The design and experiment of hydraulic power intelligent instrument

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Abstract—In this paper, a newly hydraulic power intelligent instrument is presented and verified. As the important of hydraulic power intelligent instrument, power sensor, which consists of flow rate sensor and pressure sensor, was developed on the base of MEMS technology. And then, with the help of soft programming and circuit design aimed at signal treatment, the hydraulic power intelligent instrument was made. An experiment using closed power recycle hydraulic system was designed verifies the application of hydraulic power intelligent instruments in the field of hydraulic system failure inspection. The results indicate that the hydraulic power intelligent instrument can identify accurately the working condition of hydraulic system.

Keywords-hydraulic; power; instrument; failure; inspection

I. INTRODUCTION

The hydraulic system is a synthesized system consisting of mechanical, electric and fluid, and is widely applied in various industry fields. It is difficult to identify the hydraulic system failure due to the characteristic of hydraulic system, such as complex contracture, mechanical-fluid coupling, and nonlinear. The hydraulic power intelligent instrument designed in this paper provides a new way to inspect the working condition of hydraulic system.

II. THE DESIGN OF HYDRAULIC POWER INTELLIGENT INSTRUMENT

A. *The principle and design of hydraulic power sensor*

In the hydraulic system, hydraulic power equals the product of flow rate and pressure. From this point, the power sensor is a complex consisting of flow rate sensor and pressure sensor, which can output hydraulic power signal after treating the flow rate signal and pressure signal.

As with the flow rate sensor, based on the research findings of ship Mechanical & Electrical Integration lab. in Dalian Maritime University [1-3] , this paper designed a pipe reducer, which can produce a differential pressure signal. This signal, whose strength reflects the size of flow rate, is caught by MEMS chip. In this way, the flow rate signal is obtained. The configuration of reducer can be seen in Fig.1. The pipe reducer is printed by 3D printer(Dimension Elite), adopting a kind of newly ABS material, which has the characteristic of higher strengthen, temperature insensitive and no reaction with hydraulic oil[3]. In this paper, diffused silicon piezoresistive pressure transducer is selected as pressure sensor, which can output a DC current signal between 4 mA and 20mA.

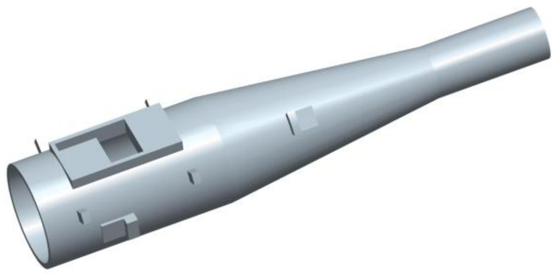

Figure1. the configuration of reducer

The hydraulic power sensor can be obtained after the assembly of flow rate sensor and pressure sensor. It is should be noted that excellent seal is essential for the connection of flow rate sensor. The power sensor is shown in the Fig.2.

Figure2. hydraulic power sensor

B. *Calibration and performance test of hydraulic power sensor*

1) *experiment environment*

Experiment platform: DY200011-00 closed hydraulic recycling system, as is shown in Fig.4

Test basis: <GBT 18459-2001 methods for calculating the main static performance specifications of transducers>

Experiment equipment: reducer flow rate sensor designed in this paper; AD693 stabilized electric power; CIG-15 flowmeter; S064C-1flow tester

2) *Experiment data*

First, fit the hydraulic power sensor to the testing hydraulic system, and then adjust the frequent of electric motor and the flow rate of hydraulic pump, changing the flow rate from 0 to 45, then 0, the step is 5. the voltage signals acquired by flow rate sensor are recorded in the Tabl.I.

TABLE I. ELECTRONIC SIGNAL ACQURED BY SENSOR

Input x （L/min）	output y （mV）				
	y_1	y_2	y_3	y_4	y_5
0.0	0.3	0.2	0.3	0.2	0.3
5.0	1.5	1.4	1.6	1.5	1.5
10.0	2.4	2.3	2.5	2.4	2.4
15.0	3.3	3.1	3.4	3.3	3.4
20.0	4.3	4.2	4.4	4.3	4.3
25.0	5.4	5.3	5.5	5.4	5.4
30.0	6.5	6.3	6.5	6.5	6.4
35.0	7.6	7.5	7.7	7.7	7.6
40.0	8.7	8.5	8.8	8.8	8.7
45.0	9.8	9.6	9.9	10.0	9.8
45.0	9.8	9.7	9.9	10.0	9.7
40.0	8.6	8.4	8.7	8.8	8.6
35.0	7.4	7.4	7.5	7.6	7.4
30.0	6.2	6.2	6.3	6.4	6.3
25.0	5.2	5.1	5.4	5.4	5.3
20.0	4.1	4.0	4.3	4.2	4.2
15.0	3.1	3.0	3.3	3.2	3.3
10.0	2.2	2.2	2.3	2.3	2.3
5.0	1.4	1.4	1.5	1.5	1.5
0.0	0.2	0.3	0.3	0.3	0.3

3) *Experiment result analysis*

The testing data in Tab I. is reasonable after inspection and can be used to analyze the performance of flow rate sensor. In this paper, the performance index of flow rate consists of linearity, hysteresis, combined linearity and hysteresis, repeatability, as well as total uncertainty, which are listed in Tab II.

