Design of 120 mm Recoiling Mortar System

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***Abstract*– We suggest and investigate the performance of a new design of a recoiling mortar system with the purpose of the mortar to be mounted on tracked/wheeled vehicles. Mounting of gun system on tracked/wheeled vehicles increases the gun mobility, efficiency and maneuverability. The potential outcome of the new design suggested in this paper is to reduce recoil force of the conventional 120-mm Russian mortar by the adoption of a recoiling-barrel mortar system rather than the fixed-barrel system currently existing in The Egyptian Armed Forces and many other armies all over the world. The maximum total recoil force in the mortar design suggested in this paper is predicted to be reduced by more than 75% compared to that in the traditional fixed-barrel mortar system.**

***Keywords—*Gun recoil systems, mortar, recoil force, self-propelled guns.**

I. Introduction

A. Principle of gun recoil

Due to firing, gun barrel and some gun parts move backwards upon the guiding parts of the cradle. These movable parts are called the recoiling parts, and their backward motion is called the recoil [1, 2]. This backward motion is limited within a certain recoil distance by the influence of the so-called recoil system. The forward motion of the recoiling parts to their initial position is called the counter recoil as shown in Fig. 1.

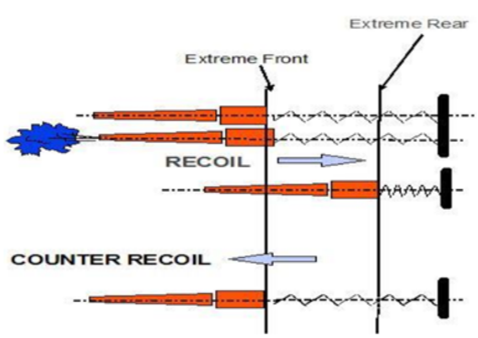

Fig. 1 Principle of gun recoil.

The recoil system consists of a recoil brake, a recuperator and a counter recoil brake.

- *The recuperator* accumulates a certain part of recoil energy for the purpose of returning the gun recoiling parts to their initial forward position after finishing the recoil.
- *The recoil brake* dissipates the rest of recoil energy and stops the recoiling parts at the specified length of recoil.
- *The counter recoil brake* is necessary for dissipating the recuperator surplus energy during counter recoil.
- Usually, the recoil brake and the counter recoil brake are incorporated in one hydraulic cylinder.

Nowadays, mounting of gun systems on tracked/wheeled vehicles is an international ongoing research trend that has a great interest by The Egyptian Armed Forces and many other armies all over the world. This paper aims to suggest and evaluate the performance of a new design of recoil system to be mounted on the 120-mm PM-38 mortar that does not adopt a gun recoil system. The paper starts with the solution of internal ballistics of the mortar in order to determine the total force of powder gases affecting the barrel. Then, the characteristics of the new recoil system are discussed. After that, a mathematical model is used to determine the free and braked recoil parameters. Finally, the recoil parameters are determined.

II. Internal Ballistics

The internal ballistics (IB) model used in this study is the “CHARBONIER- SUGOTS” model [3] that is a well-known model for the solution of IB task of classical (non-leaking) weapon systems. Some modifications to the “CHARBONIER-SUGOTS” were performed by Polansky in order that the model can be used for solving the IB of mortars [4]. Polansky’s approach accounts for the tiny leakage of gases in front of the projectile.

The parameters that can be determined by the solution of IB task according to the model are:

a) Pressure inside the barrel (p).
b) Projectile velocity down the barrel (v).
c) Temperature along the length of the barrel (T).
d) Relative burnt mass of the propellent (ψ).
e) Time duration (t).
f) Volume behind the projectile (C).

The IB parameters are solved in the different periods of projectile motion in the barrel, namely: ignition, burning and expansion periods. The phenomena occurring in these periods are as follows:

A. *IGNITION PERIOD*

This period starts with the ignition of primer mixture due the impact of firing pin onto the primer screw (capsule). The generated flame may be amplified using an igniter to ensure the simultaneous and instantaneous ignition of the whole propellant charge. The igniter is simply a bag or a tube of black-powder. The hot gases inside the closed volume develop a pressure value of about pi=2:5 MPa (pi is the ignition pressure). At the end of such period all propellant grain surfaces are inflammatted.

