Experimental Stress Analysis of Casting Pedestal and Proposals for Increasing of Its Lifespan

František Trebuňa[1], František Šimčák[2], Jozef Bocko[3], Miroslav Pástor[4] & Ingrid Delyová[5]

Abstract: After more than ten years of operation of casting pedestal the cracks occur in its supporting structure. In the paper is given a procedure for analysis of supporting structure of casting pedestal with the aim to determine reasons of failures and to propose modifications that ensure its future operation.

Keywords: Experimental stress analysis, Traverse beam, Residual stresses

1. Introduction

Casting pedestal (Fig. 1) is one of the most important equipment of steelworks with continuous casting of slabs. In the technological flow it serves for transportation of ladles with liquid steel between converters and tundish of machine for continuous casting. During the operation, the structure of casting pedestal is exposed to dynamic loading due to transported mass of ladles with liquid steel, because the traverse (Fig. 2) out on roller bed reversible rotational movement around vertical axis o_v and the traverse of pedestal tilts around horizontal axis o_h.

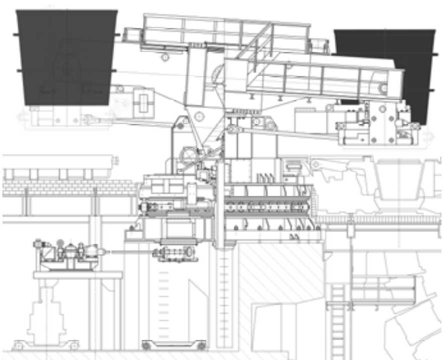

Fig. 1. Casting pedestal with ladles

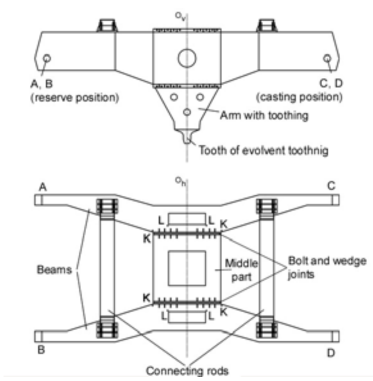

Fig. 2. Traverse of casting pedestal

[1] *Dr.h.c mult. prof.Ing. Franišek Trebuňa, CSc; Department of mechanics and mechatronics, Faculty of mechanical engineering at Technical University of Košice; Letná 9, 042 00 Košice, Slovak republic; frantisek.trebuna@tuke.sk*
[2] *prof. Ing. František Šimčák, CSc; Department of mechanics and mechatronics, Faculty of mechanical engineering at Technical University of Košice; Letná 9, 042 00 Košice, Slovak republic; frantisek.simcak@tuke.sk*
[3] *doc. Ing. Jozef Bocko, CSc; Department of mechanics and mechatronics, Faculty of mechanical engineering at Technical University of Košice; Letná 9, 042 00 Košice, Slovak republic; jozef.bocko@tuke.sk*
[4] *Ing. Miroslav, Pástor, PhD; Department of mechanics and mechatronics, Faculty of mechanical engineering at Technical University of Košice; Letná 9, 042 00 Košice, Slovak republic; miroslav.pastor@tuke.sk*
[5] *Ing. Ingrid Delyová, PhD; Department of mechanics and mechatronics, Faculty of mechanical engineering at Technical University of Košice; Letná 9, 042 00 Košice, Slovak republic; ingrid.delyova@tuke.sk*

The welded carrying system of casting pedestal consists of middle part and two beams. The traverse beams are connected with middle part by bolt and wedge joints (Fig. 2).

During the operation of casting pedestal are in hinges A, B or C, D placed the ladles by hinging supporting baskets. Process of casting results to the following loading combinations of traverse: hinges A, B - full ladle, hinges C, D - ladle with rest of steel; hinges A, B - full ladle, hinges C, D - without ladle; hinges A, B - without ladle, hinges C, D - ladle with rest of steel. Due to symmetry of pedestal are the hinges A, B and C, D interchangeable.

