Development of Mathematical Model for Vacuum Damped Recoil System

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Abstract - *A recoil system is defined as an assembly of components whereby the forces acting on a gun and its related mount during a firing cycle can be controlled and limited to certain parameters by one or more recoil mechanisms. The conventional recoil system are quite complex and certain problems are arises due to more moving parts, to overcome the problems in conventional recoil system here attempt to develop vacuum damped recoil system. Vacuum damped recoil system is simple and has limited moving parts which increase the reliability of system. To know the behavior of vacuum damped recoil system mathematical model is developed with the help of variables of experimental model. To formulate mathematical model variables of experimental model of vacuum damped recoil system such as recoil length, vacuum generated, force, weight of barrel and recoil time are related with each other by using Non-dimensional analysis.*

Key Words: **Recoil time, Recoil length, Non-dimensional analysis.**

1. INTRODUCTION

The function of a recoil system is to moderate the firing load on the supporting structure. This moderation is accomplished by prolonging the time of resistance to the reaction force caused by the action of the gun on the propellant gases. If no resistance is offered, the reaction force will be as great as the action force caused by the propellant gas. In other words, if the gun tube is rigidly fired to the gun mount / carriage, the supporting structure is subjected to the full force of the propellant which is very high for large guns. To withstand such a force, the structure has to be not only strong and heavy but also wide-based to prevent tip over. As the gas pressure propels the projectile toward the muzzle, it exerts an equal and opposite force on the breech, which tends to drive the gun backward. The recoil system suppresses this force gradually and also limits the rearward movement.

2. EXPERIMENT MODEL

An experiment model of vacuum damped recoil system is shown in fig - 1. An experiment model is consist of following main parts –

Pneumatic Cylinder: It is main part of vacuum damped recoil system, in which vacuum is generated.

Vacuum Gauge: it is used to measure vacuum generated in pneumatic cylinder.

Barrel: Is connected to piston rod of cylinder and which is of 2 kg in weight.

Load Cell: Load cell is used to measure force exerted on barrel.

Indicator: Indicator is used to indicate force measured by load cell.

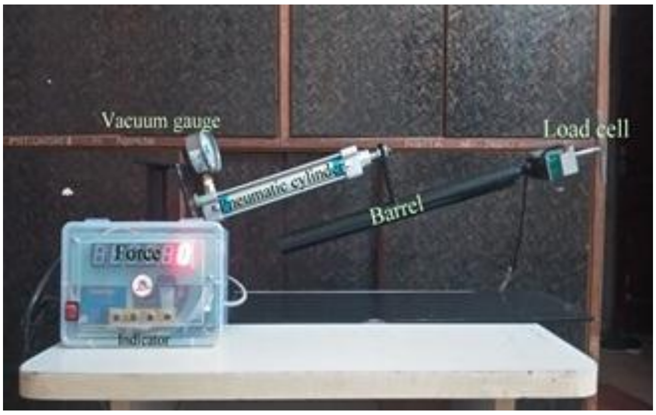

Fig -1: Experimental Model of vacuum damped recoil system

3. IDENTIFICATION OF VARIABLES

Table -1: Variables of mathematical model

Sr. No.	Variables	Notations	Units
1.	Recoil time	t	Second
2.	Force	F	N
3.	Displacement (Recoil length)	l	mm
4.	Vacuum pressure	p	N/mm^2
5.	Diameter of cylinder	d	mm
6.	Weight of barrel	w	Kg

The variables are used for mathematical model are tabulated in the above table -1. In the study of vacuum damped recoil system the mathematical model is develop for recoil time and force.

4. METHDOLOGY

For mathematical modeling of vacuum damped recoil system the Buckingham's π theorem are used, which state, "if there are n variables (independent and dependent variables) in a physical phenomenon and if these variables contain m fundamental dimensions (M, L, T), then the variables are arranged into (n – m) dimensionless terms. Each term is called π term." The final equation for the phenomenon is obtained by expressing any one of the π terms as a function of others.

