MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

NEW CONCENTRIC HYDRO-SPRING RECOIL MECHANISM

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ABSTRACT

Developments of tank gun recoil system have led to the design of new concentric hydro-spring recoil mechanisms for the purpose of compactness and high performance. This new recoil mechanism is used in the modern high power tank guns. This work is intended for the analysis of the function as well as the determination of the performance of this new system. A mathematical model is established for the calculation of the recoil parameters of this new system. Another mathematical model is established for the classical recoil system. Experimental measurements are performed during actual firing to validate the mathematical model. A comparison is held between the recoil parameters of two tank guns, the first is equipped with the new hydro-spring recoil mechanism, whereas the second uses the classical recoil system.

1. INTRODUCTION

The recoil system is nearly the most important mechanism which controls the whole gun function and performance. It influences to a great extent the design of the whole gun carriage and the gun stability during firing. Besides, it plays a noteworthy role in the recent endeavours to increase gun power and accuracy of fire. Recently, the use of the concentric hydro-spring recoil system (fig. 1) exhibits a noticeable improvement of modern tank guns.

Any recoil system consists mainly of recoil brake, recuperator and counter recoil brake. The braking of barrel recoil is achieved by the hydraulic resistance of recoil brake which stops the recoiling parts after an assigned recoil track. This hydraulic resistance is evoked by the flow of liquid through variable throttling orifices. The pneumatic or spring recuperator accumulates a certain part of recoil energy in order to be used for recuperating the recoiling parts of the gun to their forward position after finishing the recoil. Also, the counter recoil has

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to be braked due to the existance of a surplus accumulated energy in the recuperator. Therefore, a counter recoil brake is also necessary.

In classical guns, the recoil and counter recoil brakes are incorporated in one cylinder, whereas the recuperator forms a separate cylinder (fig. 2). These two cylinders are mounted parallel to the barrel axis. The new concentric hydro-spring recoil system is formed only of one cylinder - concentric with the barrel -incorporating the three recoil mechanisms. In addition, this cylinder acts also as the gun cradle. The system consists of barrel sleeve, recoil brake piston, recuperator spring, counter recoil brake valve and the outer cylinder. The needed variable throttling orifice is achieved by the variable inner diameter of outer cylinder (cradle).

2. FUNCTION DURING RECOIL

When firing, the recoil brake piston -connected with the breech ring- moves backwards due to barrel recoil. Thus, the liquid in space (I) is forced to flow into other spaces. The direction, and distribution of flow depend on the recoil track (X_R):

When $\Delta > X_R > 0$

The distance (Δ) is the length of piston head plunger. The liquid in space (I) is forced to flow mainly inside the piston head cavity (space II) where it opens the inertia valve. Also, a minor portion of liquid flows in the gap between the piston head plunger and the front part of outer cylinder. Both flow portions are gathered once more in space (III) and they contribute in creating the hydraulic resistance in this extent of recoil.

When $\Lambda > X_R > \Delta$

In this interval, the major part of liquid flows from space (I) to front of piston head passing through the annular orifice between piston head and the nearly conical inner surface of the outer cylinder (cradle). This conical surface forms the variation of throttling orifice with the recoil track. Thereby, the required variable hydraulic resistance is created. A minor part of liquid flows into space (II), where the originated relevant hydraulic resistance is very small except towards the end of recoil when the annular orifice of the main flow decreases excessively.

3. FUNCTION DURING COUNTER RECOIL

During counter recoil, no liquid flow takes place through orifices until the vacuum in recoil brake cylinder is eliminated. This vacuum is originated due to the pulling of piston rod cylinder out of recoil brake during recoil. The counter recoil distance after which the vacuum is eliminated is:

$$\rho = (A_{PR}/A_P).\Lambda$$

where: A_{PR} .....cross-section area of piston rod.
A_P .....maximum cross-section area of piston head.
Λ .....maximum recoil track.

Therefore, during counter recoil, the function is divided into three intervals:

When $\rho > X_{CR} > 0$

No liquid flow takes place. Thereby, no hydraulic resistance is originated. The inertia valve is closed.

When $(\Lambda - \Delta) > X_{CR} > \rho$

The liquid in front of piston head is forced to flow back through the annular orifice between piston head and inner conical surface of outer cylinder, producing the main hydraulic resistance of counter recoil. Another flow takes place inside the piston head cavity through the eight holes of the inertia valve.

When $\Lambda > X_{CR} > (\Lambda - \Delta)$

The liquid in space (III) is divided in two portions. The first passes inside the piston head cavity through the eight holes of inertia valve, while the the second passes through the annular gap between piston head plunger and front part of outer cylinder. Both portions of liquid flow contribute in creating the hydraulic resistance which secures fluent braking and stopping of counter recoiling parts.

4. CALCULATION OF HYDRAULIC RESISTANCE

The path of liquid is divided into several sections at every change, either in dimensions of flow area or in direction of liquid flow. The recoil system under investigation is divided into seventeen sections.

