DYNAMIC ANALYSIS OF BRIDGE CRANE WITH ONE MAIN GIRDER DURING TELPHER MOTION WITH FULL LOADING

Prof.dr. Ilir Doçi, Prof.ass. Shpetim Lajqi*, Msc. Blerim Morina
Faculty of Mechanical Engineering –University of Prishtina, Kosovo (ilir.doci@uni-pr.edu)
*Corresponding author (shpetim.lajqi@uni-pr.edu)

Abstract: *This paper deals with dynamic analysis of bridge crane with one main girder during telpher motion in order to determine dynamic behavior and oscillations while carrying full load. During the telpher motion the main girders and side girders are heavy loaded parts while they undergo forces, moments and oscillations from lifting mechanism that carries workload. The method of analysis is the comparison of results gained through modeling and simulation and experimental measurements. The analysis will be concentrated in finding the nature of dynamic forces, moments and stresses that acts on main crane's parts and finding the extent and form of oscillations that can cause damage and failures. Also the interest is to study the effects of load swinging in crane's stability. Results will be shown in the form of diagrams as the solution results of the tested system. Crane is modeled from standard manufacturer, as a special type of Bridge Crane with one main girder and telpher. Conclusions of these analyses are useful for design considerations, dynamic behavior and safety.*

Keywords: BRIDGE CRANE, TELPHER MOTION, MAIN GIRDER, DYNAMIC ANALYSIS, OSCILLATIONS, MODELING, SIMULATIONS

1. Introduction

Companies that work with Bridge cranes have difficulties dealing with oscillations and swinging of workload, which can lead to safety problems. Bridge crane taken for study is special type of overhead cranes with one main girder, mounted in factories and warehouses, and have three main working cycles: load lifting and lowering, telpher motion and crane travel. Usually they work with big and heavy loads, which are attached on the Hook. Telpher is mounted below the girder and connects with Hook through Pulley system, Lifting cables and Drum. In these cranes heavy oscillations are mainly caused due to load overloading, improper connection of load in cables, and inadequate speed of motion. These can lead to stability problems, break of parts, cables damage, etc.

This work is based in the theory of crane dynamics, multibody dynamics, systems design, modelling and simulations.

In Fig.1 and Fig.2 is represented Bridge crane taken for analysis from manufacturer *Prim Co Company, Type* JP100 [1]. Crane is mounted in rails on the walls of the factory. It has one main girder, and two side girders (left & right). Weight of workload & Pulley system is $Q = 5150\ kg = 50.5\ kN$. Elevated position of girders is H = 6.5 m. Length of main girder is $L_m = 12\ m$. Mass of main girder is $m_m = 2000\ kg$. Velocity of telpher is $v_{te} = 0.33\ m/s$. Diameter of telpher wheels $D_v = 150\ mm$. Telpher is moving on 4 wheels, 2 per each side, mounted on main girder's edges (Fig.1).

In literature [3], [5], [6] it is estimated that the beginning of the telpher motion is the most difficult process concerning the dynamic behavior of crane.

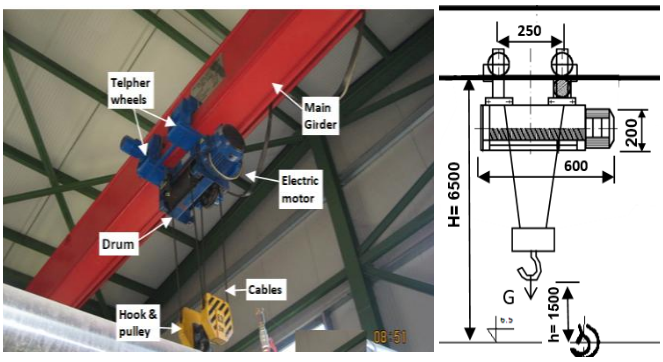

Fig.1. *Telpher of crane and its dimensions [1]*

2. Modelling and simulations of Bridge crane

In Fig.1 and Fig.2 is presented bridge crane in the working environment, which is also modeled in software (Fig.3) [2], [8]. Lifting mechanism is designed in the form of double pendulum. Working load has prismatic form with dimensions 1m x 1m x 1m, connected on 4 carrying cables with the Hook and Pulley.

