INFLUENCE OF LOAD SWINGING ON DYNAMIC BEHAVIOR OF L-TYPE PORTAL CRANES DURING FORWARD TRAVELLING

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*Section***:** MECHANICS, DYNAMICS, STRENGTH AND RELIABILITY, THEORY OF MACHINES AND MECHANISMS

Abstract**:** *Portal Cranes are used for load carrying in industrial and transportation sites. They have complex structure with big dimensions and many mechanisms with high security requests. In this work, we will study the influence of load swinging in dynamic behavior of Single girder L- type portal crane, in case of forward motion- travelling with full loading using computer modelling and simulations. Studying the behavior of portal cranes proves to be difficult using physical experimentation and measurement devices. Creating the crane's computer model and applying simulations is useful method to study dynamic occurrences, which helps explaining the reasons of oscillations, failures and accidents of cranes, and gives conclusions that can be useful for design considerations and safety. The analysis will be concentrated in finding the nature of forces, moments and stresses that acts on crane's construction and effects the stability, particularly at the start and end of travelling motion. Also, the study will look to find main parameters that contributes on the negative effects of load swinging. For this purpose, we designed "virtual portal crane" using model design and simulation applications. Crane is modeled from standard manufacturer, as a common model of L type portal cranes.*

Keywords: PORTAL CRANE, LOAD SWINGING, TRANSLATIONAL MOTION, OSCILLATIONS, MODELING, SIMULATIONS

1. Introduction

Main cycles of work of Portal Cranes are: lifting and lowering the load, Travell of trolley, Travelling of crane- translational movement forward and backwards, and sometimes rotation of lifting mechanism with load. Their working usage is high, sometimes without break during the working times. The work of portal crane while travelling with weight (load) is considered difficult process with high oscillations, high dynamic strains, concerns of stability, particularly when it carries maximum load. This is mainly caused by swinging of load during work of crane. The importance of study is to find the intensity, type and nature of impact of load swinging on entire crane.

Fig.1. *Portal Crane in working environment*

Table.1. Technical features of Portal Crane [2]

Crane Parameters	Value
Load Capacity	5000 kg
Columns height	11 m
Columns distance beetwen	30 m
Girders dimensions	2*1.5*47.6 m
Travel speed forward	8÷18 m/min
Travel Length	147 m
Total Weight	510 kN (52000 kg)
Weight of one column	80 kN
Weight of Trolley	19.3 kN
Power of motors, kW	2*7.41 kW
Crane Material	St.37
Crane Rails Dimensions	40x30 mm x 30 m

Study will be done for the Crane of type *Mostovna* [2] shown in Fig. 1, which was available for testing in the factory of local company. It is a single girder Gantry Crane L Type, with Overhead Trolley and Electric Hoist system. It lays with its wheels on rails, which are mounted on Basement. (Fig.2). Results of research will be required for some main parts of portal crane. Speed is considered main parameter that influences swinging of load [2]. In orden to prove this, study will be done for twotravel speeds, v_{min} = 8 m/min and v_{max} = 18 m/min, to determine the impact of speed in load swinging and dynamic behavior of crane. Results will be represented with graphs and tables and compared.

2. Modeling of portal crane and simulations

Model of Crane with its main parts is created with software [3]. Results will be achieved using Numerical methods (Kutta-Merson) and Finite Elements Method (FEM), supported by software in order to achieve best results. Working load has prismatic form with dimensions (1.5*1.5*1.5 m), with mass Q = 5000 kg connected on 4 carrying cables. Carrying cables are connected with the Hook and above with pulley system that connects to Drum with 2 lifting cables. (Fig.2). The load height from basement is 1.5 m. It is positioned on the center of crane's work space. We consider that best results will be achieved if the study is done with max carrying load Q = 5000 kg, as given by manufacturer (Table 1).

