Experimental Study on Reconstruction of Articulated Disk Spectrum Based on LabVIEW

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Abstract. In order to realize the requirements of the down-line test of the articulated disk spectrum produced by an enterprise, this paper designs a set of automatic test system for the articulated disk. The working principle of the system is elaborated. The fuzzy PID algorithm is used to realize the precise control of the angle through the LabVIEW software platform. The CAN bus is used to realize the communication between the test bench and the articulated disk under test. Finally, the reliability of the test system is verified by the actual test, and the final test bench meets the requirements of the company and is accepted successfully.

1. Preface
Articulated disk is an important part of the front and rear carriage connection of articulated passenger cars. It is mainly composed of articulated plate, connecting pin and thrust rod. It is responsible for the support, traction and steering of the front and rear carriages. In order to meet the off-line test requirements of the articulated disk produced by an enterprise, the road spectrum of the articulated disk in the actual use process should be simulated, mainly including Angle and speed. Electro-hydraulic servo valve is used to realize the Angle control of circuit spectrum reproduction, and CAN bus communication is used to realize speed simulation and running state monitoring of test pieces. Combined with relevant test requirements, the simulation experiment and comparative study of articulated disk products are carried out by using fuzzy PID control algorithm.

2. Test system design
The road spectrum of the articulated disk mainly includes information such as Angle, speed and gear position. In order to realize the road spectrum reproduction of the articulated disk, it is actually required to simulate the Angle, the vehicle speed and the gear state of the articulated disk during the test.

2.1 Angle Reproduction
The articulated disk shall overcome the pressure of the hydraulic cylinder in the process of rotation, and the maximum test pressure shall be 15Mpa. For this reason, an electro-hydraulic servo Angle control system is designed in this paper to realize the precise control of the hinge turning Angle. As shown in FIG.1, the power source is a plunger pump driven by a three-phase asynchronous motor. The inlet pressure of the servo valve is adjusted by adjusting the opening size of the proportional overflow valve.
By adjusting the size of the opening of the servo valve to drive the motor rotation, through the reducer finally realized the rotation of the articulated disk. Pressure sensors and pressure gauges are provided at key positions on the hydraulic pipeline, and Angle sensors are installed at the connection between the test bench and the articulated disk.[2]

\[ \text{Figure 1. Schematic diagram of the hydraulic system} \]

During the test, the value of the Angle sensor is converted to the controller through the acquisition card A/D. After the calculation of the controller, the analog signal is output to the servo amplifier through the acquisition card D/A module to control the opening size of the servo valve, so as to realize the Angle control of the articulated disk. By continuously reading the Angle value of the test circuit spectrum into the controller, the Angle reproduction of the articulated disk can be realized.

2.2 Vehicle speed, gear position controls
In order to simulate the reliability of the articulated disk under various operating conditions, in addition to the Angle, it is also necessary to simulate the speed and gear of the articulated disk (the parameters of different types of products are different) and other parameters, which are fed back to the articulated disk by the vehicle during the actual use of the articulated disk. Therefore, this part of simulation can be realized through CAN communication simulation. During the test, the measurement and control software reads the real-time speed and gear position of the articulated disk at a specific Angle in real time, and sends it directly to the articulated disk through the communication between the upper computer and the articulated disk ACU. The articulated disk then feeds back the pressure, current, emergency valve and other information under the running state. By comparing the feedback signal with the standard signal, we can judge whether the articulated disk is qualified.[3]

3. Fuzzy controller design

3.1 Structure of the fuzzy PID controller
The fuzzy PID controller is composed of two parts, namely the fuzzy inference and the conventional PID controller. Its structure is shown in the FIG.2. The fuzzy PID controller is based on the conventional PID controller and adopts the method of fuzzy reasoning. According to different Angle deviation \( e \) and Angle deviation change rate \( e_c \), the three parameters of PID are self-tuning online to improve the dynamic performance of the controlled object. The method of adjustment is 

\[ K_p = K_p' + \Delta K_p, K_i = K_i' + \Delta K_i, K_d = K_d' + \Delta K_d \]

and the \( K_p', K_i', K_d' \) is the preset initial value, and the \( \Delta K_p, \Delta K_i, \Delta K_d \) is the modified value obtained by the fuzzy inference.
Figure 2. The principle of fuzzy PID.