B. *BURNING PERIOD*

At this period, the projectile starts to move. The amount of developed gases increases, so the gas pressure inside the weapon barrel and consequently the propellant burning rate. The velocity of the projectile tends to have a steady increase, which in turn increases the volume behind the projectile base. On reaching certain projectile velocity, the increase in volume takes such a rate that the developed gases lose their ability to increase the gas pressure. At such moment a state of equilibrium between the rate of evolved gases and the rate of volume change is reached, and the gas pressure reaches its maximum value. Furthermore, the quantity of newly evolved gases in not enough to maintain such maximum pressure, and the pressure value starts to drop. At the end of burning of the propellant, the pressure reaches the value pE and is called the all burnt point. And where the relative burnt thickness (Z) is chosen as the independent variable.

C. *EXPANSION PERIOD*

Even after the end of propellant burning, the hot gases still have a considerable amount of internal energy to perform work. The gases acting on the projectile base increase its velocity on the account of gases internal energy. The gases expansion obeys polytropic law. The projectile travel down the barrel(x) will be the independent variable.

After the solution of the system of equation provided in [4], the results of the IB parameters at the main points of projectile motion are presented as shown in Table 2. In addition the variations of all parameters with respect to time (t) and projectile travel (x) are shown in Fig. 2 and Fig. 3.

III. THE NEW RECOIL SYSTEM

The new recoil system suggested in this paper can be classified as a simple recoil system [1, 2]. This means that the system can be described as a piston-cylinder arrangement in which the piston is connected to the barrel, whereas the cylinder is fixed to the cradle. A helical spring that works as the gun recuperator exists behind the piston. Simple recoil systems are usually found to be concentric with barrel axis as most Western tank guns, e.g. M60 and M1A1 tanks.

TABLE I
Values of IB parameters are the main points of projectile motion

	Time (t) (s)	Projectile travel (x) (m)	Projectile velocity (v) (m/s)	Pressure (p) (MPa)
Start of projectil e motion	0	0	0	0.0185
Point of p_{max}	0.00660	0.239305	153.073	103.87
End of burning	0.00793	0.52695	240.5433	87.787
Muzzle point	0.01128	1.54	345.0982	29.0477

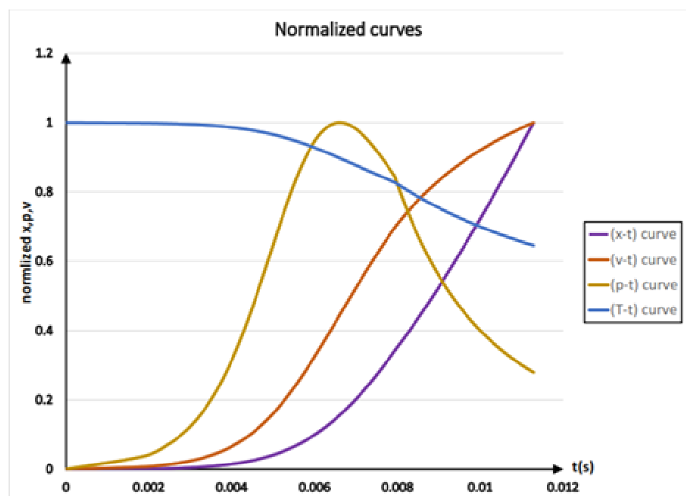

Fig. 2 Normalized ballistic values vs time

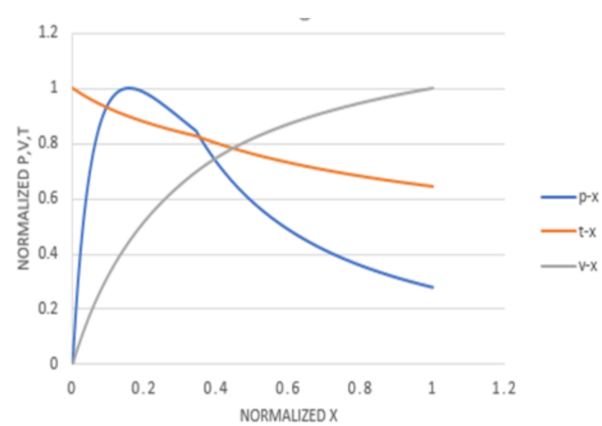

Fig. 3 Normalized ballistic values vs projectile travel

The same recoil system of the M60 tank gun is used in the current study. Minimum modifications are suggested in the construction of the recoil system in order that the system can be used with the new recoiling mortar system. A cross-sectional view of the new recoil system is shown in Fig. 4. Parts 4, 5, 8, 9, 10, 11, 11 and 16 are the main components of Recoil system of 105mm Tank gun. Parts 1 and 23 is the main components of the used mortar (Barrel, Breech body with its firing mechanism). Part 6 and 22 are new components used to fix the barrel (1) with the piston (4). Part 2 "ring" is used as two separate parts to adapt and guide the barrel (1) as the diameter of sleeve (5) is greater than the outer diameter of the barrel (1).

