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ANALYSIS OF WORKING LOADS AND A FATIGUE LIFE PREDICTION OF A SPECIAL RAILWAY CRANE LOAD-BEARING STRUCTURE

Bohuš LEITNER, Jaromír MÁCA

Bohuš Leitner, Assoc. Prof. , PhD., Jaromír Máca, Prof, PhD.,
Faculty of Special Engineering, University of Žilina, Dep. of Technical Sciences and Informatics, ul.1.mája 32, 010 26 Žilina,
SLOVAKIA

***Abstract**: The aim of the paper is to present briefly some results of realized analysis of load-bearing steel structure loads of special railway crane PKP 25/20i which was utilized in some specific ad relatively hard working conditions. Working loads which rise during different regimes of the crane engagement were determined by means of COSMOS/M software and were verified by an extensive experimental measurement with following comparison of obtained results. Developed and verified virtual model of the structure will be used in an analysis of acting working loads influence to be able to forecast fatigue life of load-bearing part of the crane.*

Key words : *Working loads, Fatigue life prediction, Railway crane, Load-bearing structure.*

INTRODUCTION

It is dedicated extraordinary attention to the evaluation of fatigue life of different technical systems structural parts all over the world because breakdowns caused by fatigue failure have often character of catastrophe. It should be a dominant effort to bring conditions of calculation or experiment near to the working conditions in that is investigated system exploited. The aim is to reduce unfamiliarity of surroundings acting factors and their interactions with processes passing in own system. A modern way of calculation of any mechanical system (e.g. large mechanical or civil structures) therefore needs in point of view of raising some working breakdowns to mostly respect dynamic and stochastic nature of all influencing working factors and related working loads.

REAL WORKING CONDITIONS OF A RAILWAY CRANE PKP 25/20I

A special railway crane PKP 25/20i is lifting equipment designed for exploitation in a limited space conditions which are met by the building of railway. His main working purpose is to lay down or to tear off rail fields of maximal length 25 m and mass of 20 tons by a complex reconstruction or by renovation of the railway. (Fig.1). Determination of real working conditions with a choice of typical loads was important for calculation of fatigue life of a crane bridge as a carrying steel structure. There was possible to build a theoretical load spectrum of a crane load-bearing structure on that base.

It was necessary thoroughly analyse functions of the crane one by one and to determine how they influence the fatigue life by building of characteristic load spectrum of crane bridge. After a theoretical analysis of single working functions were following characteristic working functions of a crane [2]:

- ***tearing off rail fields*** - the limiting function of a machine (high load of a crane bridge by high mass and dynamic effects by tearing off rail fields out of gravel bed),
- ***laying down rail fields*** - the limiting function of a crane,
- ***auxiliary working functions*** - manipulation of carriages, travel of a crab (type of

complemented cycles, low influence on the total fatigue life of crane bridge),

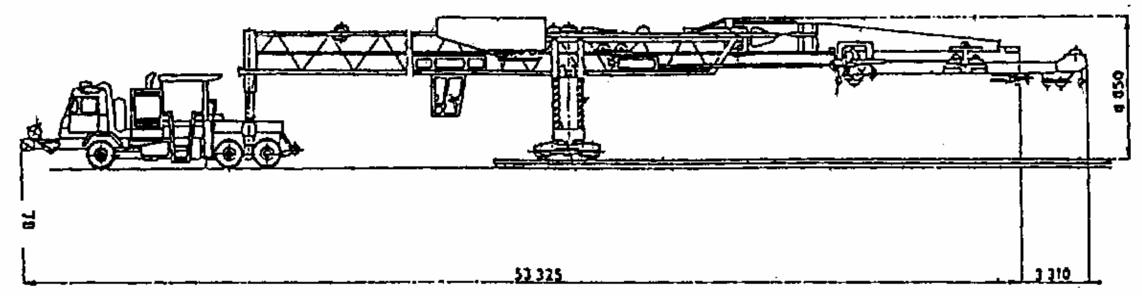

Fig.1: A Special Railway Crane PKP 25/20i.

