Energy Study of Bucket Positioning Systems on Wheel Loaders

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***Abstract*- In order to make the next generation of wheel loaders more efficient an energy study is conducted on four different loader linkages to find what linkage is most energy efficient. This is a popular summary of the master thesis "*Energy Study of Bucket Positioning Systems on Wheel Loaders*".**

I. INTRODUCTION

With today's rising fuel cost and tougher regulations of emission there is a need of more fuel efficient solutions for construction equipment, such as wheel loaders see Figure 1. All parts of a system needs to be evaluated and this summary is a comparison between different linkages on wheel loaders, when it comes to their use of energy. A linkage is the part in front of the wheel loader that can move up and down, see Figure 2. Four different linkages is in the thesis compared when it comes to their weight, parallel-adjustment, energy consumption and total cost of ownership (TCO). Based on the results, one linkage is recommended. A loader linkage is the part in front of a wheel loader that can be lifted up and down. The linkages that were compared are called TP, Z, TPC and TBM-linkage and all have different design layouts.

Figure 1 A Volvo wheel loader. [1]

When designing a linkage there are many factors that need to be taken into account. A linkage needs to be able to lift a load through a certain movement including picking the load up and dumping the load in another position. It needs to provide and withstand the forces and torques that act on the linkage while operating. Its geometry needs to physically fit; usually the boom-link of a linkage is in the way for where the cylinder ideally should be placed. It often results in a design with a wide linkage that partly will block the view for the driver. The energy consumption for a linkage will partly depend on the hydraulic system that supplies the cylinder with fluid flow and pressure. It is hard to estimate how the hydraulic system and the mechanic system of a linkage behaves together, and this is why simulations were used to investigate the energy consumption for all four linkages. For a comparable result, all the linkages use the same model of the hydraulic system, i.e. the same pump size and control system.

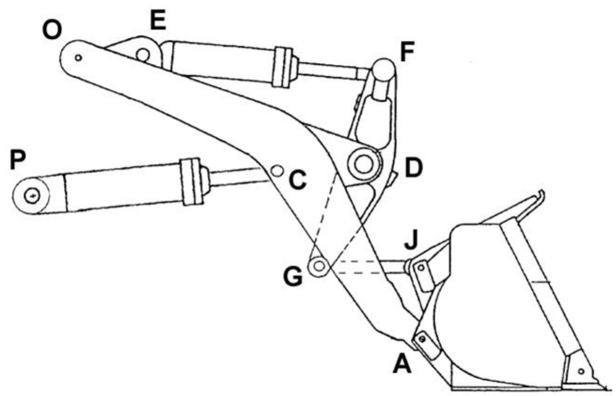

Figure 2 Z-linkage, the most used linkage. [2]

II. METHOD

The hydraulic system and the mechanics of the linkage were modeled with *AMESim* and the regulators to control the linkage were modeled with *SimuLink.* The code for the simulations has been written in *MatLab* and will co-simulate with models from both software in order to find the energy consumption of the linkages.

III. WORK CYCLE

Since a wheel loader usually is used for both lifting pallets, with forks, and lifting gravel with a bucket, two types of work cycles needed to be developed. A fork cycle could look like this; lifting the pallet up from ground, lifting it to a certain height while maintaining the pallet parallel all through the lift, put down the pallet on a shelf and then lower the linkage without a load. A bucket cycle could look like this; when the

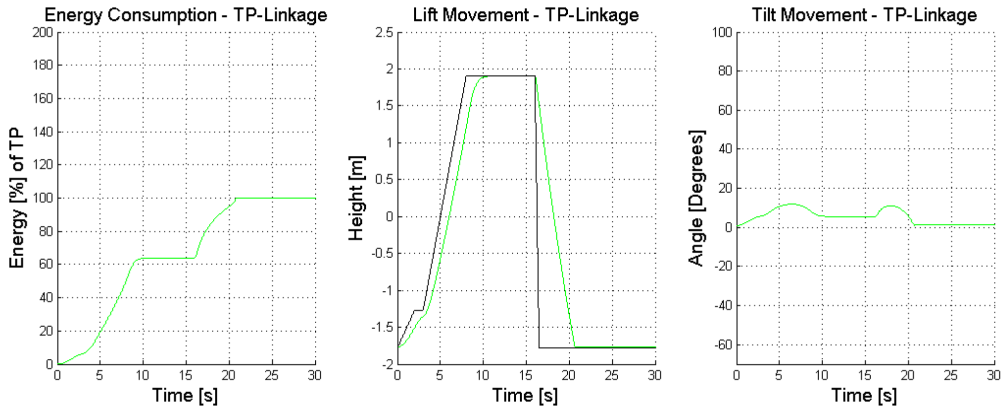

Figure 3 Simulation results of lifting and lowering the TP-linkage. Black curve is reference height and green curves are the results from simulations.

bucket is in a pile of gravel, lift the linkage up a bit and at the same time tilting the bucket in, then lifting the bucket to top position while tilting the bucket out, in order to keep the load parallel, then emptying the bucket, and then lowering the empty bucket.

