Handgun Mechanisms Analysis

MARIUS VALERIU CIRMACI
OCTAVIAN DUMITRU ORBAN
VIOREL TUDOR TIGANESCU
TRAIAN ROTARIU
Armament Integrated Systems Department
Military Technical Academy
81-83, George Cosbuc Ave, Sector 5, Bucharest, Postal Code 050141
ROMANIA
http://www.mta.ro

Abstract: In this paper, experimental and computer aided methods are used in order to simulate the dynamic behavior of a 9 mm handgun when fire. As known, firing process is a complex phenomenon which involves cap percussion, powder burning, bullet movement down the gun barrel and it's propulsion on the trajectory. An accurate and secure shooting needs a very fine control of all these processes. Also, the handgun mechanisms movements are in standing to influence drastically the fire precision. For these purposes we analyzed some particular aspects of a handgun dynamic, using high level CAD system Solid Works, DAQ systems, B&K signal acquisition and processing device Pulse 3560D and other testing devices developed in our laboratory.

Key-Words: - Handgun, Cycle Diagram, Experimental Device, CAD

1 Introduction

The organizing principle of a handgun, regarded as a fire system made by gun itself and ammunition, arises two major aspects in any gun analysis. These are, obviously, related with the ammunition and the handgun. While the cartridge must fit the loading chamber geometry and loading system requirements, the powder is to be tested in order to generate the necessary power for bullet propulsion (with minimum energy required) and to complete the weapon's functional cycle. Less powder energy could decrease the bullet velocity, affecting it's efficiency and stability on the trajectory or could lead to malfunction in loading the new cartridge (in case of automatic functioning). In Fig.1 is shown the case of bullet retention right at the EPVAT barrel mouth, due to a decreasing of initial powder quantity (so that a decreasing of loading density) with cca 61% in weight.

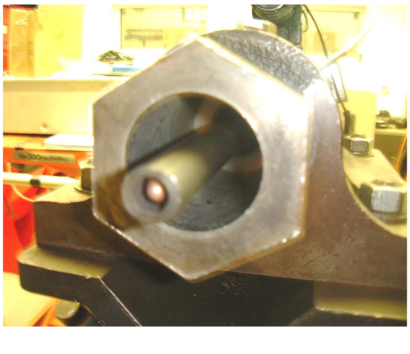

Fig.1 Bullet retention in EPVAT barrel

One consequence of more powder energy could be that it causes very dangerous events, as breaking the handgun and injuries to the personnel. By the other hand, the handgun mechanisms should follow the operating cycle in a recurrent manner. In automatic weapons the continuous transfer from one function to the next is controlled by the operating (or functional) cycle of the weapon. Automatic functioning can be achieved only for part of the functional cycle, to give semiautomatic operation, as in handguns. By short, the operating cycle means to fulfill a sequence of events as follow: cartridge inserting into the chamber, locking the chamber by the breech block, primer (cap) percussion, unlocking the chamber (after the bullet was fired), removing the empty cartridge case from the chamber and ejecting from the weapon. After that, the next cartridge must be loaded into the weapon by removing a round from the magazine. All these operations are shown in cycle diagram, which analysis is used either to design a new gun starting from a comparation one or to evaluate if one specific weapon works in an accurate manner. According to NATO standards, there are a series of tests required for ammunition, for weapon and for weapon – ammo system, in order to carry out the qualifying procedures. Even the handgun simulation is more related to the weapon design process than to homologation or testing and evaluating procedures, this is useful when analyze the handgun functioning in simulated situations which are dangerous to carry out in practice but are not totally avoidable.

2 What is necessary to build a model?

The work presented in this paper arises from the idea to build a model that could simulate the handgun dynamic behavior in several cases submitted to normal or abnormal loading conditions or with different ballistic parameters of propulsion powder. In order to fulfill this purpose, primarily is necessary to build a model which "acts" similar to the real handgun, in laboratory controlled conditions.