- ***travel of a crane*** - function between basic technological workings (no important influence on fatigue life of crane bridge),

It is obvious from the analysis of working conditions that the most exacting working conditions are the tearing off the old rail fields and that this function has the decisive influence on fatigue life from the point of view of number of cycles and loads.

SELECTION OF A MEASURING CONDITIONS

On the base of knowledge of fatigue life theory and analysis of working conditions was decided that an experimental measurement would be done in a real practice. The measurement was planned to realise by the renovation of a railway track. Before an actual measurements there was necessary to determine critical locations of the crane bridge and to realise a theoretical analysis of working conditions of a crane. These were chosen on the base of static conditions calculations using model of standard software package COSMOS/M - Fig.2.

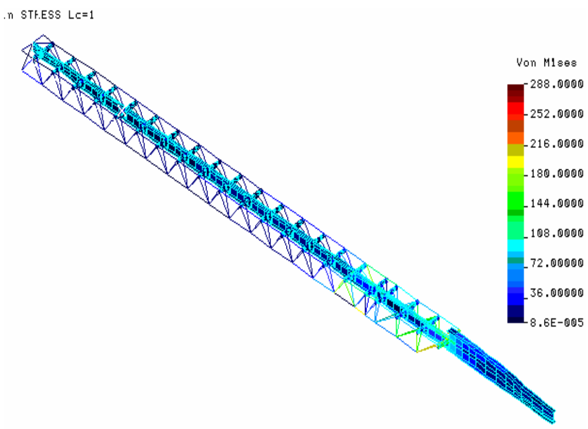

Fig.2. FEM Model of a Crane PKP 25/20i.

The outputs of them were the locations for location of tensiometers on the crane bridge according to Fig.3. The measuring equipment was built of tensiometric pitch-ups (type C120), tensiometric set (M1000) with amplifier of signal (M1101), equipment for data transfer (DAS-16), computer HP Pavilion DV6799 and PC and printer.

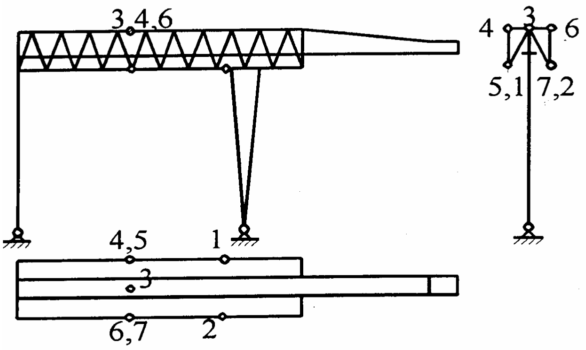

Fig.3. Locations of tensometers on a crane bridge

ANALYSIS OF MEASURED DATA

By analysis of measured values of progress of stresses was determined:

- ***Stress by tearing off rail fields has a periodical character.*** The dynamic increase of stress was about 10-20 % of the maximal amplitude, what is nearly in harmony with a standard. The most expressive progress of stresses was determined during tearing off, start, stopping and lazing down rail fields. The measured value of stress amplitude was average 175 MPa (Fig.4),

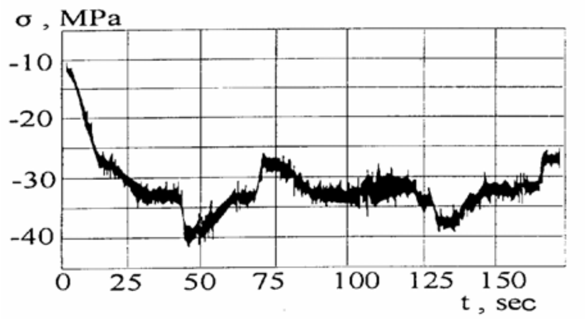

Fig.4. Stress by tearing off, start, stopping and lazing down rail fields.

