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Approximate Method for Finding the Maximum Pressure Rise in Cushioning Chamber Used in Hydraulic Jack

by

T. UEMATSU and A. KAMATA

SUMMARY

In hydraulic jack, before the piston pushing a load comes to an end of stroke, it must be retarded to avoid impinging against the cylinder cover. For this purpose the pressure in the cylinder on the opposite side of piston is raised by making a narrow passage to throttle the flow of exhausted oil at the end of piston stroke (so-called cushioning chamber).

However, if the maximum pressure in cushioning chamber rises over the some limiting value, the cylinder wall will be in danger to burst. The pressure rise relates to magnitude of load, piston velocity and characteristics of oil pump (generally, displacement type pump is used).

It is necessary to estimate the maximum pressure rise in cushioning chamber for designing hydraulic jack of large capacity.

The authors obtained the approximate value of maximum pressure rise in cushioning chamber using the equation of motion of piston with load and characteristics of oil pump. This approximate value was checked by experiment.

Dr. UEMATSU is Professor Emeritus of Osaka University and Professor of Osaka Electro-Communication University, Neyagawa, Osaka, Japan

Mr. KAMATA is Engineer of Osaka Jack Mfg. Co., Osaka, Japan

INTRODUCTION

In a hydraulic jack, there has been no slide value as used in a steam engine and the pressure oil is sent, by an oil pump, to the both sides of piston through a distributing valve and a load comes in motion. Therefore, when the piston reaches at the end of stroke, leaving the matter as it is, it may impinge against the cylinder cover.

In order to avoid the danger of impact, the retreat of exhausted oil is throttled. Consequently, between the piston and the cylinder cover, the so-called cushioning chamber is composed and the pressure there, is raised up to prevent the motion of piston.

But when the designing of throttling is in fault, there may be possibility of bursting of the cylinder caused by the extreme rise of pressure p_e in the cushioning chamber. It, accordingly, is necessary to estimate the maximum pressure rise in cushioning chamber, when designed.

We are now going to state about an equation to estimate the maximum pressure rise derived after drawing deduction from the equation of motion of piston and an approximate equation which is checked by experiment.

THEORY OF PRESSURE VARIATION

Until throttling of a piston at the exhaust side begins, a piston as well as a load keep steady motion at velocity v_o. Consequently, the following equation is available:

$$0 = p_{do}A_d - p_{eo}A'_e - \mu G_L. \tag{1}$$

As shown in Fig.1, the throttling starts when J_1 comes to J_2 and since time t is estimated from the moment and the piston displacement x from the position, the motion of piston expressed in equation form is

$$\frac{G_p+G_L}{g}\frac{d^2x}{dt^2} = p_d A_d - p_e A_e - \mu G_L. \tag{2}$$

On the other hand for the oil pump, the displacement type is generally used. Judging from the pressure characteristic shown in Fig.2(b), the following equation is expressed, assuming p'_d itself acts on piston

$$p'_d = \frac{p'_{ds}}{v_o A_d - Q_r}\left(v_o A_d - \frac{dx}{dt}A_d\right). \tag{3}$$

According to our experiments, the pressure p'_d is expressed approximately in the following form:

$$p'_d = p'_{ds}\,\frac{t}{t_s - \tau_r}. \tag{4}$$

But p'_d of Eq.(3) and that of Eq.(4) being equivalent, therefore we get

$$\frac{t}{t_s-\tau_r} = \left(v_o - \frac{dx}{dt}\right)\Big/\left\{v_o - \left(\frac{dx}{dt}\right)_{t=t_s-\tau_r}\right\}.$$

From the above equation, the piston velocity is

$$\frac{dx}{dt} = v_o - \left\{v_o - \left(\frac{dx}{dt}\right)_{t=t_s-\tau_r}\right\}\frac{t}{t_s-\tau_r}.$$

Now we assume

$$\tau_r \fallingdotseq 0, \qquad (dx/dt)_{t=t_s-\tau_r} \fallingdotseq 0,$$

then we produce

$$\frac{dx}{dt} = v_o\left(1 - \frac{t}{t_s}\right). \tag{5}$$

The abscissa in Fig.2(a) indicates time and that in Fig.2(b), rate of discharge, and (a) and (b) seem not to correspond in their abscissas but in view of Eq.(5), we can acknowledge their correspondence approximately at least.

