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Comparison of Fuel Consumption between Wheel Loader with Hydrodynamic and Hydrostatic Transmission

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***Abstract*— The current study presents results of four days real tests of fuel consumption of wheel loaders with hydrodynamic and hydrostatic transmission. In the theoretical part is made a clarification of the meaning of "Fuel efficiency" and "Fuel consumption". Main criteria for evaluation of the mentioned parameters are pointed. A description of different transmission types with their advantages and disadvantages was done. The real test place and working environment was performed. The results of the tests and following conclusions were shown.**

***Keywords* - fuel consumption, transmissions, wheel loaders, hydrostatic, hydrodynamic.**

I. INTRODUCTION

Modern front-end loaders are widely used in loading and unloading activities and transport processes in large industrial and mining enterprises. With the increasing demands to reduce the carbon footprint of such sites, the need for lower fuel consumption for this type of equipment is constantly increasing. In progress and already in use, although not so widespread, are developments of all-electric machines. However, there are still unsolved issues before them, such as the capacity of the batteries to operate for more than eight hours, as required in the above-mentioned enterprises, the recycling policy of the batteries, the same performance in different atmospheric conditions, as well as the longevity of the electric motors and components of the new systems, which in turn is related to the training and experience of the service engineers who will support the machines in question.

Currently, the hydrodynamic automated transmission is widely used in medium and heavy-duty front-end loaders (machines with a net weight of more than 12 tons) using an internal combustion engine [1, 2]. In smaller machines in the weight class from 4 to 10 t, as well as in telescopic loaders, fully hydrostatic transmissions are used [3]. This rule of distribution of transmissions according to the weight class is not accepted by only one manufacturer - Liebherr, which incorporates hydrostatic transmissions in its medium and heavy class machines. In the recent past, some manufacturers have put into production the so-called hybrid transmissions, which practically combine both mentioned varieties, but they become very expensive and the savings they make are offset by the higher price.

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It is an indisputable fact that the advantages of one type of transmission are the disadvantages of the other, and here comes the question: When is it economically advantageous to use a front loader of medium and heavy class with a hydrodynamic transmission and when a machine with a hydrostatic one? The test presented in this report provides an answer from the point of view of fuel economy.

II. A BRIEF OVERVIEW OF THE TRANSMISSIONS TESTED

The principle of operation of the hydrodynamic transmission can be illustrated with Fig. 1 [4].

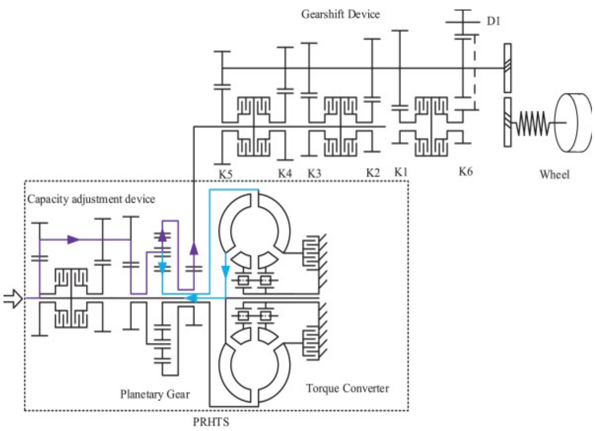

Fig. 1. Principle of operation of hydrodynamic transmission [4].

An internal combustion engine drives a hydro transformer, which in turn transforms the torque and transmits it to a planetary automated gearbox. After the operator of the machine has set the mode determined by him, a control unit drives the corresponding packs of friction discs, which in turn engage the necessary gears, and the power flow through the output shaft of the gearbox is transmitted to a transfer case, which in turn drives the cardan shafts and respectively the wheels of the machine [2,4,5,11]. This report is not intended to analyze the principle of operation of the individual elements of the transmission and power train, but only to acquaint the reader with the general principle of operation of the drives considered here.[2]

Main advantages of hydrodynamic transmissions are:

- Trouble-free operation for long transport distances (over 500 m in one direction);
- Good behavior of the machine and precise shifting of gears when driving on slopes;
- Better reliability indicators when the machines work over 20,000 hours.

Disadvantages of hydrodynamic transmissions are:

- The transmission itself is made up of more parts and elements;
- It is not possible to ensure a completely stepless change of the speed modes, it is a face change of gears;
- Worse indicators of fuel economy when working on short distances (up to 20 m in a direction), typical for loading and unloading activities.

The hydrostatic transmission provides a completely stepless transmission of the torque, and for the whole internal combustion engine it drives axial-piston pumps that suck working fluid from a reservoir and transmit it under a given flow rate and pressure to hydraulic motors connected to the wheels of the machine [3, 4]. In practice, hydro motors, as a principle of working, do not differ from pumps, but they work on the opposite way, converting the applied pressure and flow rate into torque. The system is controlled by the operator through a hydraulic distributor [3, 5, 6, 7, 12].

Principle of operation can be seen in Fig. 2 [3].

