LABORATORY TESTING OF A HYDRAULIC MOTOR OPERATING WITH CYCLIC LOADING

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Abstract

Testing and monitoring all parameters of a hydraulic gerotor motor in laboratory conditions is necessary due to the fact that the motor operates for approximately 500 hours with a cyclic load. Recording all its parameters during operation will show if and how its parameters set by the manufacturer change. The conducted tests determine the conditions for the correct operation of the hydraulic motor in normal mode, as well as in the mode of operation under cyclic loading (loading/unloading). An algorithm was used to study the reliability and service life of the hydraulic motor under the operating conditions thus tested.

Keywords

Lab Study, Hydraulic Motor, Hydraulic System, Hydraulic Flowmeter, Service Life

1. Introduction

Hydraulic machines and elements are a main part that finds application in many technical areas - test bench, transport, agricultural - economic, road - construction, industrial, etc. The requirements for drive systems are increasingly high from the point of view of increasing their service life, failure-free, as well as reducing the time for repairs. The more complex the hydraulic system [4], the more difficult and, accordingly, the slower it is to perform system diagnostics, which in turn leads to loss of time and money for its owner. In the present work, a main element is examined, which is subjected to wear in laboratory conditions, since it is subjected to the greatest load, including cyclical. The testing of a hydraulic motor on the test bench is related both to the correct operation and to determine its longevity and reliability, as well as to make a forecast for future prevention or repair of the motor, so that emergency stops of the system do not occur.

2. Aim of the study

The main purpose of the present work is to test the hydraulic motor, taking all its parameters in laboratory conditions and to compare them with the data provided by the manufacturer for this hydraulic motor. The laboratory testing of the hydro-motor is carried out to the maximum extent with the parameters [1], and the way it works in real conditions.

The testing of a hydraulic motor is related to the coverage of the parameters set by the manufacturer, as well as to give a preliminary assessment based on the test of its reliability and durability.[2].

To fulfill the above-mentioned goal, the following main tasks have been defined:

- Testing and parameterization of a hydraulic motor in a laboratory environment;
- Hydraulic motor parameters monitoring;
- An algorithm was used to study the reliability and service life of the hydraulic motor under the operating conditions thus tested.

3. Test bench hydraulic system operation modes

The hydraulic test bench [3] where the hydraulic motor is tested has the following parameters and equipment, presented in Figure 2,3,4 and Table 1. A hydraulic diagram of the test bench is presented in Figure 1.

The hydraulic stand is equipped with numerous measuring equipment, such as a hydraulic flow meter (a hydraulic motor coupled with the necessary measuring equipment), temperature sensors, speed sensors, a torque meter for measuring torque, a thermal camera, measuring various electrical quantities, etc.

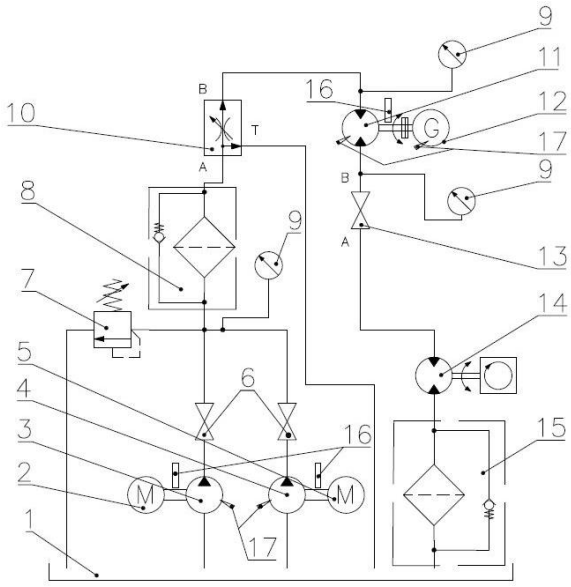

Fig. 1 Hydraulic diagram of the test bench.