- ***The manipulation with railway carriage using turn able part of crane bridge was characterised by a non-stationary process*** by which measured values of stress were in average 20 MPa (Fig.5),

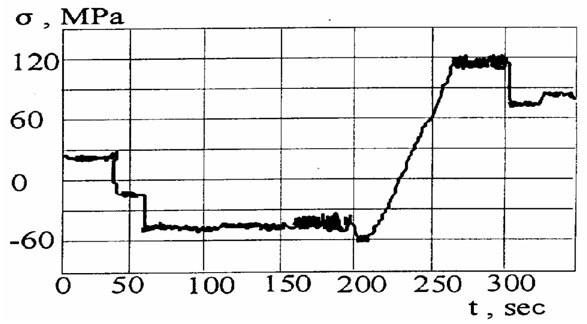

Fig.5. Stress by manipulation with railway carriage using turntable part of a crane bridge.

- ***Travel of a crane to the next rail field was characterised by a non-stationary progress*** of stress increase, by which a maximal absolute value of stress increase was 34 MPa (Fig 6.).

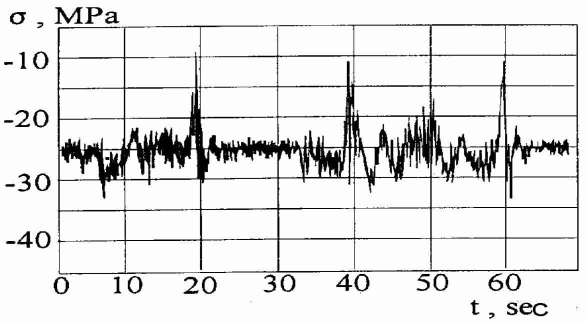

Fig.6. Stress by travel to next rail field

SPECTRUM OF LOADS

On the base of an analysis of working conditions and results of experimentally measured increase of stresses during working of a crane was possible to construct a real spectrum of loads [2] (Fig.7).

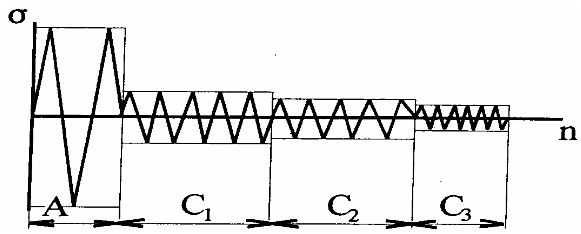

Fig. 7. A real spectrum of loads

Single working cycles introduce characterristiccally working conditions of a railway crane, which consist of following working cycles:

- A - tearing off old rail fields ***(σ=175 MPa, n=1250)***
- C - auxiliary working cycles
  C1 - free travel of crabs ***(σ=40 MPa, n=3000)***,
  C2 - travel to the next rail field ***(σ=34 MPa, n=1250),***
  C3 - manipulation with of railway carriages ***(σ = 20 MPa, n = 650)***.

THE ESTIMATE OF WORKING FATIGUE LIFE OF CRANE PKP 25/20i CARRYING STRUCTURE

The general procedure of life prediction from point of view of fatigue damage was based on realization of following activities:

- determination of the most significant working regimes and factors of typical working conditions from point of view of structure loads and their following activities,
- identification of carrying structure critical parts and determination of their working loads,
- elaboration of the real working spectrum of crane carrying structure and its utilization by determination of typical working conditions,
- analysis of choice material properties and estimate of effects of different types of notches, connections and nonlinearities in examined points of structure and
- application of suitable hypothesis of fatigue damage cumulation and quantification of predicted fatigue life of selected parts of carrying structure.

1. The most significant working regimes

The activities connected with technology of tearing off the old rail fields and laying down the new ones were identified as the most significant working regimes of mentioned crane and some of accessory processes as no-load run of a crab, handling of railway bogies (undercarriage) and travelling to the following rail field too. The effect of surroundings low temperatures was chosen from surrounding conditions because they cause freezing of the rails bed and following increase of the pulling force by tearing off rail fields. The effects of surroundings conditions connected with unevenness (longitudinal or transverse) of newly laid down rail bands was not taken into account because the have not an expressive effect on crane working.

2. The identification of critical parts of supporting structure

The virtual FEM model was elaborated and verified to use in the procedure of identification of supporting structure critical parts. The stresses experimentally obtained were utilized during the actualization of the FEM model in order to obtain the maximum adequacy of the model comparing to the real structure. It was determined from static and dynamic analyses realized. The critical parts are namely upper and lower beams of supporting structure (EL232, EL237, EL89 and EL93) and places near of locking connection of C and D parts (EL335) - Fig.8.

