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RESEARCH ON THE METHODS OF DETECTING AND REMOVING SLIDE VALVE FAILURE*

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Abstract: Various ways for detecting slide valve failure are discussed in the paper. Specifically, a new method for detecting slide valve sticking state is first presented. The method does not depend on any special sensor and is only based on the detection of oscillation current wave within a valve coil. Results of theoretical analysis and experimental research are given for comparison. In order to remove a slide valve sticking online, a concept and method of "electrical hammer" is introduced. At last, an application example of the methods is discussed. In fact, it is an electro-hydraulic turbine system with failure diagnosis, fault-tolerant and trouble removal functions.

Key words: fault-tolerant control, failure diagnosis, trouble removal, slide valve, hydraulic sticking.
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INTRODUCTION

Various electro-hydraulic valves are widely used in industry. Slide valve or spool, as a basic structure, plays an important role in various electro-hydraulic converter systems, including servo valve, proportional valve and on-off valve systems. Spool failure can very possibly put the whole system out of control, so much attention has been paid to valve failure diagnosis and trouble removal methods. As well known, the most ordinary valve problems are sticking spool and valve coil disconnection. Since the later is usually easy to find, this research focuses on detecting and freeing a stuck spool, as official statistical data show that, over 60% of hydraulic turbines operating in China are troubled by hydraulic valve sticking (or disconnection). Obviously, it is necessary to develop an effective method for detecting and disengaging a sticking spool.

Up to now, the main methods for detecting a sticking valve are based on detecting the pressure or flux of the electro-hydraulic system. For an electromechanical integrated valve, the sensor (such as displacement sensor, induction coil, acceleration sensor etc.) can be installed inside the valve. But no doubt, all these methods depend on some sensors that not only enhance system cost but may also bring some structure or installation problems.

This paper will first discuss various ways of detecting a valve sticking state. Then, recent research results of a new method for detecting a sticking spool are introduced. Based on the detection of oscillation current, the method and its circuit can provide the information on sticking state without the use of any sensor. So it is completely different from other methods. Aimed to resolve the problem of the sticking valve detected online, the concept and method of "electrical hammer" introduced here is essentially a two-way strike action applied to the sticking valve. At last, as an application example of the methods mentioned above, we introduced an electro-hydraulic stream turbine system device with failure diagnosis, fault-tolerant and trouble removal functions.

STICKING VALVE DIAGNOSIS METHOD BY OSCILLATION CURRENT DETECTION

The electro-mechanic converter is the input unit of the electro-hydraulic control component. It changes the control amplifier's electric signal into a mechanical parameter (such as force or displacement). The magnetic field is the medi-

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um in the energy conversion. Electrical, magnetic, hydraulic and mechanical factors are interrelated and interact with each other. Our purpose is to find a new method for abstracting information that reflects the effect of the stuck hydraulic on the electrical circuit. The method does not need any sensor and disengages the sticking valve by electrical means.

1. Theoretical analysis

A stuck proportional valve can be feasibly disengaged by " the electrical hammer" effect since it has large electro-hydraulic conversion power. As an example, we will analysis a proportional valve. The voltage equation describing the dynamics of proportional valve is(Lu et al., 1988):

$$U_c = (R_c + r_p) \cdot i + L \cdot \frac{di}{dt} + K_v \cdot \frac{dx}{dt} \quad (1)$$

Where R_c and r_p are coil resistance and amplifier resistance, U_c and i are coil voltage and current, L is dynamic inductance coefficient, K_v is speed opposing electromotive force coefficient, $dx/dt = v$ is spool movement speed. In normal working condition (static state), the equation describes the character of the oscillation current. L and K_v are coefficients affected by many factors, and are mainly decided by the magnetization character of the soft magnetizer, the position of the spool, and the whirlpool effect on the dynamic process. Actually, the value of L, K_v changes little in the whole operating range, and can be considered as constant.

From the equivalent circuit of oscillation current (Fig.1) we can see that switch K is connected to point 1 at the time $[0, \alpha T]$ while at the time $[\alpha T, T]$ the switch K is connected to point 2. The oscillation current has a periodic waveform with period T(Liou, 1987). In the current waveform (Fig.2), the value of $i(0)$ is determined by the control signal, here $(0 < \alpha < 1)$.

