

# DEVELOPMENT OF MECHANICAL VIBRATOR WITH VARIABLE AMPLITUDE

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## ABSTRACT

Mechanical self excited vibrator is frequently applied for compacting in civil engineering field. For compacting deep soil, large amplitude with low frequency is necessary. But, vibrational propagation point of view, above condition is difficult to apply, always.

Small amplitude with high frequency vibrational compaction is required in sometime, though compaction is limited in soil surface.

Because vibration effect on environment is reduced. For this situation, we developed variable amplitude vibrator with rugged structure, In this new device, amplitude is controlled by rotating screw nut mechanism, either manual, or stepping motor.

Vibrator amplitude is function of two parameters of amplitude setting value and supply pressure, By making pressure high, amplitude converges setting value. Frequency is roughly inversely proportional to setting value, In pressure range up to 4Mpa, vibrational amplitude is adjustable 0-12 mm. In this condition, we obtained maximum frequency of 140 Hz, in small amplitude setting .

Performance of this new device, is assumed promising as new compactor. So that, detailed test results is shown in this paper.

## KEYWORDS

mechanical vibrator, hydraulics, variable amplitude

## 1 INTRODUCTION

Developed vibration exciter is aimed mainly for construction machinery field.

Vibration generation mechanism is classified by inertia mass type and direct drive type. Former example is unbalance mass rotating type by hydraulic motor or electric motor.

Latter example is servo controlled and self excited type. Servo type is easy to control vibration amplitude and frequency. But sophisticated electronics is not suited for construction machine application.

Therefore, we tried to develop self excited vibrator with variable amplitude by simple mechanism.

## 2 CONCEPT OF VARIABLE AMPLITUDE DESIGN

### 2.1 Principle of self excited vibration generating mechanism

Fundamental constitution for mechanical vibrator is shown in Fig. 1.

This mechanism is frequently observed in percussion mechanism of construction machinery field.

Main piston has position sensing spool which switches control pressure from high to low or vice versa.

By this control pressure, attached control piston moves right and left and switches main piston pressure.

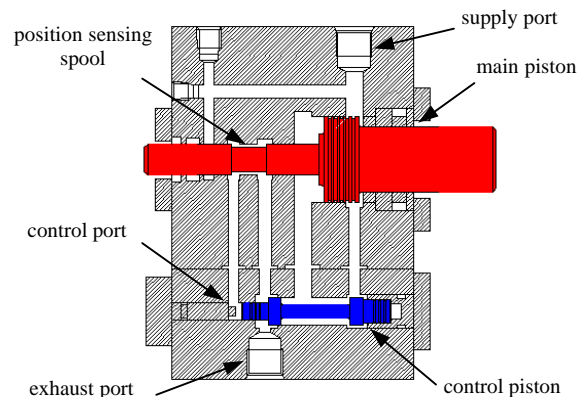


Fig.1 Constitution of mechanical vibration

Through combination of above two mechanisms, constant amplitude self-excited vibration takes place.

### 2.2 Concept of variable mechanism

Mechanical vibrator amplitude is determined by sleeve metering width  $L_f$  and position sensing spool distance, as shown in Fig. 2.

That is, vibrator amplitude is determined by  $A = L_f - X_f$ ,

By choosing large  $X_f$ , amplitude becomes small and frequency becomes high, because switching of oil flow becomes fast.

If we can contrive a mechanism to change  $A$  from zero to assigned value, variable amplitude vibrator will be obtained.

Contrived variable amplitude mechanism is shown in Fig. 3, where position sensing spool integral to main piston is made hollow and three holes are drilled vertically.

Two variable spool blocks driven by each reverse direction feed screws are inserted in the hollow spool.

This device is possible to control oil flow amplitude by moving two variable spool blocks to different direction by rotating feed screw.

Stepping motor was adopted to move variable blocks.

### 2.3 Design of variable amplitude vibrator

Critical point of this variable amplitude mechanism is relied on screw nut mechanism. Therefore, nut rotation should be stopped.

By structural limitation, only way to realize above condition is to use key way between outer hollow and inner spools.

How to make leakage small is technical or machining problem.

Determination of amplitude of this device is explained by Fig. 3.

Where  $L_v$  is fixed value which is distance of hollow spool hole,  $X_v$  is variable value which is distance of variable spool block outer edge. Amplitude  $A$  is determined like  $A = X_v - L_v$ .

