{s\max} = F_0 + \Delta F_s = F_0 + \frac{k_s}{k_s + k_p} \cdot F_{\max} \tag{1}$$

so the amplitude of the force $\Delta F_s/2$ in the bolt depends on both, stiffness k_s of the bolt and stiffness k_p of the flange. By increasing ratio k_p/k_s, the force amplitude in the bolt decreases while higher value of prestress F_0 is needed in order to ensure the contact between connected parts. On the other hand, from the point of fatigue safety of bolts this change has positive impact.

On the base of analytical computations and computations by the finite element the following values of stiffnesses method were determined $k_p = 3{,}44 \cdot 10^6$ Nmm^{-1}, $k_s = 2{,}95 \cdot 10^6$ Nmm^{-1}. Minimal force of prestress in order to ensure contact between connected parts is $F_0 = 738$ kN, maximal force amplitude in bolt ΔF during operation was 215 kN.

For the most loaded connecting bolt the values of the stiffness were $k_p = 6{,}186 \cdot 10^5$ Nmm^{-1}, $k_s = 4{,}72 \cdot 10^5$ Nmm^{-1}, minimal force of the prestress $F_0 = 400$ kN and maximal force amplitude in bolt ΔF during operation was 154 kN.

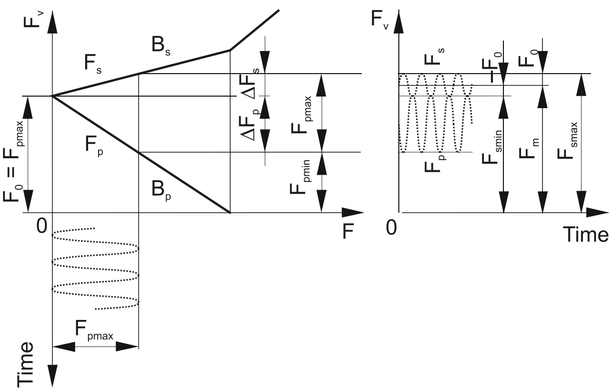

Figure 7. **Vanishing loading of bolt connection with prestress**
Slika 7. **Gubitak opterećenja u vijčanom spoju s prednaprezanjem**

DETERMINATION OF STRENGTH OF ANCHOR AND CONNECTING BOLTS, SUGGESTIONS FOR INCREASING THEIR LIFETIME PERIOD

For the strength computation of prestressed bolts following factors were taken into account [8]:

- static shear stress τ, invoked by friction moment in thread (torque) during tighten of bolt,
- static tension stress σ_t, invoked by maximal force in bolt,
- time-dependent pulsating tension stress determined by average value of stress σ_m and amplitude σ_a.

For the static component of the shear stress τ following was used:

$$\tau = \frac{8F_0 \operatorname{tg}(\gamma + \varphi')d_2}{\pi d_3^3} \tag{2}$$

where:

F_0 - force of prestress in bolt,
d_2 - middle diameter of bolt thread,
d_3 - inner diameter of bolt thread,
γ - angle of pitch of bolt thread,
φ' - friction angle.

Static component of shear stress τ is substantially influenced by the friction in the thread of bolt and nut.

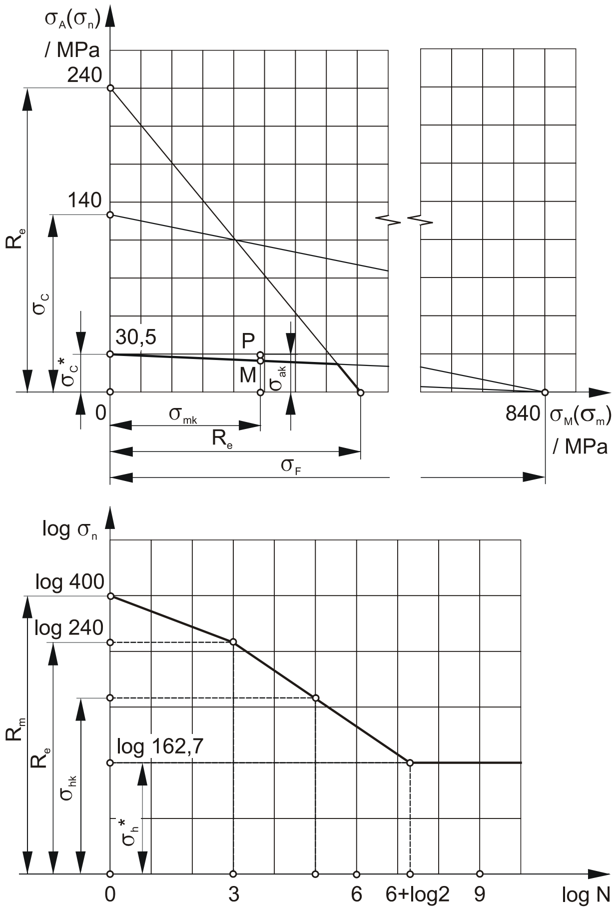

Figure 8. **Simplified Haigh diagram and lifetime curve - anchor bolt**
Slika 8. **Pojednostavljen Haighov dijagram i krivulja vijeka trajanja - sidreni vijak**

Time-dependent pulsating tension stress in bolts has static component σ_m and amplitude component σ_a. They are computed according to relations:

$$\sigma_m = \frac{4F_m}{\pi d_3^2},$$

$$\sigma_a = \pm \frac{4F_a}{\pi d_3^2} \qquad (3)$$

where:

F_m - mean value of pulsating axial force in bolt,
F_a - amplitude of pulsating axial force in bolt.