Now we take $\tau_r \ll t_s$ in Eq.(4), we gain

$$p'_d = p'_{ds}\,t/t_s. \tag{6}$$

Likewise, we take for p'_e,

$$0 < t < \tau_e ; \quad p'_e = p'_{emax}\, t / \tau_e , \tag{7}$$

$$\tau_e < t < 2\tau_e ; \quad p'_e = p'_{emax} + (p'_{emax} - p'_{es})\{1 - (t/\tau_e)\}, \tag{8}$$

$$2\tau_e < t < t_s ; \quad p'_e = p'_{es} = const.. \tag{9}$$

Here from Eq.(1) and Eq.(2), the following is obtained.

$$\frac{G_p + G_l}{g}\frac{d^2x}{dt^2} = p'_d A_d - p'_e A_e + p_{eo}\left(\frac{A'_e}{A_e} - 1\right)A_e$$

But p_{eo} is nearly equal to the atmospheric pressure, moreover, $A'_e/A_e > 1$ and $A'_e/A_e \fallingdotseq 1$ (1.19 in our experiment). Then we can express above equation as follows:

$$\frac{G_p + G_l}{g}\frac{d^2x}{dt^2} = p'_d A_d - p'_e A_e . \tag{10}$$

Eq.(10) is integrated with Eq.(6), (7), (8), (9) about t from 0 to t_s. The result calculated is

$$-\frac{G_p + G_l}{g} v_0 = p'_{ds} A_d \frac{t_s}{2} - \left\{ p'_{emax}\tau_e + p'_{es}\left(t_s - \frac{3}{2}\tau_e\right)\right\} A_e .$$

Consequently the following equation is presented

$$p'_{emax} = \frac{G_p + G_l}{g A_e}\frac{v_0}{\tau_e} + p'_{ds}\frac{A_d}{A_e}\frac{t_s}{2\tau_e} - p'_{es}\left(\frac{t_s}{\tau_e} - \frac{3}{2}\right). \tag{11}$$

p'_{emax} or the maximum pressure rise in cushioning chamber is obtainable with the Eq.(11), though being its approximate value.

COMPARISON BETWEEN THEORY AND EXPERIMENT

Our experiments present

$$\tau_e \fallingdotseq 0.02 \ s, \quad t_s \fallingdotseq 4\,\tau_e .$$

But it is undesirable, in view of accuracy, to get the value required for Eq.(11), from the measurement of phenomenon that occur in a short time as in this case. And what is more, the estimation of p'_{emax} requires much trouble in designing. In consideration of these points, we get

$$t_s = 2\,l_s / v_0 , \qquad t_s = 4\,\tau_e$$

from Eq.(5), and

$$p'_{ds} \fallingdotseq p'_{es}$$

from $p_{do} - p_{eo} \fallingdotseq p_{ds} - p_{es}$ in our assumption. Therefore, we express Eq.(11) as to be

$$p'_{emax} = \frac{G_p + G_l}{g A_e}\frac{2 v_0^2}{l_s} + p'_{ds}\left(2\frac{A_d}{A_e} - \frac{5}{2}\right). \tag{12}$$

We take p_{ds} is to be the limiting pressure of relief valve, and p_{do} is fixed by the capacity of jack. And there exists the equation $p'_{ds} = p_{ds} - p_{do}$. Putting those estimated value into the equation, p'_{ds} is obtainable.

The value of p'_{emax} obtained from experiments and that obtained from Eq.(12) are shown in Table 1.

The experimental value may contain some inaccuracy owing to the difficulty of estimation in so speedy phenomenon, and it leads to a discord with the value obtained from Eq.(12).

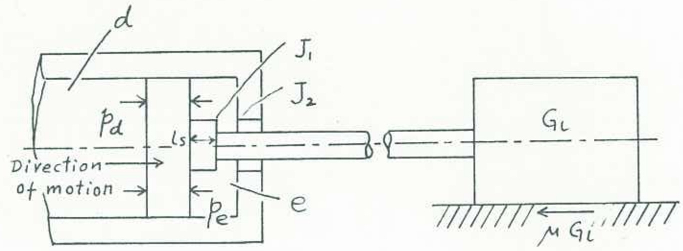
We consider it is acceptable to estimate p'_{emax} value practically even in this state of things.