2.1 Definition of hypothesis

First, the forces which act over the breech block – barrel – bullet system must be considered. These are as shown in Fig.2, where:

P_i - Force acting on the breech block, P_p - Force acting on the projectile, N_t - Force acting on the barrel when high pressure in loading chamber, N_i - Reaction force of the barrel acting on the slide (breech carrier), r_{N_t} - Force which the projectile acts on the barrel, r_{N_p} - Resistant force at projectile advancing, $R(x)$ - Resistance of elastic forces, d_c - diameter of loading chamber at considered section

Second, in dynamic theoretical study of semiautomatic operation, the handgun is considered rigid fastened on a fixed stationary base. Thus, the general form of the motion equation is:

$$M_{red}\frac{dV}{dt}+V^2\left(\sum_i \frac{\nu_i}{\eta_i} m_i \frac{\partial \nu_i}{\partial x}+\sum_j \frac{\chi_j}{\eta_j} J_j \frac{\partial \chi_j}{\partial x}\right)=F_{red} \quad (1)$$

where: M_{red} - Reduced recoiling mass, V -Leading part velocity, ν_i - Transmission ratio between the motion of the leading part and driven parts which have m_i masses and which executes a translational motion, m_r - Recoiling mass, $\eta_{i,j}$ - Kinematic couple efficiency, χ_i - Transmission ratio between the leading part and driven parts which executes a rotation, J_j - Moments of inertia for the parts which executes rotations, F_{red} - The force acting on the recoiling system, focused on the leading element.

The reduced recoiling mass is calculated as bellow:

$$M_{red}=m_r+\sum_i \frac{\nu_i^2}{n_j} m_i+\sum_j \frac{\chi_j^2}{n_j} J_j \quad (2)$$

Third, the friction forces between the slide and the weapon's body are ignored, as well as the frictions in the fire cock axis and the friction between barrel and slide during the unlocking motion.

Fourth, the mechanical energy loss from the mechanical work of internal forces inside the springs material are ignored (retrieval spring and the fire cock spring).

Finally, the planar motion of the barrel caused by cam geometry is decomposed in two other motions: one is a short translation during which takes place the full separation between barrel and slide, followed by a rotational motion around point A (situated in the longitudinal symmetrical plan, at the intersection between barrel's mouth plan with the slide's interior face).

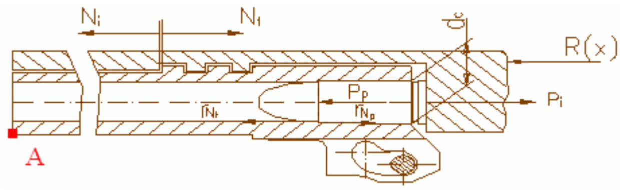

Fig.2 The forces which act over the locking system

3 Experimental handgun analysis

All measurements and tests were made on two types of 9 mm semiautomatic handguns.

3.1 Cycle diagram of weapon to design

For a conventional semiautomatic weapon with one barrel the cycle diagram respects the scheme bellow.

Functional cycle time = time between shots									
1	2	3	4	5	6	1	2	3	…

Fig.3 Handgun functional cycle succession

1 – unlocking and opening the breech block, 2 – extracting the cartridge case, 3 – ejecting the cartridge case, 4 – inserting a new cartridge into the chamber, 5 – closing the breech, 6 – locking the breech

For graphically representing of relative movements and timings of the different pieces and mechanisms in a weapon, two methods are used. These are the Cyclograph and the Functional Diagram. While the cyclograph depicts the individual parts and mechanisms which are dependent on the main part displacement of the automatic system, the functional diagram depicts the displacement, velocity and

acceleration as a function of time for different parts or mechanisms.
Even if the cyclograph shows only length dimensions, when designing a weapon this is the first step, as this make possible to determine the basic length of weapon's parts to provide the required automatic function. The functional diagram is used mainly to calculate the rate of fire, as it develops in real shooting time. Also, using force transducers, velocity / acceleration transducers (or simple / double differentiating the displacement transducers signal), other dynamic characteristics of handgun functioning could be find out. These could be the recoiling force, velocity and acceleration of the leading part or the prancing angle. The simulated model should meet as much as possible the real behavior handgun when the simulation restrictions are similar to the real ones.
For a better understanding of the handgun mechanisms and how they work, a weapon was cut off as in Fig.4. This is not usually necessary when drawing the cyclograph but can be useful, especially with using a high speed camera (if the weapon is still suitable for fire).

