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DIAGNOSTICS AND OPTIMISATION OF CRANE TRACK DURABILITY IN METALLURGICAL PLANT

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Abstract

This paper deals with questions concerning technical diagnostics and optimisation of fatigue durability for the crane track beams installed in a metallurgical plant. The fatigue durability is determined using a strain gauge measurement in order to calculate the relevant residual durability of the crane track beams. Consequently, there are proposed suitable measures that are necessary with regard to the next operation of the given crane track, which is supporting a bridge crane.

Key words: diagnostics, bridge crane, crane track, strain gauge measurement, residual durability

1. INTRODUCTION

This paper describes a professional verification of crane track beams, determination of residual durability of selected beams and suggestion of necessary measures with regard to possibility of future operation of the whole crane track. There were analysed the most seriously loaded beams in one of metallurgical plants in the framework of the company U.S.Steel Košice, Ltd.

An overhead crane, which is also known as a bridge crane, is a type of crane where the hook-and-line mechanism runs along a horizontal beam that itself runs along two widely separated rails. Often it is situated in a long factory building and it runs on rails along the building's two long walls. The bridge crane typically consists of a single beam or a double beam construction. These kinds of cranes can be built using typical steel beams or a more complex box girder type.

Double girder bridge crane is more typical when needing heavier capacity systems from 10 tons and above. The advantage of the box girder type configuration results in a system that has a lower deadweight yet a stronger overall system integrity. Also included would be a hoist to lift the items, the bridge, which spans the area covered by the crane, and a trolley to move along the bridge. The most common overhead (bridge) crane application area is the steel industry. At every step of the manufacturing process, until it leaves a factory as a finished product, steel is handled by means of an overhead crane. Raw materials are poured into a furnace by crane, too and hot steel is stored for cooling by an overhead crane. The finished coils are lifted and loaded onto trucks or trains by overhead crane as well as the double girder bridge cranes are used to handle steel.

It is a well-known fact that the crane tracks, which are used as supporting and guiding systems of the bridge cranes, are extremely loaded during operation of the cranes mainly if these cranes are not only applied in load lifting but also as transport means. Typical operations where cranes are applied as transport means as well are those in metallurgical plants.

Questions concerning diagnostics and optimisation of the steel structures, which are loaded dynamically, are analysed in many publications, e.g. [1, 3, 8, 9, 10, 11, 12].

There are applied various experimental and computational methods specified for analysis of dynamical loading and fatigue durability of the supporting steel structures. Some of them are described in [4, 7].

Diagnostics and optimisation of the crane track durability, which are the main topics of this article, are also analysed in [18, 19].

Authors of this paper dealt with the given technical problems in their publications [2, 4, 5, 6].

In order to solve this given issue a crane track used for guiding of four cranes with lifting capacity from 14t to 32t was chosen in a metallurgical plant. The main tasks performed by these cranes concern loading of sheet coils on the lorries and wagons.

2. SPECIFICATION OF THE CRANE TRACK

The analysed part of crane track consists of single „I"-shaped beams that are 1 800 mm high and 18 000 mm long. One of beams is different from all others; it is 3 296 mm high and 36 000 mm long. Every beam is reinforced vertically and bolted together with columns, as well as each other, up to one third of its high. There are also "braking portals" arranged in rows under some of simple beams with length 18 000 mm, Fig.1.

Fig. 1. Single crane-track girder 18 000 mm long with brake portal

Positioning of braking portals required a special adjustment of beams by means of metal sheets, which are welded crosswise to the lower flange of „I"-shaped beam in a certain small distance left and right from the middle of beam, in order to transfer braking forces, i.e. inertial forces (arising during braking of crane) from the main beam of crane track into the breaking portal.

There were analysed together 9 beam sections of crane track with 18 000 mm long beams (from this number 5 beams were equipped with braking portal) and one analysed beam section was different from all others; it was 36 000 mm long.

All experimental measurements were performed only from one side of crane track because of their accessibility, as well as due to very strong safety rules in the metallurgical plant. Thus, all data necessary for calculation were transformed suitably also to the opposite part of given investigated crane track.

The cross-section of the crane track beam is illustrated on Fig.2.

