COMPARISON OF THE ENERGY CONSUMPTION OF THE HYDRAULIC CONTROL SYSTEM OF THE UDS 114

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This article deals with the comparison of the energy consumption of the hydraulic control system of the working mechanisms of the telescopic excavator UDS 114. There is described the hydraulic system of the excavator. In order to compare the individual losses in the hydraulic circuits for controlling the working mechanisms, the hydraulic oil flow rates through the OTC H50 meter were measured. Firstly, for the machine before a repair and subsequently after the repair. For each hydraulic circuit, the hydraulic oil flow rates between the pump and the distributor and then between the distributor and the appliance were measured at first. The overall power losses of the hydraulic circuit is then determined from particular calculations. From these calculated power losses of individual hydraulic circuits, the efficiency of individual hydraulic circuits in the state of the machine before and after repair was evaluated.

KEYWORDS
loss, hydraulic, flow rate, pressure

1   INTRODUCTION

At present, the development of construction machinery has shifted rapidly and it is at a very high level. Higher demands are demanded on their performance, maintainability, operational costs, versatility, low fuel consumption, and so on. Satisfying these ever-increasing requirements would be unfeasible without the using of a hydraulic circuit. The hydraulic circuit can be divided into particular elements that has an individual influence on the energy losses in the flowing hydraulic oil. Because these elements are in series (consecutively) in the hydraulic circuit, we can summarize their loss influences and thus obtain the entire loss of a hydraulic circuit. If it is necessary to determine the total loss energy, it is necessary to determine it at the output of the hydraulic circuit (for the appliance). [Exner 1991]

The main losses occurring in the hydraulic circuit include pressure losses. The pressure losses are divided into three types:

- losses, that are produced in lines, straight pipe friction losses,
- local losses,
- losses, that are produced in individual hydraulic elements of the circuit. [Pivonka 1987]

2   MATERIAL AND METHODS

2.1   Description Of The Telescopic Excavator UDS 114

Universal finishing machine UDS 114 is the earthmoving machine mounted on the undercarriage of Tatra 815. The UDS 114 excavator is mounted on the Tatra 815 chassis by a lower frame with four pull-out stabilizing supports. The lower frame is a rotatable connected with the upper assembly. On the rotating frame the upper assembly is mounted a drive unit of the finishing machine - the four-stroke, liquid-cooled, six-cylinder engine Zetor 8701.102. This engine drives three hydraulic pumps through the drive box. One is the gear pump U 80L (Jihostroj Velesin) and two are piston control pumps SPV 23 (ZTS Dubnica nad Váhom). These allow the excavator to achieve five basic motions of the working tool:

- lifting and lowering the external arm,
- extending and inserting the inner telescopic arm,
- rotation of the working tool (using a rotating head),
- opening and closing the working tool,
- rotating the upper assembly of the excavator UDS 114. [Team of OTS authors 1986]

Figure 1. Telescopic excavator UDS 114

1 – the basic external arm, **2** – the inner telescopic arm, **3** – the rotating head, **4** – the depth five-teeth shovel of the 0.63 m³ volume, **5** – the positional arm, **6** – the lower frame, **7** – the Tatra 815 undercarriage.

2.2   Hydraulic System Of The UDS 114 Telescopic Excavator

The hydraulic system of the UDS 114 excavator consists of three main independent hydraulic circuits. The source of the pressure fluid are two SPV 23 control piston hydraulic pumps and one the U 80L gear pump of the constant flow rate. The first one the SPV 23 hydraulic pump delivers the hydraulic fluid through the RS 32 distributor to the linear hydraulic motor of the inner telescopic arm. The second one the SPV 23 hydraulic pump supplies the hydraulic fluid through the RS 32 (Hydracol) distributor to the linear hydraulic motors of the boom lift. The U 80L gear hydraulic pump delivers the hydraulic fluid through the RS 25 (Hydracol) distributor to:

- the rotating hydraulic motor of the upper assembly turn HMB 630 U (ZTS Brno),
- the linear hydraulic motor of the working tool,
- hydraulic circuits of the boom lift and the extension of the telescopic boom (acceleration of motion),
- rotating hydraulic motors of the rotating head UMN 80 (Jihostroj Velešín).