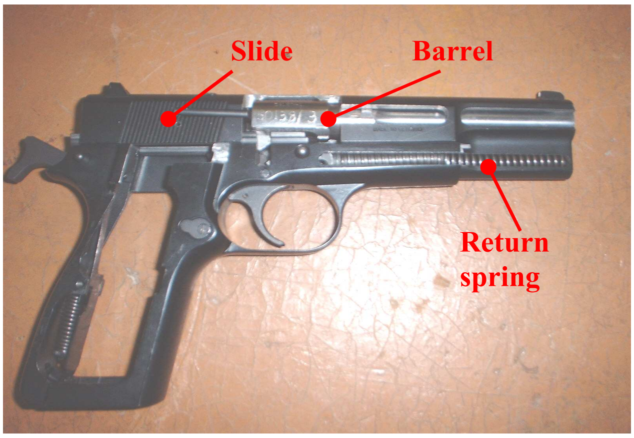

Fig.4 Sectioned weapon

The functional diagram was measured with an experimental device presented in Fig.5.


Fig.5 Experimental device for handgun tests

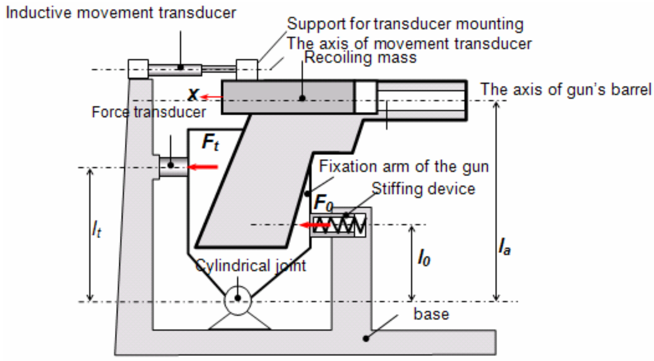

Fig.6 Experimental device- schematic representation

The gun is rigid fastened to the device through an arm jointed with the device base. The gun's barrel axis is orthogonal with the arm-support joint axis, having the barrel in horizontal position. The movement of the fastening arm is blocked by the force transducer. The stiffening device assures a constant force, F_0. The value of pressing force is chosen high enough to eliminate oscillations. Between device frame and mobile part of the gun is mounted a displacement transducer. Force transducer and displacement transducer are coupled through adequate amplifiers to a data acquisition system which affords simultaneously recording of the measured units, for an operational cycle of the weapon. The values measured with the displacement transducer represents the position, as function of time, of the recoiling leading part of the gun (the slide), $x(t)$. By derivation, from one can obtain the velocity and acceleration values of the leading part, $\dot{x}(t)$, respectively $\ddot{x}(t)$.
The recoiling force values obtained with force transducer are good to be known because they affect the weapon prancing angle value, and thus, the gun precision. Also the transmitted impulse to the fire man is an important thing to be analyzed.
During fire, the prancing momentum of the gun, M_r, will tend to rotate the gun in the fixing device, around the cylindrical joint. Because of the rigid mounting, arises an reactive momentum , M_t, generated to the level of force transducer which measures a bigger force, F_t. Because of friction momentum in the arm joint is small enough, this can be neglected.
Thus, the explicit equilibrium equation will be:

$$F_r l_a + F_0 l_0 = F_t l_t \qquad (3)$$

F_0 is the initial value indicated by force transducer,

$$F_0 = \frac{F_{t0} l_t}{l_0} \qquad (4)$$

Thus, the recoiling force of the gun becomes:

$$F_r = (F_t - F_{t0})\frac{l_t}{l_a} \qquad (5)$$

The measured cyclograph shows successive events having the relative displacement values as bellow. The relative values are regarding to total leading part displacement. The capital letters B, D, F, G, H are to indicate the same events on the diagram in Fig.8.

Function		Slide displacement
Complete displacement		100
rearwards	uderslide	9
	Unlocking, B	9 – 15,3
	cartridge case extraction	15,3 – 68,6
	case ejection, D	68,6
	cartridge feed	68,6 - 100
forwards	cartridge feed, F	81,7 - 100
	cartridge insertion, F - G	15,3 – 81,7
	Locking, G - H	9 – 15,3
	underslide	0 – 9

Fig.7 Handgun cyclograph expressed in percents

The values above will be used when building the handgun assembly, to verify and to correct the simulated handgun's cyclograph.