3. SIMULATION OF CRANE TRACK LOADING

The main purpose of the performed stress calculation simulation of the crane track was to provisionally estimate the potential maximum stress value in those places where the sensors are placed on the bottom flange of the crane track focusing on measured fields. The similar questions are also analysed by authors of publications [13, 14, 15, 16]. A specific and interesting application of the FEM analysis is presented in [17], namely it concerns the tower crane.

The developed calculation models were created for application of the Finite Element Method in the program COSMOS/M. For simulation the calculation models of rail fields both with brake portal and without it were created.

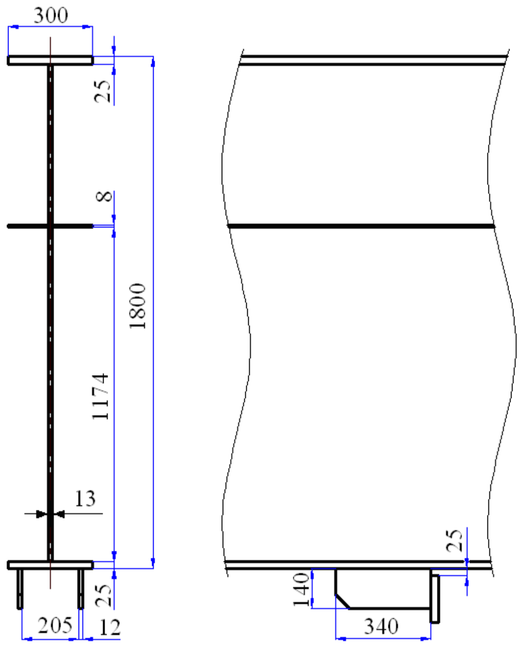

Fig. 2. Cross-section of the crane track beam equipped with brake portal

3.1. Model of the FEM-mesh

In order to simulate both types there were applied the volume elements TETRA10. In Fig.3 the detail of finite elements for the net framework is presented in contact point of rail with brake portal and in Fig.4 the detail of finite elements for the net framework is demonstrated in the middle of field span without brake portal.

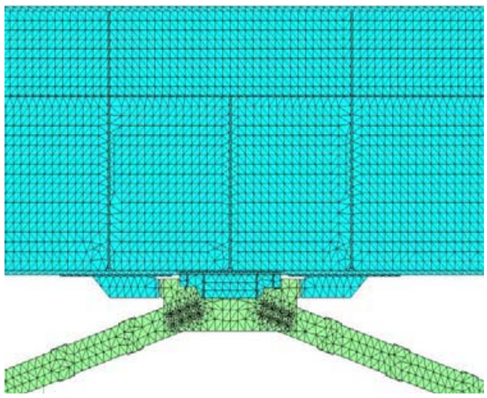

Fig. 3. Detail of crane-track support with brake portal in the field 69-70

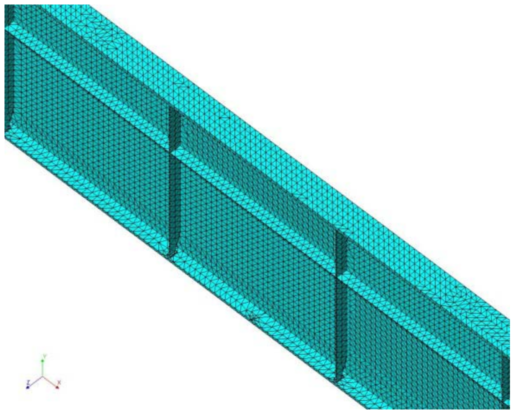

Fig. 4. Detail of FEM-mesh finite elements in the middle field span without brake portal

3.2. Processing of results obtained from computational analysis

The calculation results obtained by means of the FEM were evaluated in the following expressions of normal longitudinal stresses σ_x, caused by bending loading of the crane track, corresponding to orientation of sensors, which were applied in strain gauge measurement.

4. STRAIN GAUGE MEASUREMENT

According to the previous theoretical analysis and visual inspection of the crane track the researchers proposed the method of experimental deformation determination and the following stress definition. The arrangement of sensors installed in the fields No. 69-70 and No. 70-71 is presented in Fig. 5.