If spool distance  $X_v$  becomes large by shifting block right and left, amplitude increases and vibration frequency decreases.

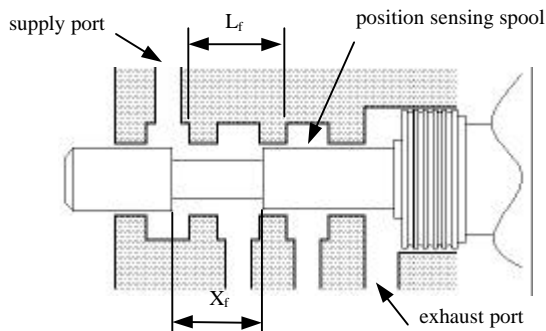


Fig.2 Mechanical vibrator amplitude setting mechanism

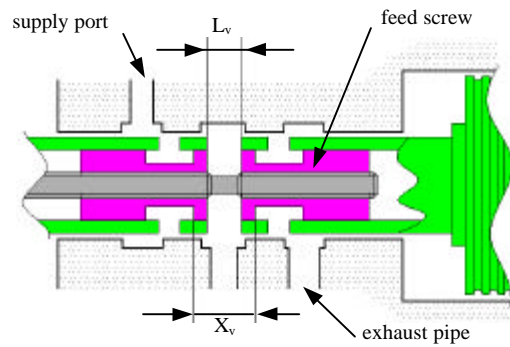


Fig.3 Variable amplitude mechanism

As discussed afterwards, this  $A$  value is lower limit of actual vibrational amplitude.

Oil flow of variable and conventional mechanism comparison are shown in Fig. 4(a)~(d).

“Flow from ps port to control piston”

Fig. 4(a) shows conventional type at left extreme position.

If main piston integral positioning spool edge point, denoted  $P_2$ , just passes sleeve metering point  $Q_2$ , supply pressure port connects to control port  $P_c$ .

By the action of attached small control piston, main piston begins to return (reverse).

Fig. 4(b) shows the case of variable type. When main piston integral hollow spool edge point  $R_2$  just passes  $S_2$  of variable spool block, supply pressure port  $P_s$  opens to control port  $P_c$ .

Then by the same action of conventional fixed amplitude case, main piston begins to return its direction.

That is, in the variable amplitude mechanism,  $R_2$ ,  $S_2$  edge points corresponds to  $P_2$  and  $Q_2$  of fixed amplitude case, respectively.

Next, let show comparison of both cases at right extreme position in Fig. 4(c), (d) respectively.

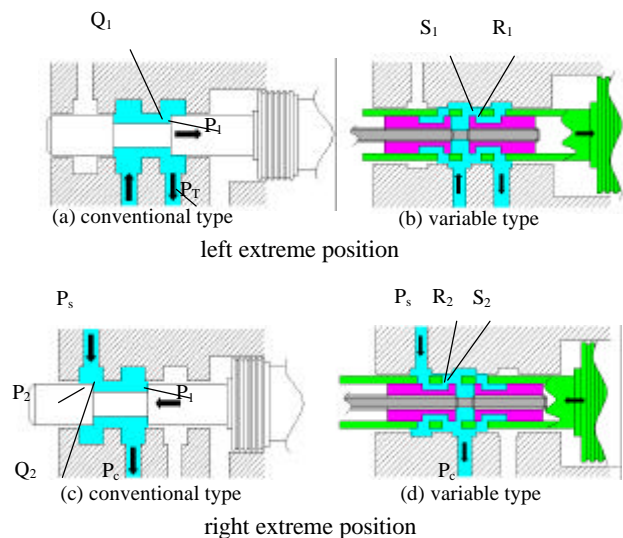


Fig.4 Comparison of conventional and variable type

In the case of fixed amplitude conventional case, if piston edge  $P_I$  passes sleeve edge  $Q_I$ , exhaust port  $P_I$  connects control port  $P_c$  and main piston reverse its direction.

On the contrary, in the case of variable amplitude case, if hollow piston edge  $R_I$  passes control piston edge  $S_I$ , then main piston begins to decelerates and reverse its direction.

### 3 SUMMARY OF DESIGN

Design critical points are (a) main piston structure (b) feed screw part.

In the former case, main piston is divided in two, that is main piston and variable piston part. Afterwards, these two components are assembled. By properly coupling two are assembled accurately without practical problem.