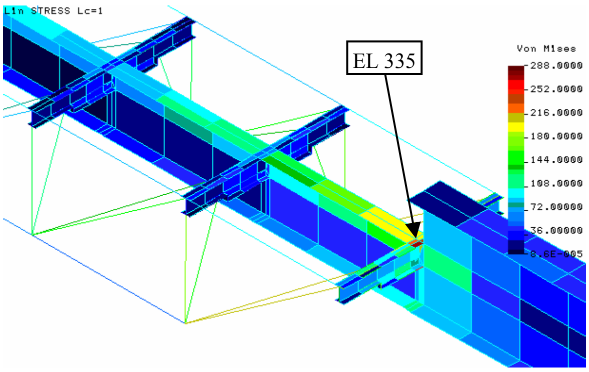

Fig.8. Detail of C and D parts locking connection

3. Material properties of structure details

Supporting structure of the crane bridge is made from the low carbon steel 11 523. The Wöhler curve of the used material was determined after the STN 270103 standard, chapter IX „Fatigue loading capacity“ for the working group II and notch group K4 to which the examined structure belongs. Obtained Wöhler curve of the 11 523 material and its parameters were utilized as an input into the suitable hypothesis of fatigue damage cumulation. Following parameters of material curve were used: **$w = 5{,}8$, $N_C = 2{,}5 \times 10^6$, $\sigma_C = 190$ MPa** and **$R_e = 355$ MPa**.

ESTIMATE OF WORKING FATIGUE LIFE OF A CRANE LOAD-BEARING STRUCTURE

The principal hypothesis’ of fatigue damage cumulation were aplied during estimate of working fatigue life of a crane PKP 25/20i supporting structure. It was made by means of quantification of cumulation fatigue damage proces too. Three principal hypothesis’ of fatigue damage cummulation were applied by selected details. All levels of stress’ measured were taken into account not only these wich value is greater as a fatigue limit.

They were applied two hypothesis’ for prediction in a practical way. There were the hypothesisi after Palmgren- Miner (P-M) and the one after Corten-Dolan (C-D) which are based on utilization of parameters of corresponding material curve and actual loading spectrum. The break-point of Wöhler curve by low carbon steels with a notch moves significantly left ward by aplying of C-D hypothesis and the damaging effects therefore are related to corrected inclined strand of fatigue curve with exponent (k*w), where k = 0,70 - 0,98.

Prediction of fatigue life after Rajcher’s hypothesis

Rajcher’s theorem was used for the fatigue damage computations in the identified critical parts of the crane load-bearing structure too. This theorem defines the fatigue damage in the critical location of the structure part induced per one second and is expressed by the following equation in form

$$D_s = \frac{\Gamma \cdot \left(\frac{w}{2}+1\right) \cdot \left[2 \cdot \int_0^\infty f^{\frac{2}{w}} \cdot S(f)\, df\right]^{\frac{w}{2}}}{N_C \cdot \sigma_C^w}, \qquad (1)$$

where w is exponent of S/N curve, σ_C is fatigue limit, N_C is limit number of cycles to failure, f is frequency, $S(f)$ is spectral power density of the stress loading process, Γ is gamma function value. Time until the next failure can be expressed (in hours) as follows

$$T = \frac{1}{3600 \cdot D_s} = \frac{N_C \cdot \sigma_C^w}{3600 \cdot f_e \cdot \left(2 \cdot s_\sigma^2\right)^{\frac{w}{2}}} \cdot \Gamma \cdot \left(\frac{w}{2}+1\right).$$

It is obvious that all the process can be realized only by means of the computer technique efficient enough. The approach in practice is that after import or calculation of the process spectral power density values *S(f)* the process standard deviation S_σ and process effective frequency f_e of the probability density will be determined.

