Design and research of hydraulic screed test bench

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Abstract. In order to meet the requirements of the performance test of the screed, a hydraulic test bench for screed is designed, which realizes the action of the screed. On this basis, the test bench measurement and control software based on LabVIEW is developed, it completes the tests and data analysis of screed. The test results show that the system has perfect functions and meets the requirements of screed test.

1. Introduction

With the development of highway construction in our country, the application of paver is more and more widely. It is one of the key equipment for the construction of base and surface layer of various grades of highway[1]. As the core part of the paver, the screed is used to tamper and compact the spreading material. Obviously, the performance of the screed determines the quality of the road. Therefore, when the paver leaves the factory, the performance test of the screed is the basis to ensure the quality of the paver. In this paper, according to the test requirements of the screed, a kind of screed test bench is designed, which can test the functions of each part of the screed, record and analyze the data obtained.

2. Design of test bench system

2.1. Hydraulic system

1. Pump 1; 2. Pump 2; 3. Reversing valve; 4. Relief valve 1; 5. Relief valve 2; 6. Flowmeter

Figure 1. Hydraulic schematic diagram
The power of the system is provided by pump 1 and pump 2 driven by two 22KW variable frequency motors respectively, and the maximum flow rate is 156L/min. Considering the difference of rated flow required by different test items of the screed, it can be used alone or together according to the actual test conditions. The maximum pressure of the system is controlled by pilot relief valve 4 and pilot relief valve 5, and the pressure is 16MPa and 10MPa respectively. The pressure is switched by directional valve 3 and used according to the test items. The system flow is measured by screw flowmeter 6 and fed back to the instrument.

In the hydraulic schematic diagram, the hydraulic system of screed is in the dotted box, which is composed of hydraulic cylinder circuit, tamper circuit and vibration circuit. The hydraulic cylinder circuit is composed of diverter valve, two position three-way reversing valve and hydraulic cylinder. The diverter valve ensures that the flow into the two hydraulic cylinders is the same even under different loads, so as to realize the synchronous action of the two cylinders. In the tamper circuit and vibration circuit, the motor speed is adjusted by controlling the flow through the proportional directional valve.

2.2. Measurement and control system
The electrical measurement and control part of the test bench includes industrial computer, PLC, frequency converter, variable frequency motor, data acquisition card, isolation module, instrument, proportional amplifier, etc.

![Measurement and control structure of test bench](image)

IPC is the core of the whole test system. It communicates with the lower computer through various interfaces. As the terminal equipment of the test system, it is used to realize the interaction between the operator and the test system. As the lower computer, PLC executes the command of the operating platform and IPC to control the test bench. It communicates with IPC through OPC server.

Data acquisition card PCI-1710u provides data acquisition and analog output functions. The card communicates with the IPC through PCI bus. Data acquisition is used to collect all kinds of sensor signals; analog output is used to control the frequency converter motor speed and finally control the system flow.

The proportional amplifier outputs the corresponding current to control the proportional valve, meanwhile the real-time current is transmitted to the upper computer through RS-485 serial bus used by Modbus protocol. This serial communication method can reduce the electrical interference in field and accurately reflect the output current.

2.3. Software design
The software of measurement and control system is developed by LabVIEW, which adopts the idea of modular programming[2]. It consists of data acquisition module, test parameter setting module, automatic test module and data recording module. The data acquisition module will obtain the electrical signals of all sensors from the data acquisition card through Advantech DAQ driver, and convert the electrical signals into actual values. The test parameter setting module can set all test
parameters, including sensor calibration parameters and hydraulic cylinder automatic test parameters. The automatic test module can complete the automatic test of hydraulic cylinder. The data recording module can record test data and generate corresponding reports.

3. Function test of screed

3.1. Expansion and contraction test of screed

In the actual operation process of paver, due to the change of the road width, it is necessary to control the extension distance of the left and right extension sections of the screed by the hydraulic cylinder, so as to realize the stepless adjustment of the paving width[3]. Hydraulic cylinder test mainly tests the pressure and speed when hydraulic cylinder extension and retraction, the purpose of the test is to verify the reliability of hydraulic. Because manual test can not accurately judge and record the movement speed and pressure of hydraulic cylinder, an automatic test method is designed in this system.