The key to the design of the parameter self-tuning controller is to establish the fuzzy relationship between the displacement deviation $e$, the displacement deviation rate $e_c$, and the three PID parameters $\Delta K_p, \Delta K_i, \Delta K_d$, and then continuously detect the displacement deviation $e$, the rate of change of displacement deviation $e_c$ during the test. Based on the above fuzzy relationship, the modified value is deduced. Then, the three parameters of the PID $\Delta K_p, \Delta K_i, \Delta K_d$ are corrected in real time, so that the control object of the PID controller obtains good dynamic characteristics and static performance.[4]

3.2 Fuzzification of input values
The fuzzification of the input values is to map the input used for the calculation to the normalized numerical interval, and obtain the membership degree of the input pair according to the quantization result and the fuzzy subset. In this paper, seven linguistic variables such as negative big [NB], negative medium [NM], negative small [NS], zero [ZO], positive small [PS], positive medium [PM], and positive big [PB] are used to express their fuzzy subsets. Therefore, define the fuzzy subset of \{e, $e_c$, $\Delta K_p$, $\Delta K_i$, $\Delta K_d$\} is \{NB, NM, NS, ZO, PS, PM, PB\}. These input values and output values are represented by a set of values $n = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$. The basic domain of the displacement deviation $e$ is [-10,10]$^\circ$; the quantization factor $K_e = \frac{n}{e} = 0.6$. The basic domain of displacement deviation rate $e_c$ is [-0.2,0.2]$^\circ$, quantization factor is $K_{ec} = \frac{n}{e_c} = 30$.

The basic domain of $\Delta K_p, \Delta K_i, \Delta K_d$ are [-0.6,0.6],[-0.2,0.2],[-2,2], the scale factor is $K_{kp} = \frac{n}{K_p} = 10, K_{ki} = \frac{n}{K_i} = 30, K_{kd} = \frac{n}{K_d} = 3$.

Figure 3. The basic domain of the displacement deviation.

Figure 4. The basic domain of the displacement deviation rate.

3.3 Establishing a fuzzy rule table
When large displacement deviation $e$ is detected, $K_p$ and $K_d$ need to be increased and decreased for better tracking performance of the system. At the same time, in order to avoid overshoot, the effect of integral coefficient $K_i$ needs to be limited, which generally makes $K_i = 0$.

When the displacement deviation $e$ is moderate, in order to obtain a small overshoot of the system, it is necessary to reduce $K_p$ and take appropriate $K_i$ and $K_d$ values to ensure the reaction speed of the system. Where, $K_d$ value has a great influence on the reaction speed of the system.

When the displacement deviation is very small, in order to make the system better steady state performance and reduce the static error, need to take a bigger values of $K_p$ and $K_i$ value, at the same time, in order to avoid the system in the volatile situation when reach the set-point, $K_d$ value according
to the displacement deviation rate of ec for choice, when the displacement deviation rate $e_c$ is very small, $K_d$ can make large; When the change rate of displacement deviation $e_c$ is large, $K_d$ should decrease.

Combine the above description, the fuzzy rule table of $\Delta K_p$ $\Delta K_i$ $\Delta K_d$ is shown in the following table.

Table 1 $\Delta K_p$ Fuzzy rule table

| $e$ | $e_c$ | NB | NM | NS | ZO | PS | PM | PB |
|-----|-------|----|----|----|----|----|----|----|
| NB  | PB    | PB | PB | PM | PM | PS | ZO | ZO |
| NM  | PB    | PB | PM | PS | PS | ZO | ZO | ZO |
| NS  | PM    | PM | PM | PS | ZO | NS | NM | NS |
| ZO  | PM    | PS | ZO | NS | NS | NM | NM | NM |
| PS  | PS    | ZO | NS | NM | NM | NM | NB | NB |
| PM  | ZO    | ZO | NM | NM | NM | NM | NB | NB |
| ZO  | ZO    | ZO | ZO | ZO | ZO | ZO | ZO | ZO |