The cycles were developed using measured data from a wheel loader. Since it is hard to simulate the part of the load being put down it was not done. Instead the simulations were run both with and without a load throughout the whole work cycle. By combining the simulations with and without a load, the energy consumption for a work cycle could be found. By adding the energy consumption for lifting the linkage with a load together with lowering the linkage without a load, a more realistic energy consumption is found. This energy consumption is used in the cost calculations for the linkages.

There are two approaches to how to control the linkage. The first have a reference lift height that is dependent on time together with a tilt angle also dependent on time. The second approach is to have a reference lift height dependent on time together with a reference angle that is dependent on the actual lift height.

IV. RESULTS

The first approach to control the linkage was not sufficient in order to move the linkage as desired. Sometimes the linkage locked itself in a position or it would move in an unintended motion. With the second approach these problems did not occur and therefor only the results from the second approach were presented in the thesis. Results from one simulation when only lifting the TP-linkage up and down without a load or using the tilt cylinder, can be viewed in Figure 3. In the middle diagram the black curve shows the reference lift height which the linkage should follow. The green curve shows how the models lift height changed during the simulation. The diagram to the right shows how the angle of the tool changed when moving the linkage up and down, the linkages parallel-adjustment. The diagram to the left shows the energy consumption used to move the linkage. This was done for all linkages, both with and without a load, and for the cases of a fork work cycle as well as for a bucket work cycle.

There is a large difference of mass for the different linkages; it can be viewed in Table 1 with normed numbers. The parallel-adjustment of the linkages did also vary between the linkages. TP had the best parallel-adjustment followed by Z and TBM, while TPC does not have any parallel-adjustment and needs to be controlled all the time in order to use the linkage.

Table 1 Masses of linkages.

Linkage	Mass [%] of the TP linkage
TP-linkage	100 %
Z-linkage	96 %
TBM-linkage	87.6 %
TPC-linkage	85 %

The energy consumption results from the simulations were together with cost calculations of the linkages used to make a TCO analysis. The results can be found in Figure 4 where each color represents a different linkage. Due to request, the linkages will be kept anonymous. The result is a function of total amount of work hours, T_{Life}, for the linkage and the share of time that is spent on driving with forks contra a bucket, S_f. One of the linkages has a lower total cost for most of the spectrum shown in Figure 4, the blue linkage. The red ellipse indicates what area is of interest in the spectrum. The area to the left of the ellipse represents less than 6,000 work hours for the machine, that is low and not acceptable, and therefore not of interest. The area below the ellipse represents that the linkage is being run with forks for more than half of the time, which probably is not common for a wheel loader and therefore not interesting either.

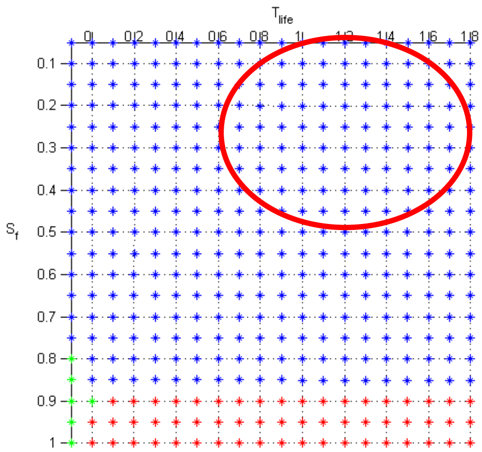

Figure 4 Total cost results as function of S_f and T_{Life}. Each color represents a different linkage.

V. CONCLUSIONS

There is a notable difference of the energy consumption of the linkages that were investigated. The mass of the linkages differed up to 15 % and the parallel-adjustment is best for the TP-linkage while the TPC-linkage does not have any parallel-adjustment at all. According to the TCO there is one linkage that is best for use in production, the blue linkage, the other linkages that performed well, did so in a configuration that is not relevant. Therefore the blue linkage is recommended to use.

Modeling and simulations of hydraulics is often a cheaper and faster way of analyze how a system will behave, and will probably be used more in the future during development of hydraulic systems.

VI. REFERENCES

[1] Volvo Group, "Volvo Group," Volvo CE, [Online]. Available: http://www.volvoce.com/constructionequipment/corporate/en-gb/AboutUs/about_volvo_group/Pages/about_volvo_group.aspx. [Accessed 21 August 2013].

[2] Volvo CE, *Internal document data*, Eskilstuna, Sweden, 2013.