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Research Article

Dynamic Analysis of Forklift during Load Lifting using Modeling and Simulations

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Abstract

Studying dynamic occurences on forklift during lifting of loads proves to be difficult using physical experimentation and current measurement devices. Creating the forklift's multibody model and applying computer simulations is very usefull method to study these occurences, which helps to explain the reasons of heavy oscillations, failures and accidents of forklifts, and gives conclusions that can be useful for design considerations and safety. The aim is to see how dynamic forces, moments, speed and oscillations effects the forklift's construction and its stability during load lifting. To do this work we designed entire "virtual forklift" using model design and simulation applications (Fig.2) [3] and performed simulations in order to gain results. Main parameters that are influential on the dynamic behavior of forklift will be analyzed and will be searched for conclusions that can be useful for better understanding dynamics of forklift. This paper identifies a set of parameters that have influence in main forklift parts, and gives results with graphs and tables with values that are dynamic in nature, with high amplitudes and frequencies that effects directly in causes of material fatigue or failure.

Keywords: *Forklift, modeling, simulation, load lifting, dynamic analysis, oscillations, FEM*

1. Introduction

Work of warehouse forklifts is characterized by various working processes – lifting weight, lowering weight, moving forward, moving backwards, moving left and right, with numerous requests and cycles which includes variety of cargo and packages that needs to be carried with variable speeds. The work of forklift while lifting weight (load) is considered most difficult process, particularly when it lifts the maximal load. Study will be done for the forklift of type *Linde H20*(*Linde Material Handling GmbH*) shown in fig. 1, which was available for testing in the warehouse of local company. Simulation will be achieved using Numerical methods (Kutta-Merson) and Finite Elements Method (FEM), supported by modelling and simulation software(Dresig *et al*,2001). Results of research will be shown for some main parts of forklift that lifst the load, with graphs and tables with resulting values and their comparisions, which offers new conclusions and good view in dynamic occurences.

2. Modeling of forklift and simulation of lifting process

After the model creation with its parts in Inventor software, its modelled parts are imported in Visual Nastran 4D software and connected with proper constraints(Dresig *et al*,2001). These constraints are rigid joints, revolute joints, rigid joints on slot, rope or revolute motor. The load that is lifted is created has prismatic form with dimensions (1200x800x1000 mm – palleted load), with mass of Q = 2000 kg which is maximal carrying weight of the forklift. We consider that best results of dynamic processes if the study is done with max carrying laod as given by manufacturer (Table 1).

Fig.1. Photo of the forklift *(Linde Material Handling GmbH*)

Simulations will be processed to achieve results of parameters which we consider are important for overall dynamic analysis(Dresig *et al*,2001). For the proper lifting process, lifting forks with load are placed in their lowest position (h=0.05 m), (Fig.3). Simulation will start without

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lifting until time t = 0.3 s (h = 0.05 m). This is done in order to have the static stability reached before the lifting process begins. After time t = 0.3 s, lifting will start by lifting hydraulic cylinders with speed v_c= 0.33 m/s, until maximal height h = 3.15 m (time t = 5.5 s), and then lifting will be stopped. Simulation will continue until t = 9 s, in order to monitor the occurences after lifting stoppage. We consider that analysing the occurences before the process start, during the process and after the process stoppage is the best way to simulate a lifting process in forklifts(Ilir Doçi,2012).

Table.1. Technical features of the forklift *(Linde Material Handling GmbH*)

Parameters	**Value**
Load Capacity	2000 kg
Mast type (standard)	2 stage
Height of mast- lowered h_1	2227 mm
Height of mast (extended) h_4	3703 mm
Lift max h_3	3150 mm
Overall width	1180 mm
Overall length l_1	3635 mm
Forks - Length l	1000 mm
Angle of mast tilt α/β	6/12°
Travel speed forward,	22.5/24.1 km/h
Lifting, with weight/without	0.33/0.40 m/s
Lowering, with weight/without	0.36/0.41 m/s
Power of motor, kW	30 kW