For the first recoil interval, the sections from (1) to (13) represent the flow from space (I) to space (III) through the piston head cavity (space II). Sections (4,14,15,13) represent the flow through the annular gap between piston head plunger and front part or recoil brake cylinder.

For the second recoil interval, the major flow is considered passing through sections (1,2,3,4,16,17) ,while the minor flow is considered passing from section (4) to section (12) and then to section (17).

According to the forces acting on the recoiling parts, the recoil motion can be divided into two periods. In the first period, both the pressure force of powder gases and the total recoil resistance are acting. In the second period, only the total recoil resistance is acting since the pressure force of powder gases vanishes after the end of the additional action of powder gases. The block diagrams of calculation of these two periods are shown in (figs. 3 and 4).

It is worthy to note that in the recoil brake there are some differences from the complete water hammer phenomena, such as:

- The velocity of liquid flow in recoil brake is variable according to the velocity of recoil.
- In the recoil brake there is no valve closes instantaneously, but the liquid flows through the annular orifice at section(3).
- Reflection of pressure waves occurs due to the change of area or flow direction.
- Damping effect due to energy losses during the braking process.

Therefore, the pressure wave is not completely reflected as in the water hammer phenomena. It is partially reflected and the other part of pressure wave travels through the annular variable orifice at section (3). Thus, it is rather difficult to go through the analysis of wave propagation. Assuming that:

- The reflected part of pressure waves will be accumulated due to the high wave velocity.
- A partial effect of water hammer pressure will be taken into consideration due to the partial reflected waves.

Therefore, it can be said that during firing, the piston moves backwards with the recoiling parts. So, the liquid is forced to flow towards the cylinder bottom. At cylinder bottom, a negative pressure wave will travel in the forward direction till the piston head. There, a part of this wave will travel through the annular orifice of section (3) and the other part will be reflected once more.

Consequently, it can be concluded that for this recoil brake, only a partially commulative effect of water hammer pressure with negative sign is considered. Moreover, the existance of recuperator spring works in destruction of the pressure waves. The theoretical calculations show that this partial effect is about [20 %] of the complete water hammer effect. So, the calculated shock pressure drop is added to the pressure evoked from other sources at each step of calculation. For the tank gun employing the classical recoil system, the comparison of theoretical and experimental results shows that the shock pressure effect is about [30 %] of the complete water hammer effect.

For every section, the local and friction losses are calculated. Also, the coefficients of contraction as well as the friction losses are calculated according to the corresponding Reynold's number. Moreover, the effect of shock pressure waves in space (I) as well as the inertia pressure are considered.

Considering the gauge pressure in section (13) or section (17) to be zero, the pressures in other sections can be calculated using the corresponding energy equations. Knowing the pressures at different sections and the areas exposed to them, the course of hydraulic resistance of the recoil brake can be determined. This is achieved by applying the regressive method for calculation of recoil system parameters [1],[2].

5. THE MATHEMATICAL MODEL

For establishing the mathematical model, the following computer programmes are performed:

1) Programme for solving the internal ballistics main task. The solution is performed for the 105 [mm] APSFDS ammunition which gives the maximum recoil impulse.

2) The main programme for calculation of recoil parameters. It contains:
   - Calculation of free recoil parameters.
   - Application of the regressive method for the calculation of braked recoil parameters.

3) Function sub-programme for calculating the hydraulic braking function of the recoil brake, as well as the calculation of pressures at different sections for the examined instant of recoil.

4) Function sub-programme for calculating the variable internal diameter of recoil brake cylinder in different places at the examined instant of recoil.

5) Function sub-programme for the calculation of the contraction coefficients of the throttling orifices according to the value of Reynold's number.

6) Function sub-programme for the calculation of the effective recuperator force at the examined instant of recoil.

For proceeding in calculation, some measurements are carried out using suitable measuring devices according to the required accuracy, such as measurement of barrel bore details, recuperator dimensions and parameters, recoil brake dimensions and other dimensions necessary for the calculations.

6. THEORETICAL AND EXPERIMENTAL RESULTS

Application of the established mathematical model is applied on the concentric hydro-spring recoil system of the 105 mm tank gun mounted on the tank M60A3. For tha matter of comparison, a similar mathematical model is established for the determination of recoil parameters of tha classical recoil system of 115 mm tank gun mounted on the tank T-62 (fig. 2). For calculating its recoil parameters, the recoil brake is divided into twenty nine sections, according to the changes in channel dimensions or flow direction. For this gun, HEAT ammunition gives the maximum recoil impulse. Real firing at zero elevation angle is carried out to validate the mathematical model. In the following, the results of both systems are presented:

A) For the concentric hydro-spring recoil system:

- Table (1): Extremum values of recoil parameters when firing at zero angle of elevation.
- Figure (5): Courses of recoil resistances vs time of recoil.
- Figure (6): Courses of recoil resistances vs recoil track.
- Figure (7): Liquid pressure in space (I) vs time of recoil.
- Figure (8): Liquid pressure in space (I) vs recoil track.
- Figure (9): Recoil velocity and track vs time of recoil.

b- For the classical recoil system:

- Figure (10): Courses of recoil resistances vs recoil track.
- Figure (11): Recoil velocity and track vs time of recoil.
- Figure (12): The experimental and theoretical values of liquid pressure in space (I) vs time of recoil.

