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Control Mechanism Analysis in Fluid Drive

Donghan Geng
Tianjin Polytechnic University, No. 399 Binshui Road, Xi Qing District, Tianjin, China, 300387
Tel.: 13752316596
E-mail: fisherw@163.com

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Abstract: In order to improve the security and reliability of industrial control system and realize the automatic detect and control of the system, this paper invents and conducts whole scheme design of a multifunctional intelligentized solenoid valve detecting system. We analyze the conditions of resonance of main test pipeline and its pressure transmission characteristics in frequency domain by impedance analysis. We conduct simulation study to the frequency characteristics of pressure radio of the main test line by adopting approximation method of fluid pipeline frequency-domain model to make reasonable physical design to the elements like geometric dimensioning and the length of fluid pipeline. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Fluid drive, Control, Features, Model.

1. Introduction

The development fluid drive and control (fluid drive for short) has been with a history of more than 200 years since Barm-ha brought forward the patent of fluid machinery with the medium of water in 1975. This discipline develops rapidly after the Second World War. The production value of Japan increases by 200 % from 1920s to 1990s. Till the early 90s, the total output value of the six main fluid-device-producing countries has reached more than 20 billion dollars. With the economic development and technology advancing, the researches of fluid derive and control application system makes giant progress. At present, it plays a significant role in the control system and energy conversion and transmission system of engineering machinery, aerospace, aviation, navigation for its advantage of high power, responsive, and high precision etc. With the joint of theoretical analysis, computer simulation technology, and the combination of experiments and study, this paper conducts deep research and discussion to the development of solenoid valve test system and related fluid control technology [1].

2. The Whole Scheme Design and Hardware and Software Design of the Detecting System

2.1. The Whole Scheme Design

The intention of design and developing solenoid valve test system is to make sure the tested-valve in the prescribed working condition and to test its various performances. The test system is able to provide with the related test ways and methods of various tested-valves, and ensure the testing experimental conditions and precisions. The experimental conditions and experimental precisions of various solenoid valve have related national regulation and industrial standard, thus, the regulations and standards should be followed in the design process, what's more, the company standards, technical requirements, practical production status should also be combined with. According to the differences of test medium, the whole test system can be divided into water test subsystem, oil test subsystem, gas test subsystem and vacuum test subsystem. Aiming at each test subsystem, we should conduct multi-branch optimal design according to the diameter range of solenoid valve and design the matched solenoid valve fixture and its return circuit. We can know from related industrial standards that the common solenoid valve has 16 dimension series with the diameter ranging from 10 mm to 30 mm. We couldn't design for all the dimensions. Thus, the design principle is to make sure the branches to satisfy the teat requirements of all dimension series, and that the size rang of each branch covers should be as wide as possible, so that the floor space and investment cost decrease, which can embody the advantages of the integrated design well. The whole structure chart of solenoid valve test system is shown in Fig. 1.

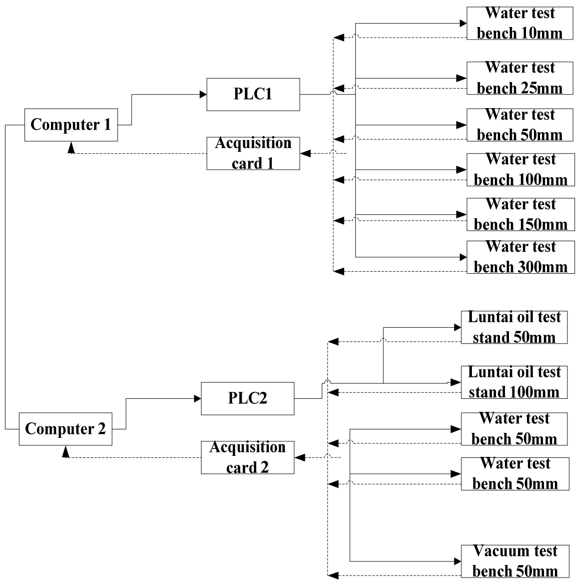

Fig. 1. The Whole Structure Chart of Solenoid Valve Test System.

