

Research and test on electrical power recovery of hydraulic motor test bench

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Abstract. In this paper, the working principle of a kind of hydraulic motor test bench based on electric power recovery has been described. Relationship between the pressure, speed, torque and other parameters of the test bench with the recovery rate has been tested and analyzed. According to the test, hydraulic motor test speed and test pressure have a certain impact on the system power recovery rate. By choosing appropriate test speed and pressure, greatly reduce of the power consumption of the test system and of system heat dissipation can be realized.

1. Introduction

Traditional hydraulic motor test benches are loaded with throttle or relief valves. The power output from the hydraulic motor is converted into heat consumption. This method is obviously not suitable for the test of high-power hydraulic motors. So power recovery hydraulic motor test bench becomes development direction[1][2].

The power recovery hydraulic motor test bench is divided into hydraulic power recovery and electric power recovery. Hydraulic power recovery is divided into hydraulic compensation power recovery and mechanical compensation power recovery[3]. Hydraulic power recovery test system has few hydraulic components, simple equipment, high system power recovery factor. But it needs a certain space position and reasonable transmission device. It is also affected by the efficiency of hydraulic components or mechanical parts, which cause the power recovery coefficient unstable and fluctuating. The electric power type power recovery system has flexible structure space layout, relatively simple transmission structure without strict restrictions on the displacement relationship between the hydraulic pump and the hydraulic motor. It is widely used attributing to high power recovery factor and stability. In 2000, Dr. Arai of Japan proposed a hydraulic pump test bench based on electric power recovery. The torque is controlled by the frequency converter to load the generator to achieve the loading. The final generated energy is fed back to the driving frequency converter in the form of direct current. Energy is circulated between drive frequency converter, load frequency converter, hydraulic pump and hydraulic motor. External power grid supplies a small amount of energy to the system through the rectifier to supplement the energy loss caused by leakage and mechanical friction in the test process. But the system was with a high cost and complex control which was



handicapped by electrical technology at that time. Also the subsequent processing of the test system was complicated and the energy recovery efficiency was not high[4]. Luo Yanan, a female engineer of Kunming China Railway Large-Scale Road Maintenance Machinery Group Co., Ltd., once published an article entitled “Design and Efficiency Analysis of High-Power Hydraulic Pump/Motor Test System Based on Electric Power Recovery”. In this paper, the principle of electric power recovery system has been introduced with analyzing and calculating on the system total power recovery rate of it.. On this basis, the parameters such as pressure and speed of the electric power recovery hydraulic motor test bench has been analyzed, which provide theoretical guidance for the further study of the hydraulic motor test system.

2. Formatting Principle of electric power recovery hydraulic motor test system

Hydraulic power recovery hydraulic motor test system hydraulic system is shown in Figure 1. It mainly includes the drive motor pump unit, the tested motor, the loading motor, the torque and rotation speed meter, the rectifying device and other auxiliary components. The oil that outputs the operation of the motor pump unit 9 drives the test motor 13 to rotate after the high pressure is formed by the relief valve 11. The variable-frequency motor 5 is connected to the tested motor 13 through the coupling and the torque-rotating speed meter 6, and under the driving of the tested motor 13, the loading motor 5 rotates to generate electric energy. The loading motor 5 applies a certain resistance torque according to the requirements of the speed and pressure settings. The electric energy generated by the loading motor 5 is fed back to the driving variable-frequency motor 9 through the rectifying device so as to reduce the driving of the variable-frequency motor 9 to obtain electric energy from the electric grid. In addition, the hydraulic motor test system uses a double gear pump to supply oil. When the required flow of the tested motor 13 is large, the double gear pump supplies oil to the tested motor 13 at the same time; when the required flow of the tested motor 13 is small, A pilot motor 13 of the dual gear pump is supplied with oil, and the other flow is directly returned to the main tank 1 through the electromagnetic relief valve 10. The direction of rotation of the test motor 13 is switched by the electro-hydraulic shuttle valve 12, the pressure of which is controlled by the loading motor 5, and is safely protected by the proportional relief valve 11 on the bypass.