During the casting are in hinges of traverse placed ladles in above given combinations. Transportation of liquid steel from converter to container is realized by turning of casting pedestal (together with traverse) around vertical axis o_V (Fig. 2) by 180°.

Full ladle in hinges A, B (reserve position) is transported to hinge positions C, D (casting position). Ladle in hinges C, D (mostly with rest of steel) is moving to reserve position from which is taken (hinges C, D are without ladle). Short time before end of steel casting from ladle in hinges A, B full ladle is given to hinges C, D and the process repeats. During operation the traverse of casting pedestal provides rickety rotational movement still by 180° around axis o_V. During the casting traverse provides additional rickety rotational movement around horizontal axis o_h so that ladles are moved in vertical direction. Rotational movement around vertical axis o_v is realized by rollers on which whole casting pedestal (Fig. 1) lies, rotational movement around horizontal axis o_h is realized by teeth on the arms with toothing and four hydraulic pistons [1].

Beams of traverse are jointed with the middle part of traverse by bolts and sunk keys (Fig. 2) that are during operation of casting pedestal (as a result of alternating and irregular loading of its arms) released. The supporting elements of traverse are composed of sheets joined by welds. Beams of traverse have closed (box) cross-section with thickness of walls that varies from 16 to 22 mm.

From the analysis of loading conditions in the bolt and wedge joints results that transfer of loading between traverse beams and middle part of pedestal is ensured mostly by wedge joints [2, 3]. As a result of periodical loading and unloading of individual wedge joints the wedges were often draw out from grooves and this is a reason of fact that transfer of loading between traverse beams and middle part is irregular. The problem was solved by fastening of upper wedges by stops [1].

During planned unavailability time and inspection of traverse there were found out failures in locations K of connection of traverse beams to flanges of bolted joints (Fig.2) and in bolted joint itself. By defectoscopy and capillary tests were detected in such locations fatigue cracks of length 50 mm to 160 mm while the longest crack crossed through whole thickness of upper traverse wall. Subsequently, it was found out that one bolt was destroyed and in bodies of several bolts was identified cracks. These failures were repaired – cracks were abraded and welded, damaged bolts were replaced by new ones (bolts M48 were replaced by bolts M52). At the same time was made decision that it is necessary to accomplish stress analysis of traverse of casting pedestal.

In the paper are given results obtained during assessment of crack initiation causes in the supporting structure of pedestal as well as the measures for ensuring its further operation.

2. Measurement of residual stresses in traverse of casting pedestal

As mentioned in previous part of the paper, during operation of casting pedestal several cracks were initiated on upper walls of traverse beams (locations K, Fig. 2). Because of crack initiation and their reparation by welding there was made decision to determine residual stresses in chosen locations of traverse beams. For the measurement was applied the hole/drilling method with using hole-drilling equipment RS 200 [3].

Position, orientation and assigning of strain-gages is obvious from Fig. 3. As can be seen from Fig. 3 the strain-gages were positioned on upper walls of traverse beam near to locations where were cracks initiated (strain-gages 1.1 to 4.1) and near to connecting rods (strain-gages 1.2 to 4.2). Strain-gage 5 was positioned on side wall of traverse beam in location where the plastic deformation was found out.