CONCLUSION

The action of the cushioning chamber is, of course, and important factor for the hydraulic jack and as its phenomena always takes place in a moment, it has been far from satisfaction to grasp the phenomena.

The authors tried to interpret this phenomena in ways of the theory and experiments and we have obtained the equation to estimate the maximum pressure rise in cushioning chamber.

But, in spite of our effort, the experiments practiced are not sufficient enough to be satisfied and we are intending to continue the study.



d : Pressure side, e : Exhaust side,
When J_1 comes to J_2 , so-called cushioning chamber is composed.
p_d: Pressure on pressure side,
p_e: Pressure on exhaust side,
G_p: Weight of piston with piston rod,
G_l: Load to be moved.

Fig.1.- Schematic Figure Showing the Action of Hydraulic Jack.

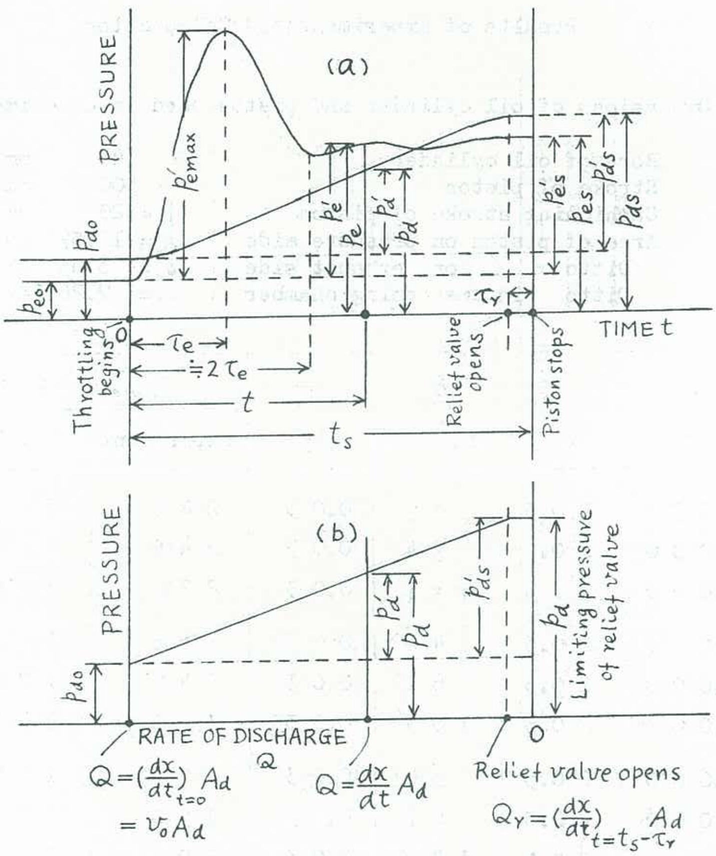


Fig.2.- Typical Pressure Variation in Cylinder (a) and Pressure Characteristic of Oil Pump (b).

TABLE 1

Results of Experiment and Calculation

Dimensions of oil cylinder and piston used in experiment:

Bore of oil cylinder	40	mm
Stroke of piston	500	mm
Cushioning stroke of piston	$l_s = 20$	mm
Area of piston on pressure side	$A_d = 12.57$	cm^2
Ditto on exhaust side	$A'_e = 8.63$	cm^2
Ditto in cushioning chamber	$A_e = 7.26$	cm^2

G_l kg	v_0 m/s	p'_{ds} kg/cm²	τ_e s	p'_{emax} kg/cm² experiment	Eq.(12)
3,000	20.5	35	0.03	225	211
3,000	20.5	54	0.03	245	229
3,000	20.5	131	0.03	220	304
2,000	20.5	46	0.03	245	163
2,000	20.5	61	0.03	240	177
2,000	20.5	133	0.035	185	247
1,000	20.5	50	0.03	170	108
1,000	20.5	67	0.03	150	120
1,000	20.5	140	0.03	200	195