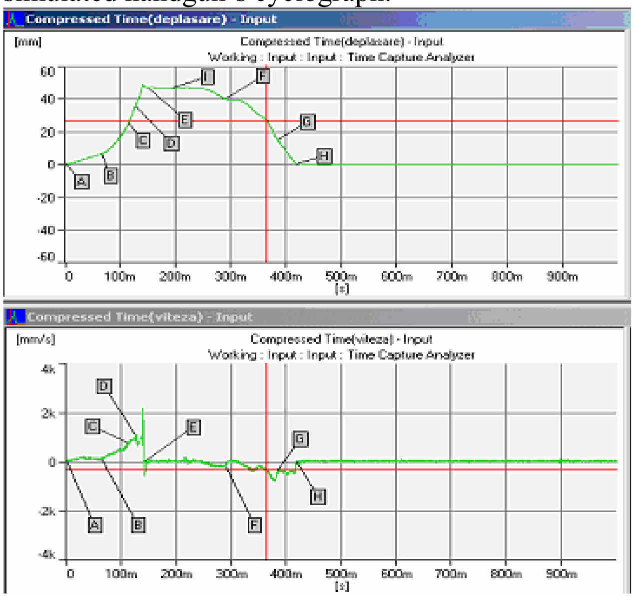

Fig.8 Leading part displacement and velocity when the mechanisms are manually driven

Is to be mentioned that base time in diagram above is not significant, while the mechanisms are manually operated, not automatically.

Further more, the measured functional diagram (Fig.9) will be used to verify and correct the dynamic behavior of simulated handgun.

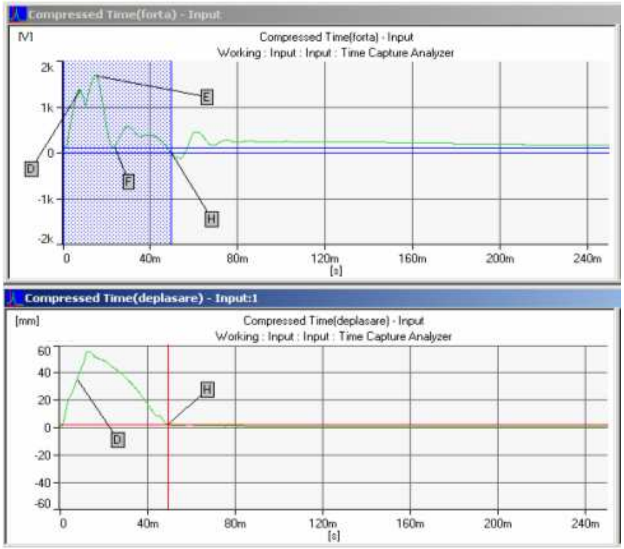

Fig.9 up - Force curve; down - slide displacement values (Functional diagram)

3.2 Relation between recoiling force and burning gases pressure

Applying the angular momentum theorem to the system which consists in handgun, fastening arm and bullet (as in Fig.6), we'll have next equation:

$$\frac{d\vec{K}}{dt} = \overrightarrow{M_t} + \overrightarrow{M_0} \text{ or scalar } \frac{dK}{dt} = F_t l_t - F_0 l_0 \qquad (6)$$

By integration during a functional cycle time, the equation (6) becomes:

$$\int_0^T \frac{dK}{dt} = l_t \int_0^T F_t dt - T l_0 F_0 \qquad (7)$$

At the ending of functional cycle all mechanical parts are in rest, with bullet exception. Neglecting the angular momentum of burning powder, the next equation can be written:

$$\int_0^T \frac{dK}{dt} = l_a m_g v_0 \qquad (8)$$

where m_g, v_0 - bullet mass and initial bullet velocity

From internal ballistics is known that

$$m_g \frac{dv}{dt} = \frac{P(t)S}{\varphi} \qquad (9)$$

where $P(t), S, \varphi$ are gas pressure inside barrel, barrel section, fictive mass coefficient. After a series of calculus, an integral relation between burning gases inside handgun's barrel and the recoiling force measured at force transducer level. This equation is as bellow:

$$\int_0^T F_r dt = \frac{S}{\varphi}\int_0^T P(t)dt \text{ or } \int_0^T \left[F_r - \frac{S}{\varphi} P(t) \right] dt = 0 \quad (10)$$