5. MATHEMATICAL MODEL FOR RECOIL TIME

Recoil time (t) is function of d, p, w, and l

$\therefore t = f(d, p, w, l)$

Or $f(t, d, p, w, l) = 0$ .... (5.1)

Hence total number of variables, n = 5

The value of m, i.e. number of fundamental dimensions is obtained by writing dimensions of each variable. Dimension of each variable are

t = T

d = L

p = $ML^{-1}T^{-2}$

w = M

l = L

Therefor m = 3

Number of π terms = n-m = 5 – 3 = 2

Equation (i) is written as $f(\pi_1, \pi_2) = 0$ .... (5.2)

Each π term contains m+1 variable, where m is equal to three and is also repeating variable.

Choosing d, p and w as repeating variables

$$\pi_1 = d^{a_1} \cdot p^{b_1} \cdot w^{c_1} \cdot t$$

$$\pi_2 = d^{a_2} \cdot p^{b_2} \cdot w^{c_2} \cdot l$$

1st π term (π_1).

$$\pi_1 = d^{a_1} \cdot p^{b_1} \cdot w^{c_1} \cdot t$$

Substituting dimensions on both sides of π_1

$$M^0 L^0 T^0 = L^{a_1} \cdot (M L^{-1} T^{-2})^{b_1} \cdot M^{c_1} \cdot T$$

Equating the powers of M, L, T on both sides

Power of M, $0 = b_1 + c_1$ $\quad \therefore c_1 = -b_1 = -\frac{1}{2}$

Power of L, $0 = a_1 - b_1$ $\quad \therefore a_1 = b_1 = \frac{1}{2}$

Power of T, $0 = -2b_1 + 1$ $\quad \therefore b_1 = \frac{1}{2}$

Substituting the values of a_1, b_1 and c_1 in π_1 term,

$$\pi_1 = d^{\frac{1}{2}} \cdot p^{\frac{1}{2}} \cdot w^{-\frac{1}{2}} \cdot t$$

$$\pi_1 = \frac{t\sqrt{dp}}{\sqrt{w}}$$

2nd π term (π_2).

$$\pi_2 = d^{a_2} \cdot p^{b_2} \cdot w^{c_2} \cdot l$$

Substituting dimensions on both sides of π_2

$$M^0 L^0 T^0 = L^{a_2} \cdot (M L^{-1} T^{-2})^{b_2} \cdot M^{c_2} \cdot L$$

Equating the powers of M, L, T on both sides

Power of M, $0 = b_2 + c_2$ $\quad \therefore c_2 = -b_2 = 0$

Power of L, $0 = a_2 - b_2 + 1$ $\quad \therefore a_2 = -1$

Power of T, $0 = -2b_1$ $\quad \therefore b_2 = 0$

Substituting the values of a_2, b_2 and c_2 in π_2 term,

$$\pi_2 = d^{-1} \cdot p^0 \cdot w^0 \cdot l$$

$$\pi_2 = \frac{l}{d}$$

Substituting the values of π_1 and π_2 in equation (5.2),

$$f\left(\frac{t\sqrt{dp}}{\sqrt{w}}, \frac{l}{d}\right) = 0$$

$$\frac{t\sqrt{dp}}{\sqrt{w}} = k_1 \frac{l}{d}$$

$$\therefore t = k_1 \frac{l}{d}\sqrt{\frac{w}{dp}} \quad \ldots\ldots\ldots\ldots\ldots (5.3)$$

From above equation (5.3), recoil time of system can be calculated. The value of k_1 calculated by using the experimental readings.

6. MATHEMATICAL MODEL FOR FORCE

Force is (F) is function of d, p, w, and l

$\therefore F = f(d, p, w, l)$

Or $f(F, d, p, w, l) = 0$ ………… (6.1)

Hence total number of variables, n = 5

The value of m, i.e. number of fundamental dimensions is obtained by writing dimensions of each variable. Dimension of each variable are

$F = MLT^{-2}$

$d = L$

$p = ML^{-1}T^{-2}$

$w = M$

$l = L$

Therefor m = 3

Number of π terms = n-m = 5 – 3 = 2

Equation (i) is written as $f(\pi_1, \pi_2) = 0$ ……….. (6.2)

Each π term contains m+1 variable, where m is equal to three and is also repeating variable.

