Kinematics of the Truck Mounted Hydraulic Cranes

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Truck mounted hydraulic cranes are widely used in the timber and in the waste disposal industry. They have a specific design, where dead weight, size in the folded position and the position of the gripper in the folded position are of particularly importance. Functionality of the crane is therefore expressed with load handling capabilities and also with the functionality during road transportation of the payload, when the crane is in the folded position on the truck. For handling of heavier loads, nowadays mainly two types of cranes are used - the K cranes and the Z cranes. The main advantage of the K cranes is higher load capacity in comparison with the Z cranes when cranes of approximately the same weight are compared. On the other hand the main advantage of the Z cranes is their capability of folding in position, transvers to truck length. In the paper the kinematics of the mechanisms of the characteristic size K and Z cranes are analysed and mutually compared. The main accent is on the discussion about their load capacity.

Keywords: Hydraulic Cranes, Crane Mechanisms, Kinematics, Cranes Folded Position, Weight, Load Capacity

1. INTRODUCTION

Generally speaking, cranes are large and heavy structures, movable in different ways. Optimization of their structure is in general oriented toward savings during the production process. Smaller final weight of an overall structure also brings up smaller energy consumption during crane operations. When truck mounted hydraulic cranes are in question the overall weight of the crane is even more important, because it presents part of the allowed truck load capacity and therefor smaller mass means more of the payload and s. All the mentioned imply smaller costs and better sustainability of the transport machine.

Optimization of the overall crane weight requires optimization of the structure and of the mechanisms. For the fatigue optimization of the structure, for example, the investigation of the crane dynamics is important. The scientific articles are dealing with the control strategies for load-swing suppression (linear motion [1-10], slewing [1, 11, 12]) and with the payload swinging and its influence on the loading of a crane’s structure ([13-18]). On the other hand the optimization of the mechanisms primarily involves static and kinematic analysis.

A study of the hydraulic truck mounted cranes and possible improvements to their performance is a study with a real-life application, because these types of cranes are widely used in timber and in the waste disposal industry which are both growing industries. The operation of these cranes involves three main motions: the slewing motion of the crane arm around the vertical axis, the radial movement of the load suspension point (folding or stretching of the boom and the jib) and the hoisting of the load (luffing of the arm). In this paper a kinematic analyses of the crane arm mechanism of the hydraulic truck mounted cranes for the timber and the waste disposal industry are introduced. The performances of the mechanisms of two most common types of such cranes are compared. The cranes of two European producers are chosen for the analyses.

2. TRUCK MOUNTED HYDRAULIC CRANES

There are two main families of truck mounted hydraulic cranes. The first family presents the large boom cranes with luffing arm consisting of one regularly telescopic boom mounted on the slewing platform (figure 1). The cranes of the other family are often called lorry cranes. They are smaller and they consist of the slewing pillar on which the arm containing the boom and the jib is attached (figure 2). The arm can perform luffing motion and can also fold.

Figure 1: Truck mounted hydraulic boom crane
(Source: http://en.wikipedia.org/wiki/File:Truck_crane.jpg, 29.05.2014)

Figure 2: Hydraulic Lorry crane
(Source: http://www.tslvanguard.co.uk/lorry-cranes, 29.05.2014)

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In the paper the second family of truck mounted hydraulic cranes is taken under the consideration, which are widely used in the timber and in the waste disposal industry. They have a specific design, where dead weight, size in the folded position and the position of the gripper in the folded position are of particularly importance. Functionality of the crane is therefore expressed with load handling capability and also with the functionality during road transportation of the payload, when the crane is in the folded position on the truck.

For handling of heavier loads, nowadays mainly two types of cranes are used - the K cranes and the Z cranes which differs mainly due to the design of the arm mechanism which enables different folding modes and on the other hand influence the crane's payload capacity. The main advantage of the K cranes is higher load capacity in comparison with the Z cranes when cranes of approximately the same weight and reach are compared. On the other hand the main advantage of the Z cranes is their capability of folding in position, transvers to truck length, which in the contrast to the K cranes ensures that during the transport of the loaded or empty crane the crane arm is removed from the truck hopper (figure 3 and 4).