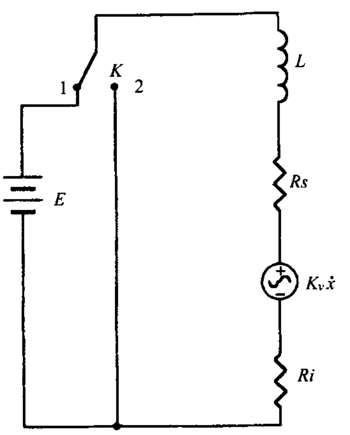

Fig. 1 Equivalent circuit of oscillation current

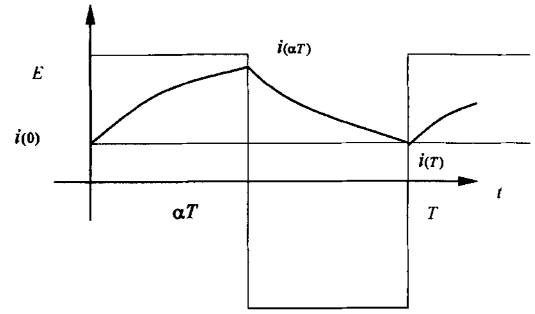

Fig. 2 The oscillation current waveform

Thus the circuit differential equation can be derived from Equation (1):

$$L \cdot \frac{di}{dt} + Ri + k_v \frac{dx}{dt} = E \quad t \in [\alpha T, T] \quad (2a)$$

$$L \cdot \frac{di}{dt} + Ri + k_v \frac{dx}{dt} = 0 \quad t \in [0, \alpha T] \quad (2b)$$

Where:

$$R = R_c + r_p$$

Assume that the coil opposing electromotive force is invariable and L is a constant, ignore the delay between the spool movement and the current, after derivation we can get the peak to peak value of oscillation current:

$$i(\alpha T) - i(0) = A \cdot E - B \cdot \dot{x} \quad (\dot{x} \geq 0) \quad (3)$$

Where

$$A = [1 + e^{\frac{R}{L}T} - e^{\frac{R}{L}T} - e^{\frac{R}{L}(1-\alpha)T}]/[R(1 - e^{\frac{R}{L}T})$$

$$B = 2k_v A \quad C = B \cdot \dot{x}$$

Based on the physical meaning and assumed premise, A and B are positive constants.

Now we can find in Equation (3) that when the spool is partly stuck, the movement opposing electromotive force C will be decreased. And if the spool is completely stuck, the movement opposing electromotive force C will drop to zero. This offers the possibility to detect the hydraulic sticking via the electrical method.

2. Experiment research

In order to validate the feasibility and effectiveness of the method of diagnosing spool failure via detecting the peak to peak value of oscillation current, we use the proportional valve load simulation device to carry out experimental research. In the experiment, the spool part sticking condition was simulated by the addition of a rigid spring while the entirely sticking condition was simulated by plugging in the handspike.

The failure simulation device and the working principle of the structure of the detection system of the experiment are given below. (See Fig.3, Fig.4)

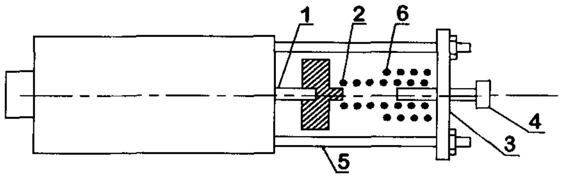

Fig.3 The failure simulation device
1. handspike, 2. spring, 3. armor board, 4. spacing bolt, 5. drop-link bolt, 6. hard spring

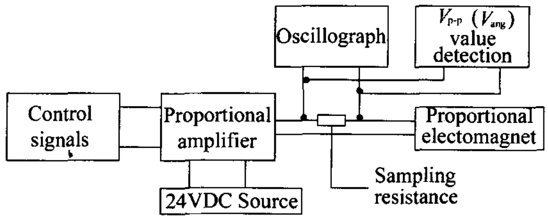

Fig.4 The working principle of the structure of detection system

Fig. 5 gives the experimental waveforms of the oscillation current in normal state (Fig.5a) and sticking state (Fig. 5b), respectively. We can find that when spool sticking occurs, the current waveform and its peak-to-peak value change obviously.

Control current is 85 percent of oscillation current (without oscillation current feedback).