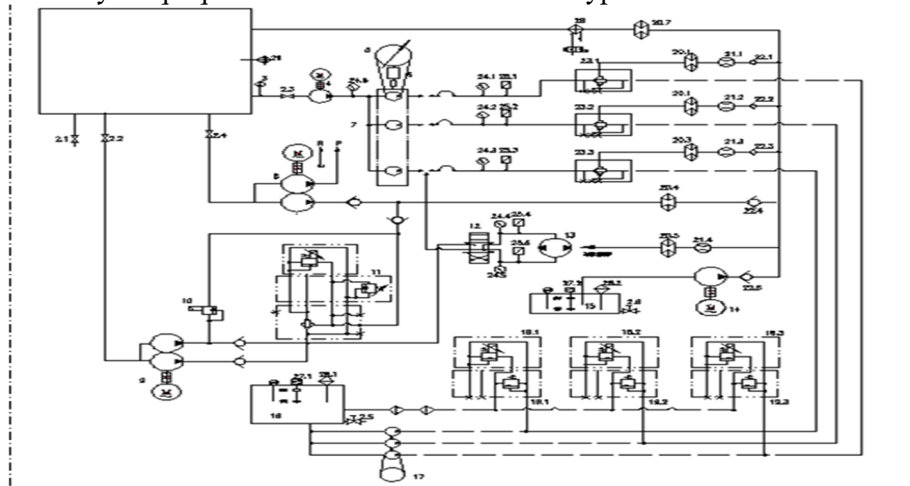


Figure.1 The hydraulic schematic of electric power recovery test system.

1. main tank; 2. ball valve; 3. temperature sensor; 4. oil filling motor pump set; 5. loading motor;
6. torque mete; 7. test pump; 8. clamping cycle motor pump set; 9. drive motor pump set;
10. electromagnetic unloading valve; 11. proportional relief valve; 12. electro-hydraulic reversing valve;
13. test motor; 14. pumping motor pump set; 15. fuel tank; 16. pilot fuel tank; 17. pilot-loaded motor pump set;
18. pilot proportional valve; 19. overlay relief valve; 20. filter; 21. flow mete; 22. check valve;
23. two-way cartridge valve; 24. pressure gauge; 25. pressure sensor; 26. cooler; 27. level gauge; 28. filter;
29. heater

2.1. Flow matching relation

When the loading pressure is lower than the set pressure of the overflow valve, the input flow of the tested motor is equal to the output flow of the fuel pump:

$$Q_P = Q_M \quad (1)$$

$$Q_P = V_P n_P \eta_{PV} / 1000 \quad (2)$$

$$Q_M = V_M n_M / 1000 \eta_{MV} \quad (3)$$

$$n_M = \frac{V_P n_P \eta_{PV} \eta_{MV}}{V_M} \quad (4)$$

Where Q_P is feed pump output flow (L/min), Q_M is the input flow of the tested motor (L/min). V_P is the displacement of fuel pump (ml/r), V_M is the displacement of the test motor, n_P is the speed of the fuel pump, n_M is the speed of the test pump. η_{PV} is the volumetric efficiency of fuel pump(%), η_{MV} is the volumetric efficiency of the test motor.

According to (4), when V_P , V_M , η_{PV} , η_{MV} is certain, test motor speed is determined by the supply pump speed, only so we can control the supply pump output flow by adjusting the rotational speed of drive for oil pump frequency conversion motor, which regulates the participants motor speed.

2.2. The pressure control of test system

According to the motor theory[5], the resistance torque on the test motor applying by the loading motor:

$$T = C_T \Phi_m I_2 \cos \varphi_2 \quad (5)$$

The output torque of the tested motor:

$$T_{MI} = p_{MI} V_M \eta_{MV} / 120\pi \quad (6)$$

$$T_{MI} = T \quad (7)$$

$$p_{MI} = \frac{120 \pi C_T \Phi_m I_2 \cos \varphi_2}{V_M \eta_{MV}} \quad (8)$$

Where, C_T is torque factor, Φ_m is air gap magnetic flux per pole, I_2 is rotor winding phase current, $\cos \varphi_2$ is motor power factor. According to (8), when V_M , η_{MV} are constant, the loading pressure of the tested motor is related to the magnetic flux per pole in the air gap of the loaded motor and the phase current of the rotor winding. So we use the vector control of frequency converter to change the value of magnetic flux per pole of air gap and phase current of rotor winding.

2.3. The calculation of electric power recovery of hydraulic motor test bench

The total system efficiency of the hydraulic motor test bench include: the efficiency from drive motor input to hydraulic pump power output, the efficiency from the hydraulic power input of the tested motor to the mechanical power output of the tested motor and the efficiency from load motor mechanical power input to load converter power output.