Figure 3: Arm of the K-crane rests on the payload

(Source: http://holz.fordaq.com/fordaq/news/ElmiaWood_Evolution_revolution_1457.html?Printable=yes, 29.05.2014)

Figure 4: Z-crane's arm is folded behind the cab

(Source: http://www.hiab.co.uk/Products/Forestry-and-recycling-cranes/Product-page/?parentProductGroupId=51949&productGroupId=51964&productId=51975, 29.05.2014)

In the paper the kinematics of the mechanisms of the K- and Z-cranes of two known European manufacturers are analysed and mutually compared. The main accent is on the discussion about their load capacity regarding the maximum available hydraulic cylinder loading.

The hydraulic lorry cranes for manipulating timber and scrap and for recycling assignments are usually denoted with the typified designation, consisting of letters and numbers. The first part of the designation is a letter which denotes the cranes manufacturer. The second part is a number, which loosely indicates the nominal load capacity in kN m. The third part is a letter, which presents the type of the crane mechanism. K- type cranes are usually designated with letter K or L and Z type cranes are denoted with letter Z. For the analysis the cranes of the characteristic nominal load capacity of 120 are chosen.

3. NUMERICAL ANALYSES

For the execution of the analyses of the mechanisms the numerical modelling in the Adams software is chosen. Four models presented in table 1 are analysed.

Table 1: Designation of the crane models

	K-type crane	Z-type crane
Manufacturer "a"	Model Ka (also denoted as Model 1)	Model Za (also denoted as Model 3)
Manufacturer "b"	Model Kb (also denoted as Model 2)	Model Zb (also denoted as Model 4)

The numerical models are introduced in figure 5. They consist of the following rigid beams: rotating pillar, luffing boom and telescopic jib. Individual beams are mutually connected with hinges. The relative position of the beams is controlled by hydraulic cylinders. In the model the rotation of the pillar around the vertical axis is not modelled as isn't the stretching of the telescopic jib. The mass of the crane elements is ignored since the research is focused on the influence of the payload.

The cranes mechanisms are loaded with unite force and the forces in the hydraulic cylinders are observed during the folding of the reach of the arm - reducing the payload lever length. In that manner the multipliers of the forces, produced in the hydraulic cylinders by the payload weight along its radial movement are calculated, which present an important indicator of the quality of the mechanism design.

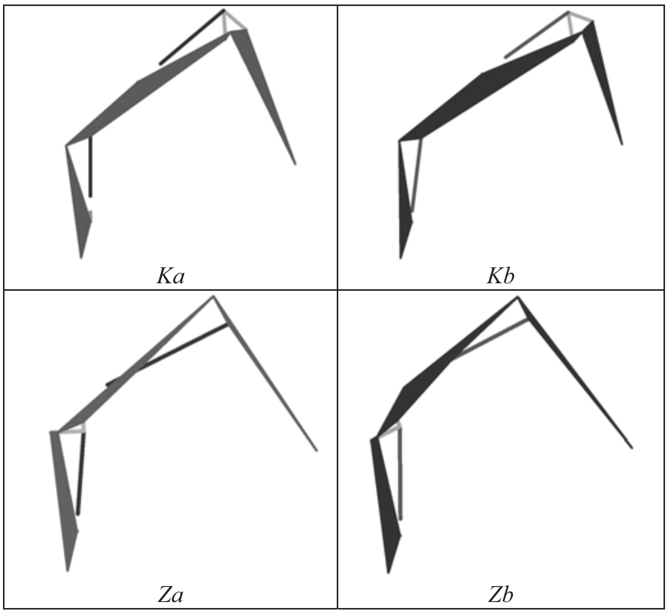

Figure 5: Numerical models of mechanisems of the cranes Ka, Kb, Za and Zb

4. RESULTS

The following results are shown for all four discussed cranes mechanisms for the horizontal radial movement of the load suspension point, located in the pillar height.

Cylinder 1 is the cylinder between the pillar and the boom, whereas cylinder 2 is between the boom and the jib.

4.1. Model Ka (№ 1)

Numerical model Ka represents the 120K crane of the manufacturer a. The force multiplier (in regard to the payload force) in the hydraulic cylinders 1 and 2 in the subordination to the arm reach are shown in diagrams in figures 6 and 7.