The variety of oil, gas and vacuum medium is comparatively less and the current diameter range is 0 mm ~ 100 mm; and when the medium can be water, oil, gas and vacuum, we choose water. Thus the test subsystem of oil, gas and vacuum is relatively smaller comparing with water test system. Thus, two test beds: 50 mm test bed and 100 mm test bed can satisfy the need of our designed oil, gas and vacuum test subsystem which is controlled by an independent measurement and control system from water test subsystem.

As the power source of the system, the power producer contains fuel tank, transducer, electrical machine, chestnut, voltage and current stabilization device, oil temperature control unit, essential analog quantity display instrument and electric check valve etc. The test bed contains control valve in various proportions, solenoid valve, various sensors, test-line block, fixture of tested-valve and power-driven cutoff valve etc. And it includes multiple test branches. The equipment cabinet mainly contains measure and control cabin, industrial control computer (with measure and control software and DAQ card) and its peripheral, PLC and interface equipment etc [2].

2.2. Hardware Design of the Detecting System

The hardware of solenoid valve test measure and control system can be divided into two parts from function, namely sense and test unit and control and information processing unit. This test system selects the LUGB spiral flow sensor produced by Beijing Kun Qi Hai An cooperation. The sensor belongs to spiral flow sensor [3]. The sensor is selected according to the internal diameter of the pipeline and its measurement range. The test system chooses the JYB-KO-B* series differential pressure transmitter of Beijing Kun He Hai A cooperation, which has precise and reliable measurement and with integrative constructure to be convenient for field installation and application and be suitable for pressure survey in various environment. Since the sensor is relatively far away from the terminal block of DAQ card, the information is put out by current. Main technical parameters of the pressure sensor are shown in Table 1.

Table 1. Sensor Parameters.

	Measured medium	Power supply	Output	Accuracy	Load capacity	Allowable overload	Measuring interface	Installation
Main Technical parameters	Liquid, gas	24 VDC	4-20 mA 0-5 V	Class A:±0.25%F.S, B±0.5%F.S	600Q 3KD	200 % F.S. 50 % F.S.	M20X1.5 screw, M12X1.5 screw	M20X1.5screw, screw fixation in the installation, customiza-tion Lu hole flange

High-pressure transducer is used in all kinds of test, so we should consider safety when choosing the range. Considering that in some situation pressure may increase rapidly, we choose the range of 0~8 MPa. We choose the WR series industrial fabricated thermal resistance temperature sensor of

Beijing Kun Qi Hai An as the temperature sensor to test the temperature of medium inside the test pipeline. This series of sensor can test directly liquid, steam, gaseous medium and solid surface temperature with the temperature ranging from 0 °C to 1800 °C the in the production process [4].

The specific scheme of pressure hierarchical measurement is that start different sensors according to the measuring pressure in the test process. When the pipeline pressure is relatively large, select the high-pressure sensor and turn down the solenoid valve of low-pressure sensor to protect it. If the pressure is less than 0.l MPa, turn on the solenoid valve of pro-valve low-pressure sensor with a range of 0-l00 KPa and the back-valve low-pressure sensor with a range of 0-20 KPa keeps off. When the pressure decreases lower than 20 KPa, the low-pressure sensor of the minimum range can be turned on and be used for measurement. If the pressure rises unexpectedly after turn on any sensor, the test system can turn off sur-sensor electromagnetic valve to protect and prevent the precise pressure sensor from pressure impact damage [5].

This system adopts the NI cooperation produced M series PCI-6224 multifunctional DAQ and its assorted terminal block 779067-010. This series of products combine analog front end, flexible timing, trigger ASIC and bus interface ASIC and the business digital technique is improved and optimized. These DAQ equipment and related signal conditioning device can make a data acquisition system with high precise. This DAQ is with the function of A/D, DIO, and counter/timer, and its main technical index is shown in Table 2.

Table 2. Technical Index of NI PCI-6224 DAQ.

Input resolution	16
Sampling rate	250 k/s
Input range	0-l0 V, -5-5 V, -10-l0 V, 4-20 mA
The analog signal input	32 single ended or 16 differential
Digital input and output	48 rode

LabVIEW schematized controlled environment internally installs rich function library, provides multiple network port and support advanced technology like mobile data transmission, which makes it more convenient to develop. The Data Socket technology of TCP/IP-based network real time data exchange programming technique is one of its characteristics. This control system adopts HOST-Link with RS-232C cable connection and realizes the communication of upper computer and PLC by the DataSocket contact of OPCServer and LabVIEW the PLC build in. [6].

