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EXPERIMENTAL DETERMINATION OF LATERAL FORCES CAUSED BY BRIDGE CRANE SKEWING DURING TRAVELLING

EKSPERYMENTALNE WYZNACZANIE SIŁ POPRZECZNYCH WYWOŁANYCH SKRĘTEM SUWNICY PODCZAS JAZDY

Crane condition depends on the large number of variables randomly changing in time. Due to the large number of parameters, skewing forces have stochastic character. Though in standards treated as occasional loads, their dynamic action in certain cases can cause fatigue damage of the crane travelling mechanisms, structure and runway components. Current European Norms have left the question of skewing forces influence upon the fatigue damage occurrence unresolved. The paper presents an experimental determination of lateral forces acting on the vertical wheels of a bridge crane using two different solutions of transducers for the direct measurement on the wheels of the cranes in operation, without changing the way of lateral guiding. As an illustration, few records of the measured wheel lateral force vs. time are shown. Presentation of such records in the form of a loading spectrum (e.g. using the software nCode), obtained during long-lasting or continuous monitoring of cranes in operation, is the first step in finding the relevant answer to the previously unresolved question.

Keywords: *bridge crane skewing, lateral force transducer, load spectrum, fatigue.*

Stan suwnicy pomostowej zależy od dużej liczby zmiennych losowo zmieniających się w czasie. Ze względu na dużą liczbę parametrów, siły skośne mają charakter stochastyczny. Chociaż w normach traktowane są one jako obciążenia sporadyczne, ich dynamiczne oddziaływanie w niektórych przypadkach może powodować zmęczeniowe uszkodzenie mechanizmu jazdy suwnicy, jak również jego konstrukcji oraz elementów toru jezdnego. Obecnie obowiązujące normy europejskie pozostawiają bez rozwiązania kwestię wpływu sił skośnych na występowanie uszkodzeń zmęczeniowych. W pracy przedstawiono metodę eksperymentalnego wyznaczania sił poprzecznych działających na koła pionowe suwnicy pomostowej. Metoda ta polega na użyciu dwóch różnych rozwiązań przetworników do bezpośredniego pomiaru sił na kołach pracującej suwnicy, bez zmiany sposobu prowadzenia bocznego . Dla ilustracji pokazano kilka zapisów pomiarów siły poprzecznej koła w funkcji czasu. Przedstawienie takich zapisów w postaci widma obciążenia (np. za pomocą oprogramowania nCode), uzyskanego podczas długotrwałego lub ciągłego monitorowania suwnicy w trakcie jej eksploatacji, stanowi pierwszy krok do znalezienia rozwiązania nierozwikłanego do tej pory problemu.

Słowa kluczowe: *skręt suwnicy, przetwornik siły poprzecznej, widmo obciążenia, zmęczenie.*

1. Introduction

The separate group of cyclically operating load transporting machines includes cranes, travelling along the invariable railway consisting of two parallel rails fastened onto the corresponding steel or concrete supporting beams, or onto the foundation on the ground. Some typical representatives of this group are bridge, gantry and semi-gantry cranes, ship-to-shore container gantry cranes, and slewing jib portal or semi-portal cranes.

All the loads acting upon the crane are transmitted from the points of their action through the structure and wheels or guide rollers, to the runway rails. Crane wheels derailment is usually mechanically prevented under constraint by the guiding means, such as wheel flanges, or horizontal side rollers. Manufacturers of transducer technologies have already offered various electronic contactless guiding systems. However, their application is limited to the newer and valuable cranes. Nowadays in use are mainly bridge and gantry cranes without any additional electronic guiding devices.

During the operation of slewing jib portal cranes, due to the slewing of their turntable, and derricking the jib, the position of the center of gravity projecting point upon the supporting plane is constantly altered. Asymmetric allocation of gravity forces at bridge and gantry cranes is caused by the loaded trolley traversing. Consequently, the general rule applies to all the previously mentioned cranes where during the load handling, vertical loads acting on the crane wheels and resistance forces change their values, thus causing the crane structure skewing in the horizontal plane. Their vertical wheels are rolling without disturbance in the „natural direction“, causing the deviation of the direction of resulting crane motion from the runway rail direction. However, the direction of motion alters when the guiding means comes into the contact with the rail head, and the crane keeps coming back into the runway direction. Such forced guiding along the runway realized by the successive interaction among the guiding means and the rail, causes complex planar motion of the crane, termed as skewing.

The purpose of this research is to propose the concept of forming the experimental data basis concerning the influence of crane skewing on the fatigue of its structure elements and traveling drive components. Such data basis is indispensible for further advancement of probabilistic calculations of cranes.

The paper gives the short survey of typical damages of crane wheels and rails caused by the undesirable consequences of excessive skewing. The main goal of the paper is to outline one of the possible ways of measuring the values of lateral forces due to skewing, without altering the function, the composition, or the form of the standardized crane wheel assembly. Two different forms of force transducers were designed for the purpose of measuring the lateral forces. The proposed technical solution was tested at the single-girder bridge crane. The obtained records of the measured wheel lateral force vs. time were processed by using the software nCode. The final results were obtained in the form of the lateral forces spectra per wheel for the period of measurement.

2. Short reference to the problems of bridge crane skewing

Forces arising in the interaction among the wheel and the rail, and corresponding velocities (projected onto the contact plane) are shown in Fig. 1. The natural direction of a crane vertical wheel rolling deviates from the rail direction, and the deviation is expressed as the skewing angle α_w.