On the base of computation the relevant values of stresses were determined:
- for connecting bolts τ_k = 71,8 MPa, σ_{mk} = 143,5 MPa, σ_{ak} = 26,7 MPa,
- for anchor bolt τ_s = 64,2 MPa, σ_{ms} = 194,3 MPa, σ_{as} = 54,0 MPa.

Assessment of resulting safety of bolt connection was realized on the base of partial safeties. For both types of bolts the values of time-dependent pulsating tension stresses were important while in computations harmonic course was

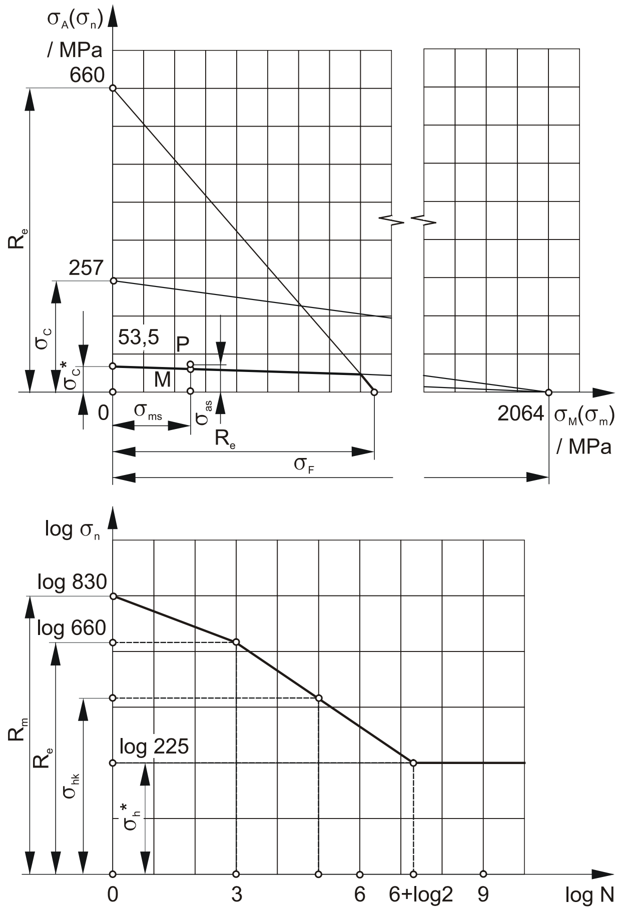

Figure 9. **Simplified Haigh diagram and lifetime curve - connecting bolt**
Slika 9. **Pojednostavljen Haighov dijagram i krivulja vijeka trajanja - spojni vijak**

considered. The bolts were reviewed in the locations of notches. The most dangerous is the first carrying thread of the nut. For the anchor bolts (strength class 4,6) and connecting bolts (strength class 8,8) the following values of