3. Dynamic Characteristics Analysis of the Main Test Pipeline

3.1. Nondestructive Model of the Fluid Pipeline

The fluid transmission pipeline with constant diameter and axial laminar flow can be described with the electric transmission line theory. In order to deduce the fluid pipeline model and its parameter, the basic equation of hydromechanics should be put into the transmission equation firstly and express the series impedance and parallel admittance into the form hydromechanics parametric. The hypothesis is shown as following:

1) The fluid is laminar flow and Reynolds number of the pipeline should be smaller than 2000;

2) Fluid is axial symmetry and without tangential velocity.

3) Fluid flow is small amplitude signal (micro-variation), whose mach number is very low, and ignoring the effect of direct current, we can believe that the flow rate of the fluid is far small than the propagation speed of wave [7].

4) The squeezability of the fluid results in the comparatively small viscosity force.

5) The pipeline is enough long comparing with the diameter, so that the influence of endpoint can be ignored.

In the above assumptions, hydromechanics basic equation is linearized and the question is simplified. We can get the continuity equation, momentum equation, energy equation and state equation, which are shown in literature [5].

Nondestructive model of fluid pipeline is the simplest model describing the frequency characteristic. It ignores the energy loss resulting from fluid viscosity as well as the heat conduction with the outside world.

Momentum equation changes

$$\partial\rho / \partial x = -\rho_0 \partial u / \partial x \,, \tag{1}$$

Given the sectional area is A, we can get:

$$\partial\rho / \partial x = -\frac{\rho_0}{A} \partial q / \partial t \,, \tag{2}$$

The gas energy equation is:

$$\frac{1}{T} \partial T / \partial t = -\frac{r-1}{\rho_0} \partial\rho / \partial t \,, \tag{3}$$

Put formula (1), (2) into formula (3), and we can get:

$$\partial\rho / \partial t = -\rho_0 r \partial u / \partial x \,, \tag{4}$$

As for gas, we assume that there isn't heat exchange, so we can calculate as the adiabatic process. Take q=uA and the above formula can change into:

$$\partial q / \partial x = -A\partial u / \rho_0 c_0 \partial t \,, \tag{5}$$

Conduct Laplace and the series impedance are shown as formula (6), and the parallel admittance is shown in formula (7):

$$Z(s) = R + Ls = -\rho_0 / As \,, \tag{6}$$

$$Y(s)=G+Cs=-As/\rho_0 c_0^2 \,, \tag{7}$$

In the nondestructive pipeline, the wave propagation velocity equals to audio propagation velocity in free space. In the real fluid pipeline, nondestructive pipeline doesn't exist. However, in the nondestructive pipeline model, we only consider the inertia and compressibility of the fluid and ignore the influence of fluid viscosity and heat conduction, so we can approximately regard the fluid as perfect fluid [10]. Thus, the calculation of transient problem simplifies a lot and we can achieve some useful result. The test proves that the result the idealized model gets can represent the basic outline of actual fluid flow [8].

3.2. Linear Friction Model of the Fluid Pipeline

Linear friction model of the fluid pipeline is also called average friction model or laminar flow hypothesis model, namely when adopting the stably stratified flow and ignoring thermal transmission effects, viscous friction loss is in direct proportion to mean velocity [9]. The momentum equation (8) will be:

$$\partial \rho / \partial x = -\frac{\rho_0}{A}\frac{\partial u}{\partial t} + \frac{u}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right) \tag{8}$$

After taking a definite integrate to momentum equation along radial direction, in order to calculate the velocity gradient $\partial u / \partial r$ on the pipe wall (r = r0), we assume fluid flow is the fully developed Hagen-Poiseuille flow, whose velocity distribution is $u(r)=2u[1-(r/r_0)^2]$ with u as average velocity. Thus, we can get the series impedance equation of average friction model, as shown in formula (9):

$$\partial \rho / \partial x = -\frac{\rho_0}{A}\frac{\partial q}{\partial t} - \frac{8\pi u}{A^2} q \,, \tag{9}$$

