# Design of the hydraulic system of a new type of combined machine tool

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## Abstract

Combined machine tools play an important role in mechanical design because of their unique advantages. It is based on general components, according to the workpiece processing needs, with a small number of dedicated components to form a machine tool, it has the advantages of low efficiency and high efficiency. In view of the current trend of development, if a flexible system is added to a combined machine tool, it will develop into today's machining center. There are many advantages of hydraulic transmission: under the same volume, the hydraulic device can produce more power than electric power. The hydraulic device works more smoothly and can realize stepless speed regulation in a large range and easy to realize overload protection. It is simple to use hydraulic transmission to realize linear motion than mechanical transmission.

## Keywords

Combined machine tool, hydraulic transmission, hydraulic system.

## 1. Introduction

The design of the hydraulic system is a part of the whole machine design. Its task is to draw up a reasonable hydraulic system diagram by using the basic principle of the hydraulic transmission, and then to determine the parameters of the hydraulic system by the necessary calculation, and then select the specifications of the hydraulic components according to these parameters. And carry out the structure design of the system.

## 2. System working condition analysis

### 2.1 Motion analysis

In this paper, a horizontal single side multi-axis boring machine tool is taken as an example to design the hydraulic system to drive its power slide platform. The work cycle is: fast forward - working - fast retreat - stop. The system parameters are shown in table 1 as follows. The dynamic sliding table adopts a plane guide, its dynamic friction $f_d$ and static friction $f_s$ coefficients are 0.1 and 0.2 respectively. The total mass of the working parts of the machine tool is 9800N, the hole one has 10 and the hole two has 5, the acceleration and deceleration time of the reciprocating motion is not more than 0.2s, and the actuating element in the hydraulic system is a hydraulic cylinder.

Table 1 System parameters of combined machine tool

| Parameter | Hole one diameter (mm) | Hole two diameter (mm) | Fast forward and fast back speed (m/min) | Speed of work (mm/min) | Fast forward stroke (mm) | Work stroke (mm) | Material hardness (HB) |
|---|---|---|---|---|---|---|---|
| Size | 13.8 | 8.50 | 6.0 | 53 | 100 | 50 | 240 |

### 2.2 Load analysis of machine tools

(1)Work load

The empirical formula of axial cutting force $F_t$ (unit N) and drill diameter D (unit mm), per rotation feed s (unit mm/r) and casting hardness HBW are the following formulas for high speed steel drilling cast iron hole [1]:

$$F_t=25.5Ds^{0.8}(HBW)^{0.6}$$

The spindle speed n and per rotation feed s are selected according to the combined machine tool design manual:

Holes for diameter 13.8mm,$n_1$=360r/min,$s_1$=0.147mm/r;

Holes for diameter 8.50mm,$n_2$=550r/min,$s_2$=0.096mm/r.

Substituting for the upper type:

$$F_t=\left(10\times25.5\times13.8\times0.147^{0.8}\times240^{0.6}+5\times25.5\times8.5\times0.147^{0.8}\times240^{0.6}\right)\text{N}=26607\text{N}$$

(2)Mass load

$$F_m=m\frac{\Delta v}{\Delta t}=\frac{9800}{9.8}\times\frac{6}{60\times0.2}=500\text{N}$$

(3)Resistance load

static friction resistance$F_{fs}$=0.2×9800=1960N

frictional resistance$F_{fd}$=0.1×9800=980N

As a result, the load of the hydraulic cylinder at all stages is shown in table 2.

