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INFLUENCE OF DESIGN CHARACTERISTICS OF THE PYRO-RECOCKING SYSTEM ON ITS FUNCTION

Reviewer: Stanislav BEER

A b s t r a c t :

The paper deals with the influence of individual design characteristics of the pyro-system used for the recocking of the automatic cannon on the magnitude of the velocity of the piston which controls the mechanism recocking. The basic design characteristics are: the cross-section of the gas port S_A, the acting area of the piston S_p,, the initial volume of the gas cylinder V_{A0} and the cross-section of the piston rod gap S_{GA}. The paper utilizes the theory published in the paper [1] in AiMT No 1/2007.

1. Introduction

The pyro-recocking system (including its theory) has been discussed in paper [1] published in AiMT 1/2007. The task of this system is to ensure the recocking of the automatic cannon in case of the misfired cartridge. This system used in the new Czech 20mm two barrel aircraft automatic cannon ZPL-20 and main features of its final part – the gas-piston arrangement - are shown in Fig. 1a. The gases from the pyro-cartridge entering into the channel flow through the gas port into the gas cylinder, where they act on the piston and accelerate it. The motion of the piston is utilized for the acceleration of the weapon mechanism. The intensity of this acceleration is influenced by the pressure of gases in the channel (when burning the propellant charge and also after the end of this burning) as it was explained in [1]. But not only by this pressure - also the design characteristics of the gas piston arrangement may seriously influence the function. To give better idea about this arrangement its complete construction is shown in Fig. 1b. This figure represents two gas cylinders (belonging to two barrels of the cannon). In each cylinder there is the piston and sliding sleeve. These sleeves ensure the filling of the required gas cylinder by gases flowing from the pyro-cartridge. The lower gas cylinder (Fig. 1b) is open for gases because the piston has transferred the sleeve into its rear position. The upper gas cylinder is out of function because its sleeve is in its front position (its orifice S_A is closed).

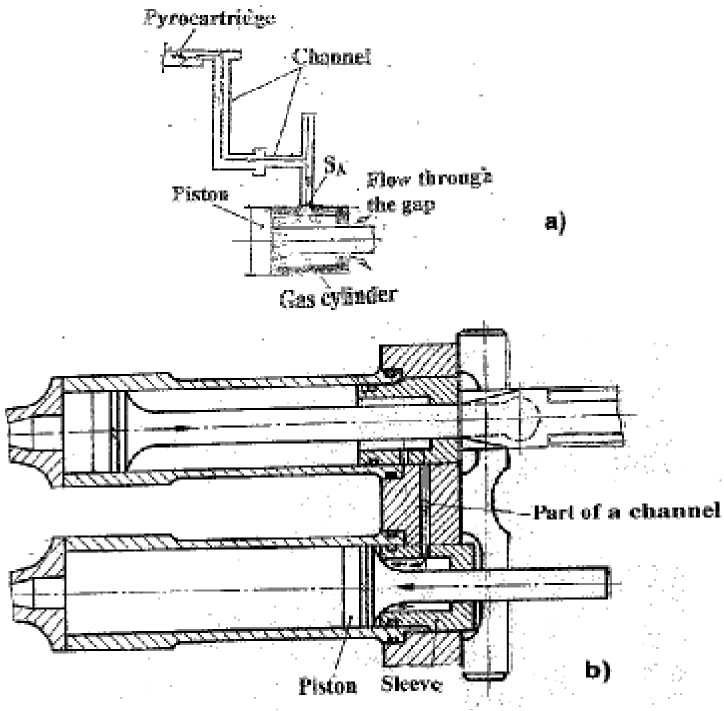

Fig. 1 Scheme of the pyro-recocking system

The initial values of design characteristics which will be changed in this paper to obtain their influence on the function utilized from [1] are:

- cross-section of the gas port S_A = 0.000028274 m^2
- acting area of the piston S_p = 0.00076105 m^2
- initial volume of the gas cylinder V_{A0} = 0.000015974 m^3
- cross-section of the piston rod gap S_{GA} = 0.000014261 m^2.