Carrying cables are connected with the Hook and above with pulley system, that connects to Drum with 4 lifting cables. (Fig.1). Load height from basement is 1.5 m. It is positioned on the center of crane's main girder. We consider that best results will be achieved if the study is done with max carrying load $Q = 50.5\ kN$, as given by manufacturer [1] , [5].

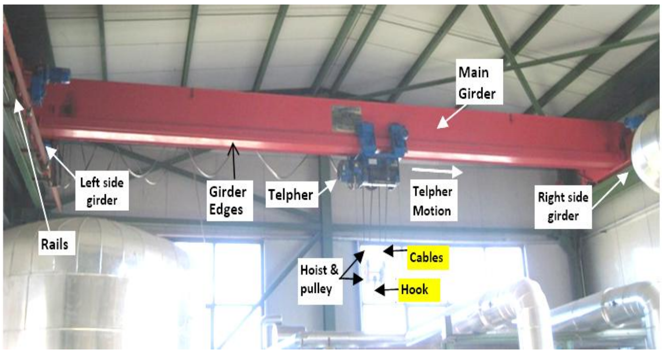

Fig.2. *Bridge crane with parts in the working environment [1]*

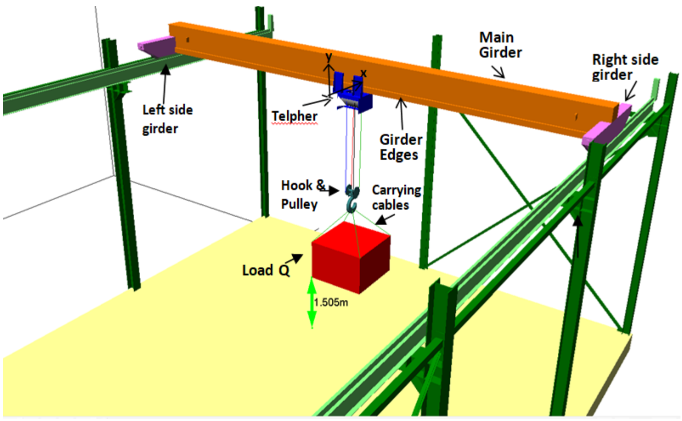

Fig.3*. Model of bridge crane in the working environment created in the software SimWise 4d [2]*

Before simulations with software, load Q is in the position of relative rest at the height h = 1.5 m from the basement. Simulation planning of telpher motion is close to real work which is important for achievement of reliable results. Telpher will move from center of Main girder towards right side Girder. Time of simulation will be t = 11 s. Simulation has three phases [3],[13]:

First phase – initial position of relative rest with no motion of telpher. Load hangs on carrying cables. Starts at time 0 s < t < 1 s.

Second phase – Is the process of motion of telpher with the speed $v_{te} = 0.33\ m/s$. Starts after first phase, between time 1s <t < 9s. Length of telpher motion is $l = 2.7\ m$.

Third phase - motion stoppage. Telpher will stop moving, but load, pulley and hoist cables will continue to swing. Starts after second phase, between time sequence 9 s < t < 11 s. Important for evaluation of the results after motion stop.

3. Experimental measurements

Measurements in crane are done in the place of work, where crane is mounted, in the factory of local company (Fig.1). They will be used for validation of results. Main measured parameter is tensile force in lifting cables – $\boldsymbol{F_{ca}}$. In this crane there are 4 branches of lifting cables connected between drum and pulley system. This is the force on lifting cables resulting from weight of load and pulley sistem which hangs and swings during telpher motion. Lifting cables lifts up or lowers the load, but for the case of telpher motion they also carry the load (Fig.2 & Fig.3) [11].

Type of lifting cables are wire ropes type 6X37, with diameter $d_c = 19\ mm$ [1]. Other properties are: Modulus of elasticity: $E = 7.58{\cdot}10^{10}\ Pa$, Minimum breaking strength $F_b = 212\ kN$, Safe Load $F_s = 42.3\ kN$ [1], [12]. Tensile force was measured with dynamometer type *Dini Argeo* attached to the Hook [10], during motion of crane (Fig.4). There were 6 measurements implemented. First measurement is done at first phase (relative rest), measurements 3,4,5, are done during telpher motion (second phase), measurement 6 is done after motion stoppage (third phase). Results are shown in Table.1.