Choosing d, p and w as repeating variables

$\pi_1 = d^{a_1} \cdot p^{b_1} \cdot w^{c_1} \cdot F$

$\pi_2 = d^{a_2} \cdot p^{b_2} \cdot w^{c_2} \cdot l$

1st π term (π_1).

$\pi_1 = d^{a_1} \cdot p^{b_1} \cdot w^{c_1} \cdot F$

Substituting dimensions on both sides of π_1

$M^0 L^0 T^0 = L^{a_1} \cdot (M L^{-1} T^{-2})^{b_1} \cdot M^{c_1} \cdot (MLT^{-2})$

Equating the powers of M, L, T on both sides

Power of M, $0 = b_1 + c_1 + 1 \qquad \therefore c_1 = 0$

Power of L, $0 = a_1 - b_1 + 1 \qquad \therefore a_1 = -2$

Power of T, $0 = -2b_1 - 2 \qquad \therefore b_1 = -1$

Substituting the values of a_1, b_1 and c_1 in π_1 term,

$\pi_1 = d^{-2} \cdot p^{-1} \cdot F$

$$\pi_1 = \frac{F}{pd^2}$$

2nd π term (π_2).

$\pi_2 = d^{a_2} \cdot p^{b_2} \cdot w^{c_2} \cdot l$

Substituting dimensions on both sides of π_2

$M^0 L^0 T^0 = L^{a_2} \cdot (M L^{-1} T^{-2})^{b_2} \cdot M^{c_2} \cdot L$

Equating the powers of M, L, T on both sides

Power of M, $0 = b_2 + c_2 \qquad \therefore c_2 = -b_2 = 0$

Power of L, $0 = a_2 - b_2 + 1 \qquad \therefore a_2 = -1$

Power of T, $0 = -2b_1 \qquad \therefore b_2 = 0$

Substituting the values of a_2, b_2 and c_2 in π_2 term,

$\pi_2 = d^{-1} \cdot p^0 \cdot w^0 \cdot l$

$$\pi_2 = \frac{l}{d}$$

Substituting the values of π_1 and π_2 in equation (6.2),

$$f\left(\frac{F}{pd^2}, \frac{l}{d}\right) = 0$$

$$\frac{F}{pd^2} = k_1 \frac{l}{d}$$

$$\therefore F = k_2\, lpd \quad \ldots\ldots\ldots\ldots\ldots\ldots (6.3)$$

From above equation (6.3), force on system can be calculated. The value of k_2 calculated by using the experimental readings.

7. VALUE OF k_1 AND k_2

The constant k_1 and k_2 in equation (5.3) and (6.3) respectively are calculated from experimental readings which are taken for two different pneumatic cylinders. For each pneumatic cylinder there are 40 readings taken. From the total 80 readings, after taking the average of k_1 and k_2 the value get as $k_1 = 0.0511$ and $k_2 = 0.213$ putting these values in equation (5.3) and (6.3) respectively, So that the equation (5.3) and (6.3) becomes,

Recoil time $t = 0.0511 \frac{l}{d}\sqrt{\frac{w}{dp}}$ ………… (7.1)

Force $F = 0.213\ lpd$ ……………… (7.2)

Thus the values of recoil time and force can be calculated by knowing the other variables from equation (7.1) and (7.2) respectively.

3. CONCLUSIONS

Thus the mathematical model is developed for recoil time and force for vacuum damped recoil system. By knowing the values of other variables like vacuum pressure, recoil length, weight of barrel, diameter of pneumatic cylinder the recoil time and force exerted on barrel calculated using equation (1.4) and (2.4) respectively. With the help of mathematical model the behavior of vacuum damped recoil system can be easily predicted.

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