TABLE II .THE VALUE OF PERFORMANCE INDEX

Performance index	value
Linearity	2.01%
hysteresis	1.71%
combined linearity and hysteresis	2.79%
repeatability	3.37%
total uncertainty	4.39%

According to the data in Tab II, although the performance of flow rate sensor designed in this paper can not reach the excellent flow rate sensor's, especially the linearity and the total uncertainty, this sensor is not designed for measuring the flow rate accurately, but for the failure inspection of hydraulic system. From this point of view, the sensor designed in this paper meets the anticipation.

C. *The inspection circuit of hydraulic power intelligent instrument*[4-7]

The inspection circuit designed in this paper consists of interface module, voltage transformer module, signal acquisition and amplification module, A/D conversion module, power calculation module, as well as wireless receiver and signal display module. The circuit principle diagram is shown in the Fig.3.

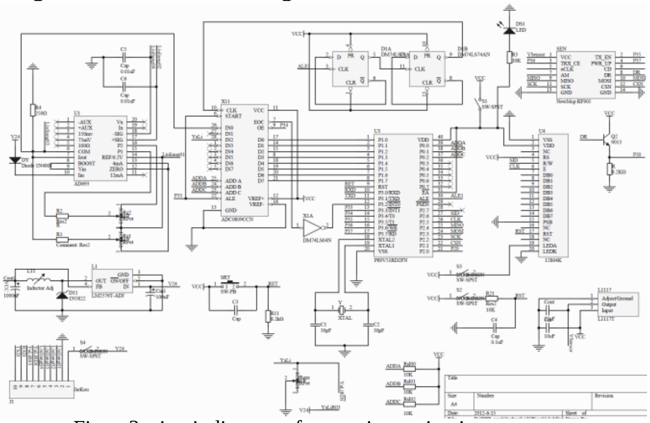

Figure3. circuit diagram of power inspection instrument

Different module plays different roles: the function of interface module is to connect external electronic power and displayer, and acquire the signal from flow rate sensor and pressure sensor; three different voltages are needed for the power inspection instrument, 24V, 3.3V, 5V. so the function of voltage transformer is to provide different voltages for the power inspection instrument; The main function of signal acquisition and amplification module is to transfer the voltage signal and current signal acquired by sensor into standard signal; in this paper, New-Msg RF905, which is manufactured by Nordic VLSL, is adopted as wireless module.

D. *Soft programming of hydraulic power intelligent instrument*[8]

In this paper, the uVision3 is adapted as soft programming platform using C language. The programme is downloaded to P89V51RD2 by the use of FlashMagic, with the help of the pins of TXD and RXD in MCU and RS232, the soft programming is debugged with CommAssistant. The soft programming in this paper consists of hardware initialized, signal acquisition, power calculation, signal display, wireless receiver and data transmission. As with the general procedure of designing soft programming, after receiving the beginning order, the wireless module acquires the signal of flow rate and pressure, and then calculates the hydraulic power, which is sent to displayer by the wireless module.

III. WORKING MECHANISM OF HYDRAULIC POWER INTELLIGENT INSTRUMENT

A. *The whole design of failure inspection*

The failure inspection for hydraulic system designed in this paper consists of PC, communication module, data transfer station, inspection instrument and power sensor. The role of above modules is described as follow: the PC is functioned for failure inspection and alarm; communication module transfers data between PC and

MCU; the data transfer station is aimed at receiving signal from hydraulic system and transferring order from PC; the inspection instrument is responsible for flow rate and pressure signal acquisition, power calculation, display and wireless transmission.

B. Data transmission

The duty of data transmission is achieved by data transfer station, which consists of MCU and wireless module. At the same time, in the case of more than one power sensor, the data transfer station harmonizes the data transmission of different power sensors, receives the characteristic parameters from different power sensors continuously, transfers the data to PC, and transfers order from PC to different sensors.

C. The transmission between data transfer station and PC

In the hydraulic failure inspection system, the function of PC is to receive inspection signal, analyze the acquired signal, and output alarm signal. The data communication between data transfer station and PC is achieved by the combination of RS232 and HL-340: RS232 transfers level signal of TTL into COM serial signal; and HL-340 transfers COM serial signal into USB signal.