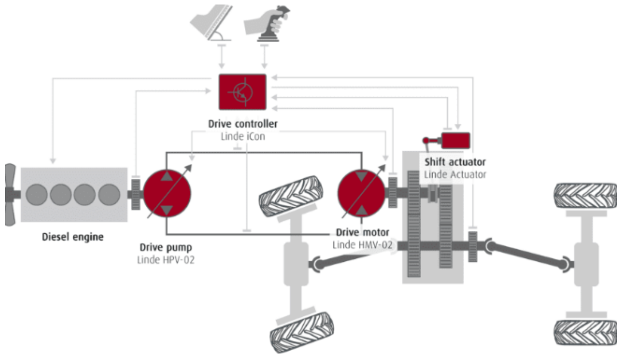

Fig. 2. Principle of operation of hydrostatic transmission [3].

Advantages of hydrostatic transmissions are:

- Completely stepless torque transmission;
- Less number of elements and a relatively elementary principle of action;
- Very good fuel economy in short cycle operation.

Disadvantages of hydrostatic transmissions are:

- Unsatisfactory performance with periodically repeated long transport distances.
- Expensive to maintain and repair. Despite the small number of elements, in the event of a hydraulic motor or pump failure, in most cases the entire unit is replaced.
- Poor reliability when operating the machine for more than 20,000 hours.

The latter drawback is explained by the aging of rubber seals and elements in hydrostatic transmissions, where any loss of working fluid has a significant effect on the transmitted power flow.

It also exists "hybrid" transmission, which combines hydrostatic with the hydrodynamic one. In this case the machine is working with the hydrostatic part on short cycles and with the hydrodynamic part in long cycles, achieving the best possible fuel consumption in both cases. In short, the transmission is working in the following way: power is transmitted through a variator unit (hydraulic pump and motor) as well as a parallel mechanical gear path (highest efficiency) to maximize the transmission efficiency over a wide range of operating conditions. The continuously variable gear ratio of the variator enables the ability to run the engine at a more efficient operating range independent of machine ground speed [8]. In this way the transmission is using the low engine rpm and achieve better fuel consumption. It is shown on Fig. 3 [8].

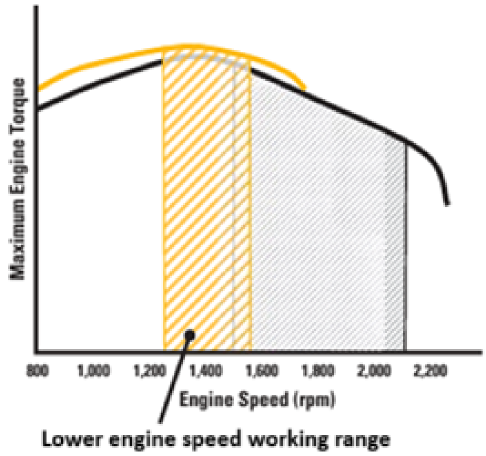

Fig. 3. Engine speed at "hybrid" transmission [8].

The rimpull control is also increased comparing to standard hydrodynamic transmission, Fig. 4 [8].

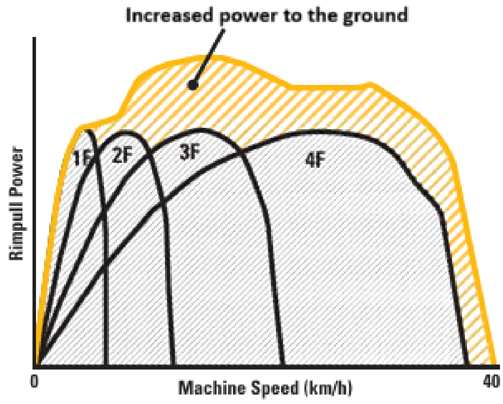

Fig. 4. Rimpull control at "hybrid" transmission [8].

The main disadvantages of "hybrid" transmissions are high price and not satisfied reliability taking in to consideration that the machine has two transmissions in one.

III. Practical Experiments

The practical measurements of the fuel consumption of two machines, each of which uses one of the described transmissions, were made in the period 19.02 - 23.02.2024 on the territory of Kaolin EAD. The first two days, the machines were tested on a short cycle of 15 m during slope material preparation (stacking and pushing material into slopes) on the territory of the Vetovo factory. The second two days of testing provided information on long-cycle fuel consumption when transporting material over 650 m in a direction over relatively straight and level terrain. The material in both cases was fireclay sand with a volumetric weight of 1.6 t/m³.

The tested machines – front loaders Volvo L150H and Liebherr 566-6, whose main technical data are given in the Tables I and II [1, 9, 10].

TABLE I
MAIN TECHNICAL DATA OF VOLVO L150H

Volvo L150H	
Engine	Volvo D13J
Power	224 kW
Operational weight	26,1 t
Static tipping load	17,8 t
Bucket volume	4,8 m^3
Transmission type	Hydrodynamic

TABLE II
MAIN TECHNICAL DATA OF LIEBHERR 566-6

Liebherr 566-6	
Engine	D936 A7
Power	203 kW
Operational weight	26,9 t
Static tipping load	15,9 t
Bucket volume	4,8 m^3
Transmission type	Hydrostatic

The two machines have almost identical technical indicators and correspond to the same class. The main difference between them is the built-in transmission.