Figure 1 shows the components of the system and are as follows: 1 – Hidraulic tank; 2 – Electric motor; 3 – Hydraulic gear pump; 4 - Electric motor; 5 - Hydraulic gear pump; 6 – Hydraulic shutoff valves; 7 – Pressure relief valves; 8 – Discharge filter; 9 – Pressure gauge; 10 - Three-way flow control valve; 11 – Hydraulic motor; 12 – Torque meter; 13 - Hydraulic shutoff valves; 14 – Hydraulic flow meter; 15 - Return filter; 16 – Tachometer; 17 – Thermometer.

Fig. 2 Hydraulic test bench.

Fig. 3 Indication of revolutions and temperature of the hydraulic test bench.

Fig. 4 Indication the hydraulic motor test, such as pressure, flow and torque.

Table 1. Hydraulic test bench system parameters.

Type		
Part number:	HGP14A001	HGP72A001
Maximum pressure, bar	175	175
Pump volume cm^3/rev	6.3	32.7
Flow rate at 1000 min^{-1}; l/min	6.3	32.7
Flow rate at 1450 min^{-1}; l/min	8.66	47.4
Electric motor		
Power, kW	1.5	7.5
Rotation frequency, min^{-1}	1450	1450
Pressure relief valves		
Part number:	PRV3/4/280	
Maximum pressure, bar	280	
Maximum flow rate, l/min	80	
Hydraulic shutoff valves		
Maximum pressure, bar	500	
Maximum flow rate, l/min	80	
Three-way flow control valve		
Part number	VRFC3/V/12	
Maximum pressure, bar	250	
Maximum flow rate, l/min	90	

The testing of the hydraulic motor was carried out with certain restrictions, with the pressure not exceeding 170 bar, since in real conditions it works with a pressure of up to 100 bar. The flow rate supplied to the hydraulic motor is regulated by means of a three-way flow control valve, and the maximum flow rate that we can supply is 56.06 l/min. The hydraulic motor used the flow rates of both pumps on the test bench, being tested with one pump after the other and finally tested with both pumps operating together.

Figure 1 shows the diagram of the hydraulic motor test bench. The parameters of the tested hydraulic motor are presented in Table 2, provided by the manufacturer.

Table 2. Hydraulic motor parameters.

Parameters of the tested hydraulic motor		
Displacement	cm^3/rev	99.8
Maximum torque	Nm	240
Max Output	kW	13
Max Pressure Drop	bar	175
Max Oil Flow	l/min	60
Min speed	rpm	10
Max speed	rpm	600
Volumetric efficiency	-	0.965
Mechanical efficiency	-	0.98
Total efficiency	-	0.97

The formulas used for theoretical calculation of hydraulic motor parameters are presented as follows [1]:

1. Rotation speed in shaft on hydraulic motor;

$$n = \frac{Q.1000}{q_m}, min^{-1} \qquad (1)$$

n – rotation, min^{-1};

Q – hydraulic flow, l/min;

$\mathbf{q_m}$ – displacement hydraulic motor, cm^3/rev;

2. Torque implemented by the hydraulic motor;

$$M = \frac{p.q_m}{20.\pi}, Nm \qquad (2)$$

M – torque, Nm;

p– pressure, bar;

$\mathbf{q_m}$ – displacement hydraulic motor, cm^3/rev;

3. Power implemented by the hydraulic motor;

$$P = \frac{Q.p}{600.\eta_t}, kW \qquad (3)$$

Q –hydraulic flow,l/min;

p– pressure, bar;

η_t – total efficiency;

P – power, kW;

The test results of the hydraulic motor on the test bench are presented in Table 3 [5], with the connection diagram of the motor test shown in Figures 4 and 5. The general diagram of the hydraulic test bench is presented in Figure 1.

Results obtained during the test of the hydraulic motor illustrate that the parameters of the hydraulic motor implemented on the test stand do not differ by a large order from those given by the manufacturer and accordingly calculated for it. The obtained differences show that the motor works with the correct parameters embedded in it and demonstrates that the cyclic load it has been working with up to this point does not affect its parameters, which is extremely important for its reliability and longevity.

Table 3. Test results of the hydraulic motor.