The practical application of the presented process was realized by the program created in the MATLAB environment. The worked computational program named FATIGUE.M was used at the fatigue life computational estimation of the load bearing structure in the selected critical points under the chosen characteristics of the crane operating conditions. In the application the following material parameters defining the fatigue properties were used: slope of S/N curve w, fatigue limit σ_c, limit number of cycle N_c and yield limit R_e; which gain the following values for the particular elements of structure (look on Fig.2). Value σ_c was during this process reduced according to the stress average value and also according to factors affecting the fatigue limit (shape, size, stress concentration in the score, treatment quality etc.).

The Rajcher hypothesis of fatigue damage cummulation was chosen from hypothesis' based on correlation theory. This hypothesis uses Wöhler curve parameters, gama function ond spectral power density (SPD) of a structure response an acting working loads. Used courses of SPD were obtainedby means of application of the virtual FEM model of supporting structure and by means of following elaboration of model analysis results using software created in Matlab environment. Obtained results of estimated measure of supporting structure fatigue life are intruduced in Tab.1.

Table 1 The estimate of fatigue life of critical elements of crane carrying structure

Fatigue life prediction based on hypothesis' [in years]	**EL 232**	**EL 89**	**EL 335**
P-M (Palmgren–Miner)	24,2	23,1	25,0
C-D (Corten – Dolan)	19,6	19,2	21,2
R (Rajcher)	20,2	19,9	20,4

Calculated estimate of working fatigue life of the railway crane PKP 25/20i supporting structure was realized in order to examine possibility to expand working life of existing and utilized structure after the term detrmined by its producer.

Demand for this procedure was made by its user. The term of life reccomended by producer was 15 years by acceptation of detrmined technical conditions and reccomendations. It was possible to declare basing on results obtained that it is possible to utilize the crane after proposed term of technical life from teh point of view of fatigue life. However the preventive checks of critical points were recommended in each 2-yers interval.

CONCLUSION

It follows from obtained results from point of view of safety and reliability of the crane PKP 25/20i working that its supporting structure - bridge of a crane) is designed sufficiently. But it is necessary to respect proposed technology of its utilization and maximum value of loads. However the non-reversible deformation and structure damage can occur during certain working conditions (for example tearing off rail field from frozen bed, strong wind impact or non-qualified manipulation and control resulting in the loss of crane stability).

It is necessary to state finally that the process of fatigue damage cumulation and depending fatigue life estimate can be made with certain probability only using certain assumptions and simplification despite of having available lot of data from the areas of fatigue and fatigue strength [8]. The cause of this is not only lot of factors connected with fatigue life but mainly their reciprocal coherences and interactions. It in necessary to understand that presented values of bridge of crane fatigue life are the approximate ones and just the real working can show how these values were exact and relevant.

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Reviewer: prof. Dr. Ing. Milan SÁGA

АНАЛИЗ НА ПРЕДВИЖДАНЕТО ЗА РАБОТНИТЕ НАТОВАРВАНИЯ И ПРОДЪЛЖИТЕЛНОСТТА НА УМОРАТА НА ТОВАРОНОСЕЩАТА КОНСТРУКЦИЯ НА СПЕЦИАЛЕН ЖЕЛЕЗОПЪТЕН КРАН

Бохуш ЛЕЙТНЕР, Яромир МАЦА

Доц. д-р Бохуш Лейтне., проф. д-р Яромир Маца,
Факултет за специално инженерство, Университет в Жилина, Катедра „технически науки и информатика”, ул. Първи май 32, 010 26 Жилина,
СЛОВАКИЯ

***Резюме**: Целта на доклада е да представи накратко резултатите от осъществения анализ на товароносещата стоманена конструкция на специалния железопътен кран PKP 25/20i, който беше използван при някои специфични и относително трудни работни условияs. Работните товари, които издига по време на различните режими на работа на крана, бяха определени чрез програмния продукт COSMOS/M и бяха проверени чрез широки експериментални измервания, последвани от сравнение на получените резултати. Разработеният и проверен виртуален модел на конструкцията ще бъде използван при анализа на въздействието на действащите работни натоварвания, за да може да се предвиди продължителността на умората на товароносещата част на крана.*

***Ключови думи :** работни товари, предвиждане на умората, железопътен кран, товароносеща конструкция.*