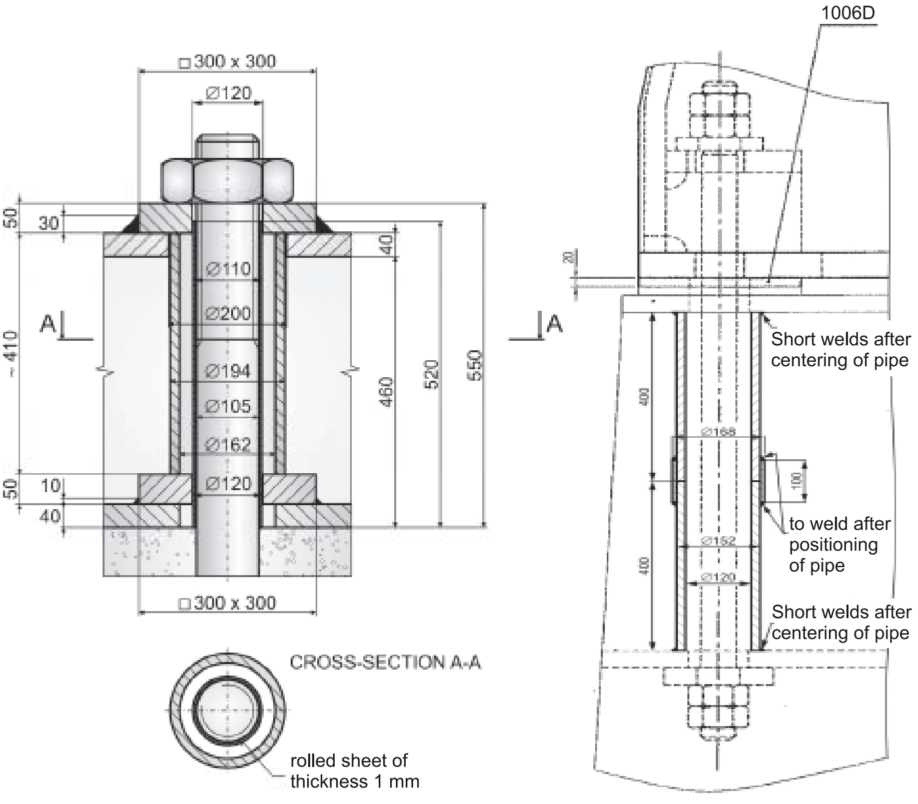

Figure 10. **Suggested improvements of flanges anchor and connecting bolts**
Slika 10. **Prijedlog za unaprijeđenje prirubnica sidra i spojnih vijaka**

mechanical properties as well as parameters which decrease fatigue strength of basic material were considered [8]:

	anchor bolts (4,6)	connecting bolts (8,8)
Yield point R_e /MPa	240	660
UTS R_m /MPa	400	830
Fatigue limit σ_C /MPa	140	257
Fatigue limit for vanishing cycle σ_{HC} /MPa	240	430
coefficient of surface quality	0,87	0,83
notch coefficient β (location of the first thread in bolt)	4	4

In Figure 8. is shown simplified Haigh diagram and lifetime curve for the anchor bolt.

In Figure 9. is shown simplified Haigh diagram and lifetime curve for the connecting bolt.

Because the connecting and anchor bolts had, on the base of computations, limited lifetime, for maximal values of stresses in bolt there was determined number of cycles until fracture [9 - 11].

From the lifetime curves the number of cycles until fracture was determined:

- for connecting bolt N = 997 000 cycles,
- for anchor bolt N = 830 000 cycles.

Because the number of cycles for converter in operation during its assumed life is higher than determined number of cycles until fracture, there were proposed changes on flanges of anchor and connecting bolts.

The aim of these improvements was to decrease variable component of loading in bolts and by this way to increase their lifetime period. The modification is carried out by putting the steel pipes between flanges in accordance with Figure 10. The pipes increase the stifness of flanges.

In addition, the modification of nuts in anchor connections (Figure 11.) was proposed, so the first carrying thread of nut is loaded by smaller loading. The treads of the bolts were cleaned, tapped (Figure 12.), lubricated and this decreased the shear stress during tighten of the nut. Above mentioned modifications allowed to increase the force of prestress in bolts so that the deflections of converter do not exceed maximal allowed values. The analysis of forces and stress fields in bolts proved that the realization of proposed modifications ensures reliable operation of the converter during the whole its lifetime period [12, 13].

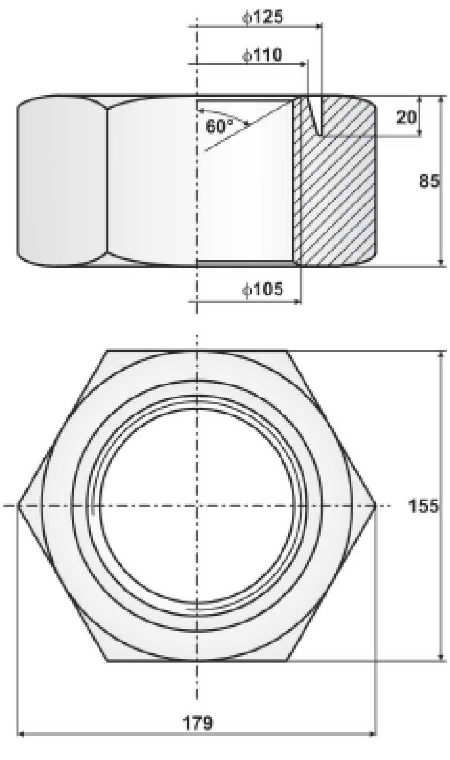

Figure 11. **Modification of anchor nuts**
Slika 11. **Modifikacija sidrenih vijaka**

Figure 12. **Cleaning and cutting of thread**
Slika 12. **Čišćenje i rezanje navoja**

CONCLUSION

The lifetime period of dynamic loaded machines and equipments is often limited by the lifetime of their bolt connections. For the case, if it is not possible to change the stiffness of the bolts in existing structure, it is necessary to optimize the relation between static and dynamic components of load by modification of flange stiffness and appropriate force of prestress.

In the paper are assessed anchor and connecting bolts of pedestal and base of the converter. On the base of theoretical computations and experimental measurements before and after modifications of the structure it is possible to conclude that:

- increasing of the flange stiffness results in favorable distribution of operational forces into bolt and flange,
- modification of compliance of nut at the area of the first five threads of nut results in smaller values of stresses in bolt,
- both previous factors cause that the bolts that worked before structural modification at the area of limited lifetime, from the point of view of fatigue loading, have after modification the lifetime that ensures operation of the converter during its assumed life,
- amplitudes of deflections in the position of bearing house of converter shell decrease on allowed demanded level determined by designer of the converter.

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