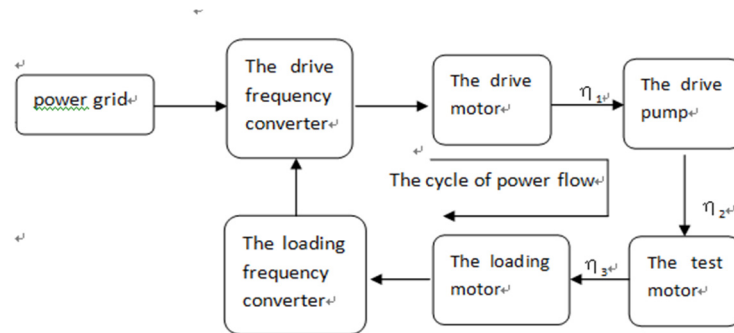


Figure.2 System energy flow diagram

According to Figure.2, the total system efficiency of the hydraulic motor test bench:

$$\xi = \eta_1 \eta_2 \eta_3 \quad (9)$$

$$\eta_3 = N_m / N_p \quad (10)$$

$$N_p = \frac{2\pi n T}{60} \quad (11)$$

$$N_m = UI \quad (12)$$

Where, η_1 is the total efficiency of drive motor pump set; η_2 is the total efficiency of the tested motor; η_3 is the electric power recovery. And the electric power recovery rate is the ratio of the output power loaded on the DC bus of the inverter to the mechanical power input to the motor. N_m is load inverter output power(W), N_p is load motor input power(W), U is the loading inverter DC bus voltage(V), I is the loading inverter DC bus voltage current(A), n is the loading motor speed (r/min), T is the loading motor torque (Nm). According to (5), (10), (11), (12), test pressure, loading motor speed will have a certain impact on the electric power recovery rate.

3. Electric power recovery hydraulic test and analysis of its test result

3.1. Introduction of test system

The hydraulic pump test system uses the Parker brand model as the PGP640 double gear pump, this pump's preset pressure is 27.6MPa(4000psi), its highest pressure is 30MPa(4351psi), both displacements are 55ml/r. The drive motor power is 132kw and the load motor power is 160kw. The design scheme of the hydraulic motor test system is shown in Figure 3.

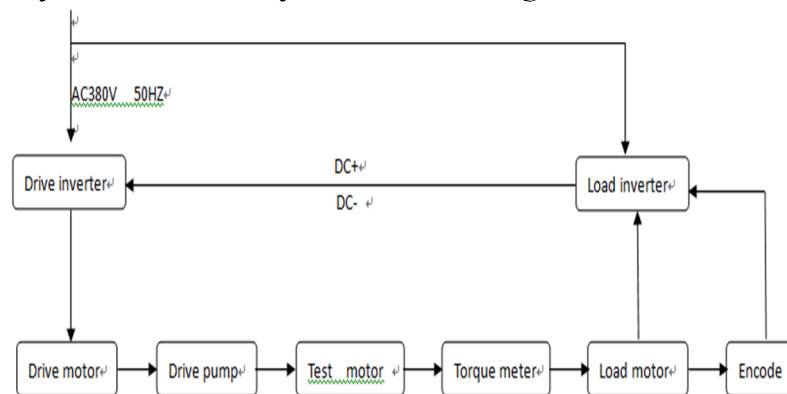


Figure.3 Hydraulic motor test system block diagram

The driving frequency converter adjusts the driving motor speed to drive the driving pump to work, and the high-pressure oil from the drive pump output drives the tested motor to work. The working

pressure of the motor is adjusted by the loading frequency converter. The loading frequency converter controls the loading motor. The loading motor is connected with the tested motor through the torque meter, and a resisting torque is applied to the output shaft of the tested motor, which forming the working pressure of the motor under test. The inverter is connected to the drive inverter through a common bus, and the energy loaded by the load motor is recycled by means of electric energy rectification-feedback-inversion to realize energy recycling, thereby, energy saving has been achieved. The loading motor and the speed encoder are matched, which constitutes an electric power recovery motor test system with excellent performance.

3.2 The effect of pressure on electrical power recovery

Table 1 is the test value of Parker gear motor with displacement of 110ml/r at a speed of about 700RPM and different test pressures. According to (10), the electric power recovery efficiency is the ratio of output electric power on the DC bus of the load inverter to the mechanical power input to the motor. According to the data tested in Table 1, the relationship between the mechanical power input of the loading motor and the electric power output of the inverter has been analyzed.