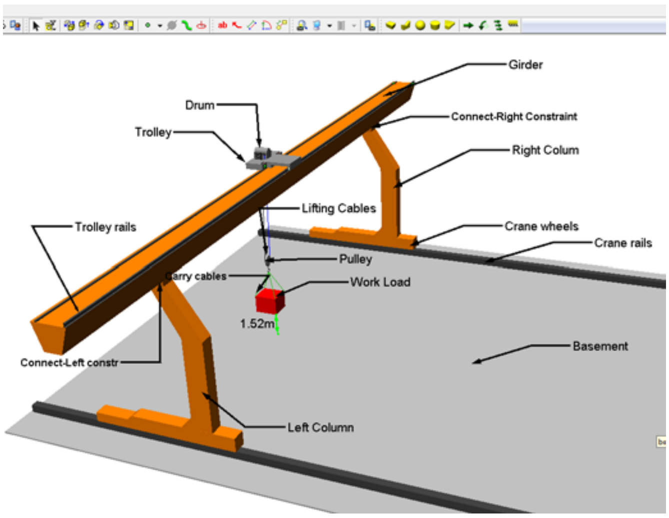

Fig. 2. *Model of Portal Crane with main parts*

For the proper scenario of travelling process, simulation will start without travelling until time t = 0.5 s. This in order to have the static stability of load hanging on cables. After t=1 s, will start the travel of crane with griven speed. Travelling will end on time t = 15 s, at length of travel L_{min} = 2 m or L_{max} = 4.5 m. For the purpose of analysis of the occurences after travel stoppage, simulation will continue until time t = 20 s. We consider that analysing the occurences before, during the process and after travel stoppage is the best way to simulate travel motion [4],[5].

3. Results

3.1. Force on lifting cables

This is the force acting on lifting cables - F_c resulting from load hanging and swinging during crane travel. Nature of this force is axial force – tension. There are 2 branches of lifting cables, which lifts and lowers the load. Maximal load in one branch of hanging cables is [1]:

$$F_{cmax} = \frac{Q}{m \cdot \eta_{ho}} = \frac{50}{2 \cdot 0.99} = 25.25\,[\text{kN}] \qquad (3.1)$$

Q = 5100 kg = 5100·9,81 N = 50 kN (Mass of load+aprox.mass of lifting devices):

η_{ho} = 0.99 - working coefficient of hoist;

m = 2 – number of cable branches participating in the lifting/hanging of weight.

Results of simulation are shown in Fig.3 and Fig.4, and in Table.2. Based on Fig.3 and Fig.4, between time $0 \le t \le 0.5$ s there is no lifting, and no force on cables. After time t=0.5 s, tension force will increase. On the intervals $0.5 \le t \le 15$ s is travel of crane. Based on Fig. 3 and Fig.4, travelling of crane is followed by amplitudes of force-tension in cables at almost entire process from start to end of travel. After travel stop, t=15 s, amplitudes are lower, but frequencies of oscillations remain high, up to ν = 15 Hz. After t = 15 s oscillations of cables continue for long time due to load swinging. Conclusion is that cables are heavily loaded with oscillations that result in high amplitudes and high number or frequencies. Maximum value of force is achieved after travel stoppage t = 10.3 s.

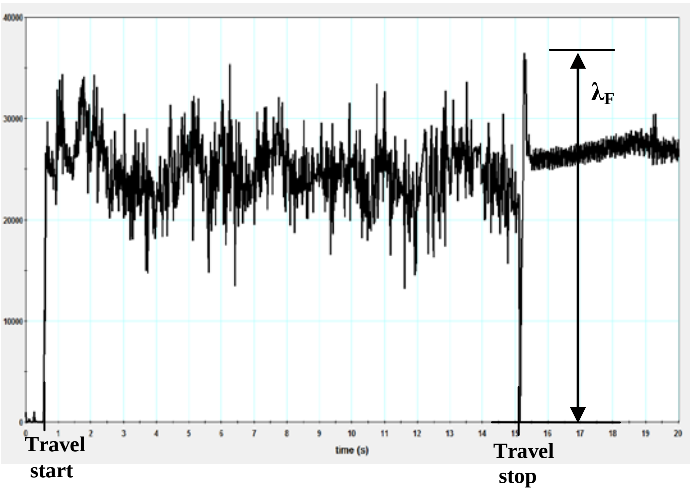

Fig. 3. *Tension force on lifting cable – speed v_{max} = 18 m/min*

On Table 2 are given results and comparison of force in hanging-lifting cables. It can be concluded that difference in speed gives difference in all parameters. It is important to emphasize the **Average amplitude of force** which is 247% higher for travel with v_{max} = 18 m/min compared to v_{min} = 8 m/min.

