MOTION ANALYSIS AND DESIGN OF ACCUMULATOR FOR HYDRAULIC ROCK DRILL[①]

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ABSTRACT A concept about the stretching ratio(β) of the hydraulic accumclator diaphragm has been put forward, and it was pointed out that in case of the stretching ratio(β) be equal to 0. 5 the corresponding gas volume and initial pressure are beneficial to the improvement of the diaphragm's service life.

Key words hydraulic accumulator diaphragm service life stretching ratio parameter design motion analysis

1 INTRODUCTION

Hydraulic accumulator is one of the basic components of a modern hydraulic power system, it has varied types to be selected and applied under different conditions. This paper discusses mainly the motion law of the accumulator's diaphragm in the hydraulic system of a hydraulic rock drill.

Hydraulic accumulator has the functions of storing and releasing energy, regulating oil flow and relaxing pressure pulsation of the hydraulic system while rock drill is operating. These functions are executed by diaphragm's motion, therefore it is valuable to research further the construction parameters of the accumulator and to analyzes deeply the operation processes of the diaphragm and to find the foundation for guiding its selection and parameter design.

2 MOTION ANALYSIS OF THE DIAPHRAGM

When analyzing the motion of the diaphragm it is assumed that

(1) Incompressibility of hydraulic fluid being.

(2) The input and output of the accumulator hydraulic fluid take only an instant.

(3) The charged nitrogen gas of accumulator obeys adiabatic process.

According to the state equation of gas under adiabatic condition

$$PV^k = C \tag{1}$$

where P —gas charge pressure of the accumulator,

V —charged gas volume of the accumulator corresponding to P,

C —constant,

k —adiabatic constant, $k = 1.4$ for nitrogen.

it is understood that,

$$P_{\min} V_{\max}^k = P_{\max} V_{\min}^k = P_0 V_0^k = P'_0 V_0'^K = C \tag{2}$$

where $V_{\max}$ —nitrogen gas volume corresponding to the lowest hydraulic working pressure of the accumulator,

$V_{\min}$ —nitrogen gas volume corresponding to the highest hydraulic working pressure of the accumulator,

V_0 —nitrogen gas volume corresponding to the natural state of the diaphragm,

V'_0 —nitrogen gas volume corresponding to the charging state of the accumulator,

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P_{max}, P_{min}, P_0, P'_0 —nitrogen gas pressure corresponding to V_{max}, V_{min}, V_0 and V'_0 respectively.

Let $\Delta V = (V_{max} - V_{min})$ denotes the working volume of the accumulator.

For convenience the following concepts are introduced;

$\gamma = \dfrac{P_{max}}{P_{min}}$ —hydraulic working pressure ratio of the accumulator,

$\alpha = \dfrac{P_0}{P_{min}}$ —hydraulic pressure ratio during the accumulator being in the "0" position,

$\alpha' = \dfrac{P'_0}{P_{min}}$ —gas charge pressure ratio of the accumulator.

It must be pointed out that the "0" position state means the natural state of the diaphragm. This is really an assumptive state.

From equation (2), equation(3) can be derived:

$$V_0 = \frac{\Delta V \gamma^{1/k}}{\alpha^{1/k}(\gamma^{1/k} - 1)} \tag{3}$$

Differentiate (3) with respect to α, we get eqn. (4):

$$\frac{\partial V_0}{\partial \alpha} = -\frac{\Delta V}{k} \cdot \frac{\gamma^{1/k}}{\gamma^{1/k} - 1} \cdot \frac{1}{\alpha^{(k+1)/k}} \tag{4}$$

From eqn. (4) we can see that V_0 is monotone decreasing with α increasing, but this attenuating is more and more slow as shown in Fig. 1.

Fig. 1 Curves about V_0-α in initial state

Although there is no extreme value for $V_0(\alpha)\left[\dfrac{\partial V_0}{\partial \alpha}\Big|_{\alpha=0} = \infty, e\dfrac{\partial V_0}{\partial \alpha}\Big|_{\alpha=\infty} = 0\right]$, a perfect value α can still be found on slow-response zone of the V_0- α curve to make V_0 be as small as possible.

