16th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2012, Dubai, UAE, 10-12 September 2012

STUDYING DYNAMIC EFFECTS ON WAREHOUSE FORKLIFT DURING FORWARD MOVEMENT WITH FULL LOADING

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ABSTRACT
Work of warehouse forklifts is characterized by various working processes, with numerous requests and loadings which include variety of cargo and packages that needs to be lifted, lowered and transported with variable speeds. This includes the movement in different configuration of terrain that can be horizontal or inclined and sometimes not flat nor strong. Also movement can be in tight and small spaces. All these activities of forklift makes it constantly subjected to various dynamic loads, which burdens all its parts, and in extreme cases can cause forklift's damages and failure, or crash in the working area and possible injury of driver or other personnel. In this work, we are going to simulate the work of forklift while moving forward - traveling. The aim is to see the effects of dynamic forces in the forklift's construction during this movement, when the working load is being carried. Reasons for doing this study are to research forklift's dynamic behavior and stability. We will study the effects of load weight, oscillations, and speed in the overall forklift stability by simulating the forward movement. By using the modeling applications and applying simulations, we consider that we will have better view of dynamic behavior for this type of transportation vehicle during the forward motion and give some conclusions for enforcing stability, safety and design considerations. To do this we designed a whole "virtual forklift" using model design applications and performed simulations.
Keywords: Forklift, dynamic behavior, forward motion, oscillations, forces, stresses, simulation

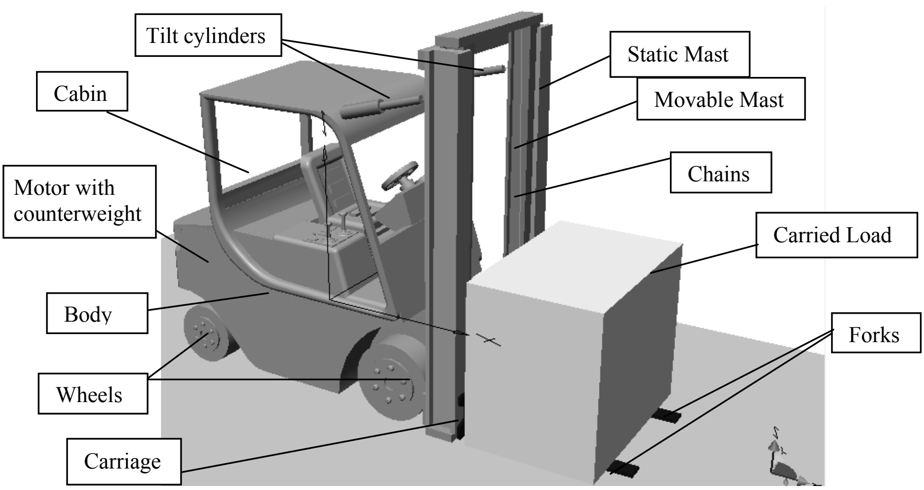


Figure 1. Model of forklift created with Visual Nastran software

1. PROPERTIES OF THE FORKLIFT

The type of forklift that will be studied is from the manufacturer *Linde* type *H20* shown in fig. 2. In table 1 are given technical specifications.

Table.1.Technical specifications- Linde H20 [1]

Parameter	Value
Load Capacity	**2000 kg**
Mast type (standard)	2 stage
Lifting max height	3150 mm
Overall width	1180 mm
Overall length	3635 mm
Forks - Width	100 mm
Forks - Length *l*	1000 mm
Angle of mast tilt α/β	6/12°
Travel speed forward, with weight/without	**22/22 km/h**
Machine weight (no load)	3895 kg
Motor type, kW	Diesel, 30 kW

Figure 2. Forklift Linde, type H20

2. MODELLING OF THE FORKLIFT AND PROCESS OF SIMULATION

In this work, we have modeled the forklift using software [2]. Every part of it is modeled based on manufacturers data [1]. All the parts are assembled properly with adequate constraints and joints in order to have as close as possible computer modeling compared with real construction. This model has lifting with hydraulic cylinders and chains, tilting with hydraulic cylinders up to 12º and travelling with 4 wheels that have different diameter of those in front compared with those in the back. After we have tested the model we are going to simulate the work of forklift during forward motion (travelling). Form of the load is prismatic with dimensions 1200x800x1000 mm (palleted load).

Process of simulation –forward motion will be accomplished with max load Q=2000 kg in two cases:

Case 1 – Load Q = 2000 kg, height of load H = 0.2 m, travel speed v = 22 km/h. Tilt angle $\beta_1 = 0$ and $\beta_1 = 12$ º.

Case 2 – Load Q = 2000 kg, load height $H_{max} = 3.150$ m, travel speed v = 11 km/h. Tilt angle $\beta_2 = 0$.

Results that we require with simulations are calculated using numerical methods applied by Visual Nastran 4D software [2]. The simulations are real time simulations and methods of calculation are Approximate methods – Runge-Kutta Method, Kutta-Merson Method and Finite Elements Method. Results will be given for most influential parameters that have high impact in the dynamic behavior of the forklift during forward motion. These parameters are: *Oscillations of the mast, Stresses in mast, Forces in parts connections-joints*, etc .

