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TESTING OF FORKLIFT TRUCK OPERATION IN PREDEFINED WORK CYCLES

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Abstract: *the paper discusses the issue of testing the energy consumption of forklift trucks versus its movement parameters, such as radius of curve, distance, speed of movement on curve due to cargo safety, braking delay due to cargo slipping off the forks or tipping over. A comparative analysis of forklift truck operation characteristics in predefined work cycles: VDI cycle and "semi-trailer loading cycle" was presented; indicators characterizing the energy consumption of the truck were developed, the analysis of results was presented and final conclusions were elaborated.*

Keywords: forklift trucks, modelling, logistics warehouse systems

1. Introduction

Modern forklift trucks are characterized by very high technical parameters in comparison to the designs from several years ago. This is facilitated by the popularization of microprocessor-controlled mechatronic solutions. The question arises as to whether it is possible to choose a forklift with the lowest energy consumption for the needs of the company? For this purpose, VDI has developed regulations specifying the conditions under which forklift trucks should be compared, the operating cycle of the truck according to VDI 2198. The energy consumption characteristics is influenced by driving parameters such as speed, curve speeds, curve radii. Nowadays, there is increasing debate about green warehouses and zero-energy warehouses. The use of forklifts is one of the factors that influence the global energy consumption of a warehouse, in addition to energy consumption due to the exchange of heat in the warehouse environment and energy consumption for other systems used in warehouses Cheema, Sepehri (2002), Al-Shaebi et al. (2017).

2. Assumptions for the simulation of movement of a forklift at predefined work cycles

Based on the process of loading a semi-trailer with a selected forklift truck - Jungheinrich EFG-220, 10 sections of work cycle were assumed and compared with the obtained results according to VDI 2198. The forklift route is illustrated in Fig. 1 (a and b). It can be assumed that it moves through a pass-through warehouse, with parallel arrangement of racks–eighty meters long. The picking width of the goods issuing area is 10 m. Semi-trailers on which cargo is delivered are 13.60 m long. It is assumed that the forklift drives up to half of the semi-trailer (it covers a distance of 6.80 m on the semi-trailer), and the pallet is taken from the middle of the rack (40 m) and from the middle vertical shelf (2 m). By repeating the presented cycle the average work is obtained Kwasniowski, Zajac (2017).

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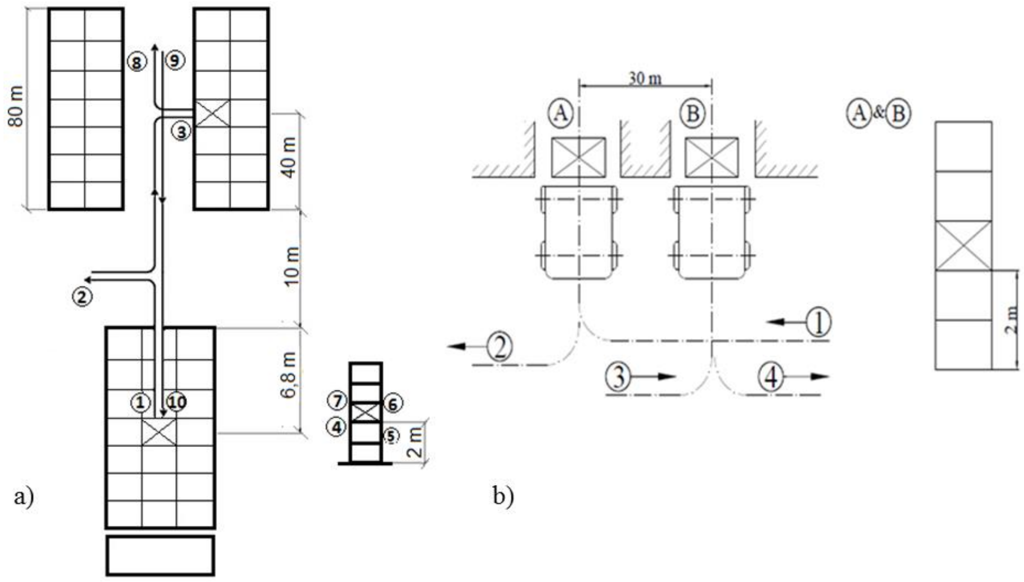

Fig. 1: (a) 'Semi-trailer loading cycle', (b) VDI 2198 cycle.

Tab. 1: Actions during the ‘semi-trailer loading cycle'.