The values of the maximum length of recoil, the total time of recoil and the maximum liquid pressure in space (I) are:

Theoretical			Experimental		
Λ [mm]	t_Λ [ms]	p_1 max [MPa]	Λ [mm]	t_Λ [ms]	p_1 max [MPa]
422,93	84,23	28,72	423,00	83,10	28,70

The following table presents a comparison between the effective parameters of the new concentric hydro-spring recoil system of the 105 mm tank gun and those of the classical recoil system used in the 115 mm tank gun:

Parameter	105 mm T.G.	115 mm T.G.
Max. liquid pressure p_1 max[MPa]	12,33	28,72
Max. hudraulic resistance K [kN]	393,4	302,0
Max. total resistance R [kN]	411,4	332,0
Max. recoil track Λ [mm]	334,4	422,9

7. CONCLUSIONS

1) The established mathematical model applied on tank guns gives very close results to those determined experimentally, and shows that it can also be applied on similar guns for the purpose of reverse engineering or for any proposed improvement or modifications.

2) The maximum pressure of liquid inside the concentric system is very low (12,33 MPa) compared with (28,72 MPa) for the classical one. The low pressure has many advantages in the design of recoil system cylinders and their stuffing boxes which has a beneficial effect on liquid sealing.

3) In spite of the low pressure level of liquid in the concentric system, the produced hydraulic resistance is relatively high (393,4 kN) due to the great working area of the recoil brake piston.

4) The concentric recoil system produces a higher total recoil resistance (411,4 kN) compared with (332 kN) for the classical one. This results in a shorter recoil track (334 mm) compared with (423 mm) for the classical system. Besides, the work done by the total recoil resistance is higher for the concentric hydro-spring recoil system due to its optimum disribution vs the recoil track (see fig. 6).

5) The concentric hydro-spring recoil system is a very simple mechanism from the view point of design, production, assembly, maintenance and repair. This is due to the use of simple and minimum number of components (compare fig. 1 and fig. 2).

6) The very compact construction of hydro-spring recoil system mounted concentrically with the barrel is optimum in tank guns where the saving of space is a major requirement.