3. SIMULATIONS AND RESULTS OF CASE 1

Simulation of this process will be applied based on time, as follows: Between time $0<t<0.3$ s, there will be no movement of forklift. In time 0.3 s<t<2 s forklift will start to move until it reaches v_{max} = 6.11 m/s (22 km/h). In time 2 s<t<4 s we have constant speed of v = 6.11 m/s. After t = 4 s, the forklift will reduce its speed (brake) until t = 5 s when it will stop travelling. This process of forward movement is similar to the one measured in real forklift.

Traveling with no tilting $\beta_1 = 0$ - First conclusion of simulation is that with max speed v = 6.11 m/s, traveling without tilting is unsafe, while during braking, load is unstable and due to inertia tents to bounce away from forks. In case of this form of traveling, load should be tied or bind on carriage. Based on simulations, traveling without tilt can be acceptable only for optimal speed v< 3 m/s.

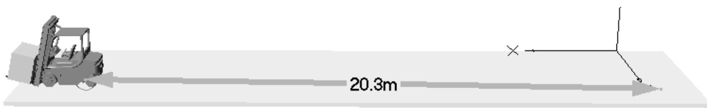
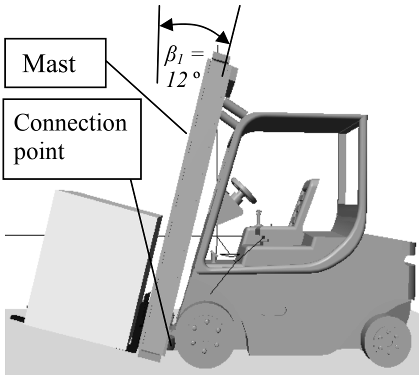


Figure 4. Traveling length of forklift from start to end point



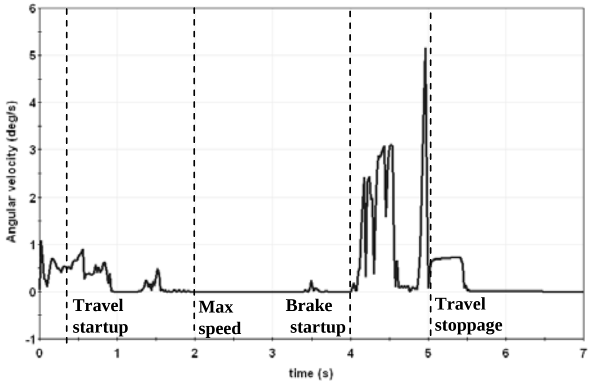
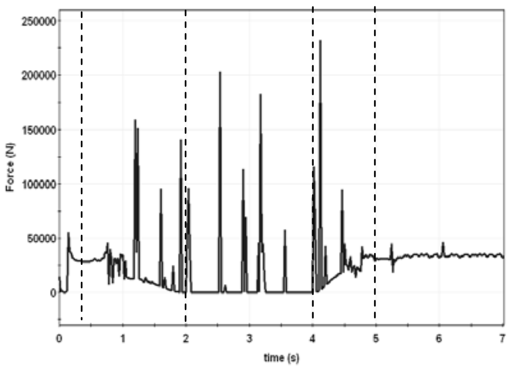


Figure 5. Forklift with tilted mast of $\beta_2 = 12^o$ *Figure 6. Angular velocity of mast (deg/s)*

Traveling with tilt angle β_1 = 12 º (Fig.5) - On Fig.6, is shown graph of angular velocity of mast around its connection point with forklift's body. It is a good parameter for defining oscillations of mast. Based on graph, we can notice that forklift undergoes heavy dynamic process with oscillations at the beginning process of traveling, in time 0<t< 1.5 s. After time t>1.5 s, when the speed reaches max value v = 6.11 m/s and until t = 4 s we have constant and almost none oscillations of mast which means stable work during traveling. After brake startup (t = 4 s) until traveling stoppage (t ≈ 5 s) dynamic process is intensive with highest values that reaches up to 5.1 deg/s. This proves that braking process at the end of traveling is intensive dynamic due to inertia force of carried load and forklift mass and needs to be considered with high importance for safety during work. Speed is most relevant parameter, and needs to be reduced in the stoppage/braking process.