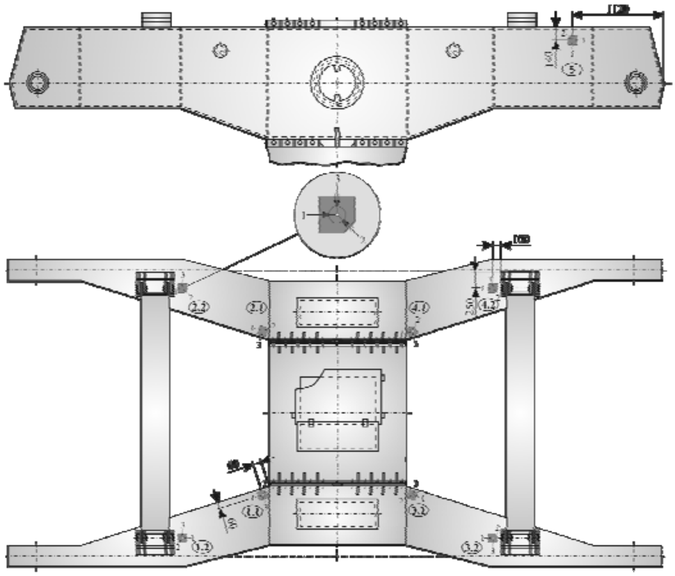

Fig. 3. Positions, orientations and assigning of strain-gages for the hole-drilling method

For illustration, in Fig. 4a) is a picture of isolated strain-gage and in Fig. 4b) is a view to drilling by equipment RS 200. From Fig. 4c) is obvious position of welded crack and strain gage after drilling.

a) b) c)

Fig. 4. Illustrative pictures from application of hole-drilling method. a) Applied strain-gage for hole-drilling, b) Hole-drilling, c) Localization of the strain-gage near welded crack

Measurement was accomplished by self-compensation strain-gage rosettes 1-RY-21-3/120 with diameter 5.15 mm and k–factor 2.07 on all grids and with using strain-gage apparatus P3. Application of strain-gages was realized by strain-gage glue X-60. Strain-gages were protected by silicone gel SG-250 and by aluminium foil ABM 75. Diameter of drilled hole was 3.2 mm. Drilling of every hole was realized in ten steps of length 0.5 mm, whole depth was 5 mm. In every step were registered magnitudes of measured strains released by drilling.

Magnitudes of residual stresses were determined by Standard ASTM E-837-01 [4] which presumes continuous residual stress distribution along hole depth as well as by integral method and method of Power Series for non-proportional distribution of residual stresses. In Table 1 are given values of principal residual stresses determined in accordance with Standard ASTM-E-837-01. Angle α is related to axis of grid of strain-gage 1 oriented in direction of grid numbering.

Table 1. Values of residual stresses according to ASTM E 837-01

Location	σ_{max} [MPa]	σ_{min} [MPa]	α [°]
1.1	135.79	13.41	-11.15
2.1	87.66	2.78	20.29
3.1	162.98	44.78	5.95
4.1	155.03	88.27	-66.92
1.2	73.49	35.76	8.52
2.2	51.82	26.63	13.55
3.2	31.89	16.74	-10.66
4.2	24.04	-13.99	68.22
5	169.63	25.23	-35.17

Measured residual stresses in analyzed locations document that their highest values are in locations of repaired welds and in locations of permanent plastic deformation. Especially important is a fact that in three drilled locations where the failures occured were determined residual stresses at levels 136 to 163 MPa while those stresses are determined from measured released strains after drilling according to ASTM E 837-01 under presumption of regular stress distribution along hole. For computation by integral method those value on the surface of supporting element reache yield point and accordingly they cause plastic defromation that significantly influences fatigue and lifespan. Very important is also a fact that residual stresses in all measured locations have positive signs which is extraordinarily negative influence from the point of view of crack initiation and spreding.

3. Experimental determination of time-dependent stress changes in traverse beams

For experimental determination of time-dependent changes of stress in the traverse beams was used the electrical resistance strain-gage method [4, 6, 7]. Strain-gage measurements were realized by strain-gage apparatus SPIDER with application of strain-gages produced by company HBM according to Fig. 5. For the strain-gage measurement of stresses in the vicinity of cracks (strain-gages 1.1 to 4.1, Fig. 5) were used strain-gage rosettes 1-XY91-10/120. Besides of this, on the sidewalls of traverse beams were applied strain-gages labeled 5,6,7,8 (Fig. 5) of type 1-XY21-6/120 with tree-shaped grid with the aim to determine shear stress in given locations. k-factor of all strain-gages was 2.05. The strain-gages were applied to the base material by glue X 60 and then they were protected by protective means SG-250 and ABM 75 of firm HBM.