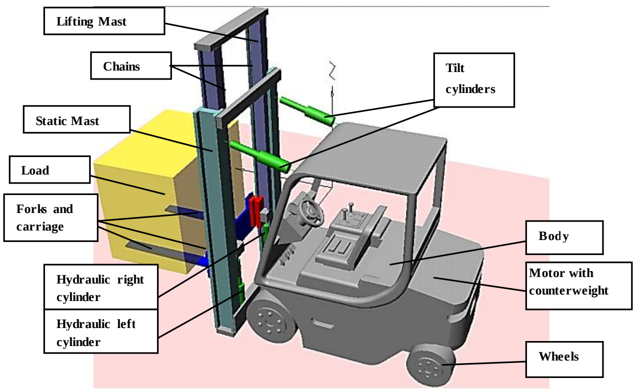

Fig. 2. Model of forklift with its main parts

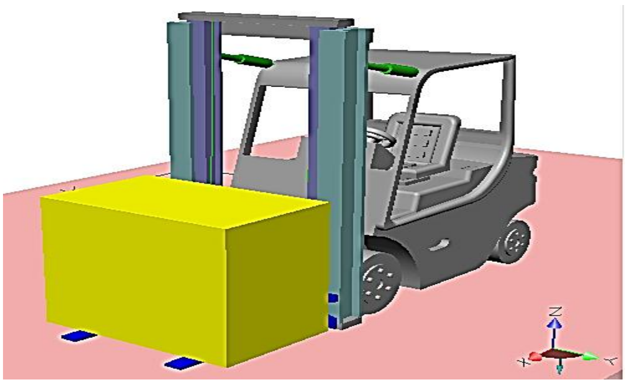

Fig. 3. Initial position - h = 0.05 m Fig

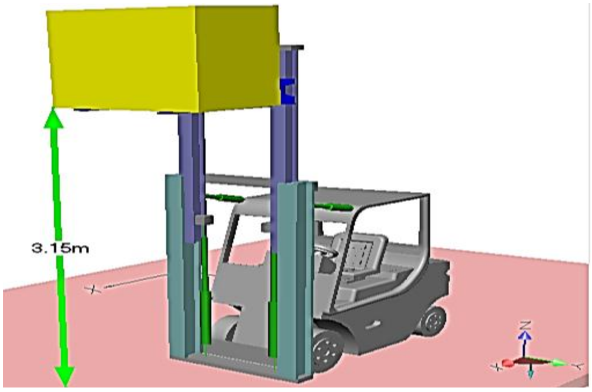

Fig.4. Heighest position of lifting - h = 3.15 m

3. Results

3.1. Force in hydraulic lifting cylinders

This is the tension force in hydraulic cylinders - F_{cv} resulting from load lifting. Results are shown in Fig.5 and Fig.6. Graphs are for left and right cylinders. Lifting load is Q = 2000 kg, and lifting speed v = 0.33 m/s. Nature of this force is axial force – pressure acting on cylinders which explains the negative value in graphs .

Based on Fig.5 and Fig.6, beetwen time $0\leq t \leq 0.3$ s there is no lifting, there is static pressure on cylinders which increases up to $F_{rcv} \approx -12000$ N. On the intervals $0.3\leq t \leq 5.5$ s (Lifting from 0 m to 3.15 m) is a period of lifting with cylinders. The force in cylinders has increased dynamic effects and oscilations that have non harmonic frequency with irregular amplitudes

Frequencies of oscilations in this period are υ = 43/(5 s) ≈ 8.5 Hz. On time t = 5.5 s (Heigth h = 3.15 m) we have lifting stop, which results in almost unload of cylinders ($F_{rcv} \approx -500$ N). This can be explained with inertial move of load and forks after cylinder stop. After this time t > 5.5 s, force in cylinders has oscillations with lower amplitudes which are less critical than from the period of cylinder lifting.

3.2. Tension force in chains

There are two chains of the forklift that lifts the load - left and right chains. Tension force is the most important resulting parameter in chains. From Fig.7, maximal values of tension force in chains is at lifting start and lifting end. In one moment of lifting end, chains are released from loading at time t=5.5 s, due to inertial forces pushing upward the load. The force in chains shows high dynamic nature, with frequencies and amplitudes that could explain the reasons of fatigue or break of chains. Static force in chains [4]:

$$F_{stch} = \frac{Q+Q_f}{m\cdot\eta_p} = \frac{2000+100}{2\cdot 0.99} = 1060.6 \text{ kg} \cdot 9.81 \text{ m/s}^2 = 10404 \text{ N}$$

Q_f = 100 kg– Mass of forks and carriage
η_p = 0.98 – working coefficient of pulley
m = 2 - number of chains pulling the load.