№	Pressure			Flow rate	Torque motor			Rotation			Power hydraulic motor
	M_1	M_2	M_3	Q	Calculation torque meter	Torque meter	Manufactures Torque meter	$n_{motor\ calculation}$	$n_{motor\ manufacturies}$	n_{motor}	P
	bar	bar	bar	l/min	Nm	Nm	Nm	min^{-1}	min^{-1}	min^{-1}	kW
1	50	50.92	50.9	2	80.9	81	79.2	20.04	19	20	0.17
2	80	82.42	82.39	2.99	130.9	131	128.5	29.96	29	30	0.42
3	100	98.75	98.72	4	156.9	157	154.6	40.08	39	40	0.68
4	110	108.85	108.81	5.1	172.9	173	170.6	51.10	52	51	0.95
5	120	119.01	118.96	6.06	189.0	189	187.8	60.72	61	61	1.24
6	130	128.57	128.51	7.03	204.2	203.9	203.2	70.44	71	70	1.55
7	140	139.07	139	7.98	220.9	219.8	219.5	79.96	80	80	1.91
8	150	148.75	148.68	8.66	236.3	235.54	234.9	86.77	86	87	2.21
9	160	160.13	160.06	8.66	254.3	253.9	253.3	86.77	86	87	2.38
10	170	169.67	169.64	8.66	269.5	270	268.7	86.77	86	87	2.52
11	50	44.02	43.93	10.03	69.9	70	67.8	100.50	100	100	0.76
12	80	74	73.87	15.01	117.5	118	111.5	150.40	150	150	1.91
13	100	94.76	94.59	19.69	150.5	151	149.5	197.29	197	197	3.21
14	120	114.89	114.64	29.31	182.49	183.00	181.50	293.69	295	294	5.79
15	107.75	102.67	102.37	35.41	163.08	165.00	162.40	354.81	355	355	6.25
16	46.77	41.29	40.89	47.41	65.58	66.00	63.50	475.05	476	475	3.36
17	43.2	35.97	35.49	56.06	57.13	58.00	55.50	561.72	562	562	3.46
18	52.32	45.09	44.62	56.06	71.62	72.00	70.20	561.72	562	562	4.34
19	57.95	51	50.54	55	81.01	81.00	81.00	551.10	552	551	4.82
20	70.8	64.5	64.06	52.41	102.45	103.00	103.00	525.15	526	525	5.81
21	80	74.18	73.76	50.48	117.83	118.00	115.50	505.81	507	506	6.43
22	100	94.55	94.16	45.97	150.18	151.00	151.50	460.62	461	461	7.47
23	120	114.79	114.45	40.82	182.33	182.00	182.10	409.02	410	409	8.05
24	140	134.87	134.57	34.76	214.22	215.00	214.10	348.30	348	348	8.06
25	160	156.9	156.68	26.75	249.21	250.00	249.10	268.04	268	268	7.21
26	170	168.11	167.93	21.08	267.02	268.00	267.50	211.22	212	211	6.09

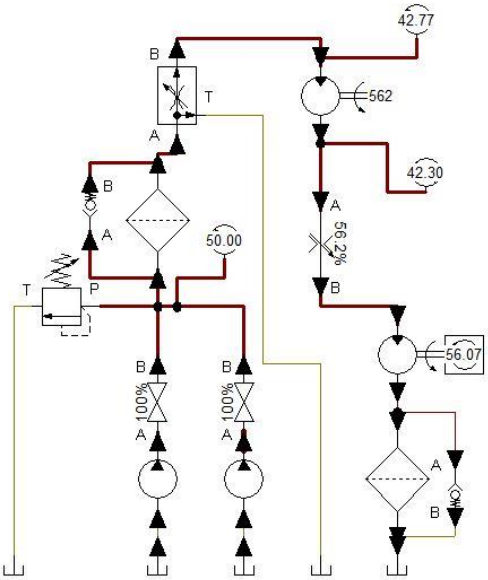

Fig. 5 Connection diagram of the motor test 1.