D. The soft programming design of PC

The purpose of the PC is to receive and analyze signals, as well as output alarm. In this paper, the soft programming is finished by Visual Basic 6.0.

1) Serial communication: it is achieved by inducing a MSComm to the Frame in Visual Basic.

2) Design data base: the data base consists of dynamic signal acquision sheet and system state parameter sheet and it is designed by SQL Server 2005.

3) graphics user interface of inspection system: it is designed for displaying parameters intuitively.

4) design the multi-instrument failure inspection system: the system is designed for achieving the function of state identification of power intelligent instrument.

IV. FAILURE INSPECTION EXPERIMENT OF HYDRAULIC POWER INTELLIGENT INSTRUMENT

A. Experiment environment

Experiment platform: DY200011-00 closed hydraulic recycling system, as is shown in Fig.4

fault simulation: backpressure relief valve opens; main relief valve opens; ball valve closes slightly

location of instrument: as is shown in Fig.4

normal condition: the frequent of electric motor is 30Hz

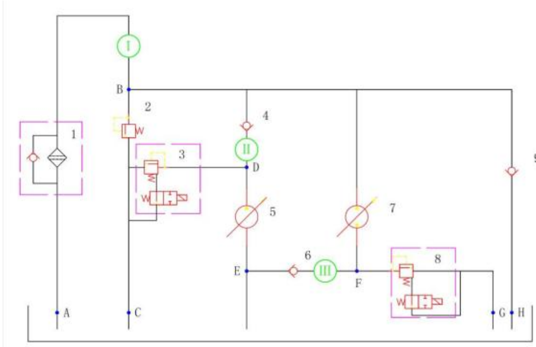

Figure5. location of inspection instruments

(note: I, II and III shown in figure are the locations of inspection instruments)

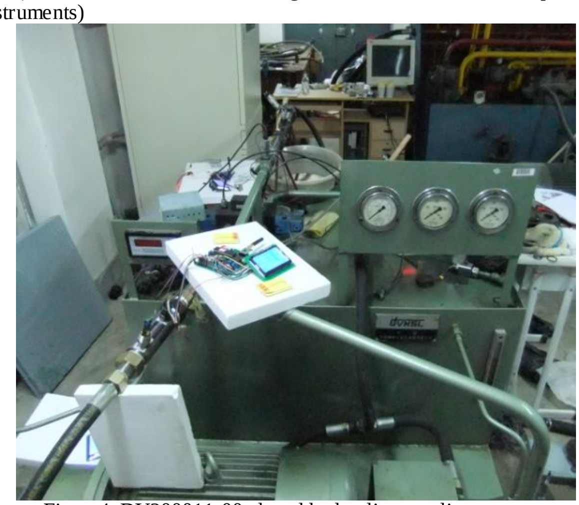

Figure4. DY200011-00 closed hydraulic recycling system

B. Experiment data

The power characteristic parameters acquired by hydraulic failure inspection system are shown in the Tab.III. And then, these power parameters are sent to condition data base where the work of grey correlation degree analysis is finished.

TABLE III. POWER PARAMETER OF NORMAL AND FAILURE STATES

Working condition	**item**	**No.1 instrument**	**No.2 instrument**	**No.3 instrument**
30Hz	1	0.487	0.281	0.042
	2	0.466	0.276	0.047
	3	0.459	0.283	0.045
	4	0.467	0.278	0.044
	5	0.454	0.289	0.043
	Ave.	**0.467**	**0.281**	**0.044**
Backpressure valve open	1	0.275	0.163	0.030
	2	0.285	0.158	0.026
	3	0.289	0.158	0.031
	4	0.282	0.162	0.033
	5	0.293	0.157	0.032
	Ave.	0.285	0.160	0.030
Main relief valve open	1	0.411	0.245	0.044
	2	0.419	0.241	0.039
	3	0.410	0.240	0.042
	4	0.422	0.249	0.041
	5	0.421	0.238	0.040
	Ave.	**0.417**	**0.243**	**0.041**
Ball valve close	1	0.870	0.491	0.043
	2	0.857	0.488	0.047
	3	0.886	0.497	0.040
	4	0.878	0.486	0.044
	5	0.879	0.495	0.041
	Ave.	**0.874**	**0.491**	**0.043**