Table.1 Gear motor 700RPM test data

Speed (r/min)	Torque (N.M)	Pressure A (MPa)	Pressure B (MPa)	Flow (L/min)	Current (A)	Voltage (V)
703.18	51.16	4.22	0.5	82.26	3.43	545
697.46	100.79	7.28	0.5	85.05	10.05	545
703.77	165.84	11.19	0.52	89.23	18.76	545
705.97	230.29	15.13	0.52	90.43	27.39	545
702.06	286.94	18.72	0.52	89.52	34.51	545
696.46	332.4	21.87	0.53	88.82	40.29	545

Bring the test data in Table. 1 into (11),(12), the relationship between the mechanical power input value of the loading motor and the output power value of the loading inverter is shown in Figure 4. Where X is the mechanical power input value of the loading motor, and Y is the output value of the loading inverter electric power.

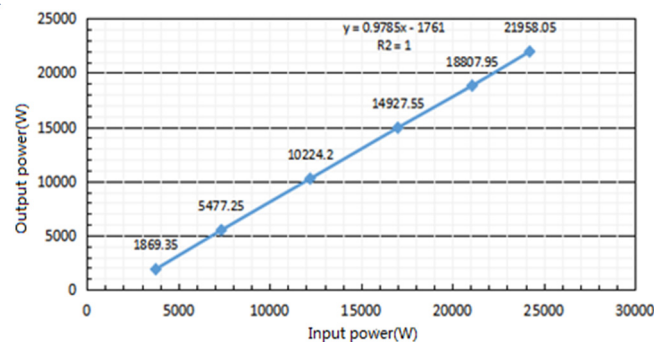


Figure.4 Mechanical power input of the loading motor-the loading inverter electric output power

$$y = 0.9785x - 1761 \quad (13)$$

Y is the loading inverter electric output power, X is the mechanical power input of the loading motor. The equation's coefficient of determination is 1, the range of its value is [-1,1], it means that the mechanical power input value of the load motor is highly correlated with the output of the inverter's electrical power output. According to (13), when the mechanical power input value of the loading motor is less than 1800w, the output power value of the loaded inverter is less than 0. When the mechanical power input of the loading motor is less than 1.8 KW, the inverter is loaded with no

electric power output. Considering the iron loss, rotor copper loss, stator copper loss, ventilation friction loss and impurity consumption of the load motor and the loss of the electronic components of the inverter, a certain degree of mechanical power input is required to perform power output.

The electric power recovery rate is obtained by bringing the inverter electric power output value and the loading motor mechanical power input value into the equation (10). And draw the mechanical power input-electric power recovery curve of the loading motor as shown in Figure 5. In the figure, the abscissa is the mechanical power input value of the loading motor, and the ordinate is the electric power recovery rate. It can be seen from the curve trend that the larger the mechanical power input value of the loaded motor, the higher the electric power recovery rate, but the increase of the electric power recovery rate becomes smaller as the input value of the mechanical power input of the motor increases. The increase in electrical power recovery tends to be smooth as the input value of the mechanical power input to the motor increases.

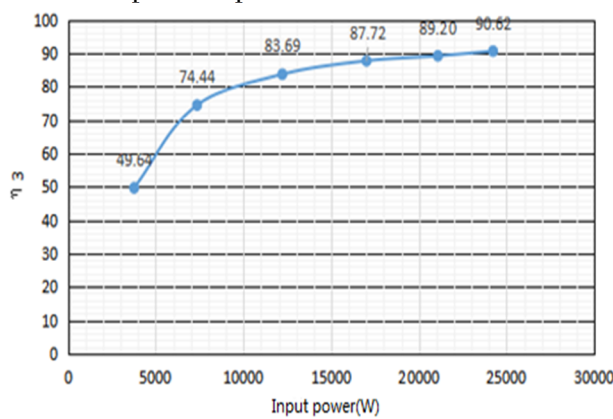


Figure.5 The mechanical power input of the loading motor-The electric power recovery rate