Measurement was accomplished for simulated regimes (with ladles of mass 230 000 - 240 000 kg – full ladles and mass 50 000 - 56 000 kg – empty ladles) and in operation regime during casting. In order to illustrate time-dependence of stress increments for one measurement during simulated regime the results of it are given in Fig. 6. In Fig. 7 and Fig. 8 are given typical time-dependent charts of stress increments for loading the ladle to casting pedestal (Fig. 7) and for rotation of pedestal (Fig. 8).

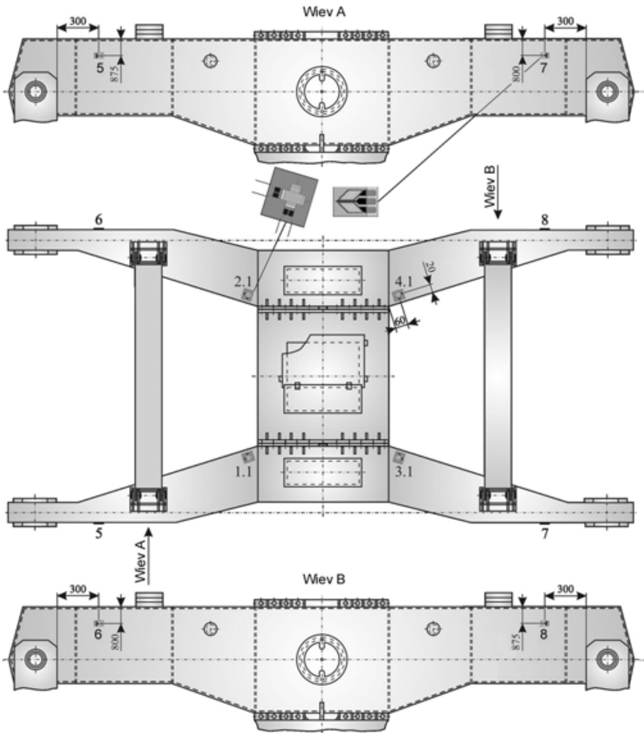

Fig. 5. Labeling of strain-gages, their orientation and position

In Fig. 9 are shown time-dependent charts of stress increments for two casting cycles of operation. Mass of full ladles during casting was approximately 260 00 kg.

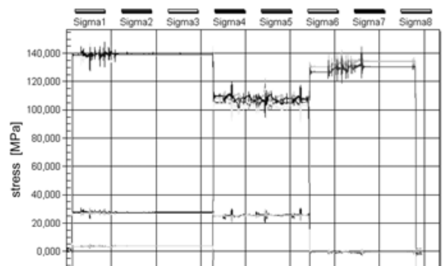

Fig. 6. Time-dependent charts of stress increments for simulated regimes

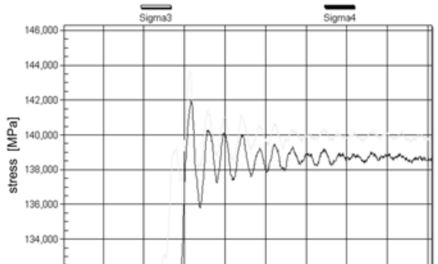

Fig. 7. Time-dependent charts of stresses - loading by full ladle

As results from the strain-gage measurements, the maximum stress amplitudes for the case of loading by ladles up to mass 260 000 kg for both, simulated and operation regimes, reach magnitude 175 MPa. Dynamical effects during rotation of pedestal invoked maximal amplitudes of stresses 27 MPa (Fig. 8), dynamical effects during loading (and unloading) of ladles invoked smaller stress amplitudes (Fig. 7, approximately 6 MPa). As results from stress charts in Fig. 6 and Fig. 9, the traverse beams are not uniformly loaded and this can be caused by incorrect centering of ladles during their positioning on casting pedestal.