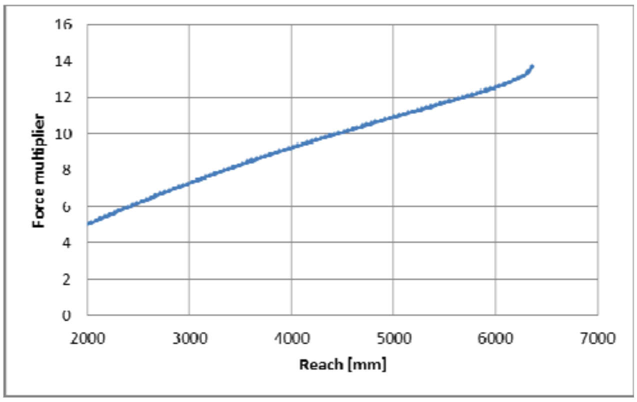

Figure 6: Reaction force in cylinder 1 of the Ka model

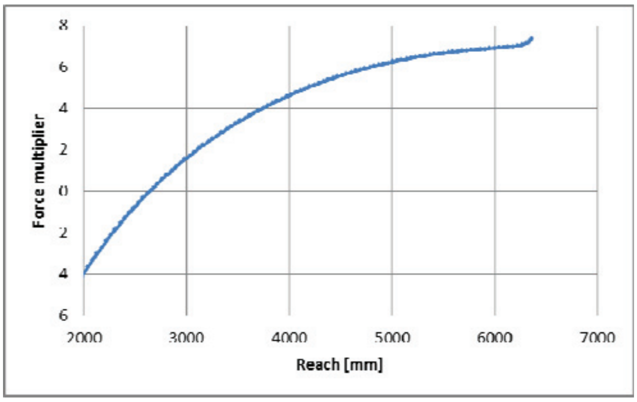

Figure 7: Reaction force in cylinder 2 of the Ka model

From the figure 6 can be seen that the force in the cylinder 1 has almost linear dependency regarding the reach elongation. The force multiplier spans from 5 at reach of 2 meters to almost 13 at reach of 6 meters. Positive multiplier values represent compression forces in the cylinders.

On the other hand from the figure 7 the highly nonlinear dependency of the force multiplier for the cylinder 2 can be observed. The force multiplier spans from -4 at reach of 2 meters to 6 at reach of 6 meters. Negative multiplier values represent tension forces in the cylinders. Tension in the cylinder 2 in the first part of the radial movement of the load suspension point is expected, because of the position of the jib as is shown in figure 8.

Figure 8: Position of the Ka model mechanism where tension forces in cylinder 2 are expected

4.2. Model Kb (№ 2)

Numerical model Kb represents the 120K crane of the manufacturer b. The force multiplier (in regard to the payload force) in the hydraulic cylinders 1 and 2 in the subordination to the arm reach are shown in diagrams in figures 9 and 10.