Since we didn't consider the thermal conduction in this model, parallel admittance equation shares the same formula with nondestructive pipeline model, as shown in formula (10). Conduct Laplace transform to them and we can get the series impedance and parallel admittance of average friction model as:

$$\begin{cases} Z(s) = R + Ls = -\dfrac{\rho_0}{A}\left(s + \dfrac{8\pi u}{A^2}\right) \\ Y(s) = G + Cs = -\dfrac{As}{\rho_0 c_0^2} \end{cases}, \tag{10}$$

3.3. Dissipation Model of the Fluid Pipeline

Fluid pipeline dissipation model is also known as distributive friction model, which considers the effect of viscidity and thermal transmission at the same time. The dissipation model is regarded as make Laplace transform to momentum equation in the accurate model of fluid pipeline frequency characteristic analysis. We can get:

$$\frac{\partial^2 U}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} - \frac{s}{v_0}\left[U + \frac{1}{\rho_0 s}\frac{\partial p}{\partial x}\right], \tag{11}$$

Making

$$V(s,\ r) = U(x,\ r, s) + \frac{1}{\rho_0 s}\frac{\partial p}{\partial x}$$

and

$R=jr\sqrt{s/v_0}$, and we can get:

$$\frac{d^2V(R)}{dR^2} + \frac{1}{R}\frac{dV(R)}{dR} + V(R) = 0 \,, \tag{12}$$

The above formula is zero-order Bessel function and its solution is

$$V(R) = C_1 J_0(R) + C_0 Y_0(R) \,, \tag{13}$$

According to the boundary conditions, when r = 0, it is in the pipe center and U is limited value, we can get $C_2=0$; when $r = r_0$, it is in pipe inner-wall, we can get:

$$U = -\frac{1}{\rho_0 s}\frac{\partial P(x,s)}{\partial x}\left[1 - \frac{J_0(jr\sqrt{s/v_o})}{J_0(jr_o\sqrt{s/v_o})}\right], \tag{14}$$

The series impedance equation of distributive friction model is shown in formula (15):

$$Q(x,s) = -\frac{\pi r_0^2}{\rho_0 s}\frac{\partial P(x,s)}{\partial x} \left[1 - \frac{J_0(jr\sqrt{s/v_o})}{Jr_o\sqrt{s/v_o})J_0(jr_o\sqrt{s/v_o})}\right], \tag{15}$$

Since the thermal conduction of fluid and pipe wall is considered, the parallel admittance equation should be getting from energy equation and state equation, as shown in formula (16):

$$\begin{cases} Z(s) = -\dfrac{\rho_0 s}{\pi r_0^2}\left(1-1-\dfrac{J_1(jr\sqrt{s/v_o})}{Jr_o\sqrt{s/v_o})J_0(jr_o\sqrt{s/v_o})}\right)^{-1} \\ Y(s) = -\dfrac{A}{\rho_0 c_0{}^2} s\left(1+\dfrac{2(r-1)J_1(jr_0\sqrt{\sigma_0 s/v_o})}{Jr_o\sqrt{\sigma_0 s/v_o})J_0(jr_o\sqrt{\sigma_0 s/v_o})}\right) \end{cases} \tag{16}$$

The nondestructive model ignores the damping, thus the peak goes to infinity at the resonance point. Linear friction model considers the damping but ignores the influence of frequency, thus its actual attenuation in each frequency is the same. The result of dissipation model is comparatively complex and its damping attenuation increase with the increase of frequency. This is identical to the working condition of real system, which adopts the dissipation model as the theory model of dynamic characteristics of main rest pipeline of electromagnetic valve test-bed.

3.4. The Algorithm Implementation of the Pressure Radio Frequency Characteristics of the Fluid Pipeline

Electrochemical impedance spectroscopy is one of common method in fluid dynamics research. Electrochemical impedance spectroscopy of the fluid pipeline is an effective way to get the dynamic characteristics of fluid pipeline system in the frequency domain by analyzing the characteristic impedance, source impedance and load impedance of the pipeline. Define the characteristic impedance as a force and define the specific value of input pressure and flow by boundary element at the input end as source impedance. Under the circumstances of satisfying a certain accuracy requirement, this paper adopts approximation method to simplify the calculation.