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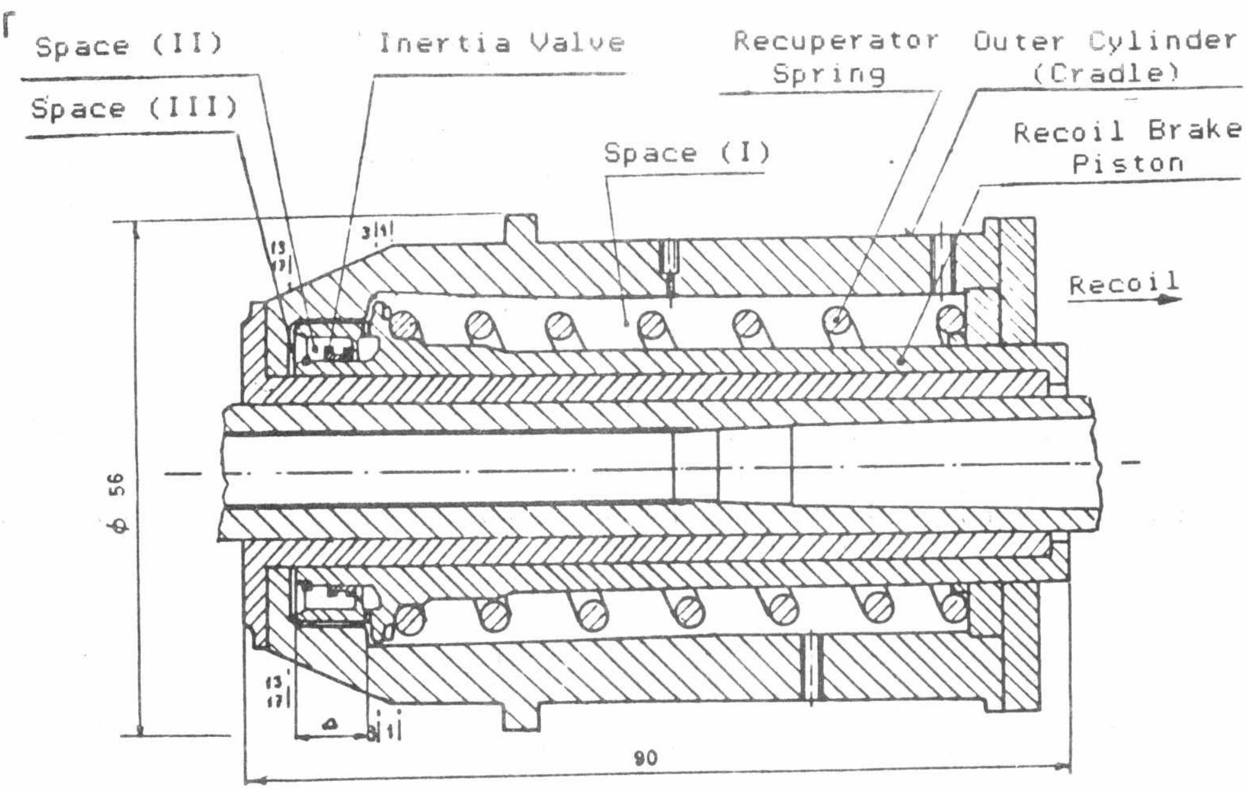
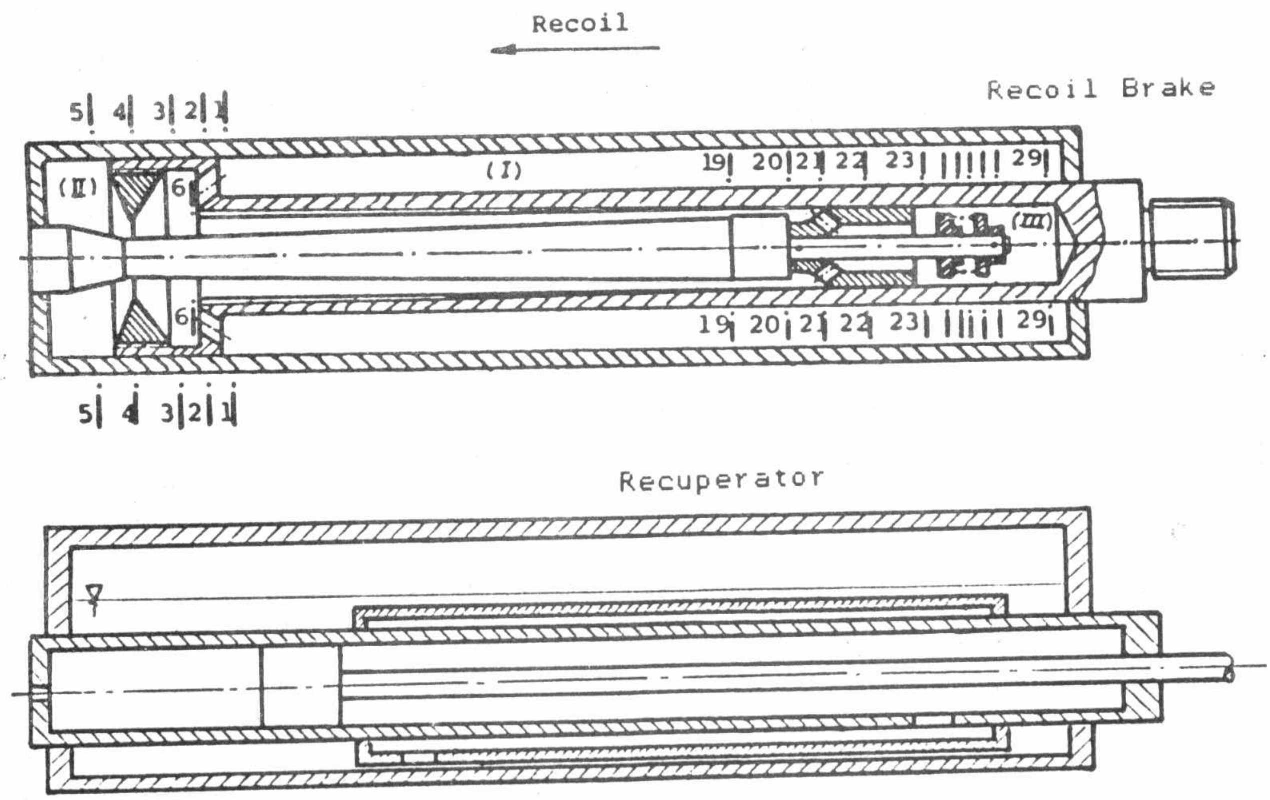
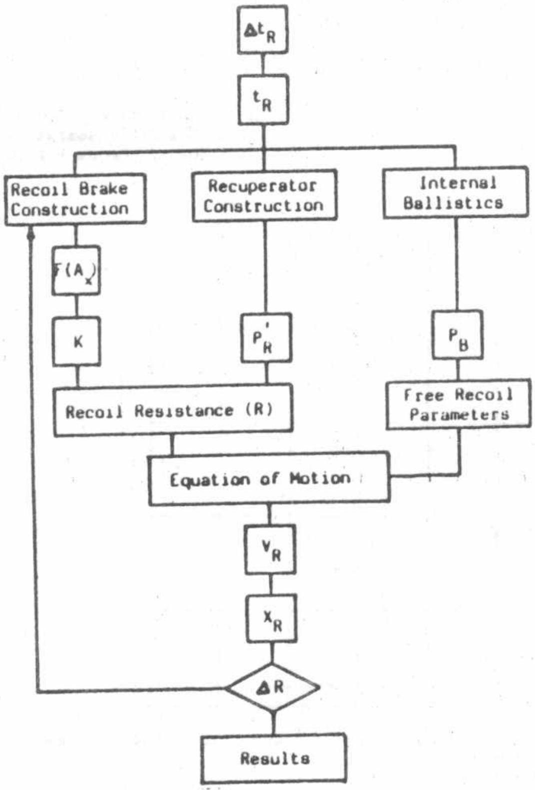