Table 2 The load value of the hydraulic cylinder at each working stage /N（ηm=0.9）

| working condition | Load composition | Load value F | Thrust F/ηm |
|---|---|---|---|
| Start | $F=F_{fs}$ | 1960 | 2178 |
| Accelerate | $F=F_{fd}+F_m$ | 1480 | 1644 |
| Fast forward | $F=F_{fd}$ | 980 | 1089 |
| Work | $F=F_{fd}+F_t$ | 27587 | 30652 |
| Fast back | $F=F_{fd}$ | 980 | 1089 |

Notes:1. The mechanical efficiency of the hydraulic cylinder $\eta_m$=0.9[2];

2. The effect of the subversion of the torque on the power slide is not considered.

### 2.3 Draw a load map and a velocity map

The load graph is drawn according to the above values, as shown in Fig. 1 below. Known velocity graph $v_1=v_3$=6m/min,$v_2$=53mm,$l_1$=100mm,$l_2$=50mm,fast back trip $l_3=l_1+l_2$=150mm. So drawing the speed diagram is shown in Fig. 2 below.

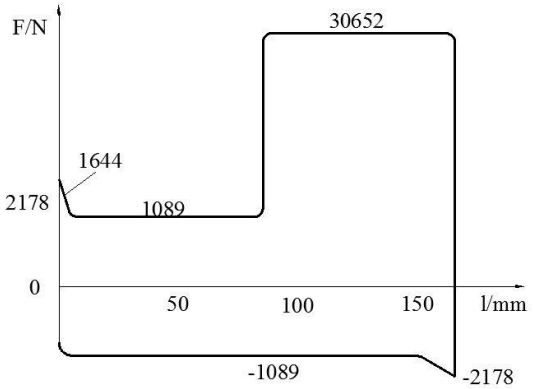



Fig. 1 The load diagram of the hydraulic cylinder of the combined machine tool

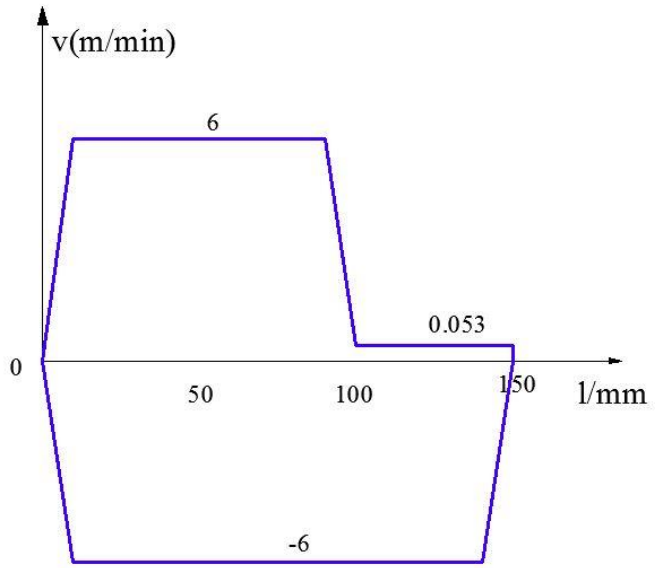



Fig. 2 Speed diagram of a hydraulic cylinder of a combined machine tool

**2.4 Determine the main parameters of the hydraulic cylinder**

The dynamic sliding table designed in this paper has the maximum load and the value of 30652N, and the load in other working conditions is lower than that of it, the reference table 3 and the table 4, the working pressure of the primary hydraulic cylinder $p_1$=3.2MPa.

Table 3 Selection of work pressure by load/MPa

| Load/ KN | <5 | 5 ~ 10 | 10~ 20 | 20~ 30 | 30~ 50 | >50 |
|---|---|---|---|---|---|---|
| Working pressure | <0.8~ 1 | 1.5~ 2 | 2.5~ 3 | 3~ 4 | 4~ 5 | ≥5 |

Table 4 System working pressure commonly used for various machines /MPa

| Mechanical type | Machine tool | | | | agricultural machinery Small engineering machinery Construction machinery structure | Hydraulic press large and medium excavator heavy machinery Hoisting machinery |
|---|---|---|---|---|---|---|
| | Grind-ing machi-ne | Comb-ined machi-ne tool | Longm-en planer | Drawin-g machine | | |
| Working pressure | 0.8~2 | 3~5 | 2~8 | 8~10 | 10~18 | 20~32 |