According to the relevant hydraulic principle, the following main conclusions: (1) Set the pressure of the system relief valve be $P_0$, the inlet pressure be $P$. When the hydraulic cylinder extends or retracts, all the oil flows into the cylinder, and the pressure $P < P_0$. When the hydraulic cylinder stops moving, all the oil flows into the relief valve, and the pressure $P = P_0$. (2) Let the cylinder diameter is $D$ and the rod diameter is $d$. Its extension pressure $P_2$ and retraction pressure $P_1$ satisfy the following relationship when under same load.

$$\frac{P_1}{P_2} = \frac{D^2 - d^2}{D^2} \quad (1)$$

Summing up, we can see that $P_1 < P_2$, now set a pressure $P'$, let $P_2 < P' < P_0$. When the inlet pressure $P < P'$, the hydraulic cylinder is considered to be moving. When the inlet pressure $P > P'$, the hydraulic cylinder is considered to stop moving. In this way, the automatic telescopic control of hydraulic cylinder is realized. The specific test results are as follows. In this test, keeping oil flow to 55L/min, since the telescopic circuit is equipped with a diverter valve, thus the flow into each hydraulic cylinder is half of the inlet flow[4]. From the actual hydraulic cylinder parameters, it can know that cylinder diameter $D=80mm$, rod diameter $d=50mm$, stroke $l=1343mm$. Also it can be seen from the above that $P_1/P_2 = 0.61$, extension time $t_1 = 14.7s$ and retraction time $t_2 = 9.0s$.

| No. | Inlet flow | Extension pressure | Retraction pressure | Extension time | Retraction time |
|-----|------------|--------------------|---------------------|----------------|-----------------|
| Left hydraulic cylinder | 55L/min | 7.2Mpa | 13.7Mpa | 14.5s | 9.3s |
| Right hydraulic cylinder | 55L/min | 6.4Mpa | 12.8Mpa | 15.3s | 9.5s |

According to the test results, the extension and retraction speed of the two cylinders are basically the same, which is similar to the theoretical value, indicating that the two cylinders have good cooperation and the diverter valve works normally. Also it is noted that there is a deviation between the ratio of extension pressure and retraction pressure and the theoretical value, which may be caused by the inconsistent load of hydraulic cylinder extension and retraction.

3.2. Tamper test of screed

The tamper mechanism is an important part of the screed, which plays an important role in the compactness and flatness of the pavement[5]. The tamper frequency of the tamper system is determined by the speed of the tamper motor, and the speed of the tamper motor is regulated by the flow rate controlled by the proportional direction valve. Therefore, this experiment tests the relationship between the input electrical signal and the speed of the tamper motor, and explores the influence of the tamper motor speed on the system stability. The results are as follows.
Figure 3. Relationship between tamper current and speed of tamper motor

It can be seen from the figure 3 that the input electrical signal is basically proportional to the speed of the tamper motor, the system pressure also rise with the increase of the tamper motor speed, and there are some deviations in the allowable range of motor speed on both sides. It is found in the test that when the speed of the tamper motor continues to increase, the screed will have resonance phenomenon. In order to determine the natural frequency of the screed, the following conclusions are drawn according to the relationship between the vibration amplitude of the system pressure and the speed of the tamper motor.

Figure 4. Inlet pressure amplitude curve

It can be seen from the figure 4 that when the tamper motor speed is 1000 rpm, that is, when the tamper frequency is about 16 Hz, the vibration amplitude of the screed is the largest, and the vibration occurs between 800-1200 RPM of the tamper motor. According to the test results, the mechanical structure of the screed should be adjusted according to the resonance frequency, and the natural frequency of the screed should be changed to avoid resonance in actual use.