The other characteristics of the pyro-recocking system in this paper are the same as mentioned in [1].

2. Influence of the orifice cross-section S_A

To obtain this influence the calculations for different values S_A have been realized. In addition to basic value S_A two new changed values of this cross-section – decreased by 20% and 40% - were taken into consideration. The results of these calculations are represented by graphs in Fig. 2 and Fig. 3. Fig. 2 shows the influence of the change of S_A on the magnitude of the piston velocity v (at the time t = 0.004 s) – see Table 1. At the basic magnitude of S_A = 0.000028274 m^2 is this velocity v = 8.04 m.s^{-1}.

The conclusion from Fig. 2 and Table 1 is that the increase of S_A decreases the velocity v. This interesting conclusion explains Fig. 3, where the pressure in the gas cylinder p_A is represented by pressure – time curves. For decreased S_A the impulse of gases on the piston (corresponding with the area bellow the pressure – time curve) is greater and therefore the piston velocity v reaches higher value. This fact is caused by the decreased flow of gases into the gas cylinder at the beginning what canses the slow increase of the pressure p_A.

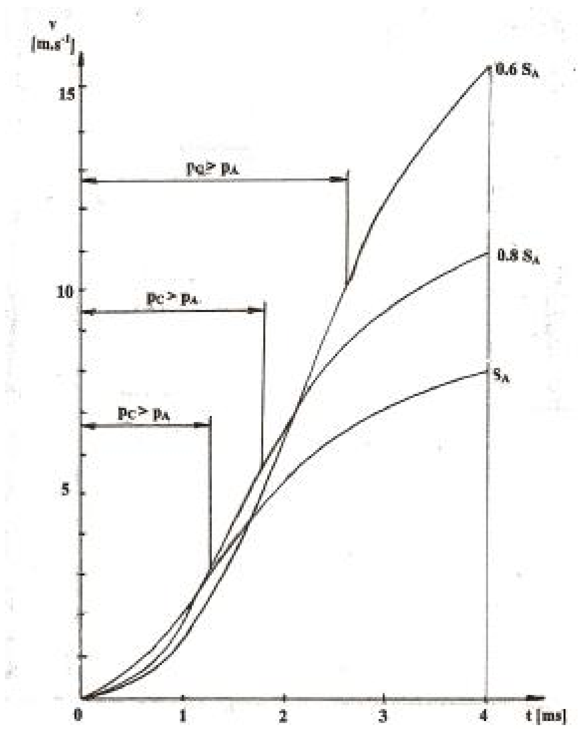

Fig. 2 Influence of S_A on the piston velocity v

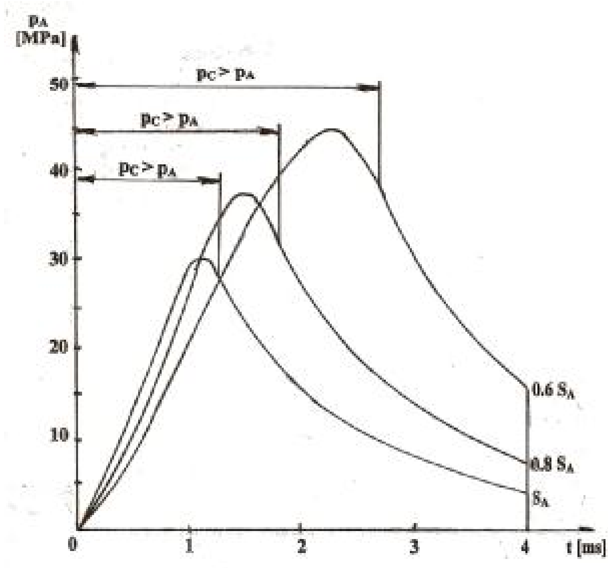

Fig. 3 Influence of S_A on the pressure in the gas cylinder p_A