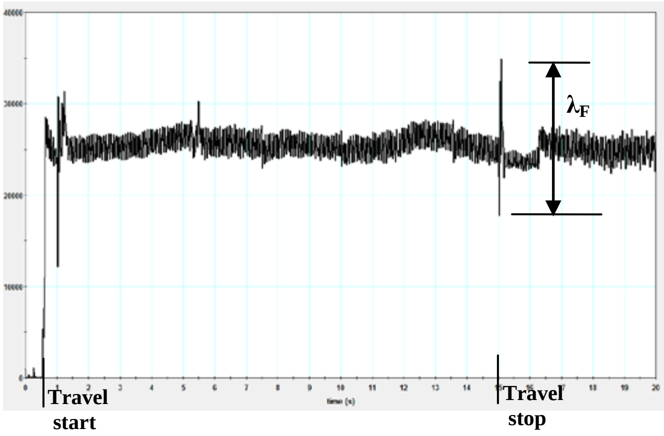

Fig. 4. *Tension force on lifting cable – speed v_{min} = 8 m/min*

Table 2. Results of tension force on lifting cables

Parameters of cables	**speed v_{min} = 8 m/min**	**speed v_{max} = 18 m/min**	**Difference in %**
Average tension Force F_{cav} (close to static)	≈25000 N	≈25000 N	≈ 0
Max tension force F_{maxc} Time and height of occurence	34900 N t = 15.1 s	36400 N t = 15.3 s	+4.2%
Dynamic coefficient: $\psi = F_{max} / F_{st}$	1.39	1.45	+ 4.2%
Max amplitude of tension force, (Peak-to-peak) Time and height of occurence	F_{maxc}=34900 N F_{minc} = 17700 N λ_F = 17200 N t = 15÷15.1 s	F_{maxc}= 36400 N F_{minc} = 0 N λ_F = 36400 N t = 15÷15.3 s	+112.6%
Average amplitude of tension force	**λ_{avg} ≈ 3400 N**	**λ ≈ 8400 N**	**+147%**
Frequency of oscillations of Force (Average)	15 Hz	13 Hz	-13.33%

3.2. Resultant force in the connection of girder and column

Crane main parts consists of one girder and two columns. Forces in the connections between these parts are important for determining dynamic effects on crane. Parameter for studying is resultant force in constraints of connection. Results are shown in Fig.5 for right girder-column connection, and Fig.6 for left girder-column connection (as seen in Fig.2). On Tab.3 are shown results of main parameters and comparison for v_{min} = 18 m/min and v_{max} = 8 m/min.