Comparing with some models above, inertial approximation model is with the characteristics of simple form, suiting for the whole frequency bands and linear approximation. This model is suit for theoretical analysis, thus it is mainly used in future research. When the number of selected terms is relatively small, the first-order approximate inertial coefficient is superior to Trikha coefficient and adopting this set of coefficients can simplify the model, thus we adopt the model coefficient of Cai Yigang. The calculation procedure flow chat of pipeline pressure transmission function is shown in the following Fig. 2.

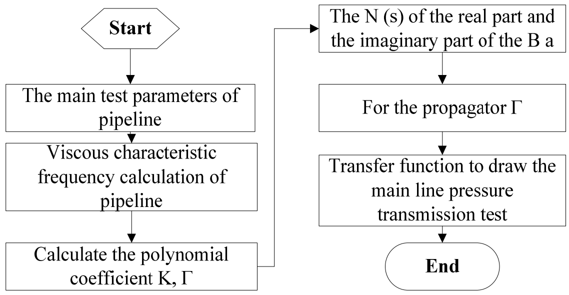

Fig. 2. Calculation Procedure Flow Chat of Pipeline Pressure Transmission Function.

4. Example Verification

This paper composites program in M-File of Matlab to calculate frequency characteristic of pressure ratio in the main test pipe: P_2/P_1. After mathematical operation, G(jw) in formula (17) is written as G(jw) =A（w）$e^{jQ(w)}$, and after taking the logarithm, we draw the log magnitude-frequency characteristics and its corresponding phase-frequency characteristics with 201 gA(w) as y-coordinate and w as x-coordinate. The received simulation curve is shown from Fig. 3 to Fig. 5.

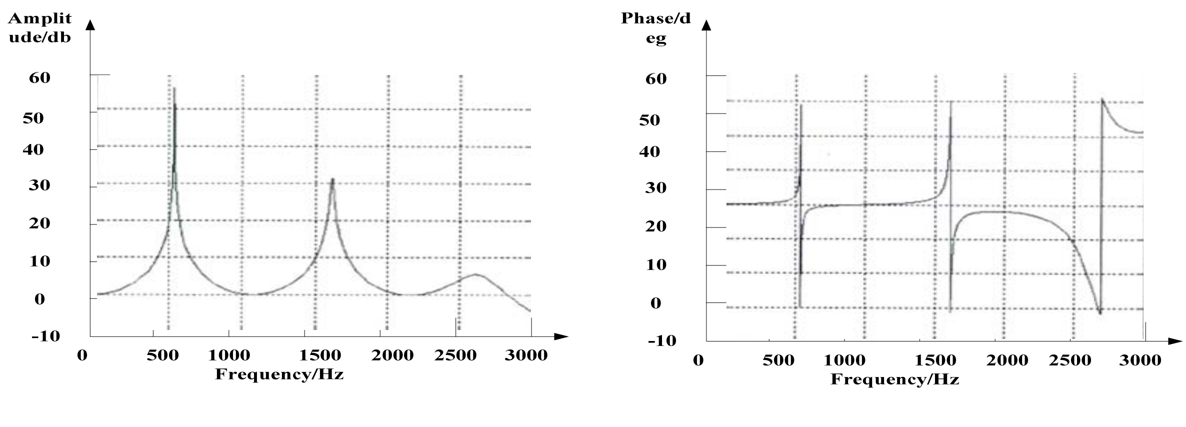

Fig. 3. Pressure Radio Frequency Characteristics of 3.5 m Pipeline.