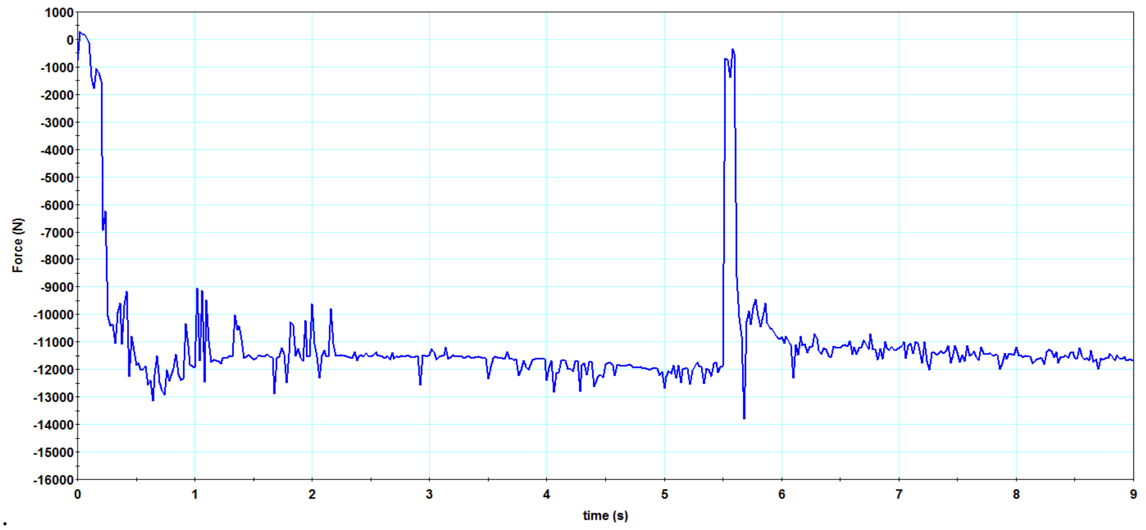

Fig. 5. Tension force on right cylinder

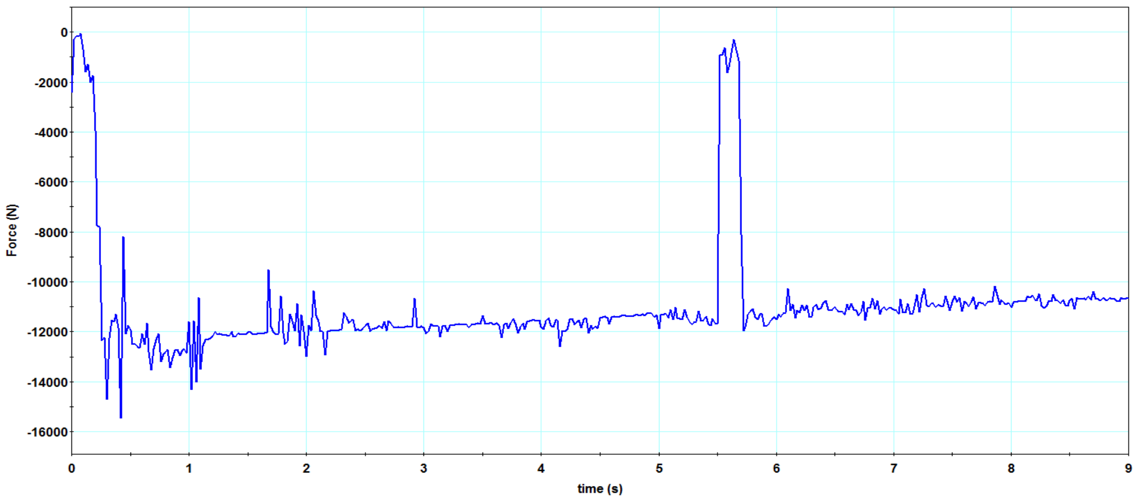

Fig.6. Tension force on left cylinder

Table 2. Results of tension force on cylinders based on Fig.6 and Fig.7

Parameters of cylinders	*Values - right cylinder*	*Values-left cylinder*
Average tension Force F_{stc} (close to static)	-12000 N	-12000 N
Max tension force F_{maxc} Time and height of occurence	-13100 N t = 0.5 s (h= 0.07 m)	-15000 N t = 0.5 s (h= 0.07 m)
Dynamic coefficient: $\psi = F_{max} / F_{st}$	1.09	1.25
Max amplitude of tension force, while lifting (Peak-to-peak) Time and height of occurence	F_{maxc}= -15100 N F_{minc} = -8200 N A_F = 6900 N t = 0.4 s (h=0.08 m)	F_{maxc}= -12500 N F_{minc} = -9000 N A_c = 3500 N t = 1.2 s (h=1.1 m)
Frequency of oscillations of Force (Average)	8.5 Hz	8.5 Hz