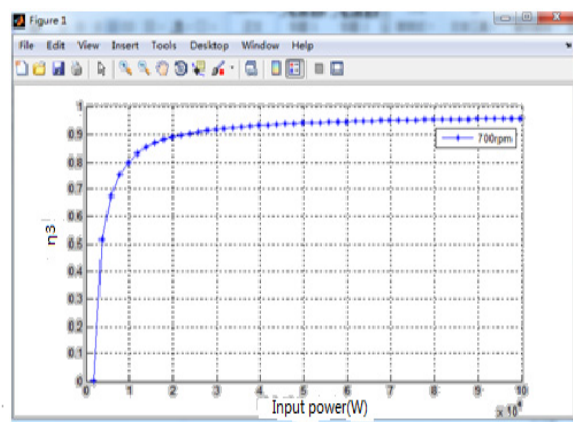


Figure.6 The mechanical power input of the loading motor- The electric power recovery rate (Simulation diagram)

$$\eta_3 = 0.9785 - \frac{1761}{x} \quad (14)$$

Where, η_3 is the electric power recovery rate, x is the mechanical power input of the loading motor.

Fig .6 is the simulation diagram of the mechanical power input of the loading motor-The electric power recovery rate. According to the diagram, when the mechanical power input of the loading motor is getting larger and larger, the electric power recovery rate changes less and smaller and approaches constant. Since the rated power of the drive motor is 132 KW, and with the hydraulic power loss and mechanical power loss between the power output of the drive motor and the mechanical power input of the load motor, the maximum input value of the mechanical power of the load motor does not exceed 100 KW. Therefore, the system has a maximum electric power recovery rate of 0.96 at a speed of about 700 RPM.

3.3. The effect of speed on electrical power recovery

In order to verify the influence of the test system on the electric power recovery rate at different speeds, we test the system at 400RPM, 500RPM, 600RPM, 700RPM, 800RPM, 900RPM, 1000RPM, 1100 RPM. The test data is brought into the equation (11) and (12), and the relationship between the mechanical power input value of the loaded motor at different speeds and the electric power output of the loaded inverter is shown in Fig. 7.

