System Design and Characteristic Analysis of Intelligent Follow-up Hydraulic Muffler

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Abstract. The pulsating flow output of plunger pump will produce pressure pulsation after flowing through the pipeline. Using hydraulic muffler to attenuate the pressure pulsation of the pipeline is an economical, reliable and easy to implement method. Intelligent follow-up hydraulic muffler, which adapts to pressure pulsation changing at any time by changing its own parameters, has become a research hotspot. Intelligent follow-up hydraulic muffler can accurately and effectively attenuate the pressure pulsation of the system and maximize the attenuation performance of the hydraulic muffler. The structure and performance of the existing intelligent follow-up hydraulic muffler are mainly introduced. The general methods, principles, advantages and disadvantages of intelligent follow-up hydraulic muffler design are summarized. On this basis, the development trend of intelligent hydraulic muffler is predicted and prospected.

1. Introduction
The flow pulsation generated by the periodic working mode of the plunger pump suction-discharge type will be converted into pressure pulsation along the pipeline. Pressure pulsation is the main factor for generating pipeline vibration and noise [1]. With the development of high pressure hydraulic system, this problem becomes more prominent. Installing a hydraulic muffler at the outlet of the hydraulic pump is a reliable and common method of vibration elimination [2]. The hydraulic muffler is manufactured according to the principle of air muffler and hydraulic fluid dynamics [3]. Through reasonable configuration of structural parameters of muffler, resonance absorption energy is utilized to eliminate vibration. The traditional hydraulic muffler is a static hydraulic muffler. After its parameters are determined, the pressure pulsation in a certain frequency range near the natural frequency of the hydraulic muffler can be attenuated. However, with the development of hydraulic system to high pressure, high speed, high power and low noise, the traditional hydraulic muffler can no longer meet the needs of the development of hydraulic system. Therefore, in order to adapt to the complex changes of pressure pulsation in practical engineering, intelligent noise reduction technology will be the focus of noise reduction technology research for high pressure hydraulic system.

Based on the current research situation, this paper systematically expounds the types and research methods of intelligent follow-up hydraulic mufflers, and explains the attenuation characteristics of each follow-up hydraulic muffler. On this basis, the development trend of intelligent noise reduction technology is predicted.
2. Structure design of intelligent follow-up H Type hydraulic muffler

2.1. Working Principle of H-type Follow-up Hydraulic Muffler
The H-type intelligent follow-up hydraulic muffler is based on the static H-type hydraulic muffler, combined with sensor monitoring technology, PLC control principle and follow-up adjusting devices added to its two mass chambers, so that the hydraulic muffler widens the attenuation frequency range of the muffler by changing its structural parameters. The working principle of H-type intelligent follow-up hydraulic muffler (as shown in fig.1) is as follows: When the rotating speed of the hydraulic pump changes, the speed sensor transmits a rotating speed signal corresponding to the rotating speed to the PLC; After the PLC automatically calculates, the pulse number and pulse frequency corresponding to the rotation speed signal are transmitted to the servo controller; The servo control transmits a voltage signal to that servo motor after receiving the signal so as to control the number of turns and the rotate speed of the servo motor; After receiving the instruction, the servo motor drives the ball screw to rotate through the coupling, thereby converting the rotation of the ball screw into the translation of the worktable, thereby realizing the accurate translation of the sliding stops 1 and 3 and controlling the flow area of the pipelines of the sections 1-2 (mass chamber 1) and 3-4 (mass chamber 2).

![H-type intelligent follow-up hydraulic muffler structure principle diagram](image)

1, 11. servo motors  2, 12. couplings  3, 13. left bearings  4, 14. left fixed support seats  5, 15. ball screws  6, 16. Nuts  7, 17. worktables  8, 18. right bearings  9, 19. right fixed support seats  10. slide block 3  20. slide block 1  21. hydraulic pipeline wall  22. hydraulic pipeline

Figure 1  H-type intelligent follow-up hydraulic muffler structure principle diagram

2.2. Research Method of H-type Intelligent Follow-up Hydraulic Muffler
Literature [4] analyzes the relationship between resonance frequency and structural parameters of H-type hydraulic muffler by using the method of centralized parameters. On this basis, on the premise that other structural parameters of the hydraulic muffler are unchanged, the two natural frequencies of the secondary hydraulic muffler are equivalent to the natural pulsation frequency and the backwash pulsation frequency of the system respectively in real time. Based on the pump speed and PLC control technology, the structural parameters of H-type intelligent follow-up hydraulic muffler and the formula for the change of pump speed are finally reasonably designed as follows:

\[
\frac{L_1(V_1 + V_2)}{d_1 - \frac{cDn_1}{10}} = \frac{L_2V_4}{d_2 - \frac{cDn_2}{10}} + \frac{\sqrt{2\pi n_e}z}{30a} = \left[ \frac{L_1(V_1 + V_2)}{d_1 - \frac{cDn_1}{10}} \right] \left[ \frac{L_2V_4}{d_2 - \frac{cDn_2}{10}} \right] + \frac{4L_1L_2V_4^2}{(d_1 - \frac{cDn_1}{10})(d_2 - \frac{cDn_2}{10})} \tag{1}
\]
\[
\left(\frac{2\sqrt{2\pi}n_{in}z}{60} \right) - \frac{L_{v_2} + V_4}{\left(d_1 - cD_{n_1} \right)} + \frac{L_{v_4}}{\left(d_3 - cD_{n_3} \right)} = \left[ \frac{L_{v_2} + V_4}{\left(d_1 - cD_{n_1} \right)} \right] \left[ \frac{L_{v_4}}{\left(d_3 - cD_{n_3} \right)} \right] + \frac{4L_{v_2}V_4}{\left(d_1 - cD_{n_1} \right) \left(d_3 - cD_{n_3} \right)}^2
\]  

(2)

In the formula, \( z \) is the number of plungers; \( n_{in} \) is the speed of the hydraulic pump, \( \frac{\text{r}}{\text{min}} \); \( L_3 \) is the length of the pipeline of the mass chamber 1, m; \( L_3 \) is the length of the pipeline of the mass chamber 3, m; \( V_2 \) is the volume of the cavity I, m\(^3\); \( V_4 \) is the volume of volume II, m\(^3\); \( D \) is the pitch of the lead screw, m; \( c \) is the thread number; \( n_1 \) is the rotational speed of the servo motor 1, \( \frac{\text{r}}{\text{min}} \); \( n_3 \) is the rotational speed of the servo motor 3, \( \frac{\text{r}}{\text{min}} \); \( d_1 \) is the initial diameter of the pipe of the mass chamber 1, m; \( d_3 \) is the initial diameter of the pipeline of the mass chamber 3, m.

2.3. Attenuation Performance of H-type Intelligent Follow-up Hydraulic Muffler

Document [5] selects the transmission loss in acoustics to evaluate the vibration elimination effect of H-type hydraulic muffler. The pulsation attenuation formula of H-type intelligent follow-up hydraulic muffler is as follows:

\[
TL = 20 \log \left( \frac{p_{\text{out}} \times Q_{\text{out}}}{p_{\text{in}} \times Q_{\text{in}}} \right)
\]  

(3)

In the formula, \( TL \) is transmission loss, dB; \( p_{\text{in}} \) is the input pressure, MPa; \( Q_{\text{in}} \) is input flow, m\(^3\)/s; \( p_{\text{out}} \) is the output pressure, m\(^3\)/s; \( Q_{\text{out}} \) is the output flow, MPa.

When the fluid medium is hydraulic oil No.32, taking 9 plunger pumps as an example, using MATLAB programming, the attenuation effect curves of backwash pulsation frequency and natural pulsation frequency of H-type intelligent follow-up hydraulic muffler are obtained according to formula (3), as shown in fig. 2 and fig.3.

As can be seen from fig.2 and fig.3, the H-type intelligent follow-up hydraulic muffler attenuates the backwash pulsation frequency and the natural pulsation frequency at the same time. The attenuation effect on each frequency segment is higher than 17 dB, and the follow-up attenuation effect is ideal. And with the increase of frequency, the attenuation degree shows a wavy upward trend. This shows that the attenuation effect for high frequency band is better than that for low frequency.
band. Compared with the previous hydraulic muffler, it makes up for the defect that the traditional hydraulic muffler can only attenuate a certain frequency range. The intelligent follow-up hydraulic muffler has the advantages of fast response, stable operation, small static error and the like. Its attenuation range is wider than that of traditional hydraulic muffler, and its attenuation effect is more ideal.

3. Structural Design and Performance Analysis of Thin Plate Vibration Intelligent Follow-up Hydraulic Muffler

The thin plate vibration type intelligent follow-up hydraulic muffler is designed on the basis of the static thin plate vibration type hydraulic muffler [6]. Using sensor monitoring technology, PLC control principle and a follow-up adjusting device added in the cavity, the follow-up device is controlled to change the volume of the cavity and the area of the thin plate, thereby changing the attenuation frequency of the muffler. As shown in fig. 4, the muffler also controls the sliding block according to the rotating speed of the pump to change the volume of the cavity and the effective length of the thin plate, thus achieving the effect of intelligently attenuating pressure pulsation.