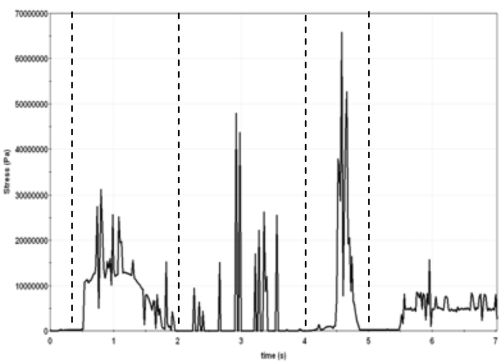


Figure 7. Force in connection point (N) *Figure 8. Stresses in mast (Pa)*

Fig.7 represents force in the connection joint between mast and body of forklift (Fig.5). Graph shows heavy dynamic force in almost all the traveling process. Max value of force is after braking (t>4s). Only after travel stop (t=5 s), oscillations tents to reduce. Fig.8 shows stresses in the mast, which also confirms the dynamic process with heavy oscillations and gives better view of oscillations in the mast. Max value of stresses is after braking - $\sigma_{1max} = 6.4 \cdot 10^7$ *Pa* at time t ≈ 4.5 s

4. SIMULATIONS AND RESULTS OF CASE 2

This is the case when load is in its highest position - H_{max} = 3.15 m. This case happens when forklift moves between racks of warehouse, where the moving space is small and moving speed is low - v ≈ 11 km/h, but load needs to be put in high positions in racks of warehouse. There is no mast tilting.

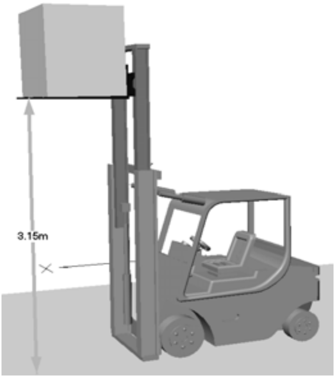


Figure 9. Max height of load

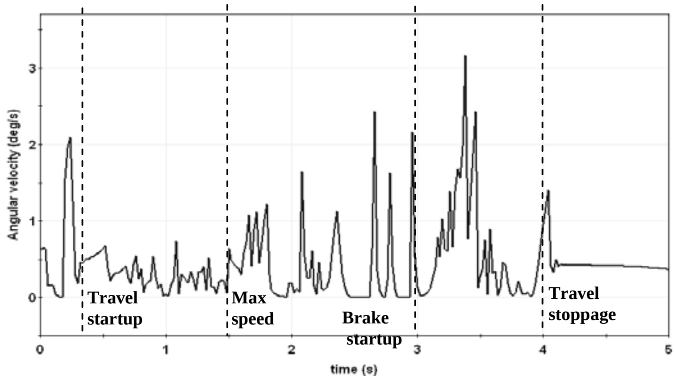


Figure 10. Angular velocity of mast (deg/s)

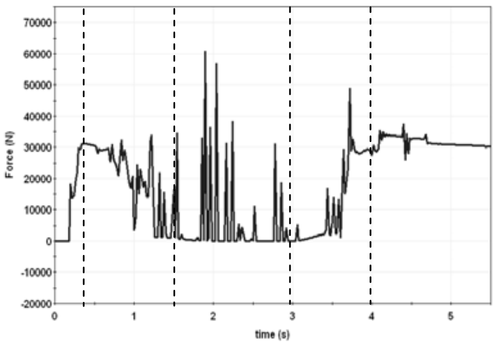


Figure 11. Force in connection point (N)

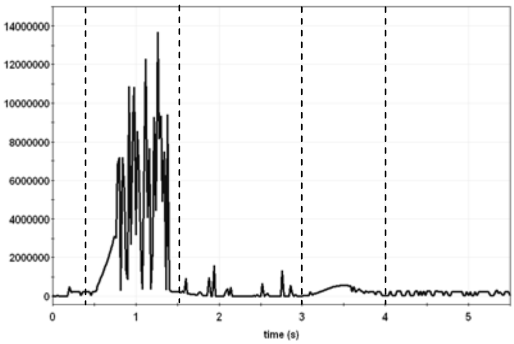


Figure 12. Stresses in mast (Pa)

In Fig. 11, force in connection point has heavier oscillations in the middle part of graph. In this part t ≈ 2 s the value of force is highest F_{max} = 60000 N, but only in short periods. After t = 3, when braking occurs, force also gains high values F ≈ 50000 N at t ≈ 3.6 s. For comparison, this force for the Case 1 has higher max values than for the Case 2. This can be explained only as effect of higher speed in Case 1. Fig.12 shows stresses of the mast, which gets highest values at the beginning of the travel, but the values of stress are much smaller than on the Case 1 ($\sigma_{2max} = 1.37 \cdot 10^7$ Pa < $\sigma_{1max} = 6.4 \cdot 10^7$ Pa).

5. CONCLUSIONS

Studying traveling motion proved that during this process forklifts undergo intensive dynamic forces and tensions which should be considered in calculations. We studied several cases of moving with different speeds and positions of load. We gave some important conclusions about the influential of some parameters in the dynamics of forklift during forward movement and effects on the work safety.

6. REFERENCES

[1] Technical Data Manual, Diesel and LPG Forklift Trucks Capacity 2000 – 2500 kg, H20, H25 SERIES 392, Linde Material Handling GmbH, 63701 Aschaffenburg, Germany.
[2] Visual Nastran Desktop 4D User Manual, MacNeal-Shwendler Corporation, Santa Ana, 2003.