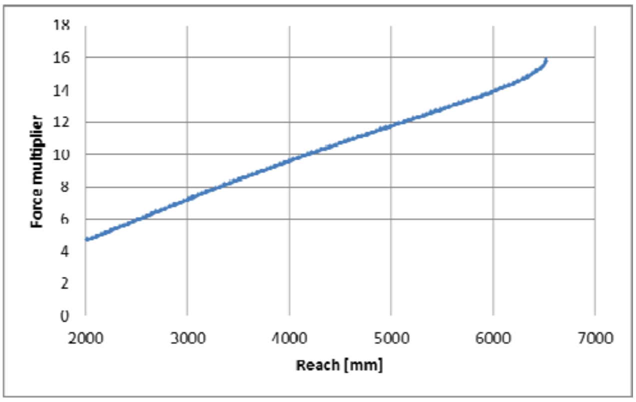

Figure 9: Reaction force in cylinder 1 of the Kb model

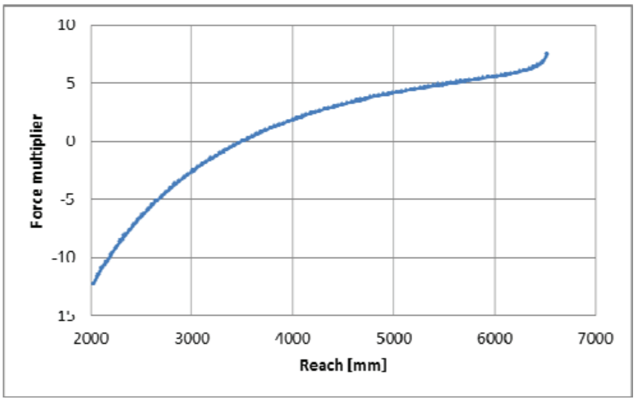

Figure 10: Reaction force in cylinder 2 of the Kb model

From the figure 9 can be seen that the force in the cylinder 1 has almost linear dependency regarding the reach elongation. The force multiplier spans from 4.8 at reach of 2 meters to 14 at reach of 6 meters. The same payload on the same reach presents greater loading of the hydraulic cylinder 1 of the crane Kb than of Ka.

From the figure 10 the highly nonlinear dependency of the force multiplier for the cylinder 2 can be observed. The force multiplier spans from -12.2 at reach of 2 meters to 7.5 at reach of 6 meters. Also in the case of cylinder 2 the same payload on the same reach presents greater loading of the hydraulic cylinder of the crane Kb than of Ka.

The characteristics for the force multiplier for the cylinder 1 and 2 are qualitatively very similar when crane of the manufacturer a and b are compared.

4.3. Model Za (№ 3)

Numerical model Za represents the 120Z crane of the manufacturer a. The force multiplier (in regard to the payload force) in the hydraulic cylinders 1 and 2 in the subordination to the arm reach are shown in diagrams in figures 11 and 12.

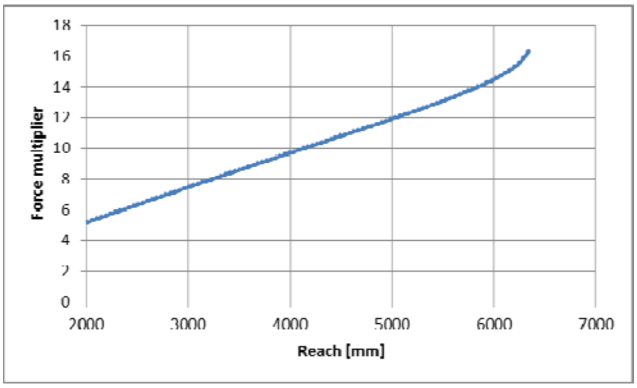

Figure 11: Reaction force in cylinder 1 of the Za model

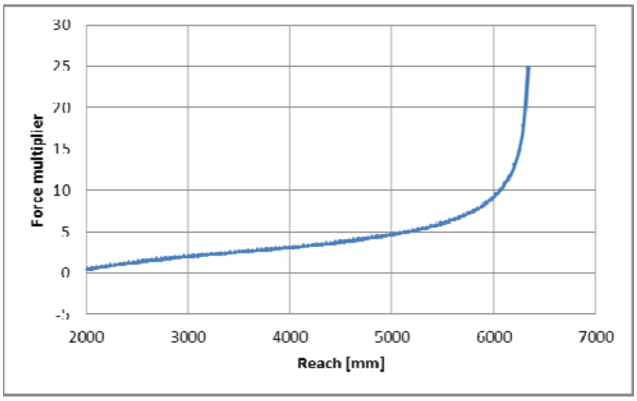

Figure 12: Reaction force in cylinder 2 of the Za model

From the figure 11 can be seen that the force in the cylinder 1 has almost linear dependency regarding the reach elongation. The force multiplier spans from 5.3 at reach of 2 meters to 14.7 at reach of 6 meters.

From the figure 12 the highly nonlinear dependency of the force multiplier for the cylinder 2 can be observed. The force multiplier spans from 0.6 at reach of 2 meters to 9.5 at reach of 6 meters. Beyond that reach the force multiplier increasing very fast and therefore this part of the mechanism working zone is not optimal.

4.4. Model Zb (№ 4)

Numerical model Zb represents the 120Z crane of the manufacturer b. The force multiplier (in regard to the payload force) in the hydraulic cylinders 1 and 2 in the subordination to the arm reach are shown in diagrams in figures 13 and 14.