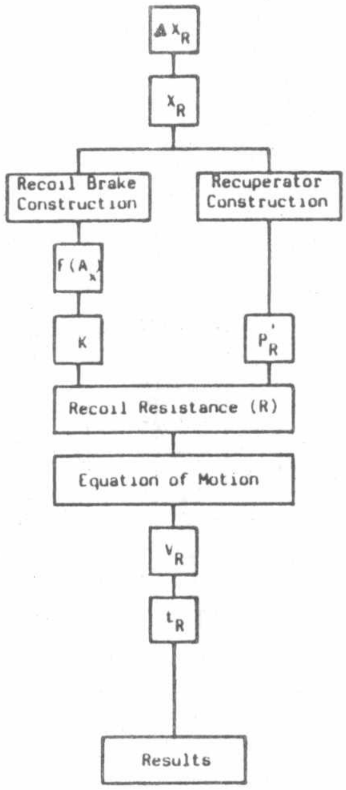
(Fig. 1) Concentric Hydro-Spring Recoil Mechanism.



(Fig. 2) Classical Recoil System.



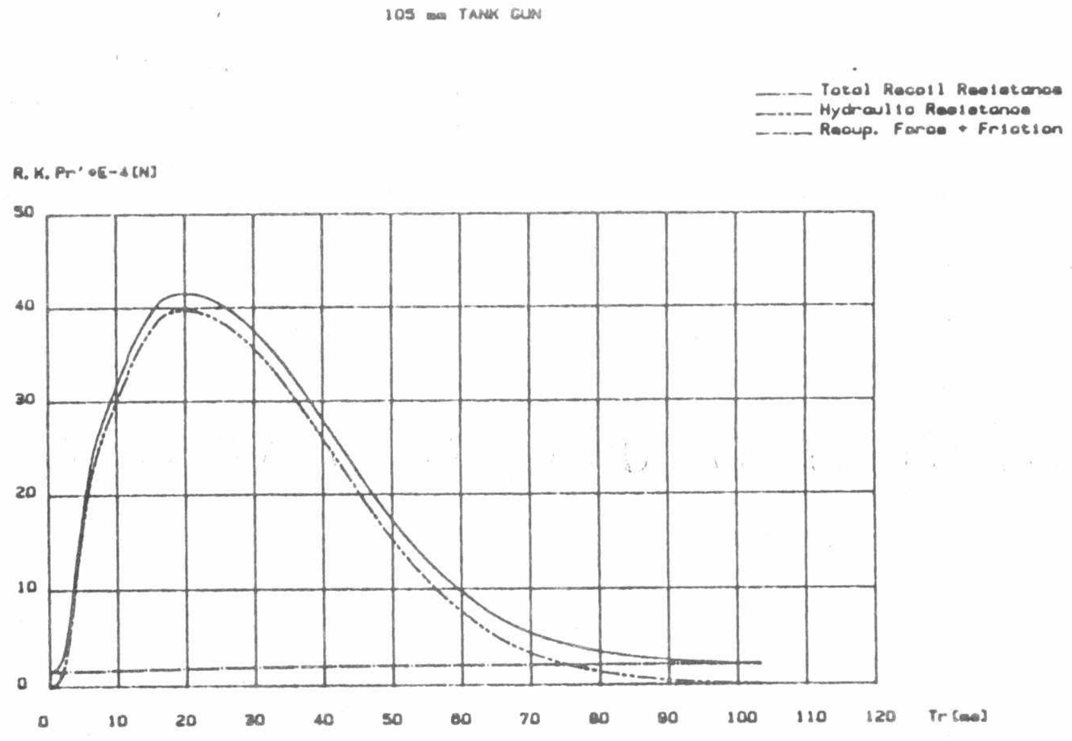
(Fig. 3) The First Period of Braked Recoil.



(Fig. 4) The Second Period of Braked Recoil.