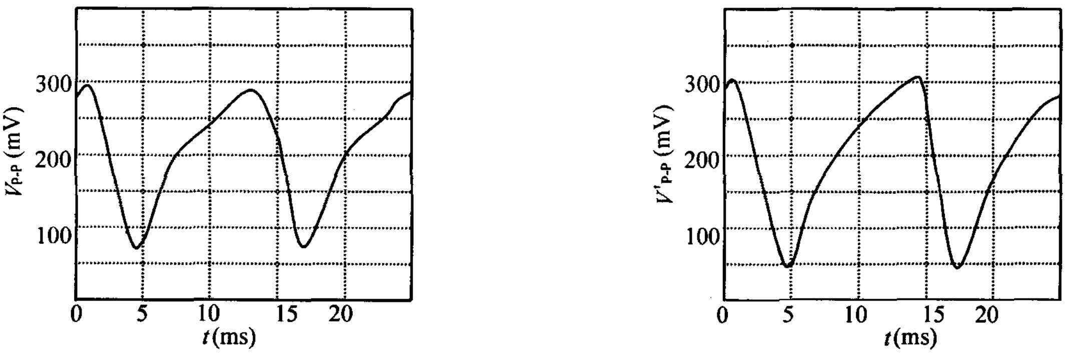

Fig.5 The experimental waveform of oscillation current
(a) normal state; (b) sticking state

Table 1 gives the peak-to-peak values (V_{p-p}) of oscillation current at certain working points in normal condition, peak-to-peak values (V'_{p-p}) in spool sticking state and their variations (ΔV_{p-p}). From the data in the table we can find that ΔV_{p-p} is about 20 mV at almost each working point. This proves the theoretical analysis result that to detect hydraulic sticking failure via detecting peak-to-peak value of oscillation current is a feasible method to detect spool sticking state.

THE CONCEPT OF "ELECTRICAL HAMMER"

Based on practical experience, when the spool is stuck, to free it, an experienced engineer will hammer the valve slightly for a few times and he may be successful. The HERION Company introduced a reversing valve with a "hammer", which can knock the spool off the sticking valve by means of a mechanical spring force and let the spool go back to its proper place (Li et al., 1997). A spring driven hammer can

Table 1 Values of oscillation signal(Wang, 1998)

$I_{avg} = \frac{V_{avg} + V'_{avg}}{2R}$	Normal state		Sticking state		ΔV_{p-p}(mV)	ΔV_{avg}(mV)
	V_{avg}(mV)	V_{p-p}(mV)	V'_{avg}(mV)	V'_{p-p}(mV)		
312.9	376.0	192.2	374.9	217.2	25.0	-1.1
393.6	472.1	159.4	472.5	195.3	35.9	0.4
504.3	605.8	178.1	604.6	201.6	23.5	-1.2
575.0	690.0	206.2	690.0	231.2	25.0	0
643.2	771.8	182.8	771.6	220.3	37.5	-0.2
710.1	855.3	181.2	849.0	200.0	19.8	-6.3

only hammer for one time and can only be used in common on-off valves.

In this paper, a concept of the so-called "electrical hammer" is presented. Different from HERION Company's hammer device, the working electromagnet is directly used to generate a varying frequency and amplitude current signal that generates an alternating electromagnetic force that produces a two-way hammer effect along the axes to free the spool from sticking online. This is our "electrical hammer" that can strike the spool any number of times required on both sides of the spool, and is also consistent with and complementary to, the trouble-shooting methods in existence which give priority to prevention. To prevent the "electrical hammer" from working on and on, timing circuit is necessary.

APPLICATION EXAMPLE

1. The working principle of the steam turbine electro-hydraulic control device with fault-tolerant function.

The electro-hydraulic converter is the weakest part of the stream turbine electro-hydraulic control (EHC) system. In order to enhance the error-tolerant ability of the stream turbine EHC control system, a new electro-hydraulic control set is presented in Fig.6(Wei et al, 1995).

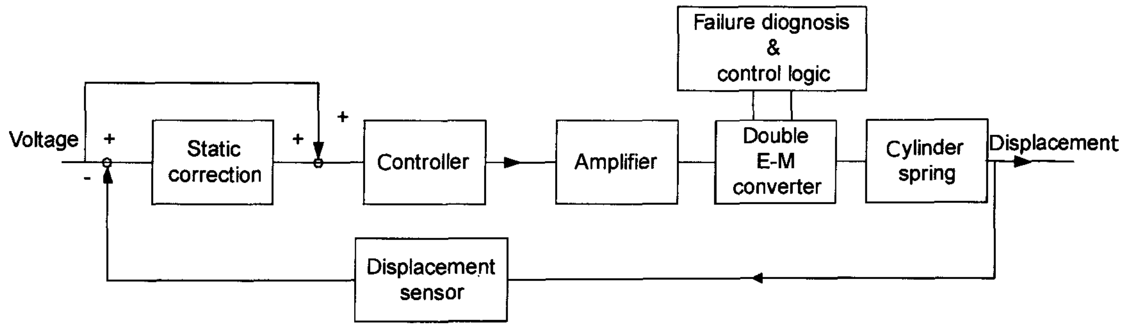

Fig.6 The block diagram of fault-tolerant stream turbine using an electro-hydraulic controller.

