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Simulation Analysis and Design for the Pressure Impulse Test

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Abstract: The pressure impulse test system is a complex nonlinear system; its control methods are very different from the traditional linear systems. The difficulty of its analysis focused on the physical realization of the entire system and mathematical model on complex pipeline system. We analyze the composition and principles of the entire test system, detailed study the basic equation of unsteady flow and do the static design which provides parameters for the dynamic simulation. Method of characteristics is used to establish the mathematical model. Then we analyze the transient process of the test system with the model, main analyze the affecting factors of water hammer wave-shaped through simulation. Finally, verify the correctness of simulation analysis model and ensure the impulse test can be successfully completed through the test of our main specimen -retractable actuator of landing gear with different combinations of key parameters.

Key words: Pressure impulse, impulse occurred device, characteristic curves method, modeling, simulation

INTRODUCTION

Hydraulic system is an important part in aerospace products. Aircraft hydraulic system is mainly used in landing gear, retractable gear plate; flaps, ailerons, horizontal tail, rudder control, inlet cone, auxiliary intake valve adjustment and so on. There are lots of failures in hydraulic systems because of high pressure, accessories precision, oil leaks and other factors (Li, 2007), most of them relate to the pressure impulse. When hydraulic system work, if the instantaneous flow rate changed greatly, making the hydraulic pressure wave peak is much greater than the rated values, this phenomenon of strong impact is called pressure impulse. The investigation showed that hydraulic system failure accounts for about 40% of the total number of failures, about 15-20% are caused by the hydraulic system in serious accidents. A large part of the hydraulic system failure due to the impulse pressure which are generated by hydraulic components, so, the pressure impulse test must be done for the hydraulic system piping and accessories. At present, the hydraulic system engineering design and analysis remain largely in accordance with the theory of steady flow but the actual system is turbulence at most time. Therefore, it is necessary to do research about the dynamic nature of turbulence (Li, 2007).

COMPOSITION OF IMPULSE TEST DEVICE

Hydraulic impulse generating device mainly composed of the main oil source system, hydraulic control valve, the auxiliary oil source system, start-up kit, monitor cabinet and other components. The high pressure generated by hydraulic impulse units test the specimens as well as the equipment itself. In order to enhance the reliability and security of the hydraulic impulse units, but also to make the impulse test system last longer, the accumulator and turbocharger was used in impulse generating device (Evans and Manley, 1986). Then the smaller source pressure can make larger test impulse pressure. Form the hydraulic impulse test system based on above analysis as shown in Fig. 1. The system consists of pump, accumulator, pressure relief valve, proportional servo valve (Martinez *et al*., 1972), solenoid directional valve, booster cylinder, specimen, pipe system and so on.

MODELING THE TEST DEVICE

The dynamic characteristic of hydraulic components and systems are very complex and must be modeled in appropriate method. The method of characteristics is a distributed parameter analysis (Evangelisti, 1969) (Fig. 2). The mathematical model of fluid within tube can be described by the wave equation:

$$\begin{cases} \dfrac{\partial P}{\partial X} + \dfrac{\rho}{A} \cdot \dfrac{\partial Q}{\partial t} + f(Q) = 0 \\ \dfrac{\partial P}{\partial t} + \dfrac{\rho c^2}{A} \cdot \dfrac{\partial Q}{\partial X} = 0 \end{cases} \tag{1}$$

where, P is pressure; Q is flow; ρ is density; c is wave velocity; x is position; t is time; A is pipe cross-sectional area; f is friction function which is non-linear function.

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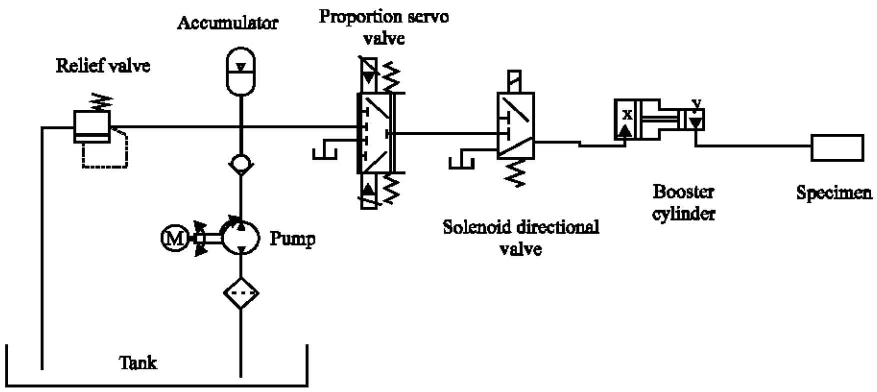