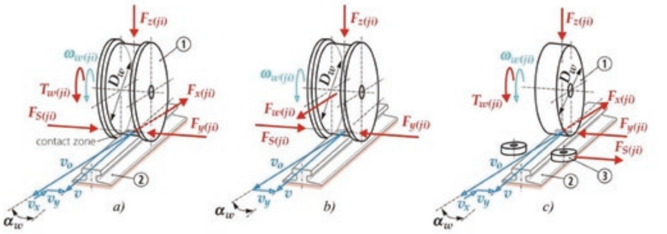

Fig. 1. Velocities and forces corresponding to the skewed crane wheel: a) driven flanged wheel; b) non-driven flanged wheel; c) driven flangeless wheel (1- vertical crane wheel; 2 - rail; 3 - horizontal guiding roller)

Driven wheel i on the rail j, Fig. 1.a, loaded with vertical force $F_{z(ji)}$ and driven by the torque $T_{w(ji)}$, rolls along the rail with tangential velocity $v_o = (D_w/2)\cdot\omega_{w(ji)}$, where D_w denotes the nominal wheel diameter. Due to its elastic slip, the driven wheel slips tangentially with the velocity v_x. When its flange comes upon the rail head, due to the axial slip with the velocity v_y, the wheel abandons its „natural direction“ and starts rolling in the rail direction with the resulting velocity v. The corresponding forces due to the tangential and axial slips are $F_{x(ji)}$ and $F_{y(ji)}$, and the skewing force $F_{S(ji)}$ arises in the contact point of wheel flange and rail head.

Non-driven wheel, Fig. 1.b, is driven by the crane structure, pulling its axle with force $F_{w(ji)}$, and rolls with the angular velocity $\omega_{w(ji)}$. In this case, no elastic slip occurs, and consequently there exists neither velocity v_x, nor force $F_{x(ji)}$.

In case of a crane with flangeless vertical wheels, Fig. 1.c, guiding along the runway rails is performed by horizontal rollers. The skewing force occurs in the contact point of the roller and the rail.

The occurrence of skewing phenomena is not equally noticeable at each of the mentioned crane types. Skewing forces at portal slewing cranes with derricking jib and container portal cranes are of no exceptional importance for the dynamic behavior and structure fatigue, because the travelling of these cranes is a mere auxiliary movement (changing the operation location). However, for gantry and bridge cranes with wider spans, the steady tendency to skewing during travelling is one of the important issues.

The most significant factors having impact on the crane motion stability and its dynamic behavior in the process of skewing, as well as on the occurrence frequency, amplitude values and history of skewing force, are [8, 17]:

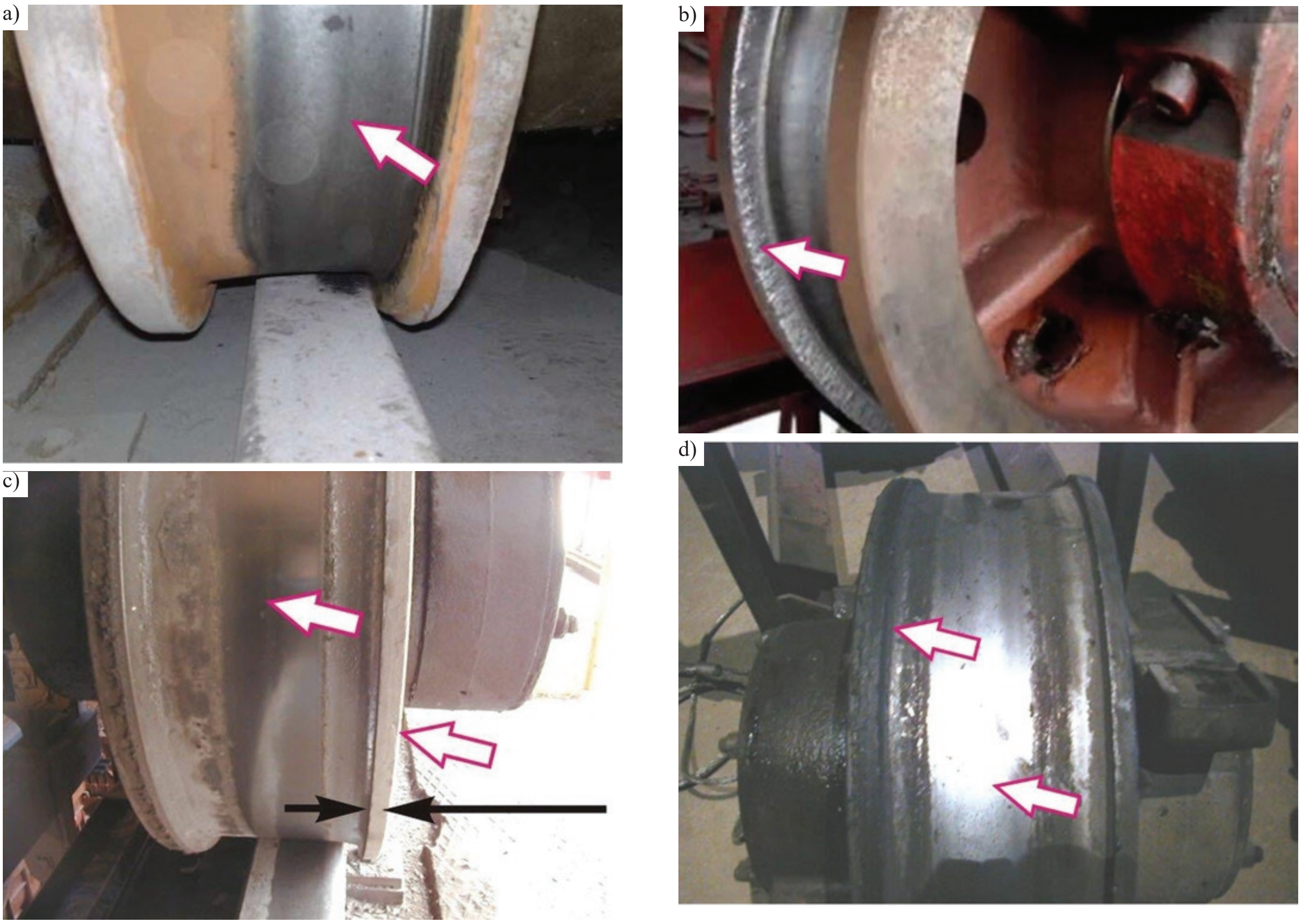

Fig. 2. (a–d) Examples of typical damage of crane vertical wheels and horizontal guiding rollers

Fig. 2. (e–i) Examples of typical damage of crane vertical wheels and horizontal guiding rollers

- factors and phenomena depending on the crane configuration, operation regimes, and environmental conditions, and cannot be altered by means of technical or technological actions,
- geometrical imperfections and deviations made during manufacturing and installation of crane vertical wheels assemblies,
- improper arrangement of horizontal guiding roller assemblies, geometrical imperfections and deviations made during installation of their components,
- geometrical imperfections made during manufacturing and installation of crane runway rails,
- deviations made during installation of crane structure elements,
- unequal angular velocities of driven wheels on both end carriages,
- irregular and incompetent maintenance of a crane and its rail track, and
- errors in crane design due to insufficient knowledge of crane skewing problems.