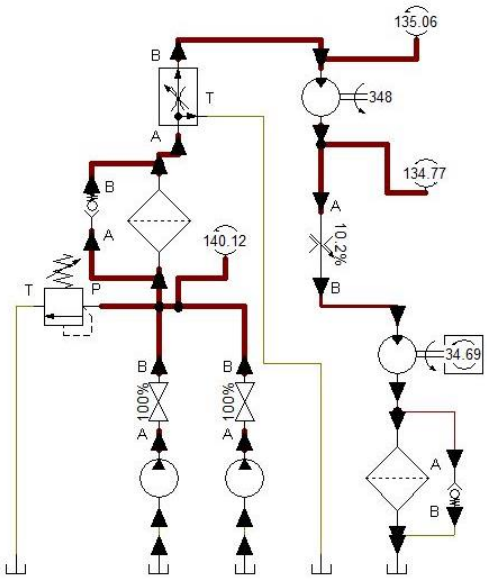

Fig. 6 Connection diagram of the motor test 2.

One of the parameters that is not recorded in table 3 is the realized drafts of the hydraulic motor during its operation, which are measured as a separate parameter for its correct operation. The internal pressures set by the manufacturer are at 50 bar – 0,9 l/min, 100 bar – 1,8 l/min and 140 bar – 2,8 l/min. The real data obtained for the same pressures are at 50 bar – 0,95 l/min, 100 bar – 2,97 l/min and 140 bar – 3,1 l/min, and these flow rates were measured with a newly built hydraulic flow meter [6].

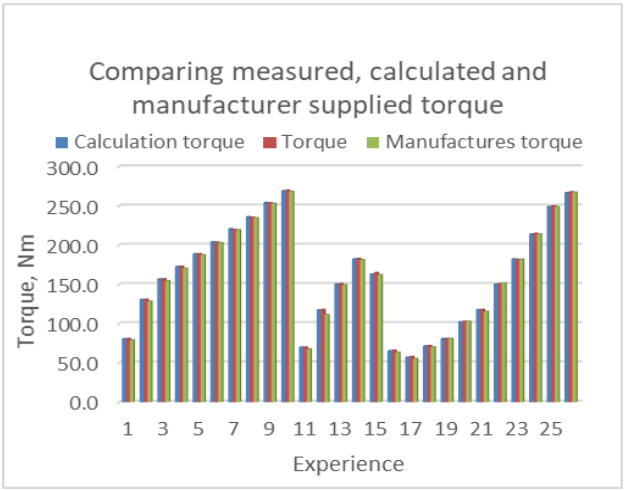

Fig. 7 Comparison of torque from measurements, calculations and set by the manufacturer.

Figure 7 shows the torque data of the hydromotor that was calculated, obtained from the experiment and provided by the manufacturer. In Table 4, only the torque of the hydro motor is sampled and Figure 8 is constructed, which shows the percentage difference in torque from the measured, calculated and the torque presented by the manufacturer. The difference in torque is up to 6%, which confirms the good operation of the hydraulic motor. The measured torque and its calculations are equated to that of the manufacturer so that we can obtain reliable data.

Figure 8 shows a plot of the percentage error distribution of the hydromotor torque. Error 1-3 is the comparison of the torque from the calculations that are taken from the test bench and the comparison with the torque specified by the manufacturer. Error 2-3 is a comparison of the torque set by the manufacturer and the torque data taken from the measuring equipment of the bench (taken ready from the connected torque meter of the bench).

Table 4. Comparing the torque of the tested hydraulic motor.