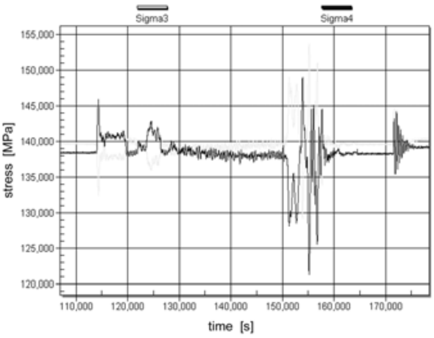

Fig. 8. Time-dependent charts of stresses - rotation of casting pedestal

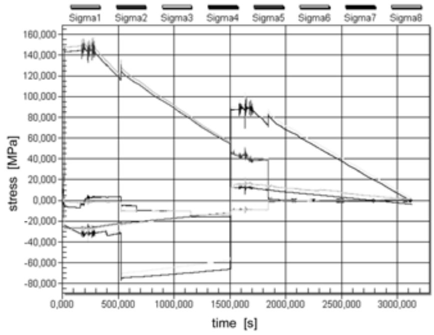

Fig. 9. Time-dependent charts of stresses for two casting cycles

4. Proposed modifications of casting pedestal supporting structure

On the basis of operator demand that the residual lifespan of supporting structure have to be increased quickly, there was accomplished detailed numerical analysis of influences of proposed modifications to stress state in supporting element of pedestal. For the numerical analysis was considered weight for full ladle 280 000 kg, weight for empty ladle 70 000 kg and weight for ladle with the rest of steel 120 000 kg.

In Fig. 10 is given the field of equivalent stresses on upper side of traverse beam of original structure of pedestal for the most danger state of loading. In Fig. 10 are seen locations K and L (see also Fig. 2) of stress concentrations in the corners of hole for the bearing (L) and in location of connection of a beam to the flange of bolted joint (K).

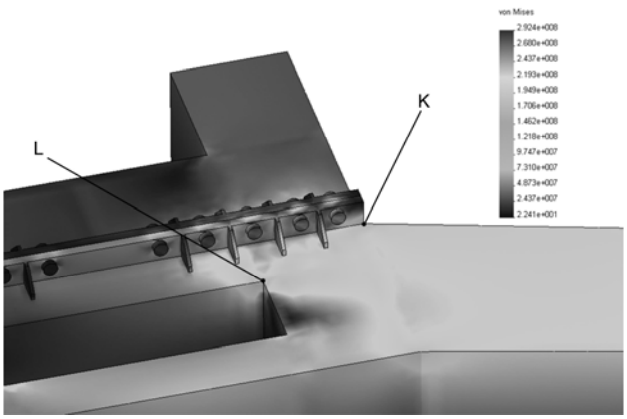

Fig. 10. The field of equivalent stresses on top side of traverse beam

Locations K of stress concentration are identical with the locations of crack initiations (see Fig. 2). In locations L (despite high value of equivalent stress) did not arise observable cracks, probably as a result of occurrences of higher radii of rounding (created by welds) as was modeled by the finite element method. Only extra penetration tests have revealed presence of crack initiations in locations L.

With respect to the known stress levels from numerical and experimental analysis it was supposed that in stress concentration locations K and L almost total degradation of material occurred [8]. It was decided to remove material from locations K and L and replace it by new one of the same type and thickness. Method of material replacement in given locations of traverse beam is apparent from Fig. 11.

With respect to supposed areas of material degradation and dimensional possibilities on the upper side of traverse beam it was proposed replacement of parts of upper flanges in the shape of circular sections with radius 200 mm according to Fig. 11. In Fig. 11 is given photograph of upper side of traverse beam after replacement of material in the corner of opening for bearing.