4. Camber detection and displacement fitting of screed
Considering that the pavement shape requires different camber of the screed, the camber state of the screed directly acts on the paved pavement, which has a great impact on the pavement construction quality[6]. So when the screed leaves the factory, it is necessary to adjust the camber of the screed to meet the pavement laying requirements. The conventional camber adjustment is completed by measuring the displacement of each part, which requires a lot of time and is very inconvenient. In this test bench the camber detection is completed by eight angle sensors installed at the bottom of the screed, and the deformation displacement of the screed is fitted by the obtained angle value. This
method is convenient for the operator to adjust the camber of the screed in real time. The figure 5 shows the installation diagram of angle sensor.

![Figure 5. Installation position of angle sensor](image)

First define the following parameter: let \( x_i \) is the position where the angle sensor is placed on the screed, \( \theta_i \) is the dip angle of the corresponding position, \( k_i \) is the slope of the corresponding position, \( y_i \) is the screed fitting displacement, \( Y_i \) is the actual displacement of the screed. Consider the following two methods when fitting the screed displacement.

4.1. Method 1: Direct fitting
Generally, we think that the dip angle of the screed is very small, so the displacement of this point can be directly obtained, and then the displacement of all positions can be obtained by adding the displacement of multiple segments. The displacement expression of each segment is shown as follows, \( x_0 \) is the position of sensor 5 in the above figure.

\[
\begin{align*}
    y_i &= x_i \tan(\theta_i) & i &= 0 \\
    y_i &= x_i \tan(\theta_i) + \sum_{j=0}^{i-1} y_j & i &\neq 0
\end{align*}
\] (2)

The displacement of the right segment is obtained by the above method, In the same way, the displacement of the left segment can be obtained. Finally, for all the points \((x_i, y_i)\), the displacement function \(f(x)\) is obtained by cubic polynomial fitting.

4.2. Method 2: Integral fitting method
First, we calculate the slope of the dip angle, then the slope function \(g(x)\) of the screed is obtained by quadratic polynomial fitting by \((x_i, k_i)\), and the displacement function \(f(x)\) of the screed can be obtained by integrating \(g(x)\).

\[
k_i = \tan(\theta_i)
\] (3)

\[
f(x) = \int_{x_0}^{x} g(x)dx
\] (4)

4.3. Test result and comparison
For the error between the fitting curve and the real value, In this paper uses a method called RSS(Residual Sum of Squares) to compare.

\[
S = \sum_{i=0}^{a} (f(x_i) - Y_i)^2
\] (5)

Since there is no reference point specified in the above two methods and actual displacement measurement, to make the calculations convenient, \(x_0\) is taken as the reference point.

| Table 2. Fitting displacement and actual displacement |
|------------------------------------------|
| Sensor position/m | -3  | -2.25 | -1.5  | -0.75 | 0.75 | 1.5  | 2.25 | 3   |
| dip°             | 0.11| 0.09  | 0.05  | 0.03  | -0.04| -0.06| -0.08| -0.09|
| Screed real displacement/mm | 0   | 0.49  | 1.45  | 3.1   | 2.35 | 1.79 | 0.64 | 0.17|
| Method 1 displacement/mm | 0   | 1.44  | 2.61  | 3.27  | 3.14 | 2.62 | 1.57 | 0.39|
| Method 2 displacement/mm | 0   | 1.31  | 2.18  | 2.64  | 2.47 | 1.89 | 1.02 | -0.12|
For method 1 and method 2 in the table, the results are obtained that $S_1 = 38.9, S_2 = 1.6$. It can be seen that method 2 is more accurate than method 1 because the nonlinear error in method 1 will gradually increase with the accumulation, so the fitting displacement will be greatly different from the actual displacement. However, it should be noticed that there is the possibility of error accumulation in the integration of method 2, when there are enough sensors in method 1, the error of each part will be reduced and the fitting value will be closer to the real value.

5. Conclusion

According to the actual test results, the design and function of the test bench meet the requirements of the screed test. It can complete all kinds of tests of the screed. Also, it has the characteristics of high precision, convenient operation and stable operation. Therefore, this test bench is of guiding significance in the design, manufacture and practical use of the screed.

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