C. *Experiment results*

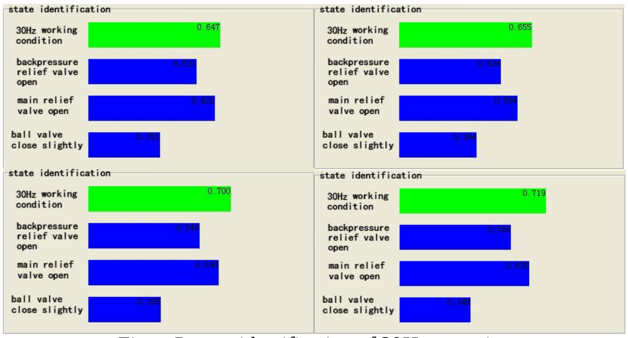

Figure5. state identification of 30Hz operation

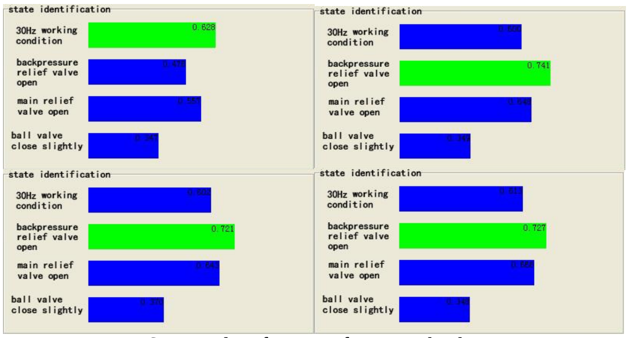

Figure6. state identification of opening backpressure

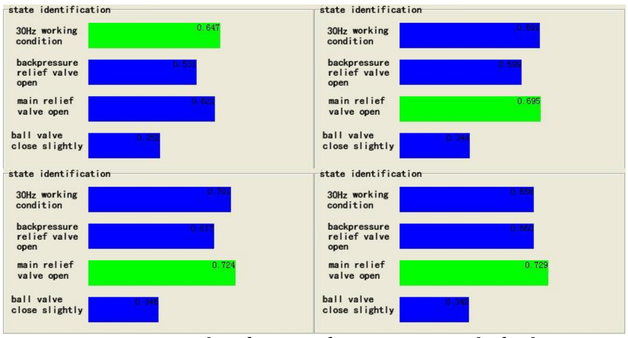

Figure7. state identification of opening main relief valve

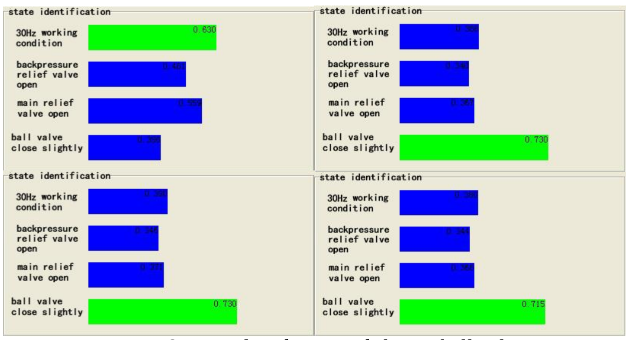

Figure 8. state identification of closing ball valve

In the interface of multi-instrument failure inspection, under the condition of normal state (the frequent of electronic motor is 30Hz), grey correlation degree calculation is done between the different states (four states) and operating parameter of system, the results indicate that the correlation degree between normal state (the frequent of electronic motor is 30Hz) and operating parameter of system is the largest, which certifying the correction of this state identification system. As is shown in Fig.5.

When opening the backpressure valve, the results of state identification were shown in Fig.6. The first picture shows the correlation degree under the condition of normal state (the frequent of electronic motor is 30Hz), the rest pictures show the correlation degree after opening the backpressure valve. Obviously, the correlation degree between operating parameters of system and backpressure valve opening state is the largest, which is consistent with the real condition.

When opening the main relief valve, the results of state identification were shown in Fig.7. We will find that it is difficult to identify the states of opening the main relief valve and normal state due to the similar correlation degree. The reason inducing this phenomenon is the little overflow of the relief valve because of clogging partly.

When closing the ball valve slightly, which means regulating the flow rate of hydraulic pump, the results of state identification were shown in Fig.8. the results indicate that the state identification is excellent..

V. CONCLUSION

The hydraulic power intelligent instrument designed in this paper can be applied in the hydraulic failure inspection system, which is verified by experiment. As a result, a newly hydraulic failure inspection method based on power acquiring is approved. During the performance test for the power sensor designed in this paper, the accuracy can not reach the excellent level, especially the linearity and the total uncertainty, but this has little influence to the designed hydraulic failure inspection system, which is verified by experiment. During the failure inspection experiment, the hydraulic power intelligent instrument can acquire power signal of inspection points continuously and real-timely. Besides, the operating condition of hydraulic system also can be identified accurately by the hydraulic power intelligent instrument.

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