

## Study of Electrical Simulation Application in Hydraulic System

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**Abstract.** Detection and analysis of hydraulic control system has become urgent concern increasingly. This paper established mathematical model about hydraulic flow and pressure pulse system through Niboer formula, Opening up new areas of research for the detection and analysis on hydraulic system.

**Keyword:** Electrical Simulation ; Hydraulic Pulse

### 1. Introduction

With developing of modern electronic technology and computer technology, the applications of hydraulic control technology is constantly expanding, it includes almost all the fields of national economy, such as manufacturing, construction, agriculture, environmental protection, mine industry, metallurgy, transportation, aerospace. Hydraulic control technology has become an essential element and key technology of modern construction machinery and engineering control technology. Following is the names of wide-varieties hydraulic system items are too numerous to enumerate and the system composition and principles are diverse from each other due to various commercial unit in different areas, therefore, the detection and analysis of hydraulic control system is focused on more and more. In the Medical Physics, NyBoer formula a method of measuring blood flow was proposed, which is given by the resistance formula and seek first derivation. It developed the relationship between electrical resistance and volume in theory, and with it we can get blood flow by volume changes related with measuring of resistance. So, by another way, we can established electrical-simulation mathematical model about flow and pressure pulses in hydraulic system.

Electrical simulation is a way to resolve a problem, which makes hydraulic system modularized. The equivalent circuit obtained by the model can deduce the relationship Between each kind of variable relations in order to explain the stability or specific issues of hydraulic system.

### 2. Mathematical Modeling

#### 2.1 Pressure and Flow Values Acquisition by the Changes in Oil Resistance of Single-loop Pipeline

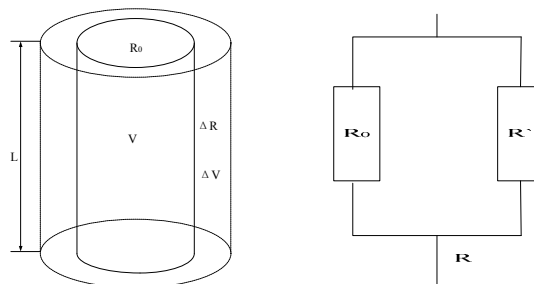


Figure 1. Single-loop model

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As shown in Figure 1, assuming that a cylindrical pipe filled with hydraulic oil, Its length is  $L$ , cross-sectional area is  $S$ , volume is  $V$ , axial resistance is  $R_0$ , resistance rate is  $\rho$ , and assuming when in expansion a flexible pipe's length is unchanged, and the resistance increased by expanded pipeline cross-sectional area, is set to  $R'$ , and then  $R_0$  and  $R'$  are set into a parallel relationship. So the value of the total resistance  $R$  can be pushed to as follows:

$$\begin{aligned}\frac{1}{R} &= \frac{1}{R_0} + \frac{1}{R'} \\ \Rightarrow R &= \frac{R_0 R'}{R_0 + R'} \\ \text{又} \because R_0 &< R' \\ \therefore R &= \frac{R_0}{1 + \frac{R_0}{R'}} \approx R_0 - \frac{R_0^2}{R'} \\ \therefore \Delta R &= R - R_0 = R_0 - \frac{R_0^2}{R'} - R_0 = -\frac{R_0^2}{R'} \\ R' &= \frac{\rho L^2}{\Delta V} = \frac{-R_0^2}{\Delta R} \\ \Rightarrow \Delta V &= \frac{\rho L^2 \Delta R}{-R_0^2}\end{aligned}$$

But hydraulic piping is generally rigid, which means that it can not considered to have an expansionary and volume changes can only be reflected on compressibility and mobility in hydraulic fluid. As a rule under normal conditions we can ignore the compressibility of hydraulic oil in low pressure system. Therefore, it is available.

$$\begin{aligned}v &= \frac{\Delta V}{S} \\ \Delta P_\lambda &= \lambda \frac{L \rho v^2}{2d} = \lambda \frac{L \rho \Delta V^2}{2ds^2} \\ \Rightarrow \Delta P_\lambda &= \lambda \frac{-L^3 \rho^2 \Delta R^2}{2ds^2 R_0^2}\end{aligned}$$

$v$  Flow velocity

$\Delta P$  Frictional pressure loss

$\lambda$  Frictional pressure-resistance coefficient

$d$  Pipe diameter

The formulas above show that the values of fluid pressure and flow change as the resistance move in proportional relationship. Negative sign indicates that when the pressure and flow rate increased the resistance decreases. As can be seen from the formula, the approach measuring resistance changes to response to changes of pressure and flow is feasible.

Obviously, according to hydraulic manual the values of  $\lambda$ ,  $\rho$  can be found out, and then the values of pressure and flow can be derived.