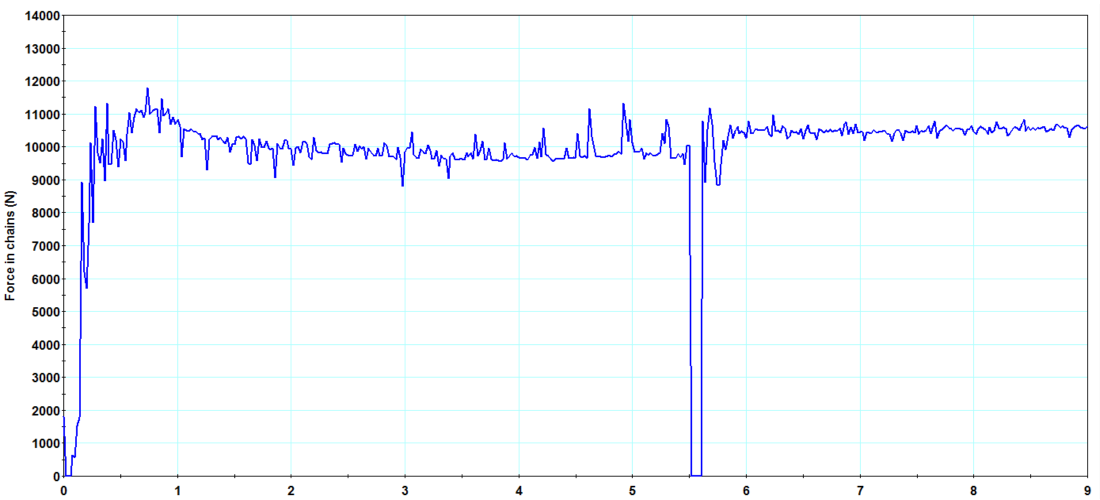

Fig.7. Tension force in right chains

Table 3. Results of parameters in chains, based on Fig.7

Parameters of chains	*Value*	*Position of lifting*
Static tension Force F_{stch}	10404 N	
Max tension force F_{maxch}	11900 N	t = 0.8 s (h= 7.5 cm)
Dynamic coefficient: $\psi = F_{max} / F_{st}$	1.14	
Max amplitude of tension force, while lifting (Peak-to-peak)	F_{max}= 11200 N F_{min} = 9650 N A_{Fch}= 1550 N	t = 4.7 s (h=2.9 m)
Frequency of oscillations of Force (Average)	11 Hz	$0.3 \le t \le 5.5$ s (0.05 m < h < 3.15 m)

3.3. Stresses in lifting mast and static mast

Stresses (von Mises) are gained using Finite Elements Methods (FEM) by meshing parts of forklift. Parts of forklift that are calculated for stresses are lifting mast and static mast which we consider are most important for stress analysis (Fig.8 and Fig.9).