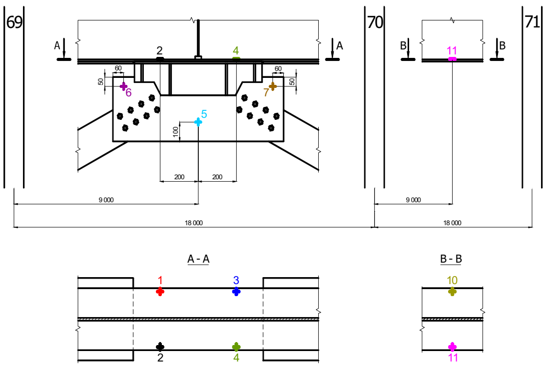

Fig. 5. Arrangement of the strain gauge sensors on the crane-track girder with brake portal in the field 69-70 and on simple structure without brake portal in the field 70-71

The strain gauge sensors HBM 6/120XY11 with the resistance value 120 Ω and with the constant of deformation sensibility 2.04 were applied for measurements. The sensors were applied by using strain gauge sealant HBM X60. The measuring and evaluation chain was created according to Fig.6.

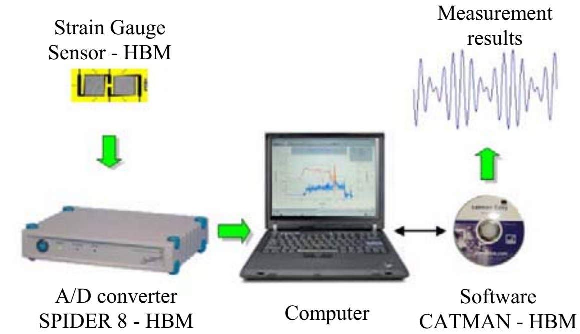

Fig. 6. Measuring and evaluation chain

After balancing of the measuring apparatus the sensors were conserved by protecting coating SG 250 (f. HBM).

From the measured values of relative deformation increments in the individual measurement modes applying the software CATMAN 2.1 the time changes of normal stress increments in the individual measured points were demonstrated and printed, see Fig.7.

The methodology of experiment consisted of seven measurements in seven different stress modes with weight of load 12 500 kg.

The total number of evaluated time records of normal stress in different points of measurements was 63, taking into consideration the chosen stress modes.

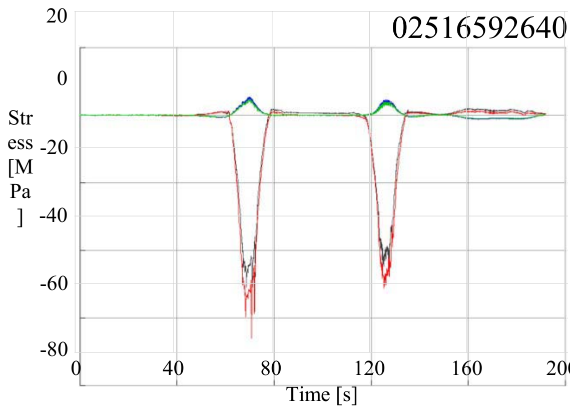

Fig. 7. Illustrative example of time behaviour concerning changes of normal stress increments

5. ACCUMULATION OF FATIGUE DAMAGE – RESIDUAL DURABILITY

Our assessment of the fatigue failure due to material fatigue was completed in compliance with the technical standard STN 73 1401. The aim of the structure assessment considering the fatigue limit state is to ensure acceptable probability of a fact that during the period of calculated fatigue durability of the structure it will not be damaged or violated due to material fatigue [6,11].

The calculation was based on data about stress cycles of girder structures during the defined fatigue durability of the crane track, i.e. from the year 1966 to the year 2005. Due to obtained results from the metallurgical plant the analysis of stress cycles of the examined crane track was carried out, the results of which are presented in Table 1 divided according to different fields between columns. The presented table served for estimation of residual fatigue durability.

Table 1. Number of cycles with regard to fields between columns

Girders between columns	**Number of cycles 1966 - 2005**	
	Cranes with average load of 11 000kg **(n_1)**	***Cranes without load*** **(n_2)**
55 -58	138 146	138 146
58 - 68	2 993 147	2 993 147
68 -76	1 473 549	1 473 549
Total	4 604 842	4 604 842

The crane operation is characterised by a specific fact that the number of working cycles performed with the load (n_1) and without the load (n_2) is identical, therefore $n_1 = n_2$.

