The Design and Specificity Analysis of The Follow-up Controlled Hydraulic Muffler

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Abstract. The hydraulic muffler is a component in the hydraulic system, its intrinsic vibration frequency and the main anti resonance frequency are closely related to the structure parameters of the mufflers. When the structure parameters remain unchanged, main anti resonance frequency is deviated from the fluctuation frequency of the system, so the attenuation effect is reduced rapidly. Therefore, it is particularly important to design a hydraulic muffler with special structural parameters that can be changed in time with pulsating frequency of the system. This paper takes the H-hydraulic muffler as the research object, which changes the structure parameters of the muffler according to the speed of the pump, so as to achieve a relatively stable pulsation absorption effect.

1. Introduction
Pump is a power component in the hydraulic pipeline. Because of the working mechanism of the pump, it will cause the pulsation of hydraulic pipelines, which will affect the working efficiency and the service life of the system. With the development of hydraulic system to high pressure and high power, vibration and noise are problems which can not be avoided. Scholars both at home and abroad have carried out extensive researches on how to reduce the fluid noise. It is concluded that three ways can be used to reduce vibration and noise in hydraulic systems: to decrease the influence of the vibration source, optimize the design of the pump and reduce the output flow pulsation of the pump; to avoid resonance and reduce pressure pulsation by arranging pipeline elements reasonably [1][2]. It is an effective and flexible method to install hydraulic mufflers, damping the pressure pulsation of the given frequency range.

There are many types of resonant hydraulic mufflers, which have been widely used in the fields of aviation, ship, engineering machinery and so on. Three types of hydraulic mufflers have been invented to solve noise problem: H-hydraulic muffler; multi chamber hydraulic muffler; fluid structure coupled vibration attenuator. H hydraulic muffler has strong universality, which can both work very well at different pressure level, and can adapt to the requirements of the installation space by local improvement. However, because of its single resonant frequency and narrow frequency band, when the fluctuating frequency changes, the attenuation effect is not obvious, that is, poor frequency variation adaptability. To sum up, the research of the follow-up controlled hydraulic mufflers is very necessary.
2. The derivation of the resonance frequency of the H hydraulic muffler

The H-hydraulic muffler is usually installed at the outlet of the hydraulic pump, and its basic structure is shown in Fig.1. The pressure pulsation of the hydraulic pump comes from point 1, then through the 1-2 section and comes into H-hydraulic muffler, the fluid goes backwards and forwards between the 2-3 section of the pipeline to ease the range of pressure pulsation wave and play the effect of liquid resistance, consuming a part of the pulsating energy. The cavity V plays the role of hydraulic volume and absorbs pressure pulsation from point 3. When the pressure pulsation frequency of the pump has the same intrinsic frequency as H-hydraulic muffler, the effect of the attenuation pulsation pressure of the muffler is the best. This is the antivibration mechanism of the H-hydraulic muffler.

In practical application, H-hydraulic muffler is adjoined to a section of pipeline and hydraulic pump, that is, the 1-2 section of the pipe. Therefore, it is more practical to obtain the resonance frequency by calculating the input impedance of point 1, and this frequency becomes the main anti resonance frequency. Because of the small structure of the muffler, resonance frequency and antiresonant frequency can be deduced by centralized parameter method [3].

As shown in Fig.1, the transfer relation of the 2-3 section pipeline is:

$$\begin{align*}
\begin{bmatrix}
P_3 \\
Q_3
\end{bmatrix} &= 
\begin{bmatrix}
1 & -(R_2 + L_2s)I_2 \\
0 & 1
\end{bmatrix}
\begin{bmatrix}
P_2 \\
Q_2
\end{bmatrix}
\end{align*}
$$

(1)

In,

$$R_2 = \frac{128\mu}{\pi d_2^2}, L_2 = \frac{4\rho}{\pi d_2^2}.$$  

The input impedance of point 3 is:

$$Z_3 = \frac{P_3}{Q_3} = \frac{K_y}{V_y}$$

(2)

According to (1)(2)(3): 

$$Z_2 = \frac{P_2}{Q_2} = \frac{L_2l_2V}{K_y s^2} + \frac{R_2l_2V}{K_y} s + 1$$

(3)

$$V = \frac{K_y}{s}$$

(4)

Change Eq.(4) into

$$\left(\frac{s}{\omega_n}\right)^2 + \frac{2\xi}{\omega_n} s + 1 = \frac{V}{K_y s}, \quad \omega_n$$ is the intrinsic resonance angle frequency of H hydraulic muffler. Because

$$\omega_n = 2\pi f_n$$

and then work out the intrinsic resonance frequency of H hydraulic muffler is:
\[ f_n = \frac{a}{2\pi} \sqrt{\frac{A_2}{l_3 V}} \quad (5). \]

As seen in Fig. 1, the transfer relation of 1-2 section of the pipeline is:
\[ \begin{bmatrix} P_2 \\ Q_1 \\ \end{bmatrix} = \begin{bmatrix} 1 & -(R_1 + L_s)s \\ 0 & 1 \end{bmatrix} \begin{bmatrix} P_1 \\ Q_1 \end{bmatrix} \quad (6) \]

The input impedance of point 1 is:
\[ Z_1 = \frac{P_1}{Q_1} = \frac{(L_1 l_1 + L_2 l_2)V}{K_s} s^2 + \frac{(R_1 l_1 + R_2 l_2)V}{K_s} s + 1 \quad (7) \]