Measure-ment No.	Time of telpher motion (s)	Tensile Force in all lifting cables - Fca (N)	Force in each branch of lifting cables (Fca/4) (N) (aprox.)
1	0	51050	12762
2	3	52200	13050
3	5	53150	13287
4	7	52600	13150
5	9	51530	12882
6	11	49850	12462

Table 1. *Results of F_{ca} with dynamometer in hanging cables*

Fig.4. *Measurements with Dynamometer of tested load during the motion of telpher, and dynamometer used [10]*

4. Results of force (tension) in lifting cables

In Fig. 5 is given the graph of Tensile Force in lifting cables - F_{ca} in one cable branch. It is a dynamic force which we will name it F_{cad}. It appears in cables while it comes from load swinging, pulley swinging and force in hanging cables. Diagram of other three cables is similar with this one, with minor changes.

Based on graph in Fig.5, we can conclude that dynamic tensile force F_{cad} in the lifting cables is close to experimental values (Table.1), which are shown with black dots. This validates results with simulations and makes them reliable and trustworthy. Force F_{cad} is dynamic in nature, with high frequencies up to $\upsilon = 19\ Hz$. Maximum value of force is achieved in time $t = 1.4\ s$, with the value F_{cadmax} = 21800 N = 21.8 [kN].

Based on strength properties of cables, it can be concluded that $F_{cadmax} < F_s = 42.3\ kN$, meaning that lifting cables of crane can handle the dynamic tensile force without major deformations.

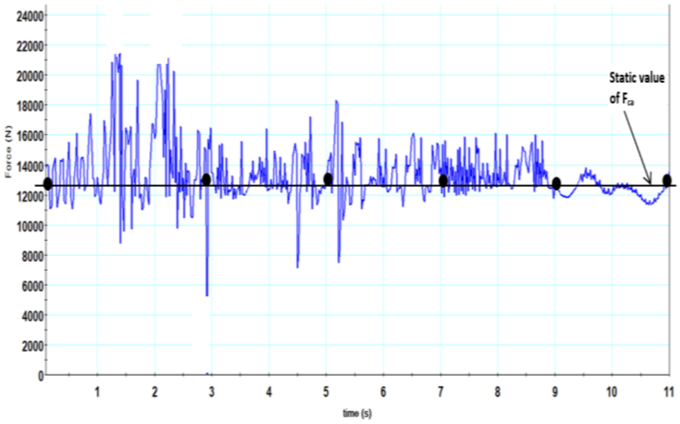

Fig. 5. *Tensile force F_{ca} in one branch of lifting cable. Black dots are experimental values from Table 1.*

Dynamic coefficient Ψ is the ratio between maximal dynamic force and static force [3],[6],[7]. Value of the coefficient is:

$$\Psi = \frac{F_{cadmax}}{F_{smax}} = \frac{21.8}{12.626} = 1.72 \qquad (1.1)$$

Static force in lifting cables can be calculated by formulas [4]:

$$F_{s\max} = \frac{F_0}{\eta_{ho}^{l}} = \frac{12.5}{0.99} = 12.626 \quad [kN] \qquad (1.2)$$

Load in one branch of the cables in resting position is:

$$F_0 = \frac{Q}{m} = \frac{50}{4} = 12.5 \quad [kN] \qquad (1.3)$$

$\eta_{ho}^{l} = 0.99$ - Working coefficient of hoist for lifting.

m = 4 – number of rope branches for weight lifting.

According to result of Ψ in (1.1), lifting cables undergoes 72% more dynamic forces compared to static forces. This value is high and a matter of concern, while it will weaken cables by time. Concerning the safety issues, this requires frequent control of lifting cables [14]. Conclusion is that lifting cables are heavily loaded with oscillations that have high amplitudes and high number of frequencies.

5. Resultant Force acting in telpher

Forces acting on telpher are passed from forces on drum and lifting cables that are connected with Hoist system, and they load the telpher while it moves (Fig.1). In Fig. 6 is given graph of Force in telpher - F_t. It is the Resultant force of all forces – tensile, bending and torsion components acting on telpher, and it is dynamic in occurrence. Maximal value of this dynamic Force is $F_{tmaxd} = 8.1{\cdot}14^4\ Nm$ and occurs in time $t \approx 4.5$ s (Fig.6). Based on graph, Static value of force is $F_{tst} \approx 5.25{\cdot}10^4\ Nm$. This concludes that the value of Dynamic Force is for 54% higher than the static force.