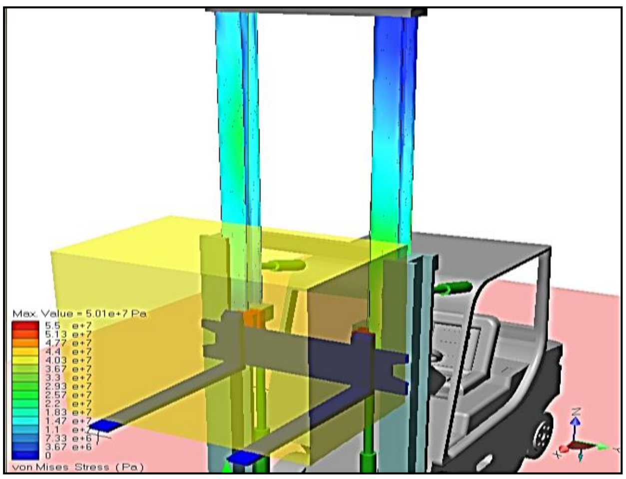

Fig. 8. Distribution of stresses in lifting mast

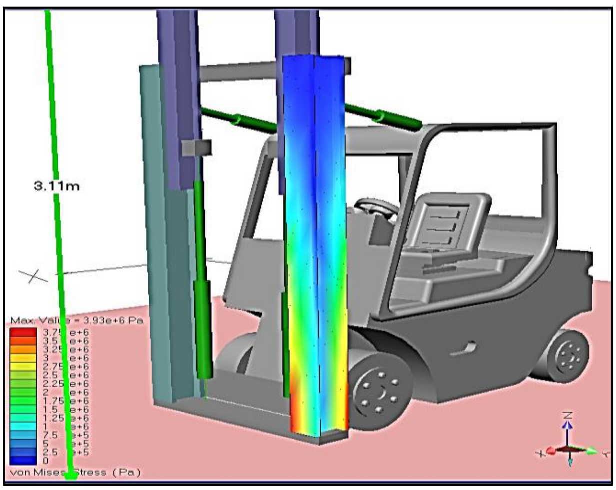

Fig. 9. Distribution of stresses in static mast

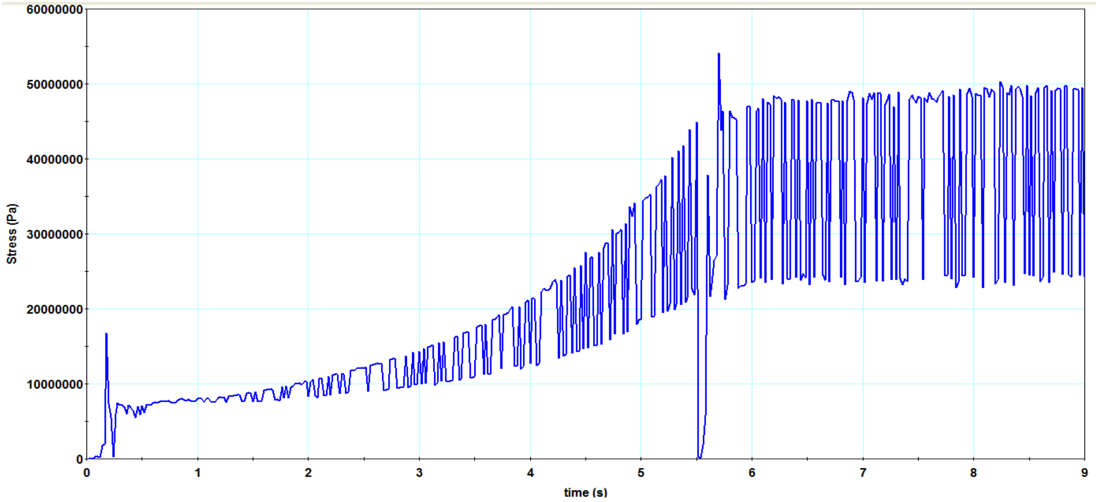

Fig. 10. Diagram of stress on lifting mast

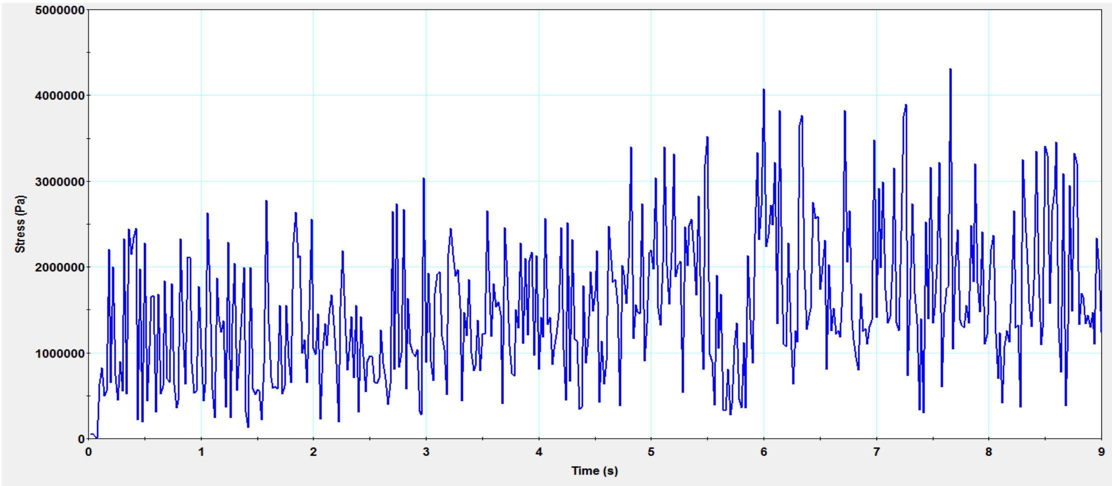

Fig. 11. Diagram of stress on static mast

Table 4. Results of stress parameters for lifting mast based on Fig.10

Lifting Mast		
Results of stress (von Mises)	*Value*	*Position of lifting*
Average stress σ_{med1} Max stress σ_{max1}	$7 \cdot 10^6$ (Pa) $7.6 \cdot 10^6$ (Pa)	- Start of lifting
Dynamic coefficient: $\psi = \sigma_{max} / \sigma_{med}$	1.08	
Average stress σ_{med2} Max stress σ_{max2}	$35.5 \cdot 10^6$ (Pa) $50 \cdot 10^6$ (Pa)	- End of lifting
Dynamic coefficient: $\psi = \sigma_{max} / \sigma_{med}$	1.42	
Stress increase trendline	$\sigma = 0.296 \cdot t^2 - 1.22 \cdot t + 8.852$	$0.3 \leq t \leq 5.5$ s ($0.05 < h < 3.15$ m)
Amplitudes of stress (A_σ) (Peak-to-peak)	$A_{\sigma 1} = 3 \cdot 10^6$ (Pa) $A_{\sigma 2} = 8.5 \cdot 10^6$ (Pa) $A_{\sigma 3} = 25 \cdot 10^6$ (Pa)	t = 2 s (h=0.8 m) t = 4 s (h=2.45 m) t = 5.5 s (h=3.3 m)
Amplitudes of stress (A_σ) Increase ratio	8.33	$0.3 \leq t \leq 5.5$ s ($0.05 < h < 3.15$ m)
Frequency of oscillations of Stress	7 Hz 16 Hz	$0.3 \leq t \leq 1.3$ s (0.05 m $< h < 0.33$ m) $4.5 \leq t \leq 9$ s ($2.8 < h < 3.15$ m)

Table 5. Results of stress parameters for static mast based on Fig.11

Static Mast		
Results of stress (von Mises)	*Value*	*Position of lifting*
Average stress σ_{med1} Max stress σ_{max1}	$1.6\cdot10^6$ (Pa) $4.1\cdot10^6$ (Pa)	$0.3\leq t\leq 5.5$ s ($0 < h < 3.15$ m)
Dynamic coefficient: $\psi = \sigma_{max} / \sigma_{med}$	2.56	
Max amplitude of stress (A_σ) (Peak-to-peak)	$A_{\sigma\text{-}max} = 3.22\cdot10^6$ (Pa)	t = 5.8 s (h=3.3 m)