[Team of OTS authors 1986]

The overall schematic of the hydraulic system of the UDS 114 exceeds editing capabilities of this paper. The overall schematic is available on demand from the first author of the paper. As an example, here is a scheme of the hydraulic telescopic boom control system.
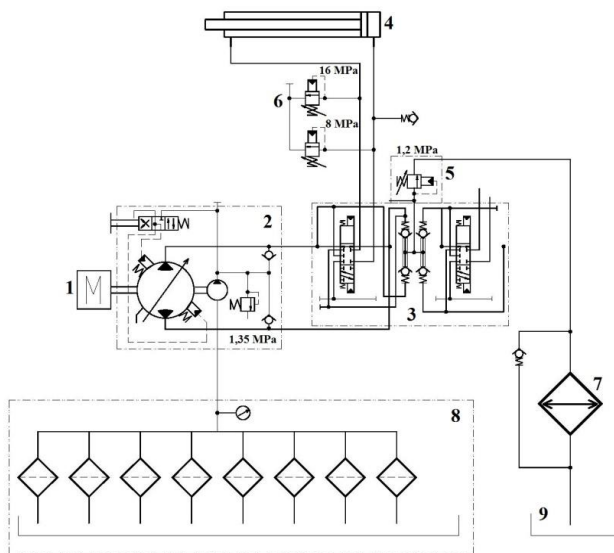
Figure 2. Hydraulic scheme of the control circuit of the telescopic boom extension

1 – the engine Zetor 8701.102, 2 – the control piston hydraulic pump SPV 23, 3 – the distributor RS 32, 4 – the linear hydraulic motor of the inner telescopic arm (110/70/4150), 5 – the relief valve PV 32, 6 – safety valves PV 20, 7 – the hydraulic fluid cooler, 8 – the hydraulic fluid reservoir, 9 – the lower hydraulic fluid reservoir.

2.3 Methods Of Measurement

For each hydraulic circuit, measurements were performed firstly between the hydraulic pump and the distributor and then between the distributor and the appliance. As an appliance, in this case, it is considered a linear or rotating hydraulic motor. The measuring device OTC H50 (Owatonna tool company, Minnesota, USA) was used to measure the pressure (0 - 40 MPa), the flow rate (0 - 200 dm^3· min^{-1}) and the hydraulic fluid temperature (0 - 120 °C) in a given hydraulic circuit. [Juza 2017]

After connecting the combined measuring device to the measured hydraulic circuit, the measurements were carried out as follows:

- Adjust the speed of the internal combustion engine to 1800 min^{-1}.
- Set up the distributor for the appropriate movement of the hydraulic motor into the working position.
- Load the hydraulic circuit by means of the measuring device throttle valve to the predetermined pressure.
- Record values of the hydraulic fluid pressure, flow rate and temperature including the engine speed of the internal combustion engine.

For the testing of the hydraulic circuits between the hydraulic pump and the distributor, the final value of the preset pressure was 17 MPa, and for testing of the hydraulic circuit between the distributor and the appliance was the final value of pressure 16 MPa. Because, it was assumed that when the load is measured and simulated at the end of the hydraulic circuit at the input to the appliance at a maximum pressure of 16 MPa, the hydraulic fluid pressure will rise at the hydraulic pump output. [Juza 2017]

Figure 3. Combined measuring device OTC H50 for measuring pressure, flow rate and temperature

2.3.1 Testing Of Hydraulic Circuit Between Pump And Distributor

During the testing of the hydraulic circuit of the lifting the external arm and the extending of the inner telescopic arm, the inlet hose was connected to the discharge of the hydraulic pump SPV 23 and the outlet hose from the measuring device was connected to the SPV 23 pump intake to keep the circuit closed. In this testing, it is necessary to set the control lever in the cabin after starting the engine to the working position so that the tested pump has the maximum oil supply. When testing the control hydraulic circuit of the upper assembly rotating, the working tool rotating, opening and closing the source of pressure fluid is the gear pump U 80L. The inlet hose of the measuring device is connected to the circuit behind the U 80L hydraulic pump and the outlet hose of the measuring device is connected to the supply of the RS 25 distributor. [Juza 2017]

2.3.2 Testing Of Hydraulic Circuit Between Distributor And Appliance

When testing the hydraulic circuit between the distributor and the appliance, the measuring device was connected to the hydraulic circuit instead of the appliance (instead of linear or rotating hydraulic motors). The supply hose to the combined measuring device was connected to the supply duct into the appliance and the outlet hose from the measuring device was connected to the return duct from the appliance. [Juza 2017]

Figure 4. The connection of the measuring device between the RS 25 distributor and the HMB 630 U rotating hydraulic motor when testing the assembly rotating hydraulic circuit