Static force is the Force in the condition when system is theoretically motionless, or in the situation of relative rest. It is the sum of weights of all devices acting below the telpher – Load Q, Cables, Hook, Hoist and Drum (Fig.1).

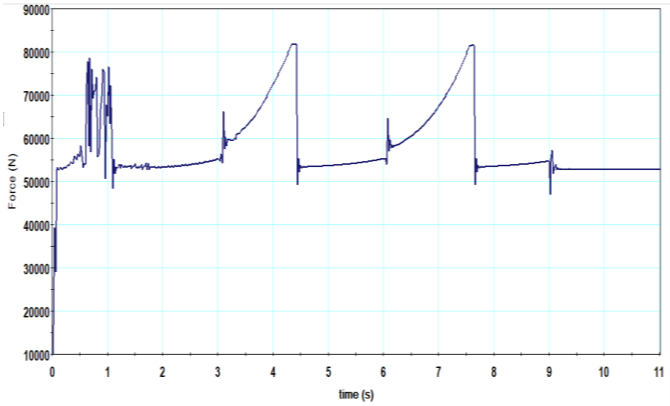

Fig. 6. *Resultant Force acting on telpher*

6. Results in main girder

Main girder is the most important and biggest part of Bridge crane. It has a cross section of Hollow Box Beam, with walls thickness of 1 cm [1], [11]. On the bottom side is mounted telpher that hangs in side extensions, where is also mounted hoisting mechanism with load Q (Fig.1 & Fig.3). Dynamics and oscillations from the hoisting mechanism and telpher are passed on girder.

Results will be achieved using Numerical methods (Kutta-Merson) and Finite Elements Method (FEM), supported by software, in order to achieve best results [2], [3].

Other properties of main girder are Elastic Modulus: E=$2{\cdot}10^{11}$ Pa, Yield Stress $\sigma_{yi} = 3.31{\cdot}10^{8}$ *Pa* ; Ultimate Tensile Stress $\sigma_{ut} = 4.48{\cdot}10^{8}$ *Pa* ; Poisson's Ratio $\upsilon = 0.29$.

Based on model created, results are achieved through simulations for main dynamic parameter – Stresses in main girder. [5], [9], [13]. Stress is the type Von Misses Stress. In Fig. 7 is shown discretization of girder in volume FEM Elements. Values of Stresses spread through girder volume and deforms the girder (Scaled by 6.274).

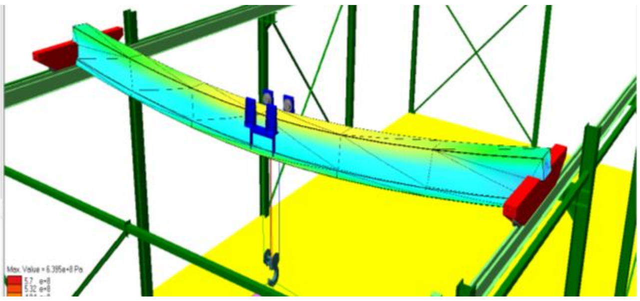

Fig.7. *Deformation of main girder (Scaled by 6.274), and contour spread of Stress*

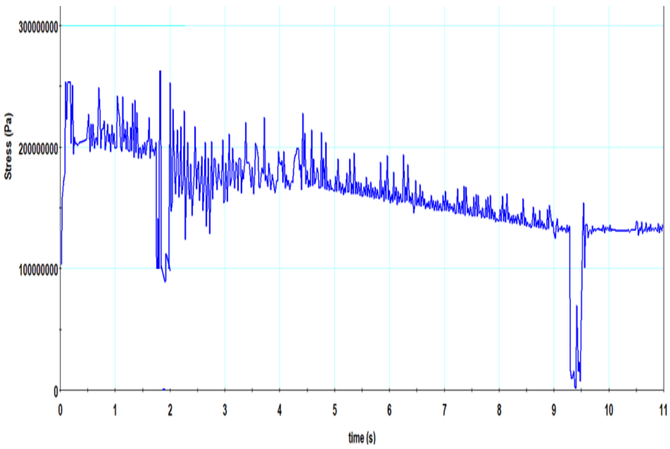

Fig.8. *Stresses in main girder*

Based on results from Fig.8, it can be conclude that main girder undergoes heavy dynamic stresses, with frequent oscillations, high amplitudes and high frequencies. Max value of Von Misses stress occurs in time $t \approx 1.8$ *s*, and has the value $\sigma_{max} = 2.7{\cdot}10^{8}$ Pa.