Assessing the fatigue durability of the examined crane-track girders of the crane tracks we had to take into consideration the results of measured time path of normal stress accumulation and the calculations in compliance with the standard STN 73 1401.

Due to the above-mentioned standard it is required to consider detail number ČD 206 for the simple crane-track girder of the crane track without brake portal, which can be characterized by detail category KD 125.

Concerning the simple crane-track girder with crane brake with bottom flange cross section 300x26 mm it is necessary to consider between detail number ČD 417 with detail category KD 50 and detail number ČD 418 with detail category KD 36 in compliance with the standard STN 73 1401. Applying the linear interpolation we can get to the detail category KD 45. Data required for the determination of fatigue durability for KD 45 and KD 125 are presented in Table 2.

Table 2. Numerical values of used fatigue durability curves

Category of detail KD	**Stress range at**		
	N_{KD}	**$N_D = 5.10^6$**	**$N_L = 10^8$**
$\Delta\sigma_c$ (MPa)	$\Delta\sigma_{KD}$ (MPa)	$\Delta\sigma_D$ (MPa)	$\Delta\sigma_L$ (MPa)
45	452	33	18
125	232	92	51

Note: N_{KD} is fatigue durability of the corresponding constructional detail, N_D – fatigue durability of the corresponding constructional detail with the number of cycles 5.10^6, N_L – fatigue durability of the corresponding constructional detail with the number of cycles 10^8, $\Delta\sigma_c$ – stress amplitude of the corresponding constructional detail at the fatigue limit, $\Delta\sigma_{KD}$ – stress amplitude of the corresponding constructional detail, $\Delta\sigma_D$ – stress amplitude of the corresponding constructional detail with the number of cycles 5.10^6 and $\Delta\sigma_L$ – stress amplitude of the corresponding constructional detail with the number of cycles 10^8.

Next, the remaining fatigue durability of the crane track crane-track girders was determined according to mode introduced in the standard STN 73 1401. The results concerning the different crane-track girders are presented in Table 3.

Table 3. Residual durability of the crane track girders

Girders between columns	**Accumulation of fatigue damage**
55 - 58*	0.3909
55 - 58	0.01287
58 - 68*	8.47
58 - 68	0.28
68 - 76*	4.169
68 - 76	0.137

Note: index * is valid for girders with brake portal.

6. SUMMARY

The fatigue damage of the crane steel supporting structure is able to cause a fatal failure of the crane during current operation. Some of the serious crane accidents are described in [20,21,22].

According to the results of the strain gauge measurements and with regard to the assessment of the obtained results, as well as after considering the valid standards, the following conclusions can be drawn:

- Considering the measured stress values in the field 69-70 of simple crane-track girder of the crane track supported by brake portal it can be determined that the fatigue durability of it is up to 95% of probability totally ended. This is proved by the fact of the fatigue crack on the bottom flange, which is propagating (Fig.8, Fig.9).

Fig. 8. Photo-documentation of a fatigue crack, side view

Fig. 9. The same fatigue crack, view from above

- With regard to measured stress values in the field 70-71 of simple crane-track girder of the crane track with brake portal the fatigue durability with 95% of survival probability is appropriate (getting near to infinity).
- The fatigue durability of simple crane-track girders of the crane tracks supported by brake portal in the field 55-56 is not totally ended with 95% of survival probability and these crane-track girders can be applied in operations (fields 55-56 are rarely used).
- The fatigue durability of simple crane-track girders of the crane tracks supported by brake portal in the fields 62-63, 69-70 and 74-75 is ended with 95% of survival probability and it is necessary to change them (put them out of service).

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REFERENCES

[1] Grega R., Homišin J., Puškár M., Kuľka J., Petróci J., Konečný B., Kršák B. 2015. „The chances for reduction of vibrations in mechanical system with low-emission ships combustion engines". *International Journal of Maritime Engineering* 157 (A4): 235-240. ISSN 1479-8751.