1	**2**	**3**	**-**	**-**
Calculation torque	Torque	Manufacturers Torque	Error 1-3	Error 2-3
Nm	Nm	Nm	%	%
80.9	81	79.20	2.15	2.27
130.9	131	128.5	1.87	1.95
156.9	157	154.6	1.49	1.55
172.9	173	170.6	1.35	1.41
189	189	187.8	0.64	0.64
204.2	203.9	203.2	0.49	0.34
220.9	219.8	219.5	0.64	0.14
236.3	235.54	234.9	0.60	0.27
254.3	253.9	253.3	0.39	0.24
269.5	270	268.7	0.30	0.48
69.9	70	67.8	3.10	3.24

117.5	118	111.5	5.38	5.83
150.5	151	149.5	0.67	1.00
182.49	183	181.5	0.55	0.83
163.08	165	162.4	0.42	1.60
65.58	66	63.5	3.28	3.94
57.13	58	55.5	2.94	4.50
71.62	72	70.2	2.02	2.56
81.01	81	81	0.01	0.00
102.45	103	103	0.53	0.00
117.83	118	115.5	2.02	2.16
150.18	151	151.5	0.87	0.33
182.33	182	182.1	0.13	0.05
214.22	215	214.1	0.06	0.42
249.21	250	249.1	0.04	0.36
267.02	268	267.5	0.18	0.19

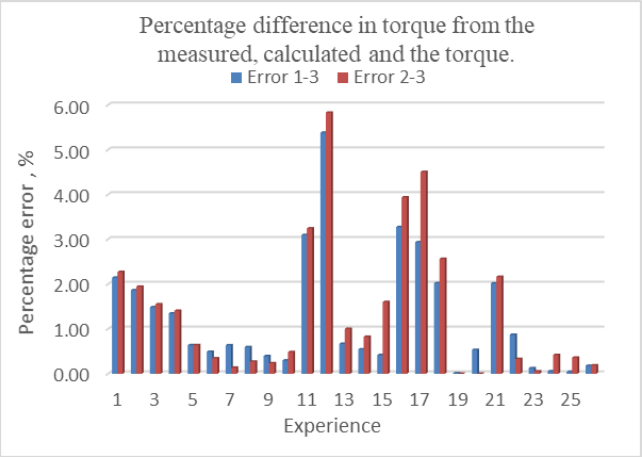

Fig. 8 Torque error analysis

4. Reliability and durability of the hydraulic motor

The reliability of the hydraulic motor depends on the overall reliability of the hydraulic system, but it is a separate component whose reliability can be considered separately from the whole system, and when the whole reliability of the hydraulic system must be calculated, it is a component of it. We clarify that the longer a hydraulic system operates, the lower the reliability of the entire hydraulic system becomes. The uptime of a hydraulic system is an exponentially distributed random variable.

Table 5. Tested hydraulic motor torque comparaison.

№	Hydraulic machine	Work machine in year	Work machine in hours	Root mean square deviation of in years	Machine failure after 1 year	Machine failure after 3 year	Machine failure after 5 year	Machine failure after 10 year	Machine failure after 15 year	Machine failure after 20 year
1	Roll - gerotor hydraulic motor	20	124800	0.0029	0.052	0.15	0.25	0.39	0.68	0.89

Table 5 presents the reliability and durability data, and in this table we enter the durability and reliability values specified by the hydraulic motor manufacturer. the results are presented for the system's average uptime, as well as the probability of a problem during operation of the hydraulic motor during 1, 3, 5, 10, 15 and 20 years of its design life.

5. Discussion and conclusion

The results of the performed laboratory tests give grounds for the following conclusions:

- The hydraulic motor operating under heavy and cyclic loads, as the main driving element, after about 500 hours of operation in these conditions, realizes almost 98% of its parameters provided [7] by its manufacturer, and it is confirmed that the motor is fit for work.
- The hydraulic bench is equipped with almost all measuring elements as well as numerous hydraulic components.
- With the presented algorithm, a preliminary assessment of the reliability and durability of the hydraulic motor can be made.
- In order to increase the durability and reliability of the hydraulic motor as much as possible, all requirements for the operation of the entire hydraulic system working with the hydraulic motor must be observed, so that it can work in its correct parameters. Regarding the correct

operation of the system, we pay attention to several basic things:

- Correct temperature range in which the hydraulic motor must work;
- Purity of the working fluid, which must be observed within precise limits;
- Viscosity of the working fluid used in the hydraulic system presented by the manufacturer of the hydraulic motor;
- Prevention and servicing of the hydraulic system.

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