Fig. 1 shows that $V_0(\alpha)$ tends to change gently when α = 1. In case of increasing α again to decrease the accumulator's size will not be meaningful and a lower α value is favourable for the accumulator to function well under lower system pressure. So value α shouldn't be too big.

Before now, the gas charge pressure of the accumulator was researched by specialists. A kind of viewpoint thought that the gas charge pressure should be lower than the lowest working pressure of the system, which is to say $\alpha' = 0.6 \sim 0.8$. But another kind of viewpoint thought it must be equalized to the lowest working pressure because accumulator is mainly used for absorbing pressure pulsation of the system, namely $\alpha' = 1.0$. However, that which is the most suitable viewpoint have not yet a clear conclusion. Therefore the "α" concept set by this paper will be undoubtedly favourable to the discussions on this problem.

From eqn. (3) it can be known that at the time of α = 1, the ratio of working volume to construction volume, $\Delta V / V_0$, has attained the minimum value, that is the minimum volumetric ratio when the diaphragm is moved toward one direction. At this moment the natural state of the diaphragm is just the critical state of accumulator comes into play. Working pressure of the accumulator is limited by its whole construction sizes, working pressure ratio equals to 1(γ = 1) is impossible yet γ = 1.15 ~ 1.25 is suitable.

3 STRETCHING RATIO OF THE DIAPHRAGM

Supposing, when accumulator is in operation, that the diaphragm stretching from its natural state resulted in the maximum volume ΔV_0, and the working volume of the accumulator is ΔV, then the stretching degree of the diaphragm can be described with $\beta = \Delta V_0 / \Delta V$, which is called the stretching ratio. Obviously, the smaller the β, the longer the serrice life of the diaphragm.

Further discussion on β is as follows:

According to definition, ΔV_0 can be expressed as

$$\Delta V = \{|V_{max} - V_0|, |V_0 - V_{min}|\}_{max} \tag{5}$$

thereby

$$\beta = \left\{\frac{|V_{max} - V_0|}{V_{max} - V_0}, \frac{|V_0 - V_{min}|}{V_{max} - V_0}\right\} \tag{6}$$

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Substituting the relative terms of eqn. (2) into eqn. (6), then

$$\beta = \left\{\frac{|P_{min}^{-1/k} - P_0^{-1/k}|}{P_{min}^{-1/k} - P_{max}^{-1/k}}, \frac{|P_0^{-1/k} - P_{max}^{-1/k}|}{P_{min}^{-1/k} - P_{max}^{-1/k}}\right\}_{max}$$

on

or

$$\beta = \left\{\frac{|1 - \alpha^{-1/k}|}{1 - \gamma^{1-/k}}, \frac{|\alpha^{-1/k} - \gamma^{-1/k}|}{1 - \gamma^{-1/k}}\right\}_{max} \tag{7}$$

let

$$\beta_1 = \frac{|1 - \alpha^{-1/k}|}{1 - \gamma^{-1/k}} \tag{8}$$

$$\beta_2 = \frac{|\alpha^{-1/k} - \gamma^{-1/k}|}{1 - \gamma^{-1/k}} \tag{9}$$

then

$$\beta = \{\beta_1, \beta_2\}_{max} \tag{10}$$

In practice, the bigger value of the eqn(10) should be taken up.

When working pressure ratio is determined, the curves $\beta_1(\alpha)$ and $\beta_2(\alpha)$ change with α are shown in Fig. 2, in which curve $\beta_1(\alpha)$ consists of A_1, B_1, C_1; the curve $\beta_2(\alpha)$ consists of A_2, B_2, C_2, ; and both curves intersect at point D. Thus $\beta(\alpha)$ changes with α is presented by the curve A_1DC_1. From this it can be seen that $\beta(\alpha)$ has minimum value at D, i. e. the diaphragm has its longest service life when operation under the state presented by D.