Undesired consequences of crane skewing are usually shown as various types of damage on vertical wheels and horizontal rollers, rails and crane structure elements. Extreme lateral loads caused by enormous skewing can even cause frequent failures, rail track degradation, demolition or plastic deformation of crane driving mechanism components, or even crane structure collapse.

Fig. 2.a and 2.c show the wheel tread (rolling surface) with clearly distinguishable lighter surfaces with metal glitter from the corroded surfaces, [10, 11]. The difference among the conditions of these surfaces indicates that the crane doesn't use the whole width of the wheel tread. In case of constant contact between the wheel flange and the same rail head, the crane travels in a straight line without any „waddling". During a longer period, this leads to wearing of only one rail head side and its corresponding wheel flange. Shallow traces of wearing on the inner wheel flange surface, Fig. 2.b, are the signs of wheel flange tending to climb onto the rail head, [2]. The examples of worn-out wheel tread and altered wheel flange geometry, [10], are shown in Fig. 2.d. Such traces occur mainly at driven wheels due to the tangential and axial slip. If wheel maintenance and condition check are not regularly carried out, the flange thickness can be considerably reduced, thus leading to its fracture, Fig. 2.f, even by minor lateral load acting, [15].

Sometimes skewing forces cause plastic deformations of a thinned wheel. In case of inadequately designed and poorly maintained wheels, these deformations can be accompanied by the occurrence of recess along the wheel circumference, in-depth hairline cracks in tread surface, and worn-out flange, Fig. 2.g, [23]. These damages arise as a result of joint action of exceptionally large vertical and lateral loads during crane operation. In case of inadequate wheel heat-treatment, vertical and lateral forces can induce flaking by layers of wheel tread surface, Fig. 2.h, especially in the case of a high temperature in the working environment (iron foundries, ironworks, rolling mills, etc.),

Fig. 3. (a-d) Examples of typical damage of crane runway rails

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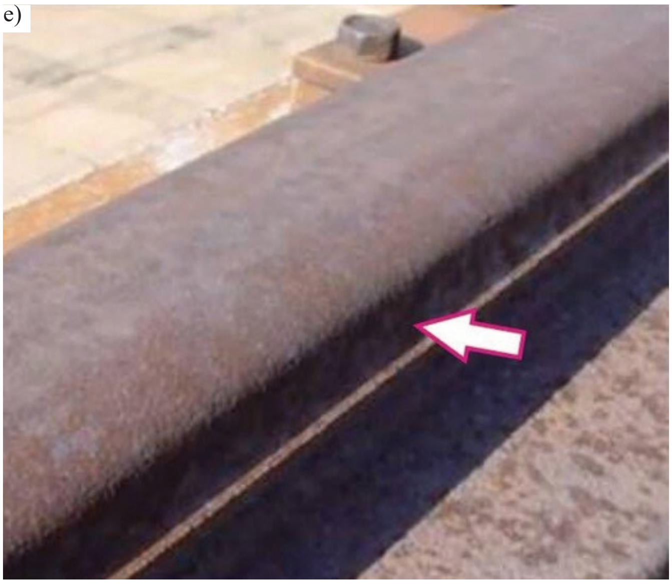

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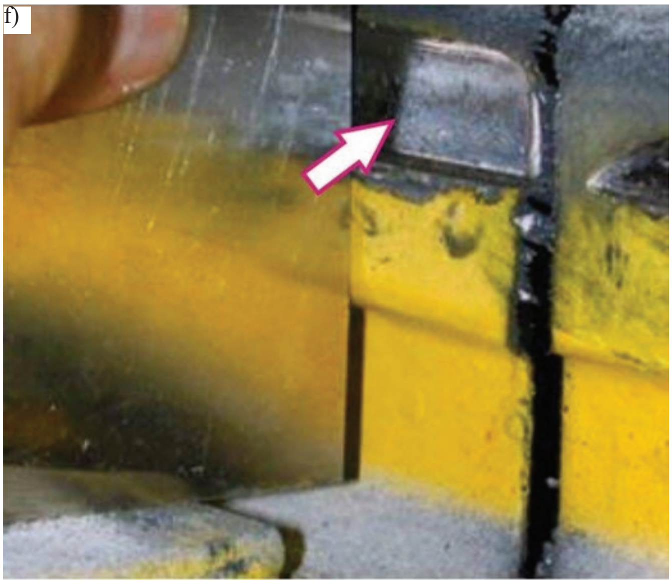

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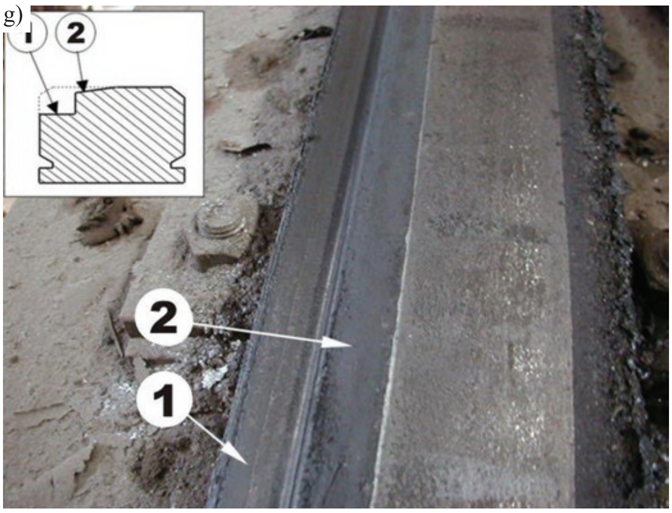