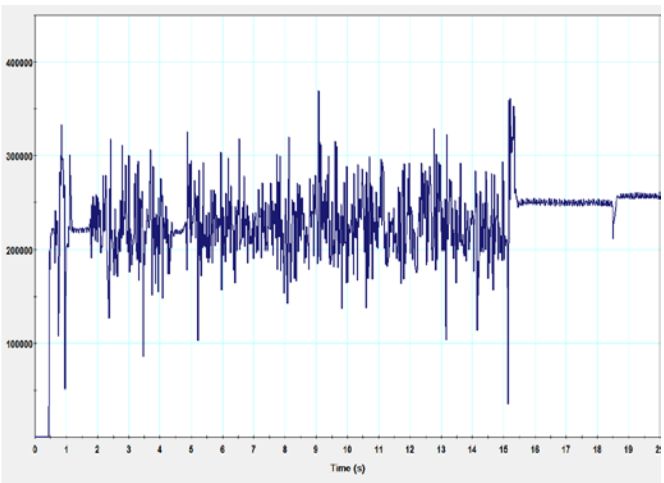

Fig.5. *Resultant force in right constraint - v_{max} = 18 m/min*

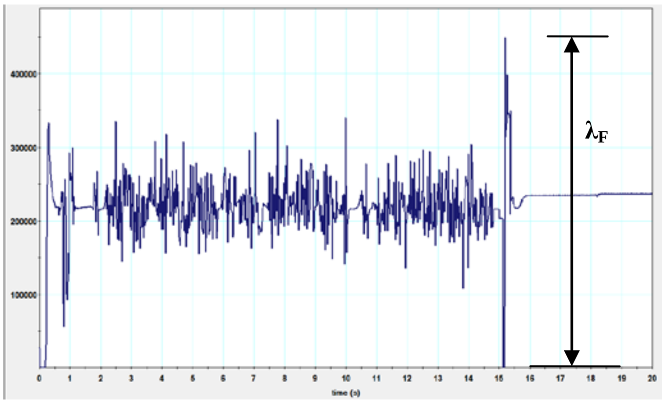

Fig.6. *Resultant force in left constraint - v_{max} = 18 m/min*

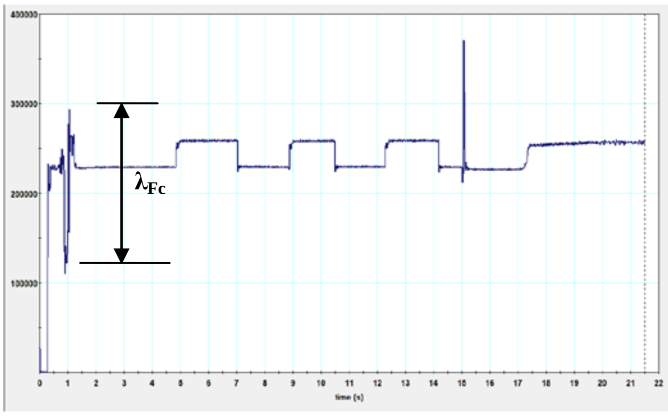

Fig.7. *Resultant force in left constraint - v_{min} = 8 m/min*

Results of right constraint for *v_{min} = 8 m/min* are similar to Fig.7

Based on Graphs of resultant force in constraints, for both cases of travel speed, it can be concluded that for minimum speed v_{min} = 8 m/min, constraints are far less strained than for maximum speed. This can be concluded by results on Table.3, particularly for parameter of *Average amplitude*. But, in both cases, maximum value of resultant force and Dynamic coefficient don't change much. Main resulting parameters and difference in % are shown in Table.3

Table 3. *Results of parameters of left constraint, based on Fig.6 and Fig.7*

Parameters of constraints resultant force – Left Constraint	**speed v_{min} = 8 m/min**	**speed v_{max} = 18 m/min**	**Difference in %**
Average resultant Force	≈230000 N	≈230000 N	
Max resultant force	≈375000 N (t = 15.2s)	≈449100 N (t = 15.2s)	≈ +19.7%
Dynamic coeff: $\psi = F_{max} / F_{st}$	1.63	1.95	≈ + 19.7%
Max amplitude of resultant force, (Peak-to-peak) Time of ocurrence	F_{max}= 290000 N F_{min} = 112000 N λ_{Fc}= 178000 N t = 1.2 s	F_{max}= 370000 N F_{min} = 34700 N λ_{Fc}= 326300 N t = 9.3 s	+53.19%
Average amplitude λ_{Fcav}	**≈30000 N**	**≈131000 N**	**+336%**
Frequency of oscillations (Average)	12 Hz	/	

3.3. Stresses on girder

Stresses (von Mises) are gained using Finite Elements Methods (FEM) by meshing parts of Portal Crane. Girders are important part of cranes for dynamic analysis while they carry most of loading and strains. Results of stress are shown graphically in Fig.9 and Fig.10. Comparision of results is griven in Table.4