From point to point	Action	Distance [m]
①-②	withdrawal of unladen forklift, decelerating to 0.9 km/h of unladen forklift	8.3
①-②	driving at a curve with a radius of 2 m (90° turn) at a constant speed of 0.9 km/h of unladen forklift	3.14
①-②	braking from 0.9 to 0 km/h of unladen forklift	0.01
②-③	accelerating to 0.9 km/h of unladen forklift	0.02
②-③	driving at a curve with a radius of 2 m (90° turn) at a constant speed of 0.9 km/h of unladen forklift	3.14
②-③	driving straight ahead from 0.9 km/h of unladen forklift, braking to 0.9 km/h of unladen forklift	41.36
②-③	driving at a curve with a radius of 2 m (90° turn) at a constant speed of 0.9 km/h of unladen forklift	3.14
②-③	braking from 0.9 to 0 km/h of unladen forklift	0.01
④	lifting the forks (2 m) of unladen forklift	2 [1]
⑤	driving of unladen forklift to rack, braking to 0 km/h of unladen forklift	1.5
⑥	lifting forks (0.2 m) of laden forklift	0.2 [2]
⑦	reversing of laden forklift	1.5
⑧-⑨	braking of laden forklift	
⑧-⑨	lowering forks of laden forklift	2.2 [3]
⑧-⑨	accelerating from 0 to 0.9 km/h of laden forklift	0.005
⑧-⑨	driving at a curve with a radius of 2 m (90° turn) at a constant speed of 0.9 km/h of laden forklift	3.14
⑧-⑨	braking to 0 km/h of laden forklift	0.04
⑨-⑩	driving straight ahead of laden forklift, decelerating to 0.9 km/h of laden forklift	52.04
⑨-⑩	driving on a semi-trailer at a constant speed of 0.9 km/h of laden forklift	6.76
⑨-⑩	braking to 0 km/h of laden forklift	0,04
	Σ:	124.15

The speeds were assumed on the basis of technical specification of the forklift manufacturer: driving of unladen/laden forklift 4.44 m/s; lifting of unladen forks 0.55 m/s; lifting of laden forks 0.4 m/s; lowering of unladen/laden forks 0.55 m/s; driving of forklift on semi-trailer 0.25 m/s; driving of forklift on curve 0.25 m/s; 2 m height describing the value of lifting or lowering in metres.

A list of all calculations for the activities according to VDI2198, i.e. accelerating, braking and constant speed driving is presented in the table (Table 2). The calculation of the cycle takes into account the time it takes to lower and lift the forks, but ignores the response time of the forklift driver to specific actions made on the vehicle.

Tab. 2: Individual actions carried out by Jungheinrich EFG-220 forklift in a cycle as per VDI 2198 on given sections.

From point to point	Action	Distance [m]
①	driving straight ahead of unladen forklift, decelerating to 0.9 km/h of unladen forklift	30
①	driving at a curve with a radius of 2 m (90° turn) at a constant speed of 0.9 km/h of unladen forklift	3,14
①	braking to 0 km/h of unladen forklift	0,01
①	lifting the forks (2 m) of unladen forklift	2
①	driving of unladen forklift to rack, braking to 0 km/h of unladen forklift	1,5
①	lifting forks (0.2 m) of laden forklift	0,2
②	reversing of laden forklift, braking of laden forklift	1,5
②	lowering (2.2 m) of laden forklift	2,2
②	accelerating from 0 to 0.9 km/h of laden forklift	0,01
②	driving at a curve with a radius of 2 m (90° turn) at a constant speed of 0.9 km/h of laden forklift	3,14
②	braking to 0 km/h of laden forklift	0,04
③	driving straight ahead of laden forklift, decelerating to 0.9 km/h of laden forklift	30
③	driving at a curve with a radius of 2 m (90° turn) of laden forklift	3,14
③	braking to 0 km/h of laden forklift	0,04
③	lifting forks (2 m) of laden forklift	2
③	driving of laden forklift to rack, braking to 0 km/h of laden forklift	1,5
④	reversing of unladen forklift, braking to 0 km/h of unladen forklift	1,5
④	lowering (0.2 m) of unladen forklift	0,2
④	accelerating from 0 to 0.9 km/h of unladen forklift	0,02
④	driving at a curve with a radius of 2 m (90° turn) of unladen forklift	3,14
④	braking to 0 km/h of unladen forklift	0,01
	Σ:	78,57

3. Calculation of motion kinematics and energy consumption of trolley

The calculation of the minimal time travel of the Jungheinrich EFG-220 forklift in the "semi-trailer loading cycle" is shown in Figure 2a and 2b, where the first diagram shows the minimal time travel of the forklift. The diagram shows the speed and driving time trend of the forklift at the various stages of travel. The second diagram is the trend of driving force at the individual stages of travel.