Frequency of oscillations of Stress (Average)	16 Hz	$0.3\leq t\leq 9$ s (0.05 m $< h < 0.33$ m)

Conclusions

Using modeling and simulations is very powerful method to study the dynamics of forklifts. We can conclude that lifting processes in forklift is of intense dynamic nature with heavy oscillations and should not be ignored for calculations and analysis of forklifts.

- Dynamic occurrences are more intense at the beginning of lifting, and until and little after the process of lifting stoppage. During this time, the process has high amplitudes of oscillations and frequencies, as shown in graphs and tables. Start of lifting and end of lifting must be taken in consideration for the stability of forklift.
- Oscillations and amplitudes of tension force in hydraulic cylinders should be taken seriously while lifting. End of lifting process should tent to be smooth with speed control in order to have less dynamic force in cylinders. (Table.2)
- Oscillations with high amplitudes of tension force in chains, and high frequencies gained in results can be the reason for their fatigue and failure. (Table.3)
- From the results of stress in lifting mast, it can be concluded that this part undergoes highest oscillations and amplitudes than other parts, and should be controlled constantly. (Table.4)
- Dynamic coefficient has highest values for static mast, expressed with stress (Table.5). This concludes that this part of forklift undergoes highest dynamic forces.
- Speed of lifting should be as minimal as possible for lifting process, in order to have smoother lifting and smaller values of dynamic parameters. Mostly this is ignored from operators, in order to achieve faster performance

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