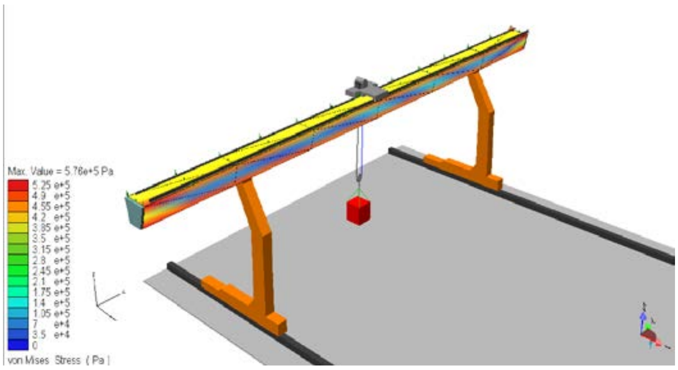

Fig. 8. *Distribution of stress on girder*

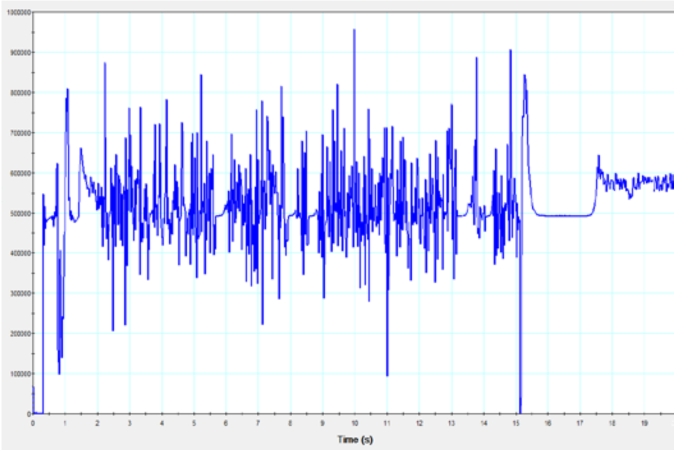

Fig. 9. *Diagram of stress on Girder - v_{max} = 18 m/min*

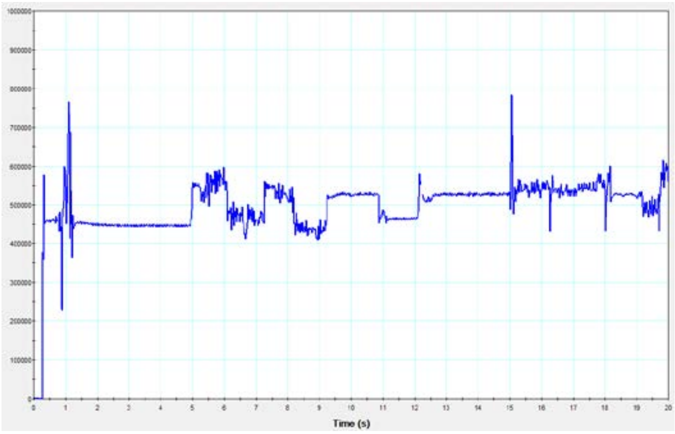

Fig. 10. *Diagram of stress on Girder - v_{max} = 8 m/min*

Table 4. *Results of stresses on girder [5]*

Results of stress on Girders (von Mises)	**speed v_{min} = 8 m/min**	**speed v_{max} = 18 m/min**	**Difference in %**
Average stress σ_{avg}	≈$5\cdot10^5$ (Pa)	≈$5\cdot10^5$ (Pa)	≈ 0
Max stress σ_{max1}	7.84 $\cdot10^5$ (Pa) (t = 1.2 s)	9.53 $\cdot10^5$ (Pa) (t = 10 s)	+21.5%
Dynamic coefficient: $\psi = \sigma_{max} / \sigma_{med}$	1.56	1.9	+ 21.5%
Max Amplitudes of stress (λ_σ) (Peak-to-peak)	$\lambda_{\sigma1}$ = 5.33 $\cdot10^5$ (Pa) (t = 1.2 s)	$\lambda_{\sigma1}$ = 8.45 $\cdot10^5$ (Pa) (t = 15.2 s)	+58.5%
Average Amplitudes of stress ($\lambda_{\sigma av}$)	7 $\cdot10^4$ (Pa)	3.4 $\cdot10^5$ (Pa)	+385.7%
Frequency of oscillations of Stress	7 Hz	16 Hz	+114%

3.4. Swinging and oscillations of workload

Pulley system with cables and working load is lifting/carrying system that passes oscillations and swinging to the metal construction of crane. On fig.12 and fig.13 are given oscillations and swinging of workload for both speeds. They are measured in degrees of swinging towards local coordinate system (º) (fig.11). Oscillations between time 0<t< 15 s are almost the same for both speeds. After travel stop t ≥ 15 s, oscillations and swinging shows higher change (Table 5). Max amplitude of oscillations increases due to the swinging of load and pulley.