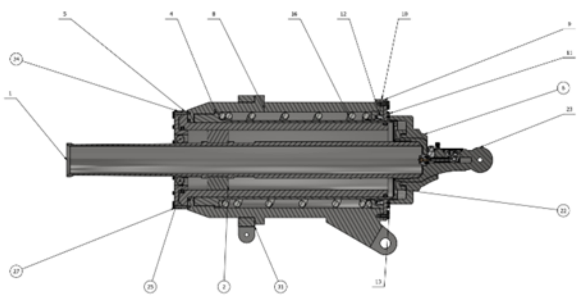

Fig. 4 A cross-sectional view of the new recoiling mortar system

A. *Description of recoil system*

The recuperator and recoil brake are grouped concentrically around the barrel. The cradle works also as the recoil brake cylinder. The recoil brake piston is fastened to the breech ring. It is constructed as a tube and slides in the barrel supporting sleeve during recoil and counter recoil. Braking is achieved by throttling of liquid through the annular orifice between the piston and the contracting inner surface of the brake cylinder. Simultaneously, the spring recuperator is compressed and accumulates the necessary energy for counter recoil.

B. *Function during recoil*

When firing, the recoil brake piston connected with the breech ring moves backwards. Thus, the liquid in chamber (1) is forced to flow around piston head through the annular orifice between piston head and the contracting inclined internal surface of recoil brake cylinder. Thereby, the variable hydraulic resistance is created.In this interval, the major part of flow takes place from chamber (1) to front of piston head passing through the annular orifice between piston head and the contracting inclined internal surface of recoil brake cylinder. This variable throttling orifice will create the required variable hydraulic resistance.A minor part of liquid will flow into piston head cavity. Its originated relevant hydraulic resistance is very small except towards the end of recoil where the main variable annular orifice decreases excessively.

III. Modelling of mortar recoil

As illustrated in [1, 2, 5], the appropriate design of gun recoil system starts with the determination of the total force evoked from this recoil system. This force, in turn, is transmitted to the gun carriage. There are very rare designs of recoiling mortar systems. The only available recoiling mortar systems are those developed by Elbit Systems Ltd.* in which the maximum recoil force is listed to be 25 tons. Therefore, the total recoil force in this paper is designed so that it does not exceed this value.

The solution of the recoil parameters starts with the free recoil calculations, in which the recoil parameters are determined considering the barrel recoils without the effect of any recoil resistance. Then, the requisite curve of recoil resistance is designed / chosen. After that, the braked recoil parameters are determined according to the recoil resistance curve.

A. *Free recoil calculations*

The free recoil velocity (W) and the free recoil distance (L) are determined in the period of projectile motion inside barrel as follows [5]:

$$\mathrm{W} = \frac{\mathrm{m_p} + 0.5\mathrm{m_w}}{\mathrm{m_R} + \mathrm{m_p} + \mathrm{m_w}} \times \mathrm{v_p} \tag{1}$$

$$\mathrm{L} = \frac{\mathrm{m_p} + 0.5\mathrm{m_w}}{\mathrm{m_R} + \mathrm{m_p} + \mathrm{m_w}} \times \mathrm{x_p} \tag{2}$$

where m_p and m_w are the masses of projectile and propellant, respectively, m_R is the mass of recoiling parts, v_p is the projectile velocity, and x_p is the projectile travel inside the barrel.

The free recoil parameters in the period of additional action of powder gases (after the projectile leaves the barrel until complete discharge of gases) can be calculated as follows:

$$W = W_M + \frac{1}{m_R} . P_M . b . \left(1 - e^{-\frac{t}{b}}\right) \tag{3}$$

$$L = L_M + W_M . t' + \frac{1}{m_R} . P_M . b . \left(t' - b \left(1 - e^{-\frac{t}{b}}\right)\right) \tag{4}$$

where t' is the time measured from the muzzle point, PM is the force of powder gases at the muzzle point, and b is the Bravin's coefficient.

The results of the free recoil parameters at the main points are presented in Table II. In addition, the courses of all parameters are shown in Fig. 5 and Fig. 6.