3 RESULTS AND DISCUSSION

In the calculations, it was primarily necessary to measure all the required geometric dimensions of the given hydraulic circuit (hoses and pipes inner diameters, length of the lines). From the schemes of the individual hydraulic circuits for controlling the working movements of the UDS 114 excavator, the individual elements arranged in series were determined. These elements were written to the appropriate table that is always relevant to a particular hydraulic circuit. The name of the element in the hydraulic circuit, the number of pieces, the calculated value of the pressure loss p_z and finally the loss power P_z are always given in each table. The pressure losses must be determined for all elements in the hydraulic circuit except the pump. These pressure losses in the individual elements of the hydraulic circuit after multiplying by a given flow rate in a given section of the hydraulic circuit mean the power loss of the element in the hydraulic circuit. The power loss will be calculated for the hydraulic pump. Summing these individual loss powers, we obtain the total loss power of the hydraulic circuit. It was necessary to calculate the pressure losses in the direct line for hydraulic hoses and hydraulic pipes according to the measured hydraulic fluid flow rates for machine states before and after the repair. Further, it was also necessary to calculate the pressure losses in the local resistances of the hydraulic circuits. For example, fittings (the conjunction between hose and steel pipe or the distributor throat), further the 90° elbow or the safety valve. Namely, for the state of the machine before and after repair. For subsequent calculations of the efficiency of individual hydraulic circuits, it was necessary to determine the values of the pressure efficiency, the geometric volume and the power consumption of pumps. Further, pressure losses for the RS 25 and RS 32 distributors that are reported by their manufacturers. From the already known values, theoretical flow rates, total efficiencies, and power losses of hydraulic pumps were calculated. The individual calculated or determined pressure losses of the elements used in the hydraulic circuits were multiplied by measured pump flow rates, for the determining the loss powers. In addition, the pressure losses of the elements behind the distributor were multiplied by the actual measured flow rate at the end of the hydraulic circuit. By this procedure, the total loss power was determined in the prepared tables for each hydraulic circuit.

[Juza 2017]

Specified values:

Gear pump U 80L:

The pressure efficiency $\eta_p = 0.94$

The geometric volume $V_g = 0.08$ dm3

The pump power input $P = 39$ kW

Piston control pump SPV 23:

The pressure efficiency $\eta_p = 0.94$

The geometric volume $V_g = 0.089$ dm3

The pump power input $P = 45$ kW

Used hydraulic oil: ISO VG 46

The density at 15 °C $\rho = 866$ kg · m-3

The kinematic viscosity at 40 °C $\upsilon = 45.92$ mm2 · s-1

p [MPa]	Q [dm³ · min⁻¹]	t [°C]	n [min⁻¹]
2	80	25	1800
5	75	25	1800
10	60	30	1720
17	46	35	1660

Table 1. Table of measured values in state before repair for the of hydraulic circuit of the upper assembly rotating between the U 80L gear pump and the RS 25 distributor

where   p [MPa]   - means the set pressure on the measuring device

Q [dm3·min-1] - means the reading of the hydraulic oil flow from the measuring device

t [°C]   - means the reading of the oil temperature from the measuring device

n [min-1]   - means the measured speed of the Zetor engine

The theoretical flow rate of the pump SPV 23

$$Q_t = V_g \cdot n = 0.089 \cdot \frac{1720}{60} = 2.55 \text{ dm}^3 \cdot \text{s}^{-1} \tag{1}$$

The overall efficiency of the pump SPV 23

$$\eta_{CHG} = \frac{Q_1}{Q_t} \cdot \eta_p = \frac{2.3}{2.55} \cdot 0.94 = 84.74\% \tag{2}$$

The power loss of the pump SPV 23

$$P_{ZHG} = (1 - \eta_{CHG}) \cdot P = (1 - 0.8474) \cdot 45000 = 6\,867 \text{ W} \tag{3}$$

Hydraulic boom lift control circuit - after repair			
Element in the circuit	number of pieces	p_z [kPa]	P_z [W]
piston pump SPV 23	1		6 867
90° elbows Ø24mm	2	29.54	67.94
pipe Ø24mm/500mm	1	10.43	23.99
hose Ø25mm/500mm	1	8.59	19.76
fitting Ø24	1	1.16	2.67
distributor RS 32	1	700	1 610
fittings Ø24	3	3.12	6.77
pipe Ø24mm/1750mm	1	32.97	71.54
hose Ø25mm/1250mm	1	19.4	42.10
pipe Ø24mm/1200mm	1	22.61	49.06
90° elbows Ø24	4	52.6	114.14
Total loss power P_{ZC} [W]			**8 874.98**

$P_{ZHG} = 6\,867$ W   calculated $\eta_{CV} = 80.28\%$ $Q_1 = 2.3$ dm³· s⁻¹
                      measured $\eta_{CN} = 79.95\%$ $Q_2 = 2.17$ dm³· s⁻¹

Table 2. Calculation of the total loss power and overall efficiencies of the boom lift hydraulic control circuit - after repair

where p_z [kPa] - means the calculated loss pressure for the hydraulic circuit elements

P_Z[W]   - means the calculated power loss for the hydraulic circuit elements

P_{ZC} [W]   - means the total calculated power loss of thehydraulic circuit

Unfortunately, the energy losses caused by the hydraulic motors are not taken into account in this paper, because during the measurement, the combined measuring device was connected at the end of the hydraulic circuit instead of the hydraulic motor. This combined measuring device loaded the hydraulic circuit to the required pressure. For each hydraulic circuit, the same table was assembled as the above Tab. 2, where the total power loss of the hydraulic circuit was evaluated.