In reference to Eq. (1)(2)(6)(7):
\[ Z_1 = \frac{V}{K_y} s \]

\[ (\frac{s}{\omega_r})^2 + \frac{2\pi}{\omega_r} \frac{s}{\omega_r} + 1 \]

Change Eq.(8)into \( \frac{\omega_r}{V} \frac{s}{K_y} \). In this equation, \( \omega_r \) is the main anti resonance angular frequency of H-hydraulic muffler, Because \( \omega_r = 2\pi f_r \), and then work out the main anti resonance angular frequency of H hydraulic muffler is:
\[ f_r = \frac{a}{2\pi} \sqrt{\frac{1}{(\frac{l_1}{A_1} + \frac{l_2}{A_2})V}} \quad (9) \]

According to Eq. (5) and (9), The intrinsic resonance frequency and the main anti resonance frequency of the hydraulic muffler are closely related to the structural parameters. When the structural parameters of the hydraulic silencer changes accordingly when the intrinsic resonance frequency and the main anti resonance frequency change. The effect of the hydraulic muffler is significant only on a specific frequency of pulsating absorption. If the pressure fluctuation frequency in the hydraulic system changes, deviated from a certain frequency, the effect of pulsating attenuation is reduced rapidly \[4]-[5].

2. The Structure design of of follow-up controlled hydraulic Mufflers

2.1. The Work Principle of the Follow-up Controlled Hydraulic Muffler

![Fig.2 The structure diagram of the follow-up controlled vibration hydraulic muffler](image)
Fig. 2 is a structure diagram of one type of follow-up controlled vibration hydraulic muffler. The hydraulic absorber is added a follow-up controlled device on the basis of H hydraulic muffler, which makes the flow area of the 2-3 section of the pipeline changed according to a certain signal, thus changing the intrinsic resonance frequency and main anti resonance frequency of the follow-up controlled vibration hydraulic muffler [6][7].

When the speed of hydraulic pump increases, the speed signal of relevant flow pulsation frequency of hydraulic pump increases at the same time, which inputs to the electrical component (it includes current amplifier, controlled amplifier, displacement sensor of electric actuator). The current signal is amplified by current amplifier, forming the input current. The input current is amplified by controlled amplifier, forming control current. The controlled current enters the analog conversion circuit board, using the A/D and D/A conversion modules to drive the electric actuator. The electric actuator makes the slider moving in the direction of X, which makes the increase of the circulation area of 2-3 pipeline, thus the intrinsic resonance frequency and the main anti resonance frequency of the follow-up controlled vibration hydraulic muffler increased. When the slider reaches the controlled displacement, then its motion stops. At this time, the intrinsic resonance frequency or the main resonance frequency of the hydraulic muffler will be equal to the intrinsic pulsation frequency of the hydraulic pump or the backwash pulsation frequency, so the pressure pulsation will be weakened greatly to the maximum extent. On the contrary, when the speed of hydraulic pump decreases, the speed signal which is related to the flow pulsation frequency of the hydraulic pump decreases. When the slider moves to the -X direction through the intermediate control link, the frequency of intrinsic resonance and the frequency of main anti resonance are reduced to equal intrinsic pulsation frequency and backwash pulsation frequency, of the pump, its motion stops.

The backwash pulsation is the main component of flow pulsation of the hydraulic pump, so the practical significance of the main anti resonance frequency of follow-up controlled vibration hydraulic muffler is greater. When the initial displacement is $X_0$ of the slider the main anti resonance frequency is equal to 70% speed of the hydraulic pump’ backwash pulsation frequency. At the maximum displacement of the slider, the frequency of the main anti resonance should be equal to 100% speed of the hydraulic pump’ backwash pulsation frequency. The straight-line displacement of the electric actuator should not be too large, so the upper limit of effective stroke is $2mm$.

2.2. Sample Analysis

Take 9-plunger hydraulic pump for example, its maximum speed is $3000r/min$. According to $f_r = \frac{nZ}{60}$, it is deduced that 100% speed of the hydraulic pump’ backwash pulsation frequency is $450Hz$, while 70% speed of the hydraulic pump’ backwash pulsation frequency is $315Hz$. Fig.3 is the static characteristic of the follow-up controlled vibration hydraulic muffler. Fig. 4 and Fig. 5 are the pulsating attenuation diagrams which depict that at the 70% speed and maximum speed, the displacement is and $X = 1.5mm$, respectively $X = 0$. 
Fig. 3 The static characteristic diagram of the follow-up controlled vibration hydraulic muffler

Fig. 4 Pulsating attenuation diagram at 70% of maximum speed
Fig. 5 Pulsating attenuation diagram at maximum speed

It can be seen from Fig. 3-5 that the speed increases from 70% of the maximum speed to the maximum speed, the stroke of the slider is 1.5 mm. At the maximum speed state, the attenuating effect of the follow-up controlled vibration hydraulic muffler is the best. The evaluation criteria of dynamic performance of follow-up controlled system is the response time, that is, the reasonable value is less than 0.1s. If the response time is too long, the significance of the follow-up controlled vibration hydraulic muffler is meaningless. The system can reduce the error of the signal response by adjusting the size of the input current on.

3. Conclusion
Through theoretical simulation of the follow-up controlled vibration hydraulic muffler, reasonably adjusts the structural parameters of the various parts of the hydraulic muffler, effectively achieves the attenuation of pressure pulsation, further provides references for future experiments.

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