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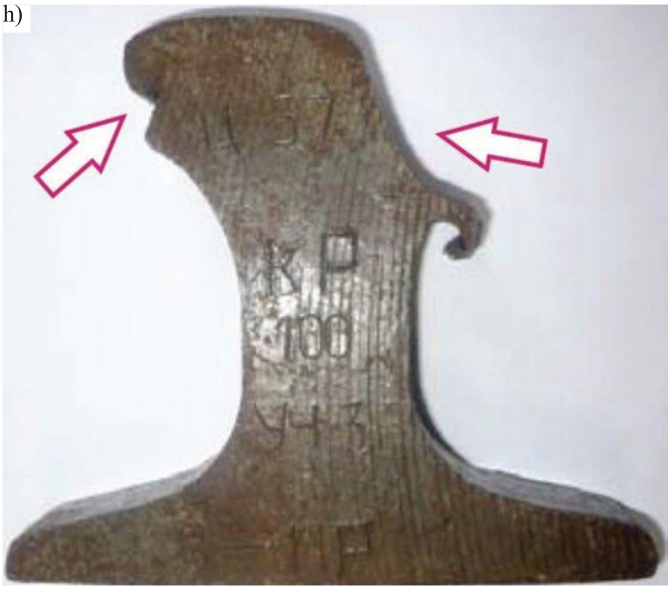

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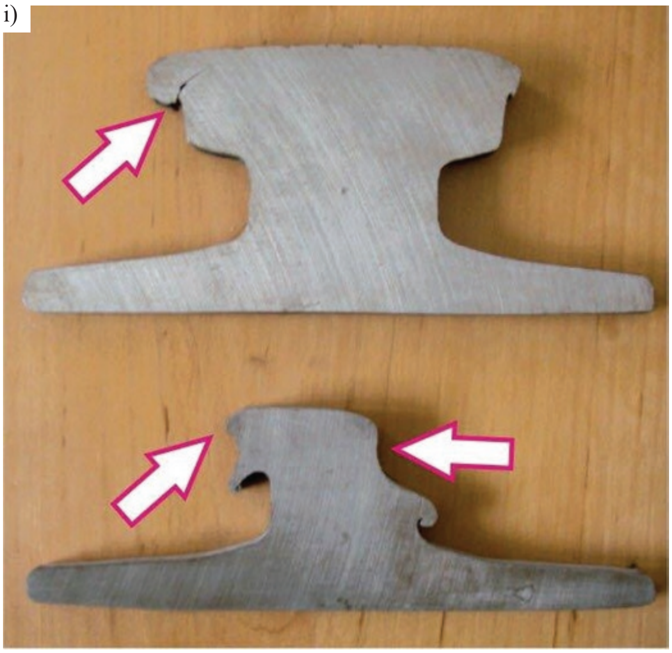

Fig. 3. (e-i) Examples of typical damage of crane runway rails

[2]. Loads due to the skewing of gantry cranes with wide spans can cause flaking of rolling surfaces even on the horizontal guiding rollers, Fig. 2.i, [25].

The most frequent patterns of crane rails damage are shown in Fig. 3. Lateral loads often cause rail deformations, Fig. 3.a, on certain track sections (primarily at gantry cranes), [25]. Due to the increased pressure in the contact point of wheel flange and rail head, wearing traces arise at both of them. When the deviations from the rail direction exceed the tolerable values, difficulties occur during travelling, even crane „wedging-in". Vertical and horizontal offset between the adjoining rail sections obstruct the normal crane travelling. Vertical offset is usually the result of errors in installation, and wheel crossing over the so developed step causes the additional high-impact loads and crane structure vibrations. Lateral loads can even cause the rail joint „opening". The horizontal rail offset occurs mainly at crane tracks with free supported rails. An example of a deformed step-like formed rail joint is shown in Fig. 3.b. The horizontal offset between the rail sections joining at an angle is shown in Fig. 3.c, [2]. Damage pattern shown in Fig. 3.d, [1], occurs mainly at rails with small roundness radius of a head edge. In case of wheels mounted at an angle, due to steady skewing the wheel flange tends to climb onto the rail head, and in extreme cases to cause the crane wheels derailment. During that process the sharp edge of wheel flange mechanically damages the rail head edge.

At the same time, bumping of skewed wheel flange into the rail edge in a joint with perpendicularly cut rail ends causes strong impact leading to flange and rail damage. In case when the crane guiding is only realized by means of one rail head side, and mainly by the same flange, flange and rail head geometry alter quickly, and traces of intensive wearing arise, 3.e, f, and g, [10, 18, 19]. During operation of heavy bridge cranes at increased temperature, e.g. in foundries and ironworks, easy recognizable patterns of rail head deformation appear, as an effect of vertical and horizontal loads acting, Fig. 3.h, and i, [11, 24].

The skewing forces can cause fatigue hairline cracks in structure elements, mainly at the end carriages of bridge cranes close to wheel bearing assemblies, main girder ends and their connections with end carriages or with rigidly connected gantry crane legs. A notable number of accidents are described in [9]. In the majority of these accidents the excessive skewing had caused the derailment of crane wheels and even the collapse of a complete crane structure.

3. Forces caused by crane skewing – Occasional or regular loads?

Majority of withdrawn national standards, e.g. PN-86/M-06514, and international guidelines, e.g. earlier versions of [7], proposed a very simple procedure for the calculations of lateral forces acting perpendicularly to the direction of a crane/trolley motion. According to the requirements of these standards, the skewing loads were not taken into account in calculations of stresses induced by varying loads able to induce the fatigue of material.