Table 2 $\Delta K_i$ Fuzzy rule table

| $e$ | $e_c$ | NB | NM | NS | ZO | PS | PM | PB |
|-----|-------|----|----|----|----|----|----|----|
| NB  | NB    | NB | NB | NM | NM | NS | ZO | ZO |
| NM  | NB    | NB | NM | NS | NS | ZO | ZO | ZO |
| NS  | NB    | NB | NM | NS | NS | NS | PS | PS |
| ZO  | NM    | NM | NS | ZO | PS | PM | PM | PM |
| PS  | NM    | ZO | NS | PS | PS | PM | PM | PB |
| PM  | ZO    | ZO | PS | PS | PS | PM | PB | PB |
| PB  | PB    | PM | PM | PS | PS | PS | PS | PB |

Table 3 $\Delta K_d$ Fuzzy rule table

| $e$ | $e_c$ | NB | NM | NS | ZO | PS | PM | PB |
|-----|-------|----|----|----|----|----|----|----|
| NB  | PS    | NS | NS | NB | NB | NS | NS | NS |
| NM  | PS    | NS | NS | NB | NM | NS | NS | ZO |
| NS  | ZO    | NS | NS | NM | NM | NS | NS | ZO |
| ZO  | ZO    | NS | NS | NS | NS | NS | ZO | ZO |
| PS  | ZO    | ZO | ZO | ZO | ZO | ZO | ZO | ZO |
| PM  | PB    | NS | PS | PS | PS | PM | PM | PB |
| PB  | PB    | PM | PM | PM | PM | PM | PM | PB |

3.4 Simulation verification

FIG. 5 is the test result of Angle control of articulated disk under sinusoidal input signal, and FIG. 6 is the error curve of Angle control under sinusoidal signal. It can be seen that the dynamic error calculated by RMS is 0.97 degrees. That is to say that the fuzzy control system can meet the test requirements of the test bench.

Figure 5. Fuzzy PID actual angle tracking curve. Figure 6. Fuzzy PID actual angle tracking deviation curve.
4. Test system software design

The software of measurement and control system is based on LabVIEW 11.0, an innovative software product of national instruments. In order to complete the off-line test of the articulated panel, the measurement and control system needs to communicate with the articulated panel, which is realized by CAN bus. The specific test process is shown in the figure below, before the test begins officially, the test bench needs to be restored to the 0 Angle position, and the Angle of the test hinge plate needs to be corrected to zero. After the test begins, the upper computer sends speed, gear and other information to the hinge plate of the test subject according to the test circuit spectrum. Meanwhile, the test bed rotates the hinge plate of the test subject according to the circuit spectrum, and the hinge plate will feedback real-time parameters, including left and right cylinder pressure and the opening and closing information of each related valve. After the test is completed, the test data and standard data are compared to verify whether the specimen is qualified. [5]

4.1 Can communication message processing

According to the different CAN communication protocols of different types of test articulated disks, a set of general CAN communication message processing mechanism is designed. The program version number is used to match different CAN message handlers, and the user can also read the program version number of the test articulated disk by himself. If CAN message matching fails, the program can report an error by itself. The related program block diagram is shown in FIG.7.

![Figure 7. CAN communication block diagram.](image)

4.2 LabVIEW software design

The test interaction interface is as shown in the FIG.8. Before the test starts, testers need to manually input the product name and product number and test the road spectrum. Click "Connect Can" to communicate with the test piece. Click "Product Zero" to zero the test bench angle. Click "Angle Zero"
to calibrate the angle of the test piece to zero. Click "Land Selection" to select the test standard road spectrum. After the above operation is completed, click "Auto Test" to start the test automatically. If testers encounter an emergency, click "Stop the test" can interrupt the test at any time.

5. Test results verification
The company's IK29B articulated disk was used for testing, the test results are shown FIG.10.

The FIG.10 the test result of the articulated disk under the actual path of “turning head + high speed lane change". It can be seen that the test system reproduces the road spectrum of the test, and the dynamic error of the standard curve and the test curve calculated by the root mean square. The test product is qualified at 0.92 degrees.
6. Conclusion
In order to carry out the road spectrum reproduction test of the articulated disk, this paper designed a set of automatic off-line test bench for the articulated disk, and developed the test software of the test system based on LabVIEW. The practical application shows that the test system can fully meet the company’s requirements for the off-line test of the articulated disk, accurately reproduce the test path spectrum of the articulated disk, and monitor the feedback parameters of the articulated disk in real time. The system runs stably and the test accuracy is high.

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