## 2.2 System Equivalent Circuit Analysis

The formula derived above, based on single-loop pipe resistance variation, obtained for the single circuit, is almost in line with the conditions. However, in the actual measurement, it must be affected by some other substances between the electrodes materials, and whose value of resistance can not be ignored. To solve this practical problem of calculation, an electric-analog parallel equivalent circuit was created as shown below.

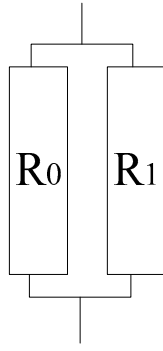


Figure2. Double-loop model

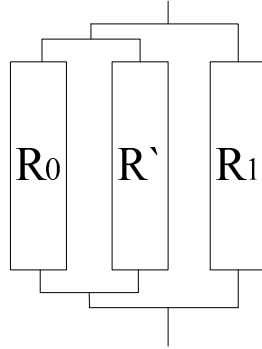


Figure 3. Double-loop model

According to this model, the whole system outside the measured pipeline can be regarded as a conductor which paralleled to the measured pipeline, as shown in Figure 2. Assuming the radius of cylindrical pipe is  $r$ , cross-sectional area is  $S_0$ , the outside system's resistance is  $R_1$ , both of the length is  $L$ , the resistivity of Hydraulic oil is  $\rho$ , the outside system's resistivity is  $\rho_1$ . Based on those assumptions above, the Initial resistance of the measured pipeline is  $R_0$ .

$$R_0 = \frac{\rho L}{S_0}$$

$R_0$  and  $R_1$  are in parallel, To simplify the research model, we can ignore the impact of capacitance. Then, the parallel resistance sum of  $R_0$  and  $R_1$  is to be calculated as  $Z_0$ .

$$\begin{aligned} \frac{1}{Z_0} &= \frac{1}{R_0} + \frac{1}{R_1} \\ \Rightarrow Z_0 &= \frac{R_0 R_1}{R_0 + R_1} \end{aligned}$$

Suppose, The resistance of hydraulic oil is  $R'$ , which is produced by compressibility due to the changes of system pressure. And then, it can be got the below.

$$R' = \frac{\rho L^2}{\Delta V}$$

$R'$  and  $Z_0$  are in parallel, then the sum resistance of hydraulic system can be calculated as  $Z$ , such as below.

$$\begin{aligned} \frac{1}{Z} &= \frac{1}{Z_0} + \frac{1}{R'} \\ Z &= \frac{Z_0 R'}{Z_0 + R'} \end{aligned}$$

$$\begin{aligned}
& \because Z_0 < R \\
\therefore Z = Z &= \frac{Z_0}{1 + \frac{Z_0}{R}} \approx Z_0 - \frac{Z_0^2}{R} \\
\Delta Z = Z - Z_0 &= Z_0 - \frac{Z_0^2}{R} - Z_0 = -\frac{Z_0^2}{R} \\
R &= \frac{\rho L^2}{\Delta V} = \frac{-Z_0^2}{\Delta Z} \\
\Rightarrow \Delta V &= \frac{\rho L^2 \Delta Z}{-Z_0^2} \\
\because v &= \frac{\Delta V}{S} \\
\Delta P_\lambda &= \lambda \frac{L \rho v^2}{2d} = \lambda \frac{L \rho \Delta V^2}{2ds^2} \\
\Rightarrow \Delta P_\lambda &= \lambda \frac{-L^3 \rho^2 \Delta Z^2}{2ds^2 Z_0^2}
\end{aligned}$$

In above equation,  $Z$  is total sum of foundation resistance about hydraulic system, namely, that is the measured part and other part of hydraulic system. Therefore its change-quantity is very small, and it may approach a minimum. So the formula (1) may be expressed as below.

$$\begin{aligned}
d_v &= -\frac{\rho L^2}{Z_0^2} d_z \\
Q &= \frac{d_v}{d_t} = -\frac{\rho L^2}{Z_0^2} \frac{d_z}{d_t}
\end{aligned}$$

Volume change-rate is proportional to the change-rate of impedance about hydraulic oil. Taking the first derivative of resistance to time can express the change rate of resistance, but also can reflect the change-rate of volume. However, in the actual process, to maintain a dynamic balance the volume change is achieved through the instantaneous flow ( $Q$ ) of hydraulic oil into this space. Therefore using change-rate of resistance can reflect the flow of hydraulic pipe. By the formula above the pressure loss  $\Delta P_\lambda$  along the way can be pushed out. Therefore, the study of this paper has opened up a new idea for establishing simulated model of pressure pulse, and researching phenomenon shock about hydraulic system.

### 3. Conclusions

In this paper, it established a mathematical model of electrical simulation and the basic idea for measuring of pressure pulse and flow about hydraulic system. By the existed-mature virtualization software of electric circuit, it can simulate the system's steady-state and transient response of pressure and flow about the detected hydraulic system. Thus, we can quickly and economically grasp various properties of the tested hydraulic system.

### 4. References

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