In accordance with the effective norms [3, 6], calculations of amplitude of axial friction force acting on the vertical wheel, and skewing force, [6, 18, 26], are even now treated on the basis of a simplified static model, although the results of a few theoretic and extensive experimental researches, [17], confirm that the dynamic effects of induced loads have to be taken into account for the qualitative and quantitative description of skewing.

Crane as a whole, its structure elements, and driving mechanisms components are subjected to various loads, which can be classified on the basis of the occurrence frequency and character of varying in time. According to [3], they are classified in regular, occasional, and exceptional, and skewing forces are classified as occasional loads (in general, occurring in load combination B, which covers regular loads combined with occasional loads), and pursuant to that, are as a rule neglected in fatigue evaluation. However, in the chapter considering the calculation of skewing forces, the next paragraph is quoted: “Skewing loads as described above are usually taken as occasional loads but their frequency of occurrence varies with the type, configuration, and accuracies of wheel axle parallelism and service of the crane or trolley. In individual cases, the frequency of occurrence will determine whether they are taken as occasional or regular loads. Guidance for estimating the magnitude of skewing loads and the category into which they are placed is given in the European Standards for specific crane types.” In accordance with the previously cited, if in certain case it has been proved that skewing forces are to be treated as regular loads, then these loads are to be taken into account in the analyses and proofs of crane structure fatigue. In [4] it is also pointed out that in certain cases loads generally taken into account only in load combination B can occur often enough to request their integration into the estimation of fatigue. In addition to that, it has been requested that the stresses occurring in structure elements due to these occasional loads are to be treated in the same way as stresses induced by regular loads.

However, neither [3], nor [6] give any further guideline of defining some indicator as the basis for determination of occurrence frequency relevant for classifying skewing forces into the group of regular loads. Solely [5] unambiguously specifies that by determining the design contact force for fatigue evaluation, skewing forces acting on the guiding rollers shall be considered as regular loads.

Analyses and proofs of fatigue strength of crane structure elements are impracticable without knowledge of loading history. Identification of relevant influences upon the fatigue and having a detailed knowledge of values of varying loads (or stresses) during usage (i.e. of designed crane lifetime) are necessary for forming the load or stress spectrum and further calculations (e.g. accumulated damage, remaining fatigue lifetime of a structure, etc.), [12].

Load spectrum is a collection of loads arranged according to the load amplitudes and frequency of their occurrence. It can be determined on the basis of:

- joining in accordance with indicators, to the one of the *norm spectra*,
- self-obtained records of a measurement on a crane in operation, or
- results of a conducted computer simulation of a tested crane during operation.

Nevertheless, the norm spectra of skewing forces still are not defined in literature. The computer simulation of a complex planar motion of a bridge crane under the action of skewing loads is difficult to conduct, due to the large number of influencing parameters of stochastic character. The most reliable results can be gathered by observing and recording the variables of interest (loads, stresses, vibrations, etc.) during long-lasting usage (especially when crane operation regime alters in time), or only during shorter, but representative periods of time. Estimation of integrity and lifetime on the basis of long-lasting crane monitoring is of ever more growing importance in design and maintenance of heavy machines, [20, 21].

Engineers and researchers have been engaged in the problem of crane skewing for almost six decades, [17]. However, the need for developing more adequate methods for determination of the dynamic loads and the probabilistic approach to the analysis of crane structure fatigue and stimulates the development of new research directions.

4. Experimental determination of lateral forces acting on bridge crane wheels

Up to these days, experimental determinations of lateral forces acting on the vertical wheels were carried out on the special redesigned laboratory bridge cranes. Almost all proposed and realized measuring methods demanded an extensive redesign of crane structure, such as additional horizontal rollers (they alter the structure of positive guiding system, and are practically useless for the certain crane types due to the implicitly requested rail track redesign), or redesign of end carriages, or additional wheel processing, etc, [8, 14, 16]. Design modifications are rarely acceptable for the crane user, or even inadmissible according to crane regulations. Due to these reasons and considerably higher expenses, the number of conducted experiments on the cranes engaged in real operation conditions is greatly reduced. The known solutions with wheel assemblies designed to be in the same time transducers for lateral forces, considerably deviate from the standardized assemblies. Their permanent usage in real operational conditions cannot insure the reliable crane usage. Consequently, the validity of obtained results is limited, and any generalization of drawn conclusions is arguable, especially in any consideration of existing cranes in long-lasting usage.

The authors have carried out an extensive series of experimental tests on a single-girder bridge crane with the rated capacity m_Q = 3.2 t and span l = 8.91 m, Fig. 4. The crane is designed for the general application in workshops with a light regime operation and an average relative loading. The weight of the crane structure and travelling mechanisms is $m_c \approx 1.3$ t, and the weight of the trolley including traversing and hoisting mechanisms is $m_t \approx 1.15$ t.

Fig. 4. Measurement of lateral forces acting on the wheels of a single-girder bridge crane

Crane structure is supported by four vertical flanged wheels (nominal diameter 200 mm) on the track runway. Both end carriages are equipped with one driven and one non-driven wheel, each one with two spherical roller bearings. All the components of wheel assemblies are manufactured in accordance with the (still in effect) Serbian standards. The design of a wheel bearing permits negligible lateral (axial) shifting. Track rails with square cross-section 40x40 mm, are intermittently welded to the upper flanges of rolled steel beams with INP 340 cross section. Crane runway beams are supported at 3.3 meters distances by cantilever overhangs on reinforced concrete columns of the lab hall and by screw connections fastened to it. Positive lateral crane guiding is obtained by the flanges of vertical wheels, with the total lateral clearance s_g = 20 mm between the wheel flange and rail head (although the recommended minimal value is 10 mm, according to [6]). The crane wheelbase is w_b = 1.5 m, and the relation of crane span to the distance of end guiding means is l/w_b = 5.94 (according to the recommendations it has to be $l/w_b \leq 6$).