Because the speed of fast forward and fast back is equal to the power slide, the hydraulic cylinder can be selected by single pole type, and the hydraulic cylinder should be connected when fast forward. In this case, the working area of the rod less cavity of the hydraulic cylinder should be two times that of the $A_2$ with the working area of the rod cavity $A_1$. That is, the relationship between piston rod diameter and cylinder diameter is d=0.707D[3]。 In order to prevent the sudden loss of load when the hole is drilling, the $p_2$=0.8 MPa is designed according to the design manual[4]. While the hydraulic cylinder is a differential connection, the back pressure of the hydraulic cylinder should be Δp, and the pressure of the rod must be greater than the non rod cavity, and it is estimated to take the "Δp=0.5MPa" when it is estimated. There is a back pressure in the oil return cavity when it returns. Take $p_2$=0.6MPa calculation here. Calculation of hydraulic cylinder area by thrust force:

$$\frac{F}{\eta_m}=A_1p_1-A_2p_2=A_1p_1-(A_1/2)p_2$$

$$A_1=\frac{\frac{F}{\eta_m}}{p_1-\frac{p_2}{2}}=0.0109\text{m}^2$$

$$D=\sqrt{(4A_1)/\pi}=118\text{mm};d=0.707D=83.426\text{mm}.$$

Get these diameters round by GB/T2348-2001[5]:D=120mm,d=80mm. The actual effective area of the two chamber of the hydraulic cylinder is obtained:$A_1=0.0113\text{m}^2$,$A_2=0.00628\text{m}^2$. According to the above D and d values, we can estimate the pressure p, flow q and power P of the hydraulic cylinder at all stages of operation, as shown in Fig. 3 below.

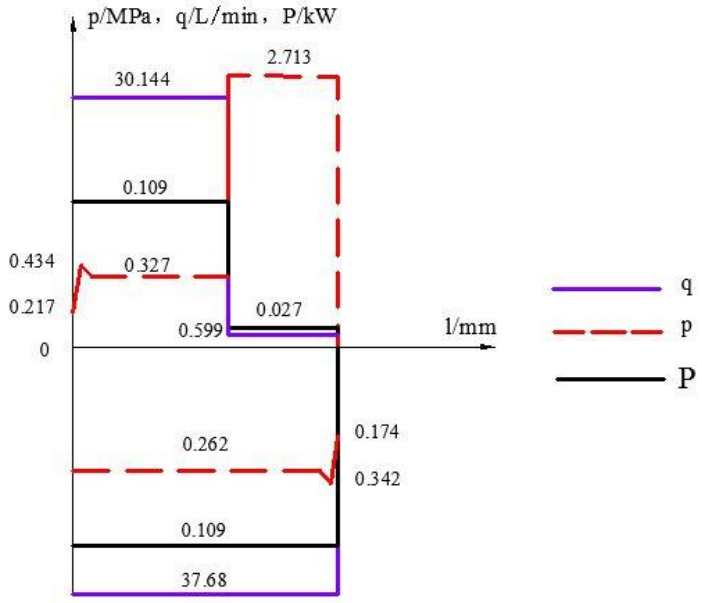
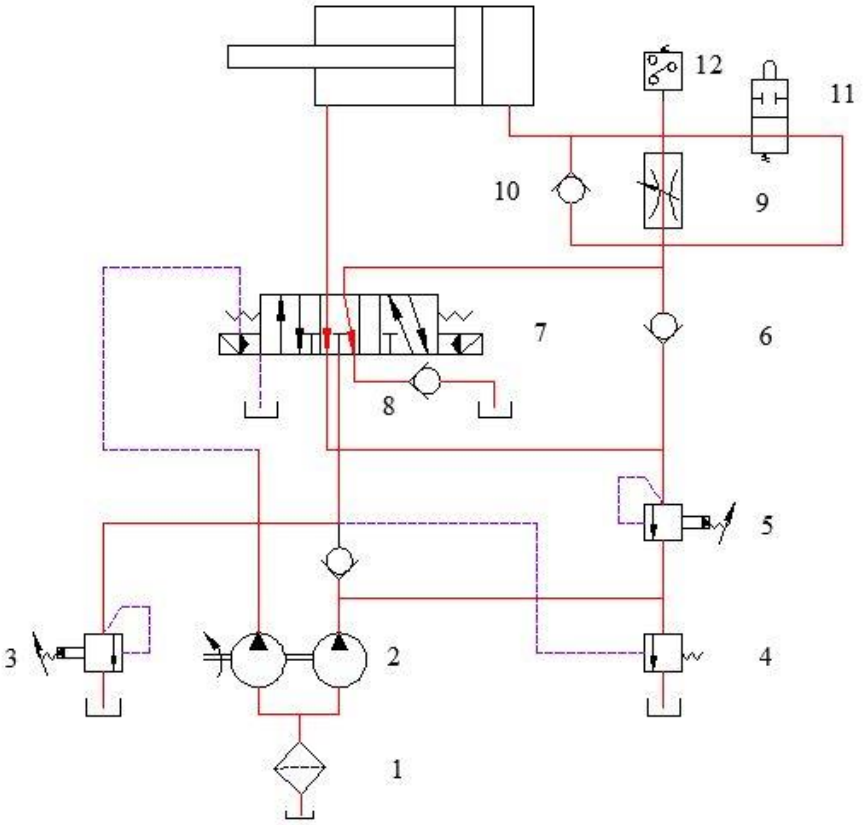