But it causes also the slow decrease of the pressure in the channel p_C (the channel is the source of gases). The result of it is that the time interval of the gas cylinder filling $p_C > p_A$ is prolonged. In the period $p_A > p_C$ (the flow of gases in the opposite direction – from the gas cylinder into the channel) the decrease of the pressure p_A is also slower. If the cross-section S_A is greater the function proceeds in the opposite way – the period $p_C > p_A$ is shorter, the impulse on the piston is lower and the piston reaches lower value of the velocity v. Table 1 shows that any percentual decrease of S_A causes much greater percetual increase of the velocity v.

Values of changed velocity *v* in *t* = 4 ms at the change of S_A

Table 1

Changed S_A	ΔS_A [%]	v [m. s^{-1}]	Δv [%]
0.8 S_A	- 20	11.09	+ 37.9
0.6 S_A	- 40	15.60	+ 94.0

3. Influence of the acting area of the piston Sp

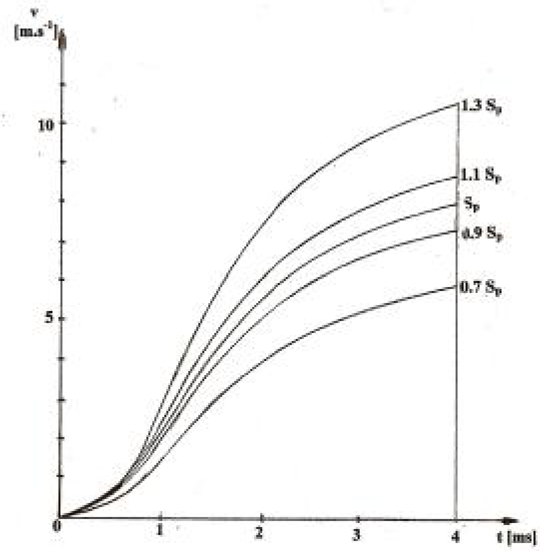

Fig. 4 Influence of S_p on the piston velocity v

Values of changed velocity v in t = 4 ms at the change of S_p

Table 2

Changed S_p	ΔS_p [%]	v [m. s^{-1}]	Δv [%]
0.7 S_p	- 30	5.92	- 26.4
0.9 S_p	- 10	7.37	- 8.3
1.1 S_p	+ 10	8.68	+ 8.0
1.3 S_p	+ 30	10.55	+ 31.2

Next design characteristics of the pyro-recocking syatem is the acting area of the piston S_p . The graphs in Fig. 4 and the values in Table 2 show, that the percentual change of the piston velocity Δv (with respect to the basic velocity v = 8.04 m.s^{-1}) is nearly the same as for the percentual change of the acting area of the piston ΔS_p .

4. Influence of the initial volume of the gas cylinder V_{A0}

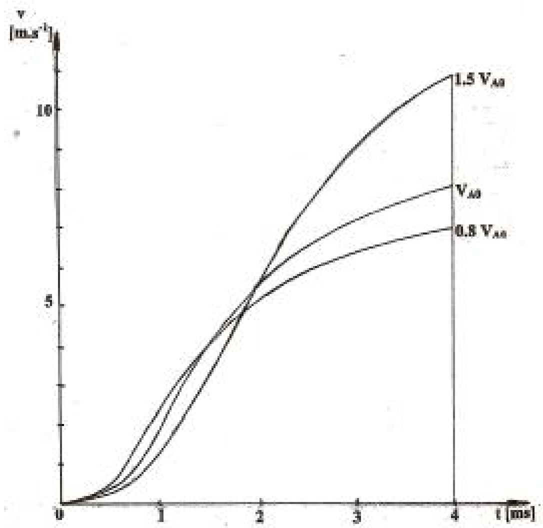

Fig. 5 Influence of V_{A0} on the piston velocity v

Values of changed velocity v in t = 4 ms at the change of V_{A0}

Table 3

Changed V_{A0}	**ΔV_{A0} [%]**	**v [m. s^{-1}]**	**Δv [%]**
0.8 V_{A0}	- 20	6.91	- 14.1
1.5 V_{A0}	+ 50	10.87	+ 35.2