Crane travelling along the rail track (at the rated velocity 30 m/min) is realized by independent end carriage drives. Asynchronous 3-phase squirrel-cage brake geared motors (with rated power 1.1 kW) of travelling mechanisms are DOL (direct-on-line) supplied, with starting softened by the „KUSA-Schaltung“. Motors are neither mechanically nor electrically synchronized, but the connection can be simply enabled by supplying them through the frequency converter Danfoss VLT 302, in order to synchronize the driven wheels of both crane end carriages as well as to „soften” crane starting and stopping.

The authors have designed two different special force transducers for the measurement of lateral forces occurring in the contact point of wheel tread and upper rail head surface, and skewing forces in the contact point of wheel flange and rail head. The aim was to develop the technical solution that enables reliable monitoring of values of these forces, on newly erected, as well as on existing cranes in usage, and that would demand only minor altering/addition in a wheel assembly.

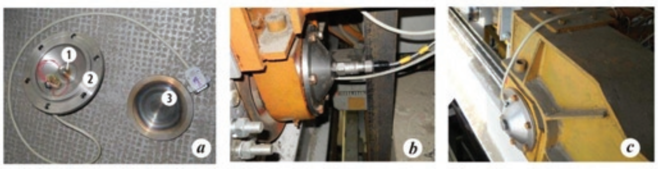

Fig. 5. Force transducer type CST: a) components; b) CST with a mounted accelerometer, fitted in the non-driven wheel bearing housing; c) CST fitted in the non-driven wheel bearing housing on the wall side

The first transducer type denoted as CST (**C**entral **S**crew **T**ransducer) is basically a screw, with a partly removed thread, shaped into the thin-walled cylinder (pos. 1 in Fig. 5.a).

The threaded hole is drilled through the screw head to enable the accelerometer mounting, Fig. 5.b. Four strain gauges are bonded to the processed surface and connected into the full Wheatstone bridge. The element is screwed into the threaded aperture, in the conically shaped cover of bearing housing, with the possibility of later fine tuning of its position (pos. 2 in Fig. 5.a). The screw top end presses the disc element (pos. 3 in Fig. 5.a) onto the outer wheel bearing ring. Transducers of this type are installed in the bearing housings of non-driven wheels, Fig. 5.b and c.

The second transducer type, denoted as HDT (**H**ollow **D**isc **T**ransducer) is shown in Fig. 6.

Fig. 6. Force transducer type HDT: a) components, b) HDT fitted in the driven wheel bearing housing - the cogwheel side; c) HDT fitted in the driven wheel bearing housing - the wall side

Strain gauges connected into the full Wheatstone bridge are bonded on a measuring element shaped as a disc with a thicken rim and a round aperture in the middle (pos. 1 in Fig. 6.a). In the mounted position the disc is pressed by the cover of bearing housing, through the four adjustable screws (pos. 2 in Fig. 6.a) onto the outer wheel bearing ring. Transducers of this type are mounted in the bearing housings of driven wheels, Fig. 6.b and c. The wheel shaft end with the driven cog-wheel of an open wheel-pair passes through the bearing housing, hence the covers on this housing side have round aperture in the middle, Fig. 6.b.

Shape and dimensions of elastic elements of both transducers were optimized on the basis of FEM analysis, in order to achieve the required sensitivity. The stress distribution in the measuring element of a CST is shown in Fig. 7.

The both transducer types have been calibrated in an accredited laboratory.

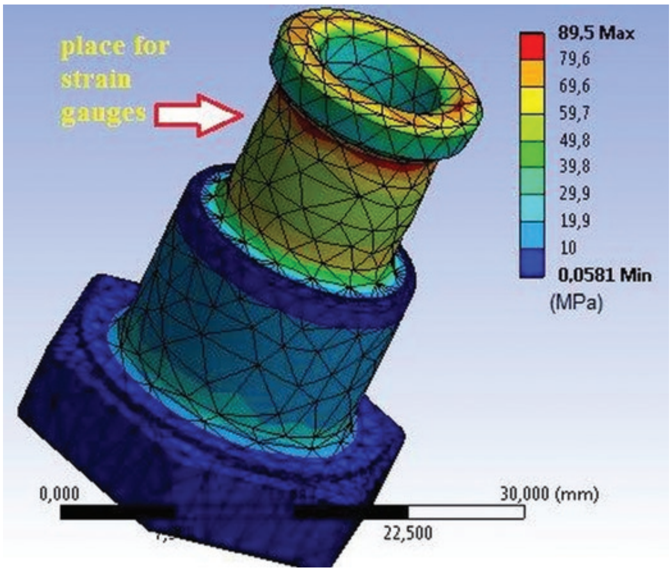

Fig. 7. Stress distribution in the measuring element of the CST, obtained using FEM software (transducer here presented without the steel bit at the top end)

Schematic outline of the system used for measuring the lateral forces and vibrations on the crane vertical wheels shown in Fig. 4. is given in Fig. 8. Due to space limitations, vibrations were registered only on the inner track sides of non-driven wheels. The data acquisition was conducted using two mutually connected and synchronized measuring amplifiers QuantumX (HBM, Germany). All the lateral force transducers were connected to the inputs of one amplifier, and accelerometers (type AC102-1A, CTC, USA) to the inputs of another one. Corresponding signals of force transducers are denoted as FY(CST1) ÷ FY(CST4) and FY(HDT1) ÷ FY(HDT4), and accelerometers as AC1 and AC2. Measurement process was controlled using the software package Catman® (HBM, Germany).

Experimental determination of lateral forces acting on the vertical wheels has been carried-out in accordance with 18 different measuring scenarios defined by varying 3 parameters: load weight, trolley position, and the way of supplying the electric motors of crane travel driving mechanisms. Calibrated casted iron weights were used as a load. Crane travelling was performed: without load, with load total weight: m_L = 700 kg and m_L = 1400 kg. Three trolley positions (R - right, M - span middle, L - left) were defined by the distances: y_R = 2.2 m, y_M = 4.45 m, and y_L = 7 m, Fig. 8. The trolley position remained unaltered during each crane travelling. For each combination of load weight and trolley position, crane travel driving electric motors were supplied DOL and through the frequency converter.