3.1. Research Method of Thin Plate Vibration Intelligent Follow-up Hydraulic Muffler

Document [6] equates the thin plate vibration type hydraulic muffler with a fluid resonance system and a structural resonance system connected in parallel, as shown in fig. 5.

On the premise that other structural parameters of the hydraulic muffler are unchanged, the Helmholtz resonance frequency of the hydraulic muffler and the structural resonance frequency of fluid coupling vibration of the thin plate are respectively equal to the natural pulsation frequency and
the backwash pulsation frequency of the system. Combining the pump speed with the servo motor speed, the following results are obtained:

\[
\frac{n_h z}{60} = \frac{c_i d}{4 \sqrt{\frac{L \pi S (10d_l - n c d_z)}{10}}}
\]

(4)

\[
\frac{n_h z}{30} = \frac{u_m^2 \delta}{2 \pi \left( R - \frac{n c d_z}{10} \right)^2} \frac{E}{12 \rho_i (1 + \eta)(1 - \nu^2)}
\]

(5)

In the formula, \(d\) is the balance hole diameter, m; \(d_z\) is the pitch of the ball screw, m; \(L\) is the balance hole length, m; \(S\) is the cross-sectional area of the cavity, \(m^2\); \(c\) is sound speed, \(m/s\); \(u_m\) is the root of the characteristic equation; \(\delta\) is the thickness of the thin plate, m; \(\eta\) is the current-carrying factor; \(\nu\) is Poisson's ratio; \(\rho_i\) is the density of the thin plate, \(kg/m^3\); \(E\) is the elastic modulus of the thin plate, \(Pa\).

### 3.2. Attenuation Performance of Thin Plate Vibration Intelligent Follow-up Hydraulic Muffler

The insertion loss [6] can be used to evaluate the silencing characteristics of the thin plate vibration type intelligent follow-up hydraulic muffler. If the pulsating pressure at the load end before installing the muffler is \(\Delta p_n\), and the pressure pulsation at the load end after installing the muffler is \(\Delta p_m\), the insertion loss is \(K_i\):

\[
K_i = 20 \log \left| \frac{\Delta p_n}{\Delta p_m} \right| = 20 \log \left| \frac{a'_{11} + a'_{12} Y_z(s)}{a_{11} + a_{12} Y_z(s)} \right|
\]

(6)

In the formula, \(a'_{11}\) is the transfer matrix coefficients for the system; \(a'_{12}\) is Output transfer matrix coefficients for the system; \(Y_z(s)\) is Load admittance for muffler.

When the fluid medium is hydraulic oil No.32, taking a 9-head plunger pump as an example, the attenuation effect of the thin plate vibration type intelligent follow-up hydraulic muffler can be obtained according to formula (6) by MATLAB programming as shown in fig.6 and fig.7.

![Figure 6: Attenuation diagram of natural pulse frequency of thin plate vibration type intelligent follower hydraulic muffler](image1)

![Figure 7: Attenuation diagram of pulsating frequency of thin plate vibration intelligent follow-up hydraulic muffler](image2)

As can be seen from fig.6, the attenuation effect of the thin plate vibration type intelligent follow-up hydraulic muffler on the natural pulsation frequency (300 Hz to 1200 Hz) ranges from 10 db to 37 db. As can be seen from fig.7, the damping effect of the thin plate vibration type intelligent follow-up hydraulic muffler on the backwash pulsation frequency (50 Hz to 330 Hz) is more than 20 db. The damping range of the thin plate vibration type intelligent follow-up hydraulic muffler is wide,
and the damping effect is better than that of the common hydraulic muffler.

4. Development Trend of Intelligent Follow-up Hydraulic Muffler

4.1. Research on Intelligent Follow-up Hydraulic Muffler of Variable Piston Pump

Variable plunger pump has been widely popularized. The output pressure and output flow rate of variable plunger pump are determined by load, and the actual situation of pressure pulsation is more complicated than that of quantitative pump. At present, there is no research on intelligent hydraulic muffler for variable plunger pump. This research will be the focus of the development of intelligent hydraulic mufflers in the future.

4.2. Theoretical Research on Intelligent Servo Hydraulic Muffler

The existing intelligent follow-up hydraulic mufflers are designed on the basis of traditional and representative hydraulic mufflers. It is a difficult point to improve the existing design theory and develop accurate and comprehensive theoretical formula of hydraulic muffler.

5. Conclusions

This paper summarizes the attenuation characteristics of two new types of intelligent follow-up hydraulic mufflers. The formula that the structure parameters of intelligent follow-up muffler change with the change of pump speed is derived.

The intelligent follow-up hydraulic muffler can simultaneously attenuate the natural pulsation frequency and the back impact pulsation frequency at different times in the hydraulic system. It provides a way for noise reduction of power plant and a theoretical reference for structural design.

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