[2] Bigoš P., Kuľka J., Mantič M., Čurilla J. 2011. „Influence of chemical-technological process on loading of the blast furnace shell". *Chemical Papers* 105 (S): 641-644. ISSN 0009-2770.

[3] Sapietova A., Saga M., Novak P., et al. 2011. „Design and Application of Multi-software Platform for Solving of Mechanical Multi-body System Problems". In. *9th International Conference "Mechatronics Location"*: 345-354. Warsaw, Poland. 21-24 September 2011.

[4] Bigoš P., Kuľka J., Mantič M., Kopas M. 2015. „Comparison of local stress values obtained by two measuring methods on blast furnace shell". *Metalurgija* 54 (1): 101-104. ISSN 0543-5846.

[5] Kuľka J., Mantič M. 2013. „Lifetime of crane ways from point of changing legislation". *Zdvíhací zařízení v teorii a praxi* 2013 (1): 29-34. ISSN 1802-2812.

[6] Faltinová E., Kopas M. 2012. „Assessment of crane rail fatigue life in a particular metallurgical plant". *Zdvíhací zařízení v teorii a praxi* 2012 (1): 25-30. ISSN 1802-2812.

[7] Mendrok K., Uhl T. 2010. „Load identification using a modified modal filter technique". *Journal of Vibration and Control*. 16 (1): 89-105.

[8] Daneshjo N., Hlubeň D., Daneshjo E., Kopas M. 2011. *Diagnostics, maintenance and reliability of machine manufacturing systems.* Düsseldorf, Germany: Publisher Dr. Enayat Danishjoo. ISBN 978-3-00-035706-0.

[9] Schwarz B.J., Richardson M.H. 1999. *Introduction to operating deflection shapes*. Orlando, FL: CSI Reliability, Week.

[10] Bijen J. 2003. *Durability of Engineering Structures: Design, Repair and Maintenance*. Cambridge: CRC Press. ISBN-10: 0849317703.

[11] Haibach E. 1989. *Betriebsfestigkeit.* Düsseldorf: VDI-Verlag GmbH.

[12] Chopra A.K. 2011. *Dynamics of structures.* Prentice Hall, Upper Saddle River.

[13] Sága M., Vaško M. 2009. „Stress Sensitivity Analysis of the Beam and Shell Finite Elements". *Communications* 11(2): 5–12. ISSN 1335–4205.

[14] Handrik M., Vaško M., Kopas P., Sága M. 2014. „Effective Finite Element Solution and Post-processing for Wide Load Spectrum". *Communications* 16 (3A): 19–26. ISSN 1335–4205.

[15] McDonald B., Ross B., Carnahan R. A. 2011. „The Bellevue crane disaster". *Engineering Failure Analysis* 18(7): 1621–1636.

[16] Kovačević D., Budak I., Antić A., Nagode A., Kosec B. 2013. „FEM modeling and analysis in prevention of the waterway dredgers crane serviceability failure". *Engineering Failure Analysis*. doi:10.1016/j.engfailanal.2012.10.009

[17] Zhang Y., Zhao J., Yao J. 2011."Static structural finite-element analysis of tower crane based on FEM". *CCIE 2011 - Proc. 2011 IEEE 2nd Int. Conf. Comput. Control Ind. Eng.,* 2: 220–3.
[18] Caglayan O., Ozakgul K., Tezer O., Uzgider E. 2010. "Fatigue life prediction of existing crane runway girders". *J Constr Steel Res* 2010(66):1164–73.
[19] Rettenmeier P, Roos E, Weihe S. 2016. "Fatigue analysis of multiaxially loaded crane runway structures including welding residual stress effects". *Int. J. Fatigue*, 82:179–87.
[20] Domazet Z, Lozina Z, Pirsic T, Architecture N. 2001. "Fatigue damage and repair of 250 kN portal crane in Shipyard". *ICF10, Honolulu, Hawaii*.
[21] Marquez A.A, Venturino P., Otegui J.L. 2014. "Common root causes in recent failures of cranes". *Eng Fail Anal* 39:55–64.
[22] McDonald B., Ross B., Carnahan R.A. 2011. "The Bellevue crane disaster". *Eng Fail Anal* 18:1621–1636.

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