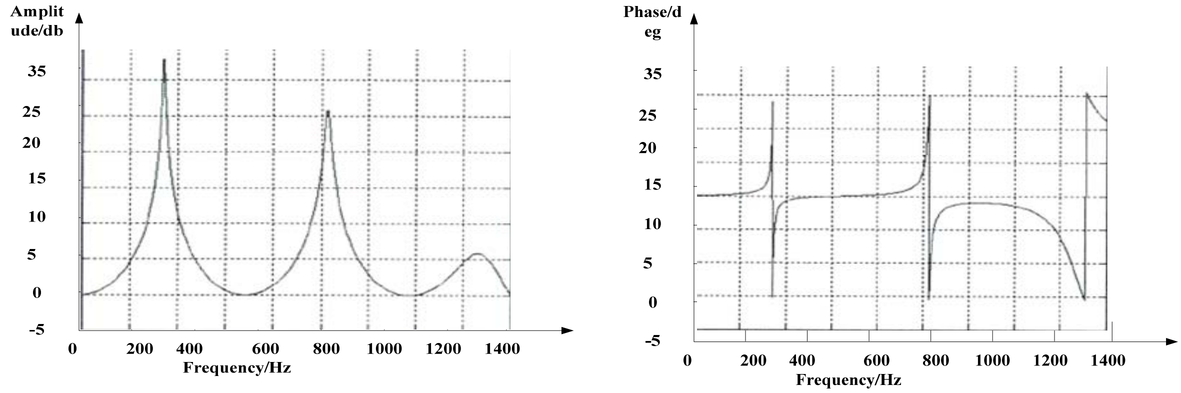

Fig. 4. Pressure Radio Frequency Characteristics of 4.5 m Pipeline.

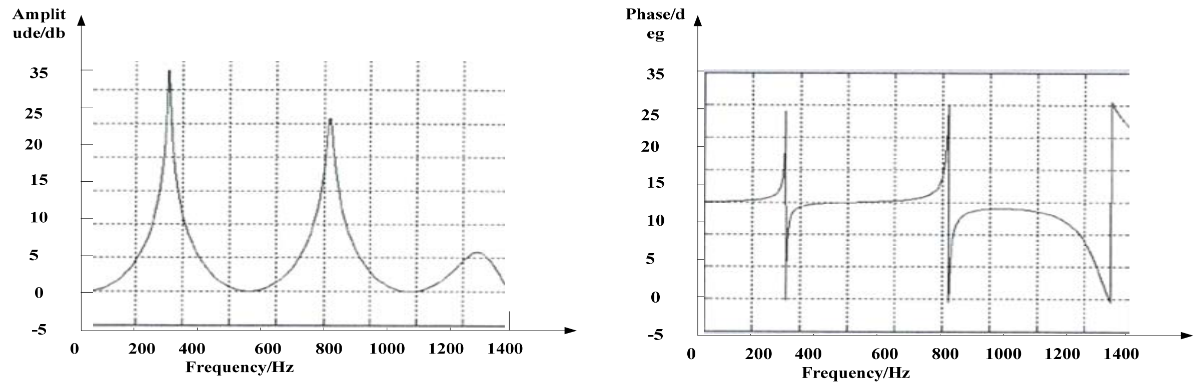

Fig. 5. Pressure Radio Frequency Characteristics of 5.5 m Pipeline.

The diameter of Fig. 3, Fig. 4 and Fig. 5 is 10 mm and the tube lengths are respectively 3.5m, 4.5 m, 5.5 m, and 6.5 m. The frequency of the highest resonance of the main test pipeline decreases with the increase of length, and the amplitude of occurred resonance slightly decreases as well. In the low-frequency stage, the pipe length is the main influence factor of the frequency of the highest resonance. The longer the length is, the lower the resonant frequency is; pipeline diameter influences little in low-frequency stage, but diameter increase can enlarge the amplitude in resonance.

5. Conclusion

As for the dynamic characteristics issue of test bed main test pipeline in solenoid valve test system, we firstly research the analytical method of frequency characteristics of fluid pipeline and select the approximated method of fluid pipeline dissipation model. Electrochemical impedance spectroscopy is an effective method to solve the dynamic characteristic of the fluid pipeline in frequency domain. In the structural design process of water fluid system of solenoid valve test bed, the condition that there will be a lot of electromagnetic valve in the productive process should be considered. Enough work space should be left between each branch, which should be arranged orderly. The height of test bench should be humanized design, which is convenient for the detection. Pumping source is installed on the floor and has some distance with the test bench. Based on the above factors, the main test pipeline should be with a certain length.

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