This value of stress is less then Yield stress $\sigma_{max} < \sigma_{yi} = 3.31{\cdot}10^{8}$ *Pa* of material given above. This concludes that structure of girder can handle the dynamic loads.

7. Moments and Forces in side girders

Side girders connect with main girder in one side, and wheels of crane in another side. Length of side girders is $L_s = 2$ *m* (Fig.1 & Fig.2). Mass of each of two side girders is $m_s = 400$ kg. In Fig.10 and Fig.11 are shown graphical results of moment (torque) and Resultant Force in Right Side Girder. They result from dynamic occurrence's in the main girder (Fig.9).

Values for left side girder are similar, therefore are not shown here. It can be concluded that side girders undergo heavy dynamic loading with high oscillation's and amplitudes.

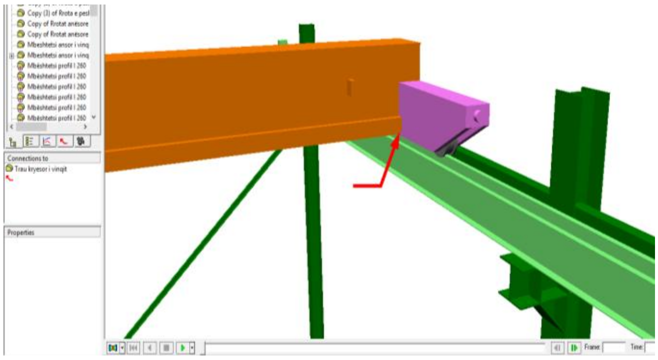

Fig.9. *Position in Right Girder of measured Moments and Forces*

Maximal value of Dynamic Moment (Torque) has the value $M_{maxd} = 6.3{\cdot}14^{4}$ *Nm* and occurs in time $t \approx 2.6$ s (Fig.10). Value of static moment is $M_{st} \approx 4.12{\cdot}10^{4}$ *Nm*. This concludes that the value of Dynamic Moment is for 53% higher, which is a matter of concern.

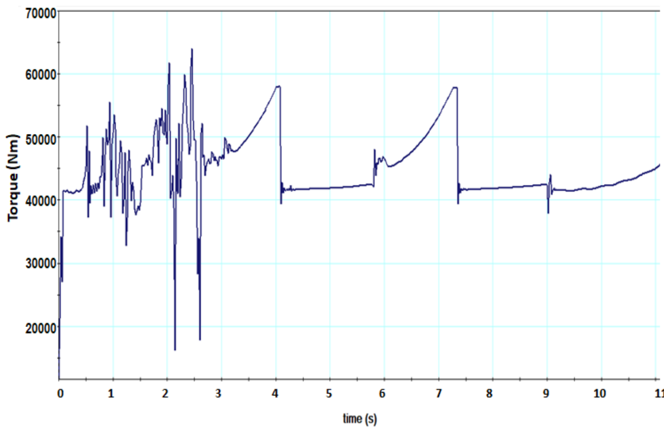

Fig.10. *Moment (torque) in right side girder (Nm)*

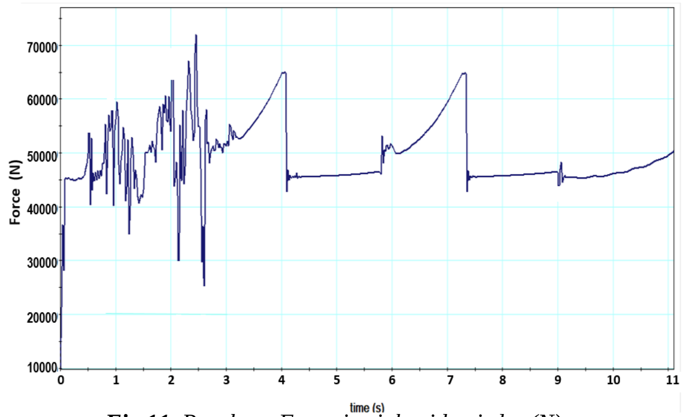

Fig.11. *Resultant Force in right side girder (N)*

Based on Fig.11, maximal value of Resultant Force has the value $F_{maxd} = 7.15 \cdot 10^4\ N$ and occurs in time $t \approx 2.6\ s$. Value of static force is $F_{st} \approx 4.5 \cdot 14^5\ N$. Value of dynamic Force is for 58% higher, which is also a matter of concern.