In the latter case of feed screw and nut, critical point is how to manufacture key way accurately, that is to keep small clearance to avoid leakage of oil.

At first, it was impossible to get low leakage structure, but, after many trial, accurate structure was obtained and leakage from key way became allowable level.

Leakage from another parts, such as, from variable hollow spool, variable spool sliding part and feed screw clearance was estimated small, by selecting proper tolerance.

### 4 EXPERIMENTAL RESULTS

Amplitude setting became possible from 0~12 mm automatically by stepping motor.

(a) Relationship between vibration frequency and supply pressure.

In the Fig. 5, obtained relationship between frequency and supply pressure is shown, when amplitude setting varies from 0~12 mm. For each setting value, self excited frequency increases proportionally to pressure. Even at zero amplitude setting, vibration was observed. This is assumed to come from inaccurate amplitude setting deviated from zero.

(b) Relationship between amplitude and supply pressure.

At the same condition of (a), obtained relationship between amplitude and supply pressure was shown in Fig. 6.

By increasing supply pressure, the corresponding amplitude was observed to reach constant value.

Discrepancy of this value to the setting value is supposed to come from inaccurate setting, too.

### 5 TECHNICAL DISCUSSION

#### 5.1 Fundamental feature of mechanical vibrator

Mechanical vibrator is very complicated system

containing dynamic phenomena induced by control valve switching, that includes (a) valve switching transient (b) oil compressibility effect (c) non-linear fluid resistance.

Therefore, simple calculation is known impossible perfectly to simulate experiment.

At the vibrator design, most important item is excited frequency but as explained above, accurate estimation is assumed very difficult.

As valve manufacturing is not so difficult, experimental approach gives exact answer faster than detailed calculation.

But, it is necessary to know by what kind of parameters excited frequency be influenced, is necessary at first. Therefore, let's consider simplified system.

Model is constituted as shown in the Fig. 7.

(i) Case of cylinder right directional movement

Fundamental equations are shown in the following.