Let β_1 be equalled to β_2 and skim off absolute value symbols, then

$$\frac{1 - \alpha^{-1/k}}{1 - \gamma^{-1/k}} = \frac{\alpha^{-1/k} - \gamma^{-1/k}}{1 - \gamma^{-1/k}}$$

Solve α at point D:

$$\alpha_D = \frac{2^k \gamma}{(1 + \gamma^{1/k})^k} \tag{11}$$

Substituting α_D into eqn. (7), obtain value β at point D, i. e.

$$\beta_{min} = \beta_D = 0.5.$$

The stretching ratio of the diaphragm $\beta_{min} = 0.5$ indicates that the diaphragm, when it moves up and down for equal value round the natural state, would be operated most ideally.

With respect to a typical state of the diaphragm moving as shown in Fig. 3, we can design the accumulator of a hydraulic rock drill in accord with the idea of minimum stretching ratio.

4 PARAMETER DESIGN OF THE ACCUMULATOR

4.1 *Design Premier*

In the light of the operational performance and technological requirement of the rock drill, the maximum working pressure P_{max} of the hydraulie system should be given, the working pressure ratio γ ($\gamma = 1.2$) should be selected as the objective value of the design, the working volume of the accumulator ΔV is determined according to the motion law of the piston and valve.

Fig. 2 Curves about $\beta_1(\alpha)$, $\beta_2(\alpha)$, $\beta(\alpha)$

Fig. 3 The diagram of the work state of diaphragm

0-0 —"0" position state of the diaphragm;
A or B —state of the diaphragm at P_{max} or at P_{min}

4. 2 *Design Requirements*

Determine the gas charge pressure P'_0, charged gas volume V'_0 corresponding to P'_0, and the gas volume V_0 when diaphragm being in natural state.

Substituting α_D (eqn. 10) into eqn. (3), then obtain

$$V_0 = \frac{1}{2}\frac{\gamma^{1/k}+1}{\gamma^{1/k}-1}\Delta V \qquad (12)$$

while

$$V_{max} = V_0 + \frac{1}{2}\Delta V = \frac{1}{1-\gamma^{-1/k}}\Delta V \qquad (13)$$

Gas charge volume V'_0 of the accumulator can be taken as V_{max} in accord to (13). In this case the diaphragm may be collided against the walls of the accumulator because at this time the working pressure is minimum. To prevent the diaphragms' collision in motion, it is proposed to take up a suitable coefficient k' to make $V'_0 = k' V_{max}$, namely

$$V'_0 = k' \frac{1}{1-\gamma^{-1/k}}\Delta V \qquad (14)$$

where

k' —amendment coefficient, take up $k' = 1.1 \sim 1.5$

From the state equation of gas under adiabatic condition $P_{min}V^k_{max} = P'_0 V'^k_0$ the gas charge pressure should be

$$P'_0 = \frac{1}{(k')^k}P_{min} = \frac{1}{(k')^k\gamma}P_{max} \qquad (15)$$

5 CONCLUSION

In accordance to the above idea, the hydraulic accumulator can be designed to increase greatly the service life of the diaphragm under the condition of no change in working volume and working pressure ratio, yet the construction volume V_0 of the accumulator is smaller than that of the original one with $\alpha' = 0.6 \sim 0.8$.

For example, when the flat bottom-bowl type diaphragm being replaced by curve bottom type diaphragm in the hydraulic rock drill made by the Tamrock Company, Finland, the service life of the diaphragm increases greatly and the collision phenomenon has also been eliminated.

In addition, the conception of "0" position when $\beta = 0.5$ provides an important basis for determining the gas charge pressure of the accumulator, which means actually to improve the design of the hydraulic rock drill.

REFERENCES

1 Qi Rinxien, Liu Shixun: Dynamic Theory and Design of Hydraulic Vibration Equipment, (in Chinese). Changsha: CSUT Press. 1989, 114– 120, 206– 210.

2 Li Dayi. Journal Beijing Institute of Iron and Steel, (in Chinese), 1980, (3), 9– 18.

3 Gerhard Oehler: In: Hydraulische Speicher. Munchen: Carl Hanser Verlag, 1962.

4 Karman T V, Biot M A: Metody matematyczne, wtechnice. Warszawa: Panstwowe Wydawnictwo Naukowe, 1958.

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