Fig. 1: Pressure impulse test schematic

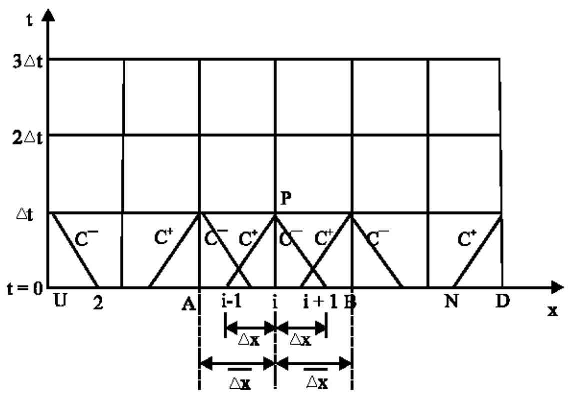

Fig. 2: Schematic of characteristics method

We will get two characteristic equations in full-differential form:

$$C^{+}\begin{cases}\dfrac{1}{c}\dfrac{dp}{dt}+\rho\dfrac{dv}{dt}+f(x,t)=0\cdots(a)\\ \dfrac{dx}{dt}=+c\cdots(b)\end{cases}\tag{2}$$

$$C^{-}\begin{cases}-\dfrac{1}{c}\dfrac{dp}{dt}+\rho\dfrac{dv}{dt}+f(x,t)=0\cdots(a)\\ \dfrac{dx}{dt}=-c\cdots(b)\end{cases}\tag{3}$$

Formula 2b and 3b are called characteristic equations. We can get equations as following with the method of discretization (Chaudhry, 1983):

$$\begin{cases}\Delta p+\rho\cdot c\Delta v+f(x,t)\cdot c\cdot\Delta t\cdots(a)\\ -\Delta p+\rho\cdot c\Delta v+f(x,t)\cdot c\cdot\Delta t\cdots(b)\end{cases}\tag{4}$$

They are transient differential equations along the characteristic line of hydraulic pipe, of which 2a along the C^{+} characteristic line family and 2b along the C^{-}. The equation is a partial differential equation and it is difficult to obtain its analytical solution but it can become practical iterative formula by the method of characteristics:

$$\left.\begin{aligned}C^{+}: p_j(t)-C_L+Z_s\cdot Q_j(t)=0\\ C^{-}: p_j(t)-C_R-Z_s\cdot Q_j(t)=0\end{aligned}\right\}\tag{5}$$

$$C_L=p_{j-1}(t-\Delta t)+\frac{\rho\cdot c}{A}Q_{j-1}(t-\Delta t)-f_{s(j-1)}(x,t-\Delta t).c.\Delta t\ -M+N$$

$$C_R=p_{j+1}(t-\Delta t)-\frac{\rho\cdot c}{A}Q_{j+1}(t-\Delta t)+f_{s(j+1)}(x,t-\Delta t).c.\Delta t+$$
$$DVTRP-\frac{DVT}{A}\cdot Q_j(t-\Delta t),\ Z_s=\frac{\rho\cdot c}{A}+\frac{DVT}{A}$$

$$DVTRP=\frac{4\cdot\rho\cdot\mu}{r^2}\cdot c\cdot\Delta t[Y_1(t-\Delta t)\cdot e^{-8000\cdot\Delta t\cdot\mu/r^2}+Y_2(t-\Delta t)\cdot e^{-200\cdot\Delta t\cdot\mu/r^2}+$$
$$Y_3(t-\Delta t)\cdot e^{-26.4\cdot\Delta t\cdot\mu/r^2}],\ DVT=196.4\cdot\frac{c\cdot\Delta t\cdot\rho\cdot\mu}{r^2}$$

where, p, Q are the average pressure and flow cross section of the pipeline, ρ is fluid density, x is distance along the pipe, v is average velocity, c is wave propagation velocity in the pipe, r, d are inner and outside diameter of the pipe, A is cross-sectional area of the pipe, μ is kinematic viscosity. The rest of device can use similar approach to modeling.