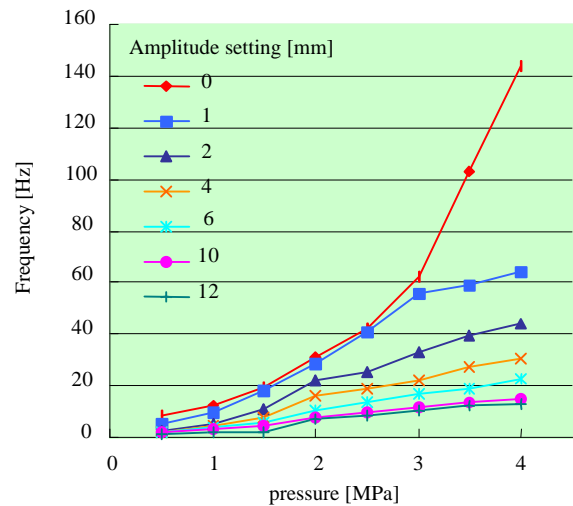


Fig.5 Relationship between frequency and supply pressure amplitude setting

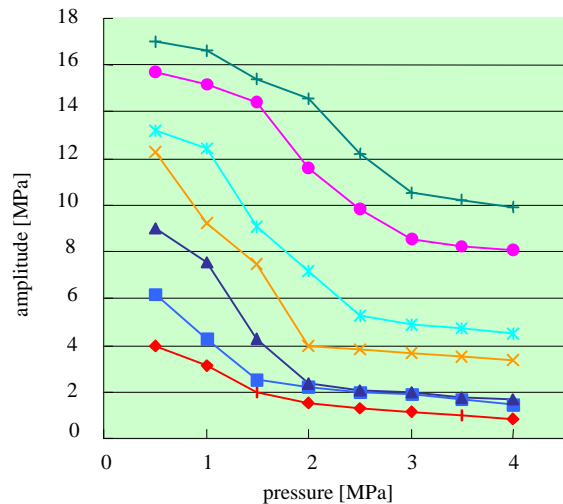


Fig.6 Relationship between amplitude and supply pressure

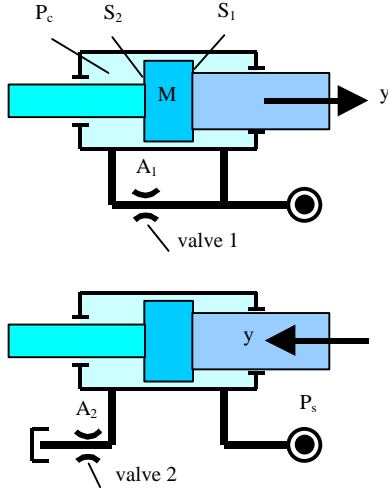


Fig.7 Simplified model of vibrator

That is,

$$M\ddot{y} = S_2 P_c - S_1 P_s \quad (1)$$

$$S_2 \dot{y} = C_v A_1 \sqrt{\frac{2(P_s - P_c)}{r}} \quad (2)$$

Where,  $C_v$  : valve flow coefficient,  $A_1$  : opening,  $\tilde{n}$  : oil density

By denoting,

$$F_0 = S_1 P_s, \mathbf{s} = S_2 / S_1, \mathbf{b}_1 = \frac{r S_2}{2} \left( \frac{S_2}{C_v A_1} \right)^2$$

$$M\ddot{y} = F_0 (\mathbf{s} - 1) - \mathbf{b}_1 \dot{y}^2 \quad (3)$$

(ii) Case of cylinder left directional movement  
Fundamental equations are;

$$M\ddot{y} = S_1 P_s - S_2 P_c \quad (4)$$

$$S_2 \dot{y} = C_v A_2 \sqrt{\frac{2P_c}{r}} \quad (5)$$

By denoting  $\mathbf{b}_2 = \frac{r S_2}{2} \left( \frac{S_2}{C_v A_2} \right)^2$

$$M\ddot{y} = F_0 - \mathbf{b}_2 \dot{y}^2 \quad (6)$$

Assuming  $\mathbf{b}_1 \approx 0, \mathbf{b}_2 \approx 0$  and denoting

$$\mathbf{a}_R = \frac{F_0 (\mathbf{s} - 1)}{M}, \mathbf{a}_L = \frac{F_0}{M}$$

When considering 1 cycle cylinder motion, right direction and reverse direction to original point, each required time  $t_R$  (right side),  $t_L$  (left side) become

$$t_R = \sqrt{\frac{2y_s}{\mathbf{a}_R}}, t_L = \sqrt{\frac{2y_s}{\mathbf{a}_L}}, \text{ respectively, by elementary dynamics calculation.}$$

Supposing 1 cycle time  $t_s$  is the sum of above both values, excited frequency  $f_s$  is defined as  $t_s^{-1}$

Cylinder design values of this study are,  
 $S_1 = 7 \text{ cm}^2, S_2 = 15.8 \text{ cm}^2, \phi = 2.25$

Therefore, approximately,

$$f_s = \frac{1}{2} \sqrt{\frac{S_1}{2M}} \cdot \sqrt{\frac{P_s}{y_s}} \quad (7)$$

That is,  $f_s$  is proportional to the root of supply pressure  $P_s$  and inversely proportional to the root of stroke setting  $y_s$ .

By the equation (7),  $f_s$  becomes 150 Hz for pressure  $P_s = 40 \text{ kgf/cm}^2$  and  $y_s = 1 \text{ cm}$ .

As fluid circuit resistance and switching delay of the system are ignored in the above calculation,  $f_s$  will become considerably large value, as a matter of fact.

Influence of damping factor was ignored at this time, because treatment is quite complicated.

## 5.2 Possible application of mechanical vibrator

This new device is supposed to have quite interesting application for compacting soil.

As previously explained, compacting deep soil, force is necessary to collapse vacant holes. In this case, large amplitude with low frequency is appropriate.

But, for surface hard compacting, large acceleration is necessary. That is, small amplitude with high frequency is effective.

This mechanical vibrator satisfies above two functions by simple variable amplitude mechanism.

In civil engineering, endurance and reliability of equipment is utmost important.

This new variable mechanism is composed of rugged hardware, so that, application to hard environment is possible.

## 6 CONCLUSION

We developed variable amplitude mechanical vibrator with rugged structure.

- 1) In this study, amplitude is confirmed adjustable from 0-12 mm, by stepping motor.
- 2) Excited vibration frequency is inversely proportional to amplitude setting.

We hope this mechanical vibrator will contribute to civil engineering field.

In closing this paper, I appreciate A/Prof. Wang Qingfeng of Institute of Mechatronic Engineering Zhejiang University for his cooperation of basic study of servo compactor.

## REFERENCES

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