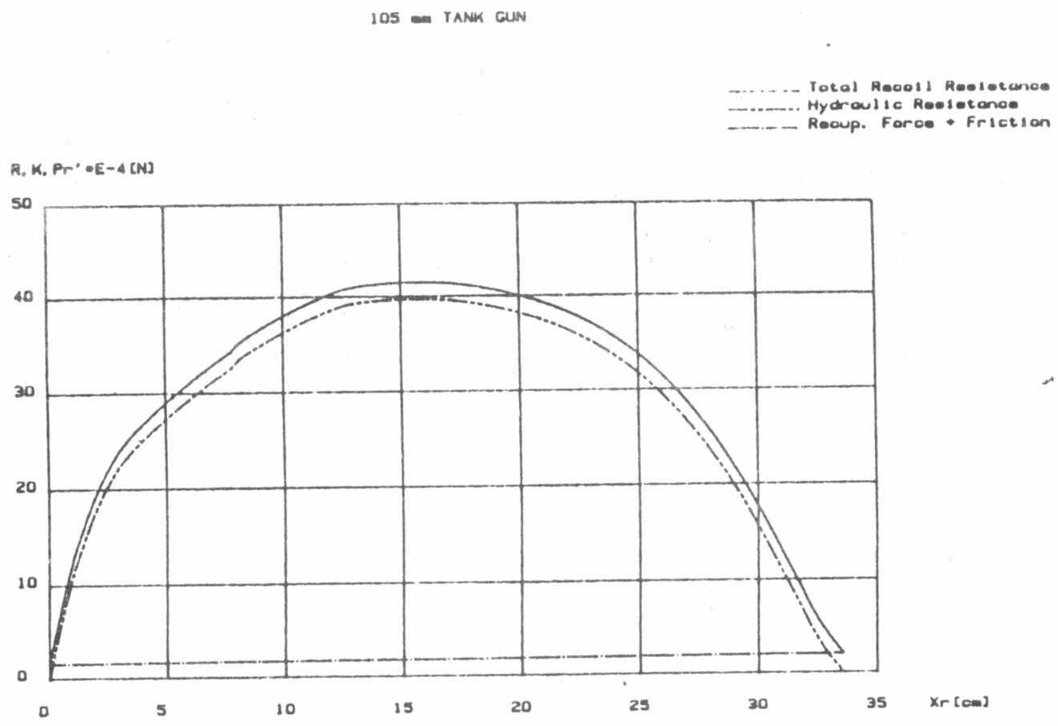
105 mm TANK GUN		
Angle Of Elevation	0.00	[deg]
Mass Of Recoiling Parts	1454.00	[kg]
Minimum Recuperator Force	1.02	[Ton]
Maximum Recuperator Force	1.57	[Ton]
Maximum Pressure In Recoil Brake	12.33	[MPa]
Corresponding Recoil Track	14.17	[cm]
Corresponding Recoil Time	18.55	[msec]
Maximum Hydraulic Resistance Of Recoil Brake	39.34	[Ton]
Corresponding Recoil Track	14.80	[cm]
Corresponding Recoil Time	19.29	[msec]
Maximum Recoil Resistance	41.14	[Ton]
Corresponding Recoil Track	14.80	[cm]
Corresponding Recoil Time	19.29	[msec]
Maximum Recoil Velocity	9.53	[m/sec]
Corresponding Recoil Track	7.01	[cm]
Corresponding Recoil Time	10.74	[msec]
Time Of First Period Of Braked Recoil	44.58	[msec]
Time Of Second Period Of Braked Recoil	59.45	[msec]
Total Time Of Recoil	104.03	[msec]
Maximum Recoil Track	33.44	[cm]

Table (1) Extremum Values of Recoil Parameters.



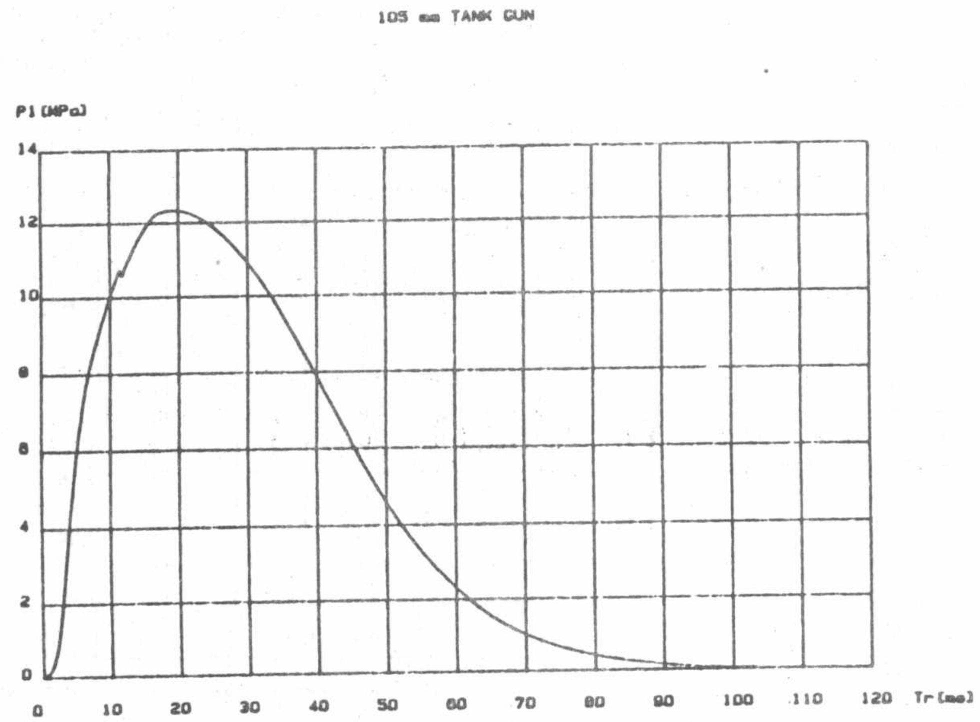
(Fig. 5) RECOIL RESISTANCES vs RECOIL TIME