The curves $v = f(t)$ in Fig. 5 for different values of the initial volume of the gas cylinder V_{A0} represent the influence of V_{A0} on the function of the gas piston arrangement in the pyro-recocking system. The result is, that after initial increase of v the decrease of V_{A0} for longer time causes the decrease of the of the piston velocity v. And in the opposite way the increase of V_{A0} increases the velocity v. The comparison is shown in Table 3.

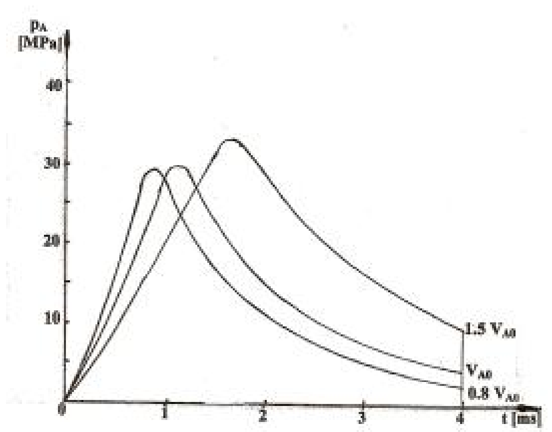

Fig. 6 Influence of V_{A0} on the pressure in the gas cylinder p_A

This result is explained by graphs in Fig. 6. The character of the flow of gases between the channel and the gas cylinder (in both directions – from the channel into the cylinder and from the cylinder into the channel) results into the increase of the area bellow the curves $p_A = f(t)$ i.e. the increase of the impulse of gases acting on the piston. The reason of this fact is mainly in the prolonged filling of the gas cylinder i.e. in the prolonged period $p_C > p_A$ in the same way like it was mentioned in chapter 2. For variants taken into consideration the comparison of mentioned time of filling the cylinder with the resultant value of the velocity at the time t = 4 ms for different values of V_{A0} is in Table 4.

Dependence of the period pC > pA and piston velocity on the initial volume V_{A0}

Table 4

Value of V_{A0}	Time of the period $p_C > p_A$ [s]	Piston velocity at t = 4 ms [m.s^{-1}]
0.8 V_{A0}	0.0010	6.91
V_{A0}	0.0012	8.04
1.5 V_{A0}	0.0018	10.87

5. Influence of the cross-section of the piston rod gap S_{GA}

The last design characteristics of the gas system is the cross-section of the gap between the piston rod and the casing. During the function of the system the propellant gases flow through this gap from the gas cylinder into the atmosphere. This causes a loss of impulse on the piston and decreases the resultant velocity of the piston v. The comparison of these velocities corresponding with different values of the cross-section S_{GA} is in Table 5.

Values of changed velocity v in t = 4 ms at the change of S_{GA}

Table 5

Changed S_{GA}	**ΔS_{GA} [%]**	**v [m. s^{-1}]**	**Δv [%]**
0.8 S_{GA}	- 20	8.19	+ 1.9
0.9 S_{GA}	- 10	8.12	+ 1.0
1.1 S_{GA}	+ 10	7.97	- 0.9
1.2 S_{GA}	+ 20	7.89	- 1.9

This table shows the decrease of the velocity v with the increase of the cross-section S_{GA} and the increase of v with the decrease of S_{GA}. But as shown in Table 5 the influence of this gap is very low.