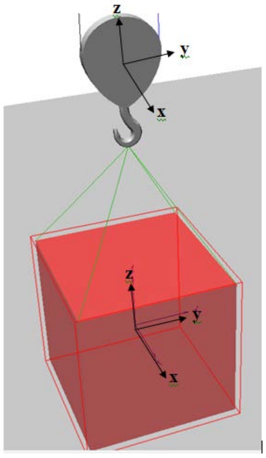

Fig.11. *Workload Load and pulley with Local coordinate systems*

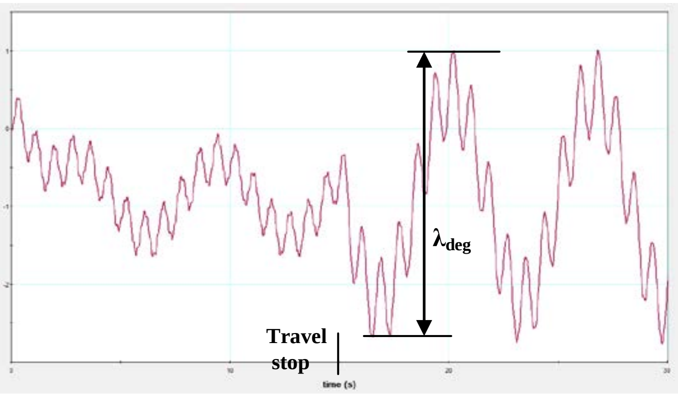

Fig.12. *Swinging and oscillations of workload around **Y** axes and max amplitude λ_{dge} – for V_{max} = 18 m/min*

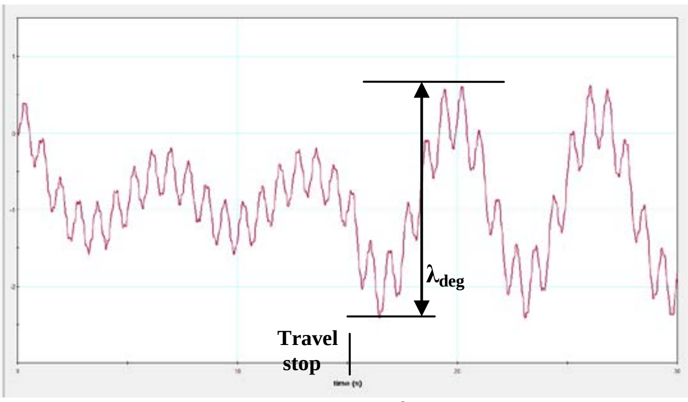

Fig.13. *Swinging and oscillations of workload around **Y** axes and amplitude λ_{deg} – for v_{min} = 8 m/min,*

On Table.5 are given results and comparison for swinging and oscillations of workload.

Table 5. *Results of swinging and oscillations of workload*

Results of Oscillations and swinging of workload	**speed v_{min} = 8 m/min**	**speed v_{max} = 18 m/min**	**Difference in %**
Max Amplitude of swinging λ_{deg}, (º) t< 15 s	1.4	1.6	+14.2%
Max Amplitude of swinging λ_{deg}, (º) t> 15 s	3	3.7	+ 23.3%
Frequency of oscillations	1.4 Hz	1.4 Hz	≈ 0

4. Conclusions

Main issues of crane travelling are intensive oscillations with high frequency and big amplitudes, and mostly with irregular occurrence. Most complex work periods are motion start and stop, which gives maximum values for all parameters, and these are the periods when load swinging has highest influence. Main parameter of influence is speed of motion that effects load swinging and other dynamic occurrences. Speed must remain in optimal value, as lower as possible to minimize negative effects of load swinging, strain on parts of crane and safety considerations. Oscillations in cranes are difficult to measure with instruments, and they can cause parts failure, materials fatigue and stability problems. They are mainly induced by load and pulley swinging that induces forces in cables, and further forces, moments and stress in other parts.

5. References

[1] Bajraktari, Musli, *Mjetet Transportuese*, Fakulteti Teknik, Prishtinë, 1986

[2] Crane manual - http://www.mostovna.si

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

[4] Ilir Doçi, Blerim Morina, *Studying luffing motion of boom on construction cranes while carrying load using simulations*, 18th International Research/Expert Conference,TMT 2014.

[5] Ilir Doçi, Musli Bajraktari, Vegim Imeri, *Studyıng dynamıc effects on warehouse forklıft durıng forward movement wıth full loadıng*, 16th International Research/Expert Conference,TMT 2012.