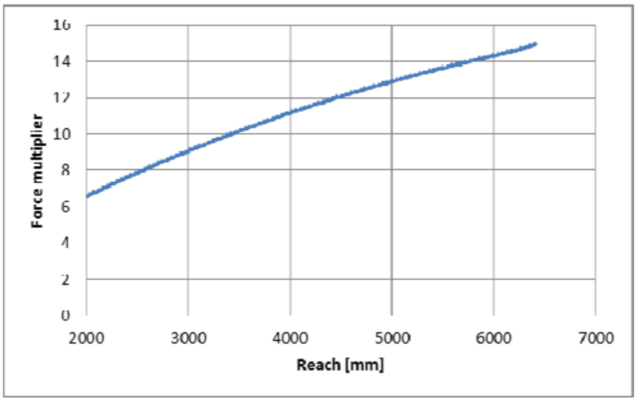

Figure 13: Reaction force in cylinder 1 of the Zb model

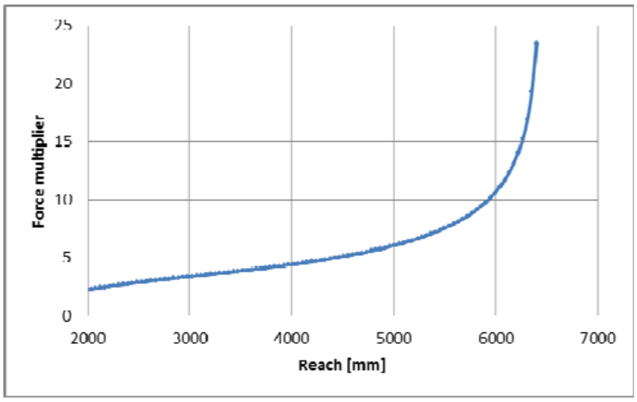

Figure 14: Reaction force in cylinder 2 of the Zb model

From the figure 13 can be seen that the force in the cylinder 1 has almost linear dependency regarding the reach elongation. The force multiplier spans from 6.8 at reach of 2 meters to 14.4 at reach of 6 meters. The same payload on the same reach presents for the major part of the span greater loading of the hydraulic cylinder 1 of the crane Kb than of Ka.

From the figure 14 the highly nonlinear dependency of the force multiplier for the cylinder 2 can be observed. The force multiplier spans from 2.4 at reach of 2 meters to 11.1 at reach of 6 meters. Also in the case of cylinder 2 the same payload on the same reach presents greater loading of the hydraulic cylinder of the crane Kb than of Ka.

5. COMPARISON OF THE RESULTS

For more efficient relative comparison of individual observed cranes mechanisms the curves of the force multipliers for the cylinder 1 are shown on the graph in figure 15 and for the cylinder 2 in the figure 16.

5.1. Force multipliers for the cylinder 1

In the figure 15 the force multipliers of the cylinder 1 of the crane models from № 1 to № 4 are shown. Solid lines present K-type of crane mechanisms whereas dashed lines present Z-type of crane mechanisms. Bold lines present cranes of the manufacturer a and thin lines present cranes of the manufacturer b.

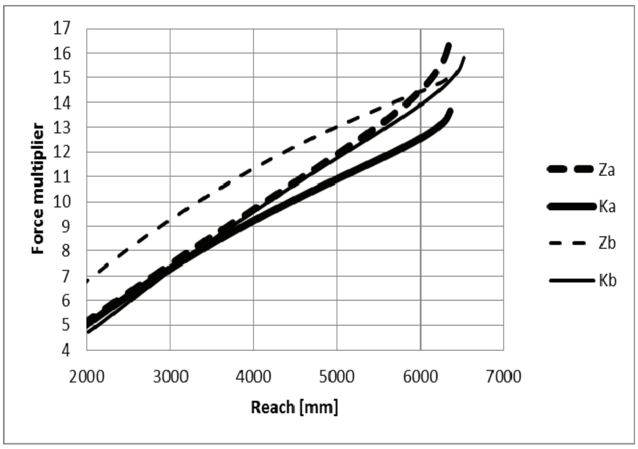

Figure 15: Comparison of the reaction forces in cylinder 1 for different crane types

From the figure 15 the following can be clearly concluded. The Z-crane of the manufacturer b has the less favourable loading of the cylinder 1, which is the cause of higher loading of the pillar and boom elements too. The Z-crane of the manufacturer a is the second less favourable regarding the criterion of the cylinder 1 loading but it is, on the other hand, very close to the characteristic of the K-crane of the manufacturer b. The K-crane mechanism of the manufacturer a is the most appropriate regarding the observed criterion, because the average force and the maximum force are having the lowest values.