Elevation Angle= 0



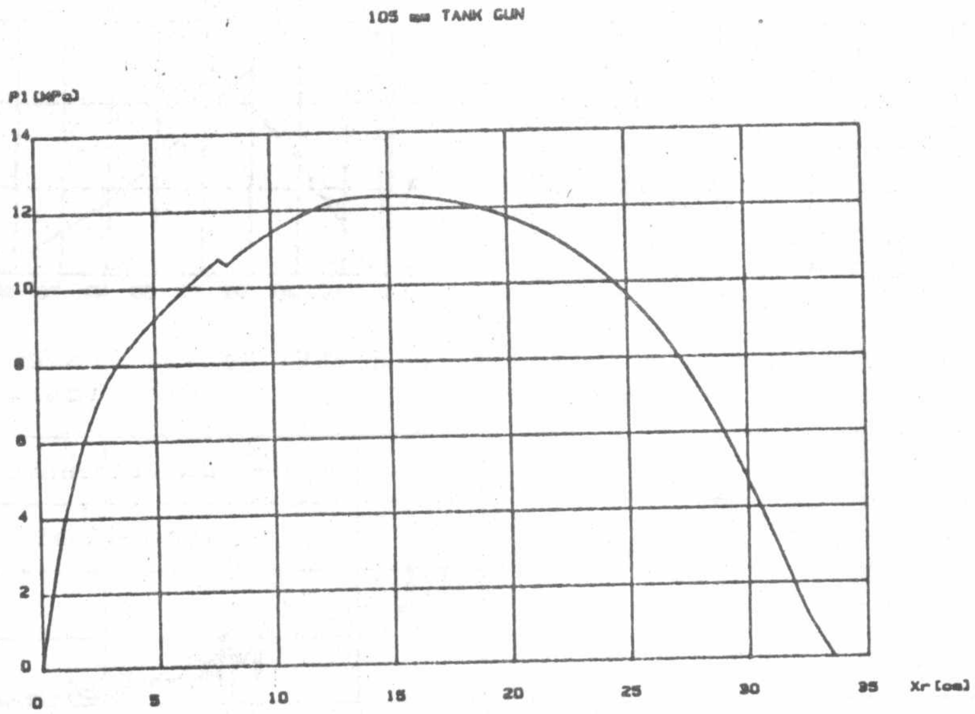
(Fig.6) RECOIL RESISTANCES vs RECOIL TRACK

Elevation Angle= 0



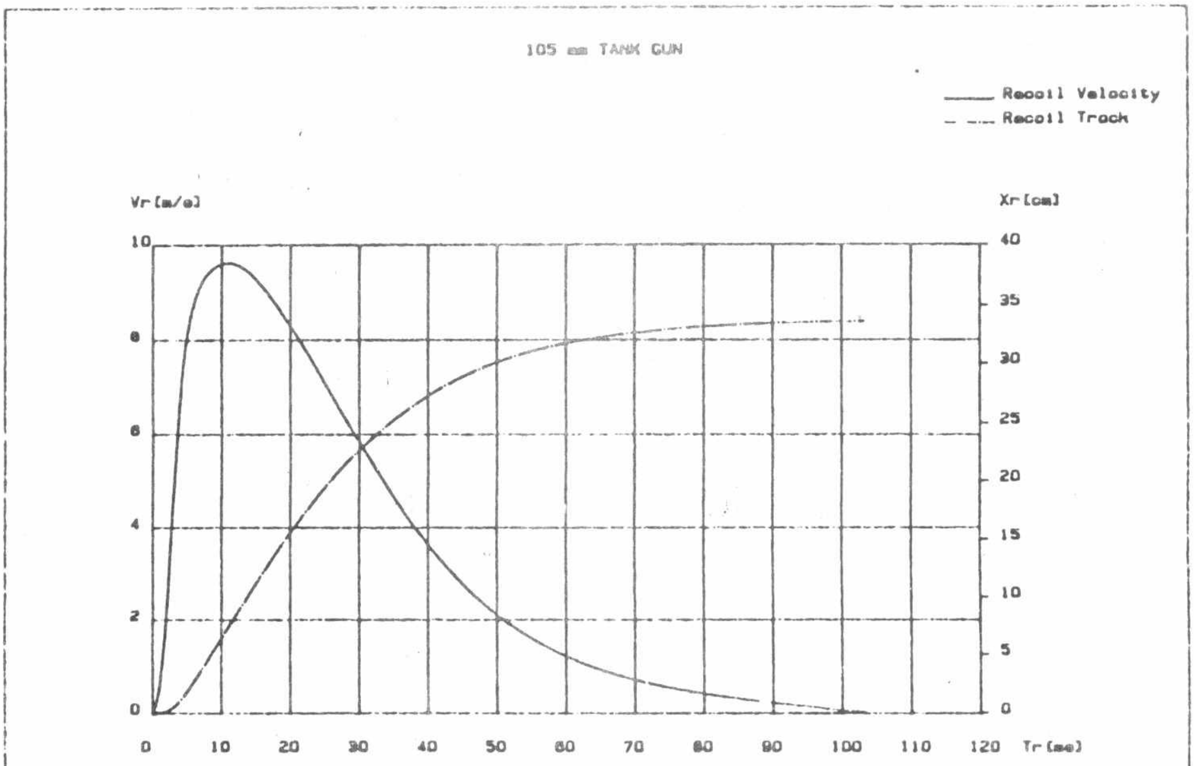
(Fig.7) RECOIL BRAKE PRESSURE vs RECOIL TIME