Fig. 3 Diagram of hydraulic cylinder working condition of combined machine tool

**2.5 Draw up the hydraulic system of machine tool**

The speed control loop is selected first. From Fig. 3, it is known that the hydraulic system of this machine tool is small in power, low in speed of sliding table, and the work load is resistance load and small change in work. Therefore, import throttle speed control loop can be used. In order to prevent the sudden loss of the load during drilling, the moving parts are pushed forward, and the back pressure valve is installed on the oil return road. Because the system adopts throttling speed regulation mode, the system must be open cycle system. Secondly, the fast motion and commutation loop are selected. The system has selected two fast motion loops, differential connection of hydraulic cylinder and double pump oil supply, to realize fast movement. Again, it is the choice of the speed switching loop, considering that the flow rate of the back to the oil is larger when the speed of the work is turned and retreats, so the electro hydraulic reversing valve replacement loop is selected to reduce the hydraulic impact. To achieve differential connection of hydraulic cylinders, three position five way electro-hydraulic reversing valve is selected. Finally, in consideration of the pressure control loop, because the system's pressure and unloading problems have been solved in the oil source, there is no need to set up special components or oil routes, that is to choose two hydraulic pumps with large and small pumps. By combining the above circuits, we can get the schematic diagram of the hydraulic system shown in Fig. 4.




1—filter 2—double vane pump 3—overflow valve 4—sequence valve 5—back-pressure valve 6-,8,10— one-way valve 7—electro hydraulic valve 9—speed regulating valve 11—travel valve 12—pressure relay

Fig. 4 Hydraulic system diagram of combined machine tool

## 3. Conclusion

It can be seen that the one-way valve 6 in the hydraulic system diagram of the combined machine tool is designed to solve the problem that the system pressure can not be established by the entry of the sliding table and the collusion of the oil circuit. And the one-way valve 8 can avoid the oil flowing back into the tank in the circuit when the machine stops working, which leads to the air entering the system and affects the smoothness of the sliding table. The pressure relay 12 can improve the positioning accuracy of the machine tool when drilling. Generally speaking, the hydraulic system designed is reasonable and perfect.

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