Failure diagnosis and control logic circuitry will diagnose the two electro-hydraulic converters and switch them accordingly to ensure the device can operate in good condition. The closed feedback loop, made up of the displacement sensor and static revise part, is used to realize the static error correct and enhance the control precision.

2. The failure diagnosis system and switch of the electro-hydraulic converter.

(1) The switch principle (Fig.7)

As can be seen in Fig.7, where 2-A and 2-B are converters (proportional valve) controlled respectively by amplifier 1 and 2. The two converter's inlets are directly connected to the oil source, their outlets are linked to the drain. The input signals of 2-A and 2-B come from the two amplifiers. The switch between the two converters is under the control of the two-position three-port solenoid valve 4 whose input signal is decided by the amplitude discriminator 3. The oscillation current signal is detected by the failure diagnosis circuit and is sent to the amplitude discriminator to ensure that if any spool sticking occurs, valve 4 can switch the 2-a and 2-b immediately. The "electrical hammer" circuit and switch circuit are used to remove the sticking online.

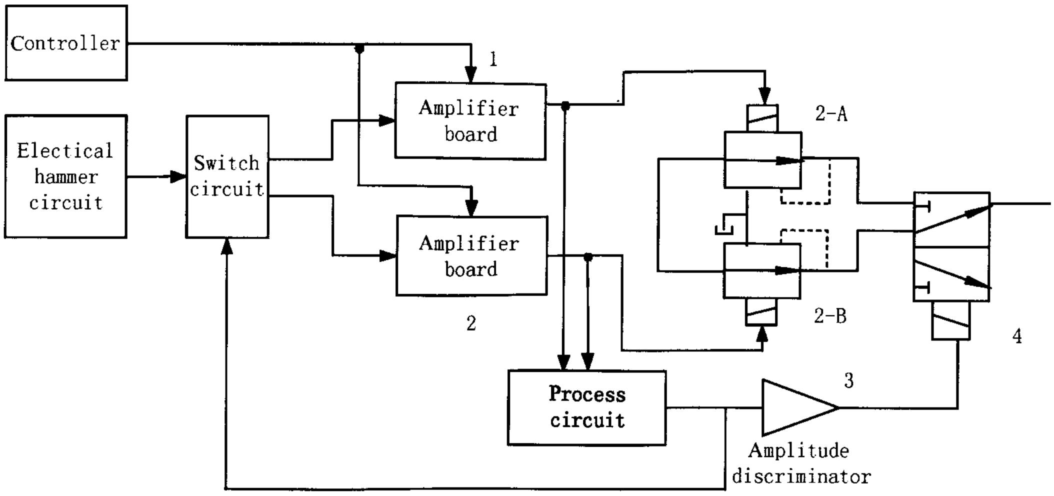

Fig.7 Failure diagnosis and switch principle of electro-hydraulic control setup

(2) Diagnosis and switch program

Keep the two converters in the same state before operation. Choose one as working converter, the other as standby. The two amplifiers send the oscillation current waveforms to the process circuits respectively. If the process circuit finds the waveforms from the two converters are not the same and its balance is beyond the initialization (generally speaking, the V_{p-p} values of the two converters are out the same if stickingoccurs), the amplitude discriminator outputs "0" or "1" to make the two-position three-port solenoid valve switch accordingly. To prevent the solenoid valve from switching frequently, the amplitude discriminator is enforced with a Smith trigger. The output of the amplitude discriminator is also sent to the "electrical hammer" circuit so that the failure of the broken-down converter can be removed online when the other converter is working.

The failure diagnosis system of the converter presented above can detect the spool failure online and remove the failure online as well. The system has strong fault-tolerant ability.

(3) Experimental result

As proof the system is fault-tolerant, if the converter fails, the valve coil is instantly disconnected, the working converter's input signal line is instantly broken, or if failure of the working converter is simulated, the amplitude discriminator orders the solenoid valve to switch off immediately, to prevent the whole system operation from being affected adversely. These results confirm out diagnosis system, which needs no sensor or controller and has strong fault-tolerant ability.

CONCLUSION

Based upon theoretical analysis and experimental study results, this new method for identifying a sticking slide valve has the advantages of not needing any special sensor and resolving valve failure online. The concept and method of electrical hammer is also brought forward. The research results have proved the feasibility and effectiveness of the above method, which can be of obvious significance for enhancing the reliability of hydraulic system.

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