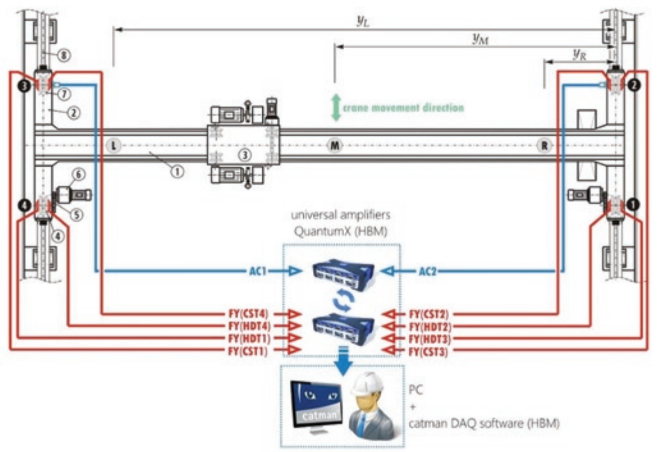

Fig. 8. Schematic outline of the used system for measuring the lateral forces and vibrations on the vertical wheels of a single-girder bridge crane, the top view positions: 1 - main girder, 2 - end carriage, 3 - trolley, 4 - driven wheel, 5 - cogwheel pair, 6 - geared electric motor with brake, 7 - non-driven wheel, 8 - track rail

5. Results and discussion

Generally, the described transducers can be also fitted into the wheel assemblies designed according to other national standards (e.g. DIN, TGL, PN, etc.). Minor redesign has to be carried out only regarding the measures and perhaps the shapes of transducer measuring element and bearing housing cover.

The results of 180 crane travels have been put on record during the experiment realization. As an illustration, the history of the lateral force acting on the wheel № 2, Fig. 8, during one crane travelling is shown in Fig. 9. The crane wheels were already before the start in the slanted position in relation to the rail direction. Electric motors of crane travelling drives were DOL supplied, with the load m_L = 1.4 t and the trolley in the position R, Fig. 8.

The complete experimental data processing has been carried out using the software nCode GlyphWorks (HBM, Germany). The most important statistical indicators necessary for conducting the fatigue analysis of structure elements have been determined. Distribution of force amplitudes corresponding with the recording shown in Fig. 9.a is presented in Fig. 9.b. The rain-flow matrix of loads, Fig. 9.c, can be used for the calculative determination of corresponding stress spectrum in the chosen point of the individual crane structure element. The joint distribution histogram shown in Fig. 9.d can be used as the basis for determination of a correlation between the force amplitudes and the acceleration.

a)

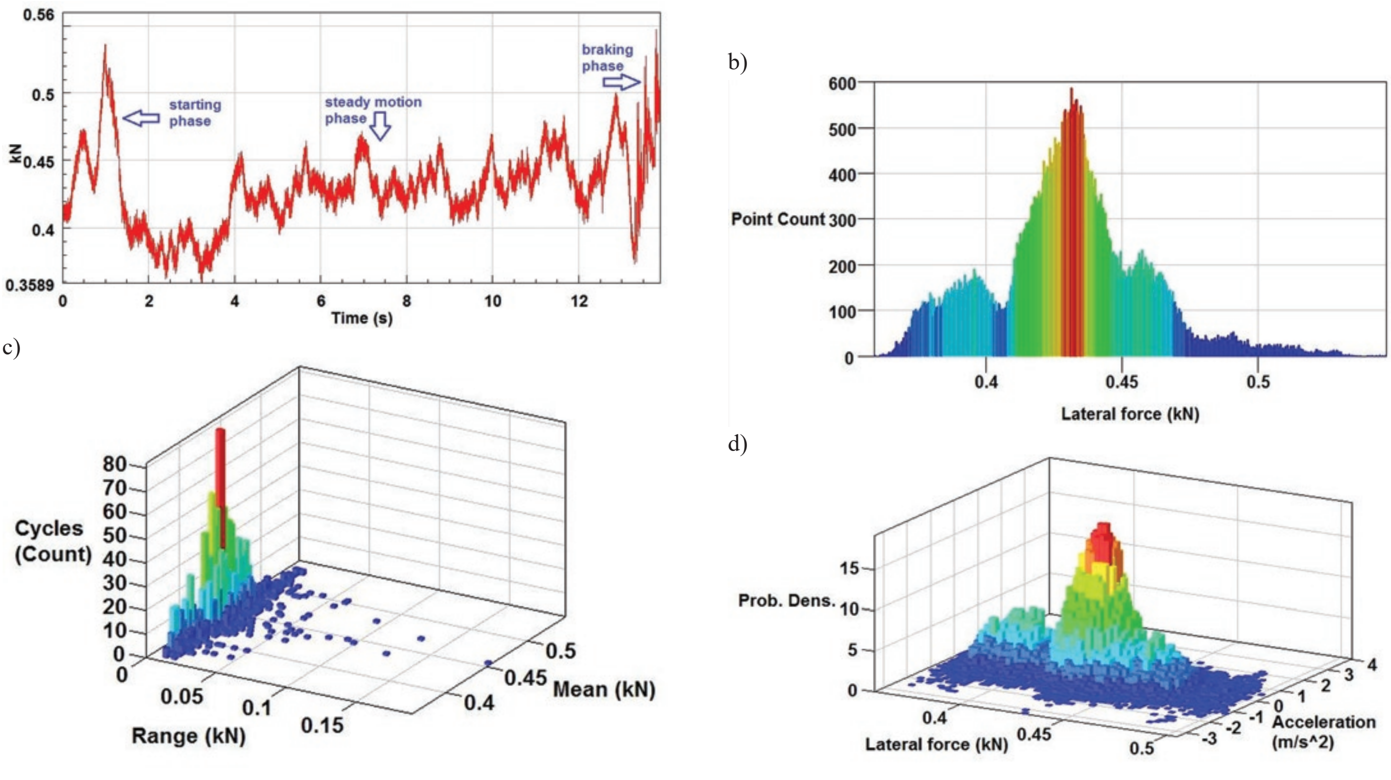

Fig. 9. The recording of wheel No2 loading history, trolley in position R, load mL = 1.4 t a), and the processed results in software package nCode: b) distribution of force amplitudes, c) rain-flow matrix of loads, and d) joint distribution histogram (force amplitudes and acceleration)