To conduct the experiment as correctly as possible, two pairs of operators were used. Each pair operated for one full day in the first and second tests. Bystanders reported the manner of work and the absence of deliberate delays or improper use of the machines.

A standard working day of eight hours in two intervals of four hours - from 8:00 to 12:00 and from 13:00 to 17:00 was adopted for the time interval of measurement.

The machines were loaded from the same fuel station in the morning at 7:50 and in the evening at 17:15 by the same employee in the presence of the observers and testers.

The results of the practical experiments are given in the Tables III, IV, V and VI.

TABLE III
RESULTS OF DAY 1 (SHORT CYCLE TEST)

Hourly fuel consumption at the end of the day, l/h	
Volvo L150H	16,10
Liebherr 566-6	14,78
Difference vs Volvo L150H	**8,2 %**

TABLE IV
RESULTS OF DAY 2 (SHORT CYCLE TEST)

Hourly fuel consumption at the end of the day, l/h	
Volvo L150H	15,83
Liebherr 566-6	14,58
Difference vs Volvo L150H	**7,9 %**

TABLE V
RESULTS OF DAY 3 (LONG CYCLE TEST)

Hourly fuel consumption at the end of the day, l/h	
Volvo L150H	16,93
Liebherr 566-6	17,71
Difference vs Liebherr 566-6	**4,4 %**

TABLE VI
RESULTS OF DAY 4 (LONG CYCLE TEST)

Hourly fuel consumption at the end of the day, l/h	
Volvo L150H	17,21
Liebherr 566-6	18,12
Difference vs Liebherr 566-6	**5,02 %**

This analysis included only the measurement of the hourly fuel consumption of the two machines, but did not affect their fuel efficiency, l/t.

To correctly present the analysis, it is necessary to define the various criteria for evaluating the machines.

Fuel efficiency is a concept that binds the means that are put into the operation of the machine, i.e. cost of fuel, to the mass the machine produces, i.e. ton of processed produce. In technical terms, this means the ratio of fuel consumption to one ton of processed material. It is measured in liters/ton [2].

Fuel consumption or fuel economy is the amount of fuel the machine uses in one hour. It is measured in liters/hour. This concept is widely used to compare machines of the same type and weight class. Although it enters the technical-economic analyzes of all users, this parameter can be misleading, if one does not understand what information is behind it. Hourly fuel consumption can be given with the engine idling. It will certainly be less than the consumption of the same machine under load. The type of material is also important. The consumption of the same sawdust processing machine will be less than when working with a blasted rock material. Since this parameter is a function of many circumstances, it is often manipulated and misused.

Any proper analysis related to the fuel economy of the machines must include the measurements or calculations of the fuel efficiency [5, 6, 7].

In the report, due to the lack of built-in measuring systems in the machines and the impossibility of weight measurements in the test conditions, only fuel consumption was measured.

Fuel efficiency is the issue to be addressed in the next test, as practice has shown that one machine scoops up more material, due to the specifics of the kinematics of the bucket's drive mechanism, which allows a greater angle of its retraction. Only then will it be able to say which of the two machines is more economically advantageous.

The presence or absence of certain systems, such as the boom vibration dampening system, which consists of batteries that dampen boom vibrations when the machine moves over a long distance with a bucket full of material, is also essential for fuel efficiency in front-end loaders. This avoids unnecessary spilling of the material from the bucket during the course. Another system that relieves the operator in periodically repeating maneuvers characteristic of short cycles is the control of the machine with a joystick. Thus, the operator is relieved from the continuous rotation of the steering wheel and the load on the shoulder joints, which affects his efficiency after working for about 3 hours. Some machines are also equipped with automatic bucket and boom positioning systems, which can also lead to improved fuel efficiency. An example is the loading of trucks of the same type.

A test to compare the fuel efficiency of the two models will be the subject of further research, for the purpose of which weighing systems from the same manufacturer will be installed on each machine, so that the same system deviation is reported for both machines.

IV. Conclusions

After the tests, the following conclusions can be made:

- The machine with hydrostatic transmission has better short cycle fuel consumption with an average of 8.05 % compared to the machine with hydrodynamic transmission;
- The machine with hydrodynamic transmission has better long cycle fuel consumption with an average of 4.71 % compared to the machine with hydrostatic transmission;
- At the end of working days, when working on long cycles, a significant heating of the hydro motors of the hydrostatic transmission machine was reported;
- Operators opined that the hydrostatic drive machine has smoother movements and is faster on short cycles;
- In the long cycles the machine with the hydrodynamic transmission has better behavior and completes the courses in less time.

To present a correct techno-economic analysis, it is necessary to make a precise study including measurement of the transferred material, especially in long cycles and to compare the fuel efficiency of the two machines.

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