Elevation Angle= 0



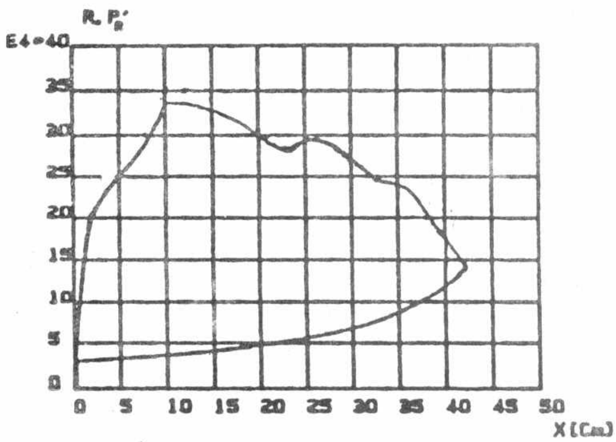
(Fig. 8) RECOIL BRAKE PRESSURE vs RECOIL TRACK

Elevation Angle= 0

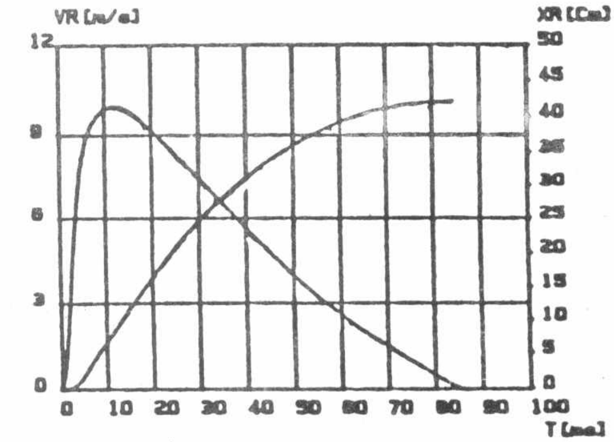


(Fig.9) RECOIL VELOCITY AND RECOIL TRACK
vs RECOIL TIME

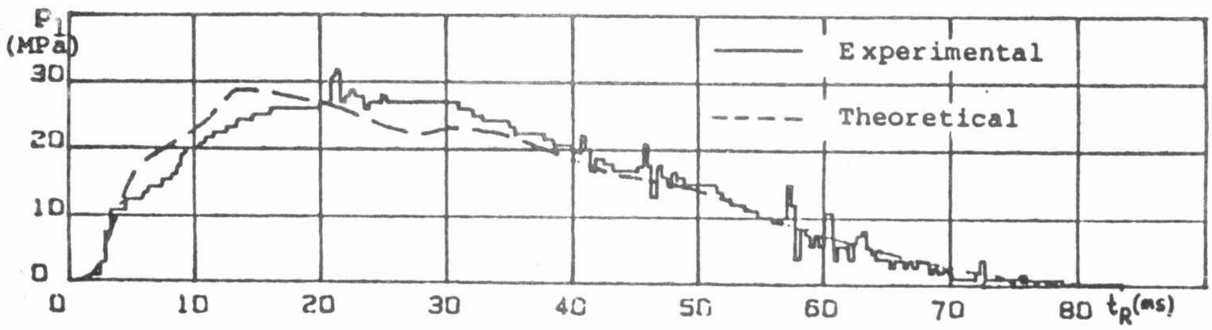
Elevation Angle= 0



(Fig. 10) Recoil Resistances.
(Classical System)



(Fig. 11) Recoil Track & Velocity.
(Classical System)



(Fig. 12) Theoretical & Experimental Recoil Brake Pressure.