6. Influence of the discharge coefficient μ_A

The chapter 2. has discussed the influence of the orifice cross-section S_A on the function of the gas arrangement. The solution of this case was realized for the case in which the cross-section S_A is equal to the cross-section of the channel S_C as it is in the Czech aircraft cannon ZPL-20 ($S_A = S_C$). Because the losses at the entrance of gases into the gas cylinder can be neglected, the value of the discharge coefficient has been chosen $\mu_A = 1$. But if the orifice cross-section is lower than the cross-section of the channel – i.e. $S_A < S_C$ - the value of this discharge coefficient is $\mu_A < 1$. It belongs to the case when the cross-section S_C is suddenly decreased into S_A e.g. by means of an orifice plate. Because the mass flow into the gas cylinder from the channel G_A depends also on μ_A it is necessary to discuss shortly its influence.

The equations for determination of the mass flow G_A through the cross-section S_A at the critical and sub-critical flow are [1], [2], [4]:

- for the **critical flow** for k = 1.26 characterized by the condition

$$\frac{p_A}{p_C} < \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} = 0.553$$

(k is the ratio of specific heats)

the formula for the mass flow is

$$G_{ACR} = m_A . S_A \left(\frac{2}{k-1}\right)^{\frac{k+1}{2(k-1)}} \sqrt{k \frac{p_C}{w_C}}$$

- and for the **subcritical flow** (p_A/p_C > 0.553 for k = 1.26)

$$G_{ASCR} = m_A . S_A \sqrt{\left(\frac{2}{k-1}\right) . \frac{p_C}{w_C}} . \left[\left(\frac{p_A}{p_C}\right)^{\frac{2}{k}} - \left(\frac{p_A}{p_C}\right)^{\frac{k+1}{k}}\right]^{0.5}$$

These formulae show, that the value μ_A < 1 really decreases the mass flow from the channel into the gas cylinder. So the influence of this discharge coefficient is the same as it was explained for the decreased value of the orifice cross-section in chapter 2. For better imagination about this influence of μ_A < 1 the result of the calculation in comparison with the case $0.8S_A$ in Fig. 2 follows:

- in the case in Fig. 2 is μ_A = 1 and for time 0.004 s is the velocity v = 11.09 m.s^{-1} ,
- for the case μ_A < 1 is μ_A = 0.9 and for the same time the velocity v = 13.11 m.s^{-1} .

That means: the **10% decrease** of μ_A causes the **18.2% increase** of the piston velocity v .

7. Conclusion

From previous discussion of the influence of individual design characteristics of the gas arrangement on the piston velocity v (for pyro-recocking system according to Fig. 1) it is possible on the base of realized calculations to mention following conclusions:

- If the cross-section of the cylindrical channel S_C equals to the **cross-section of the gas port S_A** (i.e. the gas flows into the gas cylinder without any throttling) the discharge coefficient is μ_A = 1 and any decrease of S_A causes the increase of the velocity v. The percentual difference of v is nearly twice greater than the percentual difference of S_A.

- The change of the **acting area of the piston S_p** causes the change of the piston velocity v in the same direction (the increase of S_p causes the increase of v). The percentual difference is nearly the same for both characteristics.

- The decrease of the **initial volume of the gas cylinder V_{A0}** causes the decrease of v and its increase causes the increase of v . The percentual change of v is less than the percentual change of V_{A0} . The ratio of both differences $\Delta v \ / \Delta \ V_{A0}$ was nearly 0.7 (see Table 3).

- The increase of the **piston rod gap S_{GA}** decreases slightly the piston velocity v (its decrease increases v), but the influence of this design characteristics is practically neglegeable.

- The decrease of the **discharge coefficient μ_A** causes the increase of v in similar way as it is mentioned for S_A .

These results can be utilized when designing the pyro-recocking system or when the change of an existing system e.g. in case of the necessity to increase or decrease the velocity of the gas piston v. It is possible to recommend three design characteristics S_A, S_p and V_{A0} for the utilization. In case of the redesign of an existing system it seems to be the most convenient the change of the initial volume of the gas cylinder V_{A0} because its change can be simple. All mentioned design characteristics can be utilized when designing a new pyro-recocking system.

R e f e r e n c e s

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