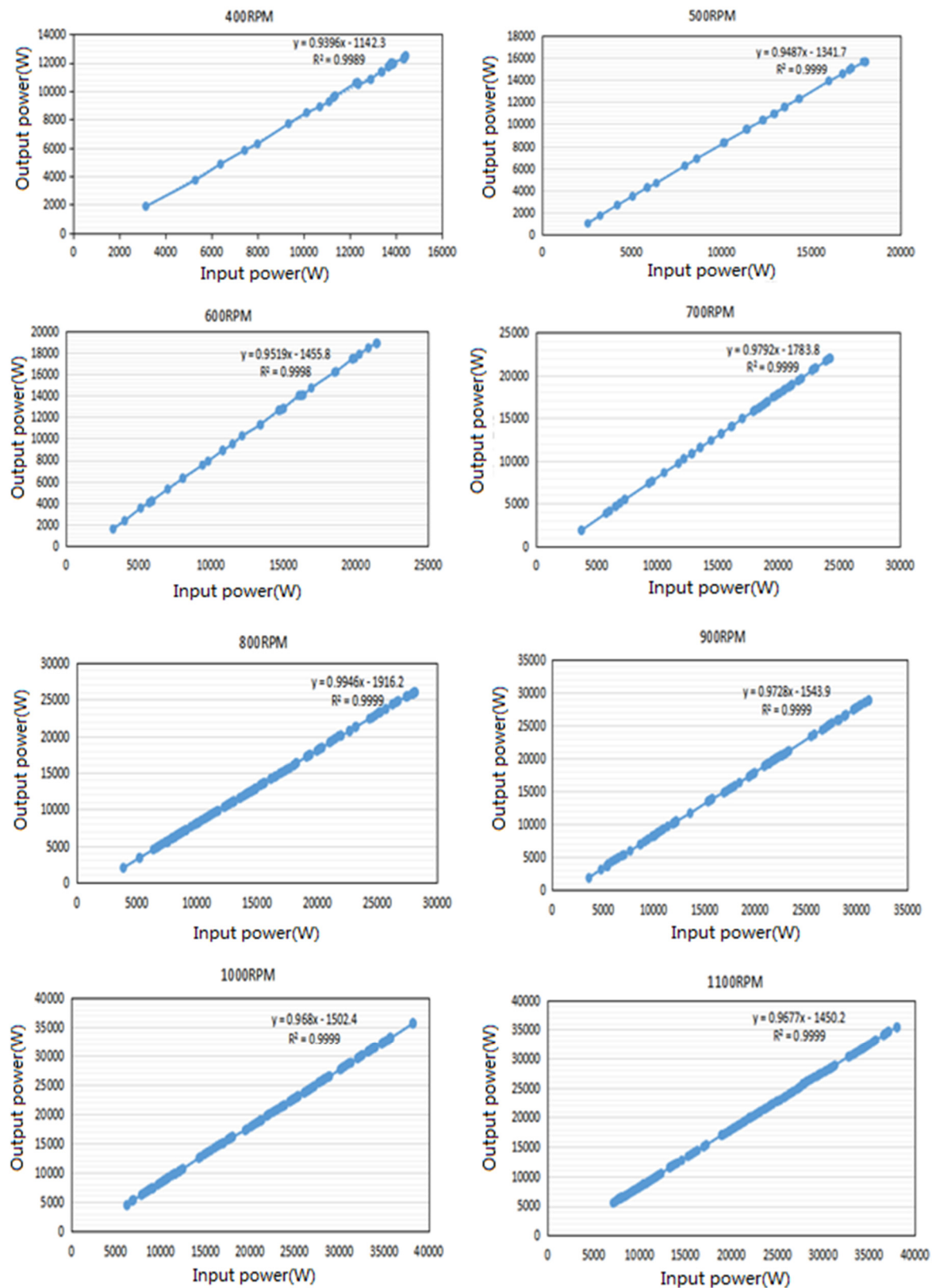


Figure.7 Mechanical power input of the loading motor-the loading inverter electric output power at different speed

According to Fig.7, for the hydraulic motor test system with electric power recovery, the mechanical power input of the loading motor and the electric power output of the loading frequency converter are approximately linear, and have no relation with speed.

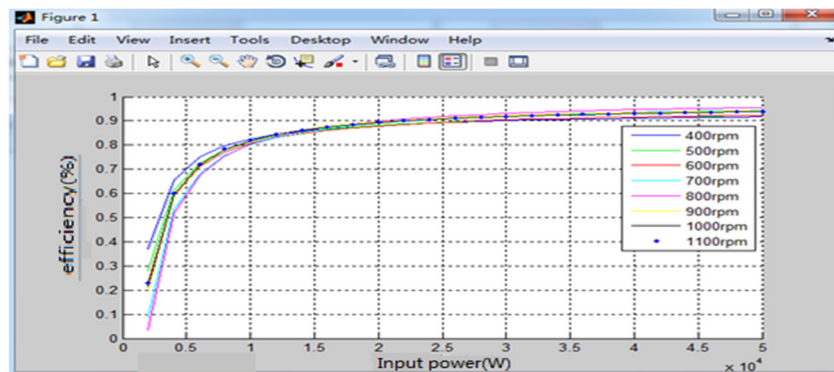


Figure.8 Mechanical power input of the loading motor-the loading inverter electric output power at different speed (Simulation diagram)

In order to analyze the effect of rotational speed to electric power recovery, Put the regression equation of load under different rotational speed motor mechanical power input and the electrical load frequency converter output in Fig 7 into equation (10), the trend diagram of load motor mechanical power input - electric power recovery has been obtained and is shown in figure 8. It can be found from the diagram that under different rotational speed, the curve meets the following conditions: loading of the motor mechanical power input value, the greater the power recovery rate is higher, and power recovery rate of change is more and more small and reaching a constant feature. It's also can be found from the picture, when the load motor mechanical power input value is less than 15 kw, the electrical system under the 400 RPM speed of recovery than other speed under electric power recovery, and electric power recovery is the lowest at 800 RPM speed; And when the load motor mechanical power input value is higher than 15 kw, the electrical system under the 800 RPM speed of recovery than other speed under electric power recovery, and a minimum electric power recovery speed at 400 RPM. The test result also shows that the test speed of the tested motor has a certain influence on the electric power recovery of the system. The cause of this result has a certain relationship with the working characteristic of motor itself has a certain relationship, including subjects rated pressure and rated speed of the motor, and also a certain connection with the loading motor run time copper loss, iron loss, rotor stator copper loss, ventilation, friction loss and the impurities such as consumption loss and the wastage of the inverter electronic components, which all have a certain influence on the calculation results of power recovery. Therefore, in some test items, the maximum power recovery rate can be obtained by selecting the appropriate test speed according to Fig.8.

4. Conclusion

The change of test speed and test pressure will affect the electric power recovery. By selecting the appropriate test speed and pressure, the motor test system of electric power recovery energy utilization can be improved, the total installed power of the system, also the power consumption of the system, can get reduced, which solved the problem of heat dissipation of high power hydraulic motor load test.

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