* Elbit Systems Ltd. is an Israel-based international defense electronics company engaged in a wide range of programs throughout the world.

TABLE II
Free recoil results

t_M	0.01128442	(s)	t_{EA}	0.166528	(s)
W_M	34.99205	(m/s)	t_I	0.027937	(s)
L_M	0.156152	(m)	W_{EA}	42.12186	(m/s)
β	3.72816	------	L_{EA}	0.834986	(m)
b	0.003276	(s)			

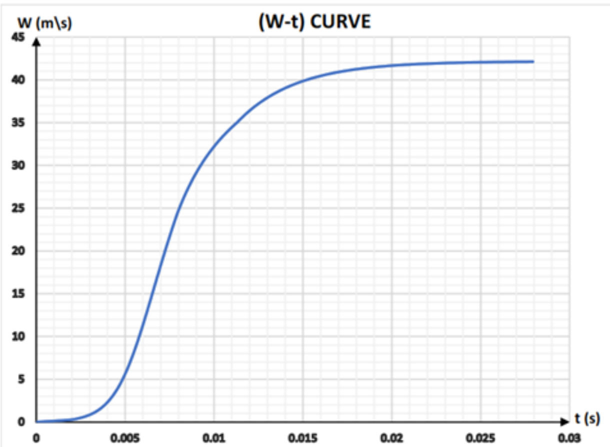

Fig. 5 Free recoil velocity vs Time

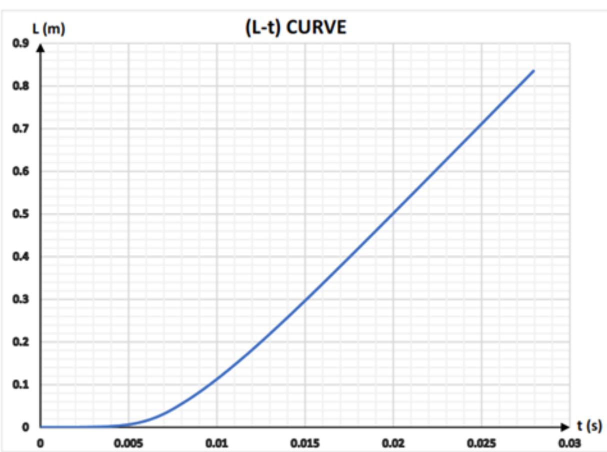

Fig. 6 Free recoil distance vs Time

B. *Braked recoil calculations*

The requisite recoil force is chosen as shown in Fig. 7. The recoil period is divided into 3 periods, namely: period of projectile motion until P_{max} , period of projectile motion from P_{max} until AAPG, and Period of projectile motion from end of AAPG until the end of recoil. The braked recoil velocity (V) and the braked recoil distance (X) are determined as follows:

I. Period of projectile motion until Pmax

$$V = W - \frac{1}{m'_R}\left(R_o + \frac{R - R_o}{2t_M} * t\right) * t \quad (5)$$

$$X = L - \frac{1}{m'_R}\left(R_o + \frac{R - R_o}{3t_M} * t\right) * \frac{t^2}{2} \quad (6)$$

II. Period of projectile motion from P_{max} untill AAPG

$$V = W - W_{t_{PMax}} - \frac{R_{EA}}{m_R}(t - t_{PMax}) \quad (7)$$

$$X_i = X_{i-1} + \frac{V_i + V_{i-1}}{2} * (t_i - t_{i-1}) \quad (8)$$

III. Period of projectile motion from end of AAPG until the end of recoil

$$V = V_{EA} - \frac{1}{m_R}\left(R_{EA} - \frac{R_{EA} - R_\Lambda}{2t_{II}} * (t - t_I)\right) * (t - t_I) \quad (9)$$

$$X = X_{EA} + V_{EA} * (t - t_I) - \frac{1}{m_R}\left(R_{EA} - \frac{R_{EA} - R_\Lambda}{3t_{II}} * (t - t_I)\right) * \frac{(t - t_I)^2}{2} \quad (10)$$