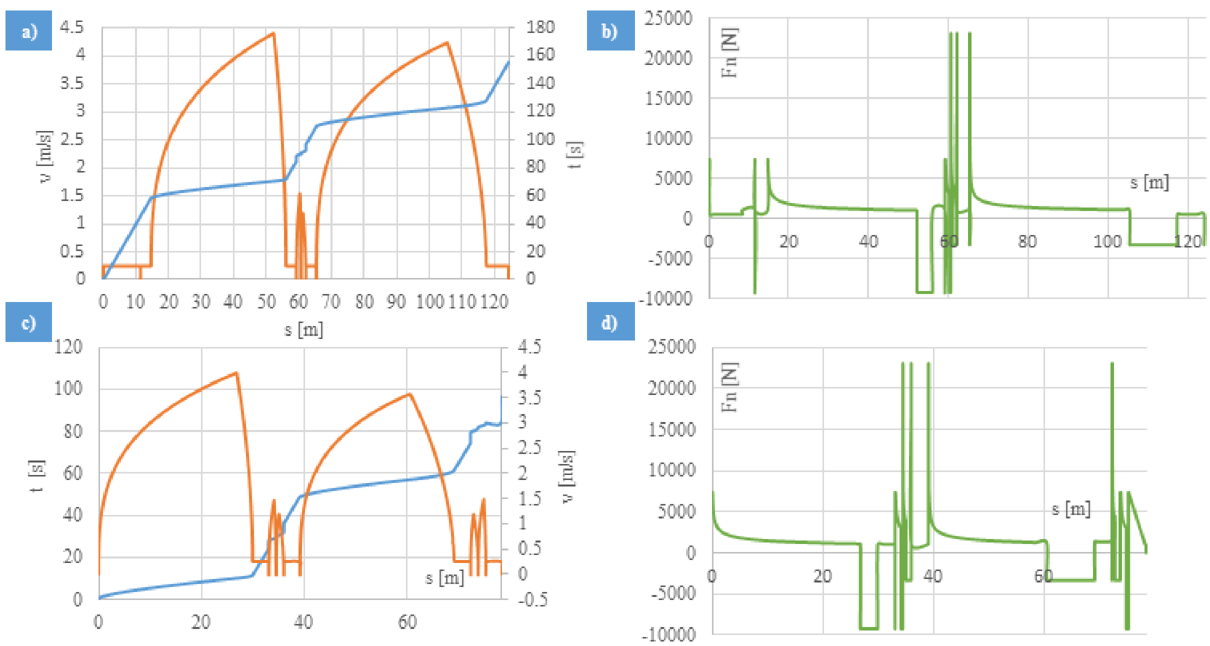

Fig. 1: a) diagram of the minimal time travel in the semi-trailer loading cycle; b) diagram of the driving force trend in the semi-trailer loading cycle; c) minimal-time travel diagram in VDI 2198 cycle; d) diagram of the driving force trend in the VDI 2198 loading cycle

The calculations of the minimal time travel of the Jungheinrich EFG-220 forklift in a VDI 2198 work cycle are shown in Figure 2c and 2d. The first diagram shows a trend of the minimal time travel of a forklift. The diagram shows the speed and driving time trend of the forklift at the various stages of travel. The second diagram is the trend of driving force at the individual stages of travel Zajac, Kwasniowski (2017).

4. Conclusions

Calculations show that the energy of lifting both unladen, as well as laden forks equals 26.63 % of the energy used for travel processes. However, the energy from lifting the forks in relation to total energy that is consumed in the process of loading the semi-trailer, i.e. from lifting and driving processes, is approximately 21.03 %. The travel process amounts to the largest portion of 78.97 %.

The studies and calculations made have shown that the energy during braking was 83.45 kJ, which gives 42.9 % of the energy used for the drive. However, by comparing the braking energy to the total energy consumed in the loading cycle of the semi-trailer, 33.88 % was achieved.

The calculation of the energy consumption of the Jungheinrich EFG-220 forklift was carried out by calculating the work performed by the truck in a single VDI 2198 cycle. The work was calculated on the basis of the drive force vs. distance diagram (www.jungheinrich.se/betriebsanleitungen/52020317.pdf).

Calculations show that the energy of lifting both unladen, as well as laden forks equals 31.84 % of the energy used for travel processes. However, the energy from lifting the forks in relation to total energy that is consumed in the VDI2198 process, i.e. from lifting and driving processes, is approximately 24.1 %. The travel process amounts to the largest portion of 75.9 %.

The studies and calculations made have shown that the energy during braking was 71.2 kJ, which gives 43.8 % of the energy used for the drive. However, comparing the braking energy to the total energy consumed in the VDI2198 cycle, 33.2 % was obtained. The obtained results can help the reader to decide which method to count the energy consumption of the pram.

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