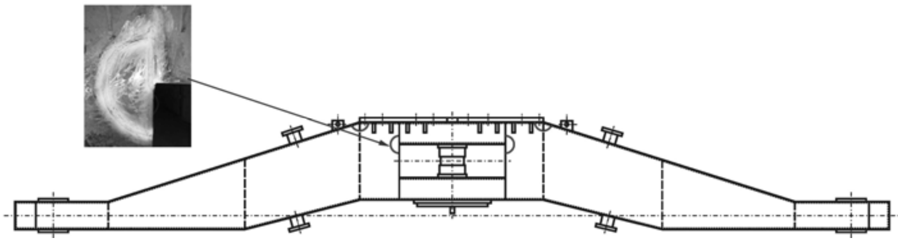

Fig. 11. Locations of replaced parts of flanges (cut-outs with radius 200 mm) of traverse beam

In order to decrease stress levels in locations K and L it was recommended to reinforce traverse beams according to Fig. 12, where is given computational model for the finite element method. In Fig. 13 is shown the field of equivalent stresses on reinforced traverse beam for the most danger state of loading.

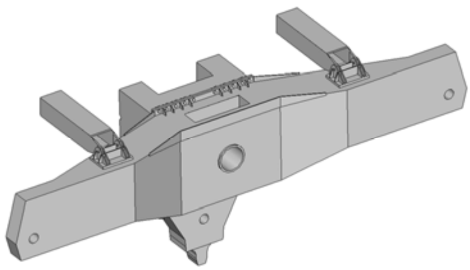

Fig. 12. Computational model of casting pedestal traverse with reinforcement

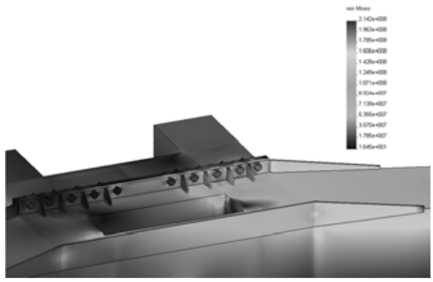

Fig. 13. The field of equivalent stresses on reinforced traverse beam

From comparison of equivalent stress fields on upper side of traverse beam before (Fig. 10) and after (Fig. 13) reinforcement results that reinforcement decreases in locations of stress concentrators K and L stress peaks by approximately 15%.

5. Conclusions

On the basis of analysis obtained during solution problems of loading of casting pedestal the following conclusions can be stated.

Due to periodical loading and unloading of wedge joints between traverse beams and middle part the successive drawing out of wedges occurred that results to irregular loading of traverse beam. This problem was solved with protection of upper wedges by stops. At the same time, in order to ensure optimal function of wedge joint, it was proposed to replace bolts M48 in bolted joints by bolts M52 that allowed increasing prestress in bolts.

In the positions of traverse beams, in locations of failures, were determined in accordance with ASTM E 837-01 tensile residual stresses at levels 136 to 163 MPa.

As results from strain-gage measurements made for simulated and operation regimes, maximal amplitudes of time-dependent stress increments for loading by ladles with mass 260 000 kg reached 175 MPa.

Numerical analysis by the finite element method has confirmed concentration of stresses in locations of cracks (locations K of connections of traverse beam to the flange of bolted joint) as well as in locations L of opening corners for bearing of traverse beam. Maximum equivalent stresses in these locations did not exceed magnitude 170 MPa.

On the basis of loading history of supporting structure and on the basis of results of numerical and experimental analysis was found out that the lifetime of traverse beam is practically exhausted.

With respect to the above mentioned facts there were proposed modifications of traverse beams. Because the analysis has lead to believe that in locations K and L of traverse beams almost full degradation of material occurred the change of parts of upper flanges in these locations has been proposed. At the same time were reinforced traverse beams in order to decrease maximal stresses. The analysis by the finite element method manifested decreasing of maximal equivalent stresses in these locations by approximately 15% that allows further operation of casting pedestal.

Acknowledgement

The authors would like to express their gratitude to Scientific Grant Agency VEGA MŠ SR for the support of this work under Project No. 1/0289/11 and Project No. 1/0265/10.

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