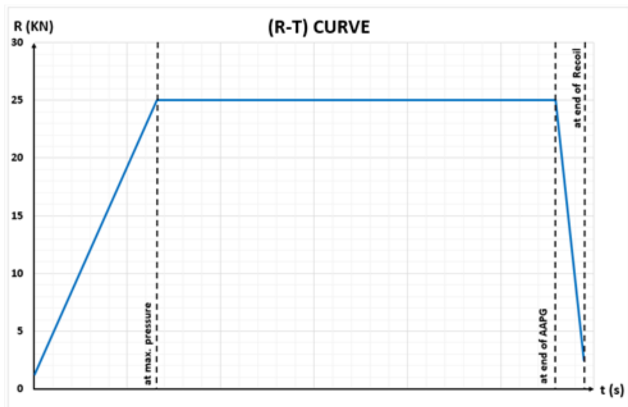

Fig. 7 Recoil resistance vs Recoil time

IV. Results

The results of the braked recoil parameters at the main points are presented in Table III. The variation of all parameters are shown in Fig. 8 and Fig. 9. It is seen that the maximum recoil force is set to be 250 kN and the maximum recoil distance is less than 0.34 m which is the same recoil distance of the M60 tank gun. This means that the current construction of the tank gun is suitable to be used for the new mortar system.

TABLE III
Braked recoil results

R_o	11594.41	**(N)**	**t_I**	0.27937	**(s)**
R_{Pmax}	250000	**(N)**	**V_{EA}**	1.4052	**(m/s)**
R_{EA}	250000	**(N)**	**X_{EA}**	0.330153	**(m)**
R_Λ	23952.81	**(N)**	**t_{II}**	0.001539	**(s)**
t_{pmax}	0.0066005	**(s)**	**t_Λ**	0.029476	**(s)**
V_{Pmax}	10.3658	**(m/s)**	**Λ**	0.330937	**(m)**

X_{Pmax}	0.011194	**(m)**			

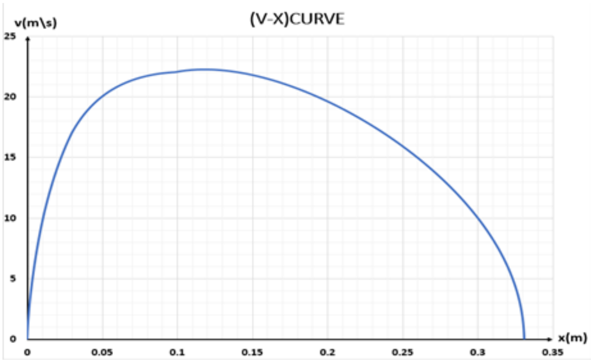

Fig. 8 Braked recoil velocity Vs Recoil distance

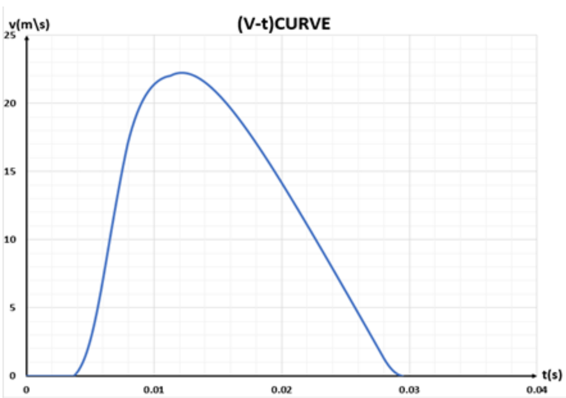

Fig. 9 Braked recoil velocity Vs Recoil time

It is also seen from Fig. 9 that the mortar recoil does not start at the beginning of projectile motion in the barrel. That is due to the effect of the spring recuperator that is originally used for the tank gun whose recoiling parts are 10 times heavier than that of the mortar.

The braked recoil parameters seen in Fig. 8 and Fig. 9 are used to design the recoil brake in the manned illustrated in [1], and it has been found that the recoil system of the M60 tank gun can be used safely as a recoiling mortar system. However, some modifications in the throttling area is needed. This can be achieved by machining process in the recoil brake cylinder.

V. Conclusion

This paper presents suggestion and modelling of a new recoiling mortar system. The novel idea in the paper is the suggestion of the use of the recoil system of the M60 tank gun as a recoil system of the mortar. The characteristics and limitations of the adoption of this idea are presented as well as the modifications that are necessary to be performed either in the construction of recoil system or in the throttling area of the recoil brake. The results show that the adoption of this recoil system reduces the recoil force by more than 75%. It is predicted that the maximum recoil force in the new design is 250 kN, whereas it has the value of 1165 kN which is the value of pressure force at the instant of maximum pressure. Future work may include further investigations of the design suggested, especially in the counter recoil, and the suggestion of the use of more powerful and smart recoil systems that lead to shorter recoil distance and less recoil force.

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