The total power losses of the hydraulic circuits in the state of the machine before and after the repair were quantified there. Due to the limited length of the paper, the only one chosen table is presented here.

Then it was possible to calculate the overall efficiency of the individual hydraulic circuits as determined by the calculations and the overall efficiency of the hydraulic circuits determined by the measurement. [Juza 2017]

Hydraulic circuit	before repair		after repair		Saving power loss [W]	Average increase in efficiency of the hydraulic circuit by [%]
	Power loss P_{ZC} [W]	calculated η_{CV} [%] measured η_{CN} [%]	Power loss P_{ZC} [W]	calculated η_{CV} [%] measured η_{CN} [%]		
rotating the upper assembly	25 359.04	34.98 32.90	8 518.11	78.16 76.61	16 840.93	43.45
lifting the external arm	19 088.46	57.58 57.44	8 874.98	80.28 79.95	10 213.48	22.61
opening and closing the working tool	25 804.16	33.84 31.49	9 789.53	74.90 74.26	16 014.63	41.92
rotation of the working tool	26 170.95	32.89 31.49	8 305.21	78.70 78.50	17 865.74	46.41
extending the inner telescopic arm	18 988.98	57.80 57.61	9 752.85	78.33 78.28	9 236.13	20.60

Table 3. Comparison of loss powers and efficiencies of individual hydraulic circuits before and after repair

where P_{ZC} [W]   - means the total calculated power loss of the hydraulic circuit

η_{CV} [%]   - means the total efficiency of the hydraulic circuit as determined by the calculations

η_{CN} [%]   - means the overall efficiency of the hydraulic circuit determined by themeasurement instead of the appliance

4   CONCLUSION

The UDS 114 telescopic excavator had approximately twelve thousand operating hours before repairing. A visible leakage of all hydraulic cylinders and visible damages of hydraulic hoses were observed on the excavator. The reduced working performance of the UDS 114 telescopic excavator has been found by the measuring of hydraulic oil flow rates in individual hydraulic circuits. Therefore, the owner of the machine has decided to carry out a more extensive repair. A total repair of the engine Zetor 8701.102 was performed on the UDS 114 telescopic excavator. Further, the U 80L gear pump was

replaced by a new one. Two axial piston pumps SPV 23 have been repaired. All linear hydraulic motors have been repaired and re-sealed. A repair of the rotating hydraulic motor of the upper assembly turn HMB 630U was performed. The repair of two gear hydraulic motors of the rotating head UMN 80 was realized. Three safety valves DPV 25 and two PV 20 were repaired. Within the repair, the RS 25 and RS 32 hydraulic distributors were re-sealed. It was necessary to replace seventeen damaged hydraulic hoses and four damaged hydraulic pipes. Furthermore, eight hydraulic oil intake filters were replaced and the hydraulic oil ISO VG 46 was completely changed.When examining the pressure losses in the straight line and the local resistances of the individual elements of the hydraulic circuits, it is obvious that the pressure losses are higher at the excavator after repair. This is due to a higher flow rate of hydraulic fluid in a given hydraulic circuit. For hydraulic circuits where the U 80L gear pump is a source of pressure hydraulic fluid, the fluid flow rate increased by 0.935 dm³· s⁻¹ on average, after repair. However, in the case of hydraulic circuits where the axial piston pump SPV 23 is the source of the hydraulic pressure fluid, an increase of the flow rate by 0.665 dm³· s⁻¹ on average has been observed. When examining the total loss power P_{ZC} of hydraulic circuits, where source of the hydraulic fluid is the U 80L gear pump, we find that the machine after repair has an average of 2.75 times decrease of the loss power P_{ZC} comparing to the machine before repair. For hydraulic circuits where the source of hydraulic fluid is the axial piston pump SPV 23, the reduction in total loss of the machine after repair is the twice on average. For hydraulic circuits where the source of hydraulic fluid is the U 80L gear pump, the efficiency is increased of more than 40 %. However, in the case of hydraulic circuits where the source of hydraulic fluid is the axial piston pump SPV 23, the efficiency has been increased by more than 20 %. [Juza 2017]

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