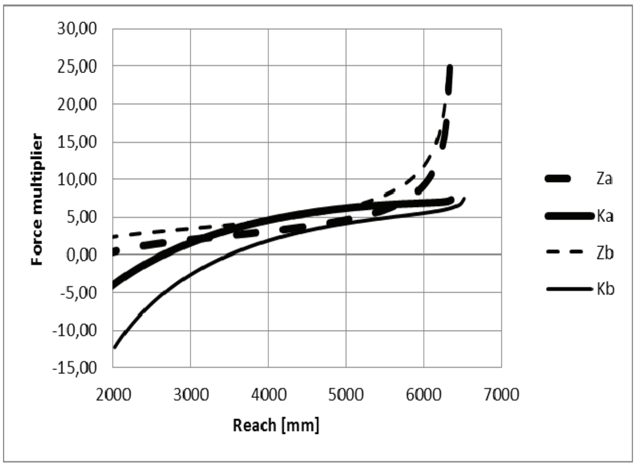

Figure 16: Comparison of the reaction forces in cylinder 2 for different crane types

5.2. Force multipliers for the cylinder 2

In the figure 16 the force multipliers of the cylinder 2 of the crane models from № 1 to № 4 are shown. Solid lines present K-type of crane mechanisms whereas dashed lines present Z-type of crane mechanisms. Bold lines present cranes of the manufacturer a and thin lines present cranes of the manufacturer b.

From the figure 16 the following can be concluded. The Z-crane of the manufacturer b has the less favourable loading of the cylinder 2 too, which is the cause of higher loading of the boom and jib elements. The Z-crane of the manufacturer a is the second less favourable regarding the criterion of the cylinder 2 loading in the beginning and at the end of the span but it is, on the other hand, in the middle part of the span, more favourable than the K-crane of the manufacturer a. The K-crane mechanism of the manufacturer b has the lowest value during the whole span, but the attention must be drown toward its high negative value at small reach. Because of that the K-crane mechanism of the manufacturer a is the most appropriate regarding the observed criterion again, because the force multiplier has the lowest average value as well as much more favourable value during the smaller span.

6. CONCLUSION

Truck mounted hydraulic cranes are widely used in the timber and in the waste disposal industry. For handling of heavier loads, nowadays mainly two types of cranes are used - the K cranes and the Z cranes. In the paper the kinematics of the mechanisms of the characteristic size of 120K and 120Z cranes are analysed and mutually compared. The main accent is on the discussion about their relative load capacity defined trough the loading of hydraulic cylinders. It is assumed that the mechanism is more optimal if the needed force multiplier is smaller.

Both crane mechanism types were analysed and cranes of two manufacturers were taken into account and therefor four different cases were studied.

It was discovered that the Z-crane of the manufacturer b has the less favourable loading of the cylinder 1 during the studied motion, the Z-crane of the manufacturer a is the second less favourable and that the K-crane mechanism of the manufacturer a is the most appropriate, because the average and the maximum force multipliers are the lowest in that case.

It was further find out, that the Z-crane of the manufacturer b has the less favourable loading of the cylinder 2 too. The Z-crane of the manufacturer a is again the second less favourable. On the other hand it should be noted that in the middle part of the span, these characteristics are more favourable than the K-cranes characteristic of the manufacturer a. The K-crane mechanism of the manufacturer b has the lowest value of the cylindr 2 loading during the whole span, but attention must be drown toward its high negative values at small reach. Because of that the K-crane mechanism of the manufacturer a is more appropriate regarding the second criterion too, because the force multiplier has the lowest average value as well as much more favourable value during the smaller span.

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