IMPULSE TEST SIMULATION OF WATER HAMMER WAVE

Digital simulation is the most effective way to solve the problem of hydraulic dynamics. The impacts can be seen when various factors change through analysis above. Comprehensive analysis has been done about their impacts on the waveform for different tube length, diameter of different cavity as is in Fig. 3.

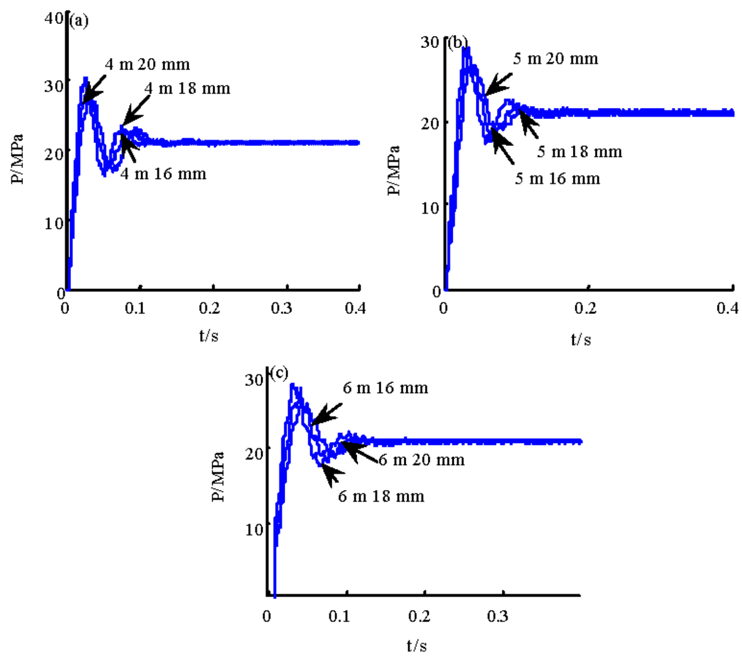

Fig. 3: Waveforms of different diameters and 4, 5 and 6 m length

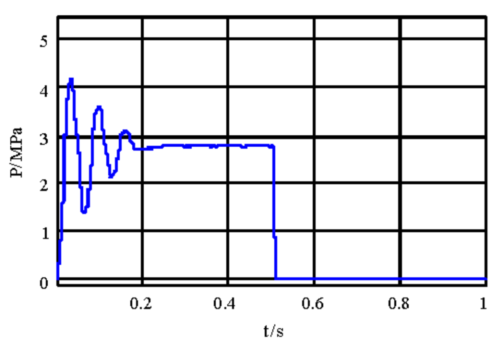

Fig. 4: Waveform of test debugging

We can get lots of useful results from the above curves. The simulation results show that the tube length and diameter of l_4 are 4 m and 16 mm will be more appropriate for the 3 L specimen. Whether, overshoot or the rate of increase has reached require standard and the smoothness is good too.

The preliminary inspection of this project has been carried out in December 2010. The debugging of water hammer wave reference to the simulation results of this part. The test waveforms are as Fig. 4. The project inspection team confirmed the results of test which were based on simulation and agreed to the project's preliminary acceptance. Successful completion of the project has important technical means for company in aircraft hydraulic system impulse test and depth technology studies which has high engineering value and economic benefits.

CONCLUSIONS

Since the control of water hammer wave affected by many factors, the impulse device must be designed by simulation analysis to determine the structural parameters. Through the above simulation analysis, some conclusions can be obtained: Tracking water hammer wave little by little is impossible even by the servo valve of good dynamic performance because of the large wave slope and instantaneous flow in the rising phase. We can only produce water hammer wave by water hammer phenomenon. In determining the mechanical structure of system, we can calculate characteristic parameters such as wave peak, slope, rated pressure on a water hammer, determine the waveform whether within the prescriptive area first, then adjust the ratio of throttle opening, the main source of oil pressure and the dynamic characteristics of proportion valve to ensure the waveform meet regulatory requirements. For the control of water hammer wave, system pressure should be raised to working pressure first and then fully open the main or auxiliary system flow valve, produce preliminary water hammer wave by controlling the solenoid valve. We can observe waveforms by the data collection during this time, and require the slope is greater than the required minimum slope, its peak value greater than the required peak pressure. Finally, achieve the required water hammer wave by feedback control. Four-way valve, cross-section of the pipe, the length of pipe between specimen and servo valve, the capacity of cavity will have great impacts on the impulse waveform. Different choices must be made refer to the simulate situation.

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