8. Conclusions

The main problem in bridge cranes during telpher motion are oscillations. It is important to identify and minimize them. To find this we created model of bridge crane and implemented simulations. Results are also compared with experimental measurements. Important part of analysis is finding proper simulations scenario that reflects real telpher motion. Results are gained for main parts of crane – lifting cables, telpher, main girder and right side girder. Based on the results, it can be concluded that analyzed parts of crane undergo oscillations that are heavy and mostly with irregular occurrence. They occur in different planes. They have negative effect which can cause damage. Values of dynamic forces, torques and stress are higher than corresponding static values, but analyzed crane parts can handle those dynamic loads. It is important to minimize oscillations in order to achieve minimal dynamic loads [5], [9]. Oscillations in cranes are difficult to measure with instruments, and they can cause parts failure, materials fatigue and stability problems. Therefore it is a good methodology to measure dynamic forces and oscillations with instruments where applicable, and other analysis to accomplish through modelling and simulations.

Another important conclusion is that oscillations occurring on Load Q and cables are passed in other parts of crane with similar form of curve, periods, and frequencies. Also, speed of telpher motion must remain in optimal value, as lower as possible to minimize negative effects of load swinging and oscillations in other parts.

Conclusions in this paper are important for safety and design considerations of these types of cranes [14]. It can be used also for analysis of other work processes, like load lifting or crane travel.

9. References

[1] Bridge crane manual JP 100 from manufacturer *Prim Co Company*, B&H: http://www.primcompany.com/?izbor=4&ID=5

[2] *MSC VisualNastran 4D User Guide*, MacNeal-Shwendler Corporation, Santa Ana, 2003.

[3] Doçi I, Buza Sh, Pajaziti A, Cakolli V, *Studying dynamic effects of motion of telpher on console cranes using simulations*. Journal of Fundamental Sciences and Applications, Vol. 21, 2015, p.337-342.

[4] Dr.sc. Musli Bajraktari, *Mjetet transportuese* (*Transportation devices)*, UP, Prishtinë, 1986.

[5] Prof.asc. Doçi Ilir, Prof.asc. Lajqi Naser, *Development of schematic design model of gantry crane for dynamic analysis and regulation of travel motion*, MTM Journal, Issue 6/2017, p.268.

[6] Dresig, Hans, *Shwingungen mechanischer Antriebssysteme, Modellbildung, berechnung, analyse, synthese,* Springer Verlag, Berlin, 2001.

[7] Shapiro I. Howard, Shapiro P.Jay, Shapiro K. Lawrence, *Cranes and Derricks,* Mc Graw-Hill, New York, 2000.

[8] Renuka V. S.& Abraham T Mathew, *Precise Modeling of a Gantry Crane System Including Friction, 3D Angular Swing and Hoisting Cable Flexibility*, IJTARME, Volume-2, Issue-1, 2013.

[9] Ilir Doci, Beqir Hamidi, Jeton Zeka, *Influence of load swinging on dynamic behavior of l-type portal cranes during forward travelling*, MTM Journal, Issue 7/2015, p.69.

[10] http://www.diniargeo.com/men/scales/weight-indicators.aspx

[11] http://www.azom.com/article.aspx?ArticleID=6022

[12] http://www.engineeringtoolbox.com/wire-rope-strength-d_1518.html

[13] Ilir Doci, Musli Bajraktari, *Studying the influencia of the load form and dimensions in dynamic behavior of bridge cranes during the load lifting using finite elements applications*, 5th International Scientific Conference On Production Engineering – RIM2005, University of Bihac, B&H, 2005.

[14] Ilir Doçi, *Siguria e Mjeteve Transportuese I (Safety of transportation Devices I)*, Book Chapter IX, Faculty of Mechanical Engineering, Prishtina, 2012.