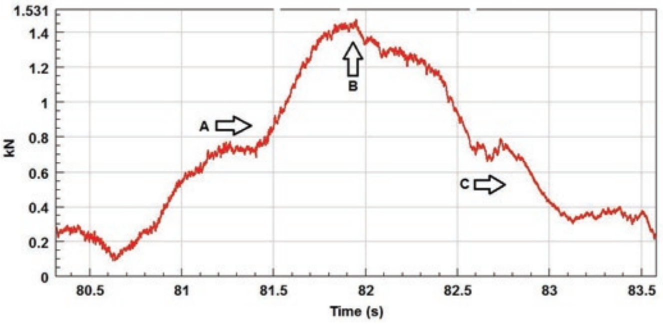

Fig. 10.The recording of wheel №4 loading history (m_L = 0, motors DOL supplied, trolley position M)

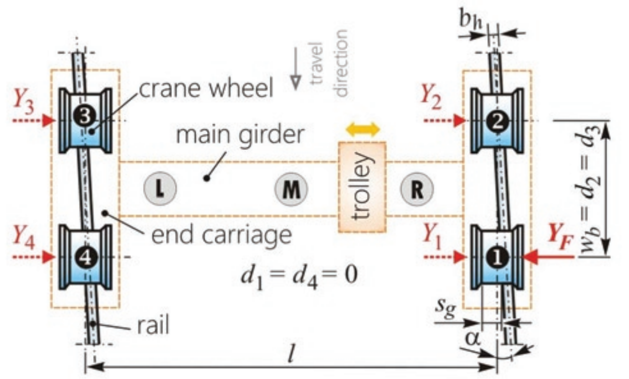

Fig. 11. Model for the rigid calculation method, according to [6]

Table 1. The resume of the calculated values of lateral, i.e. skewing forces

Load, [t]			m_L = 0			m_L = 0.7			m_L = 1.4			m_L = 3.2		
Trolley position:			L	M	R	L	M	R	L	M	R	L	M	R
Force, [kN]	lateral (due to axial slip)	Y_1	0.85	1.16	1.44	0.99	1.49	1.93	1.13	1.82	2.43	1.50	2.67	3.72
		Y_2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Y_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Y_4	1.47	1.16	0.88	1.99	1.49	1.05	2.51	1.82	1.21	3.85	2.68	1.63
	skewing	Y_F	2.32	2.32	2.32	2.98	2.98	2.98	3.64	3.64	3.64	5.35	5.35	5.35

The values of wheel lateral forces were considerably higher in the starting and braking phases of crane travelling, Fig. 9.a. These impacts were less expressed during transitional phases with the travelling drive motors supplied through the frequency converter. During crane travelling with a steady velocity, the lateral force values varied within a relatively narrow range. Nevertheless, in this phase the abrupt value changes due to the interaction between the wheel flange and the rail head can be noticed, too. The recording detail is shown in Fig. 10, where the wheel flange run into the rail head can be clearly spotted (force value increase in period A), followed by hitting the top value of skewing force (in period B), and the gradual wheel flange separating from the rail head (in period C).

According to the experimental results, the trolley position influence on the values of measured lateral forces was practically irrelevant. This can be partly explained by the narrow crane span. Before drawing any conclusion on this subject, it is necessary to carry out a series of experimental researches on the heavier cranes with wider spans.

The results also confirmed the relevant influence of the way of supplying the electric motors of travelling drives on the skewing force value, especially in transient motion phases.

Experimentally defined values of lateral forces acting upon the wheels of the single-girder bridge crane are lower than the values calculated on the basis of the crane model according to [6], Fig. 11 and Tab. 1. The calculated values of lateral forces acting on some of the wheels are equal to zero, but that does not correspond with the actual values, especially when the bearing prevents the wheel from lateral movement. So, the experimentally measured force values are not in a consistence with the values calculated according to [6].

6. Conclusion

The most suitable and probably the only possible way to comprehend the influence of skewing on the fatigue of crane structure and traveling drives is to form a „catalog“ of skewing forces spectra. For that purpose, an extensive systematic experimental research carried out on cranes of various types and operating in realistic conditions, is indispensible.

The presented technical solution for the monitoring of lateral loads can be incorporated into the more complex systems for monitoring the crane structure condition (mainly of special importance and value) during its usage, if it is technically and economically justified. Simultaneous measuring of lateral forces and vibrations on crane vertical wheels is realized in order to initiate the development of faster, simpler, and more efficient way of gathering the data needed for the forming of corresponding crane structure load spectra.

On the basis of results obtained through the experiments conducted on a single-girder bridge crane with the capacity 3.2 t, and the span 8.9 m, with used 2 transducer types and varied 3 parameters (load weight, trolley position and electric motors supply source), the next conclusions have been drawn:

- both transducer types were reliable in operation, and turned out to be suitable for fitting into a new/existing standardized crane wheel assembly without changing its structure or function, with just a minor redesign,
- experimental data processing was carried out, and the main statistical indicators needed for the fatigue analysis of crane structure were calculated, using the software package nCode GlyphWorks,
- experimentally defined values of lateral forces acting on crane wheels were lower than the values calculated according to the rigid calculation method, [6],
- the influence of the trolley position on the values of measured forces was practically irrelevant, possibly due to the short crane span, low crane capacity and light load weights, and
- the results confirmed the influence of the type of supply source (frequency converter or DOL) of travelling drives electric motors on the force values, especially in transient phases of motion.

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