The signification of equation (10) is that, during a functional cycle time, the recoiling force values are linear dependent with gas pressure value. This is very helpful when simulating the handgun, because the barrel is not usually designed to carry out pressure measurements inside it. For this purpose there are special devices like EPVAT barrel or even barrels with special modifications. So that, measuring the recoiling force with an experimental device, it possible to find out the function form to be applied on simulated mechanisms. Local differences between recoiling force values and pressure values are due to weapon parts and mechanisms movements. These are receiving or transferring energy and their inertial behavior delay the transmitting of pressure effect in recoiling force.

4 Building the handgun model

For automatic cycling of a handgun, the following major parts and mechanisms are required:

- Barrel;
- Slide;
- Weapon body;
- Return spring
- Recoil system;
- Cartridge feeding system;
- Extraction mechanism;
- Ejection mechanism;
- Feed mechanism;
- Trigger mechanism;
- Firing mechanism

After building the model, as shown in Fig.10 and Fig.11, it must be refined by successive operations, in order to fit the real behavior of the handgun in experimental work.

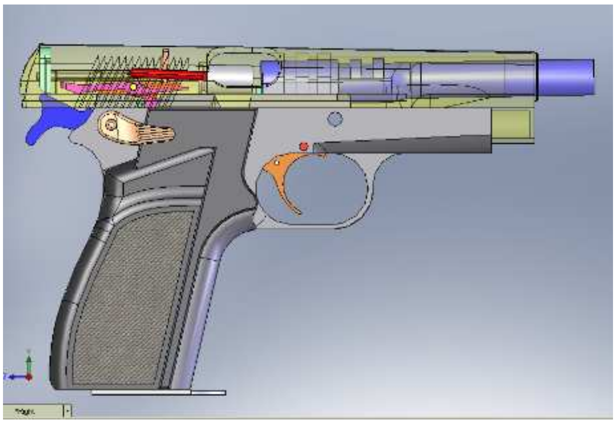

Fig.10 The handgun model

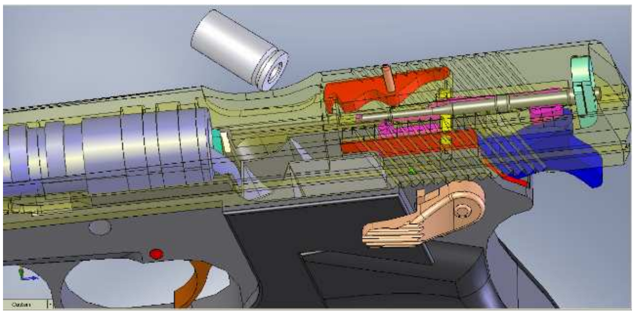

Fig.11 The cartridge case ejection moment

In this process is helpful to create design variables, for a better analyze in critical points or critical functioning moments.

the better the model is, the more hypothesis used in theoretical study are to be eliminated. This lead to a great similitude between the real dynamic behavior and the simulated one, which is the purpose of our work. As an example, a theoretical analyze of how the friction force in mechanisms is presented by short. As in 2.1, the friction forces between the slide and the weapon's body are ignored in theoretical dynamic study due their small values. By the other hand, when fire environment is not clean, an improper functioning could arise right due to an increasing of friction forces values.

In forward movement, there is no more gas pressure inside barrel, so that the elastic force of return spring becomes motor force. By an analyze of mechanisms movement, can be observed that the recoil force has two components: an elastic one, gave by the elastic spring force and variable one, as in equation bellow:

$$F_{re} = K_e x \text{ and } F_{rf} = -sign(\dot{x})\left|F_{rf}(x,\dot{x})\right| \quad (11)$$

Thus, two observations can be done:

- The minimum value of recoil force during rearward period is lower limited by the elastic force of return spring;
- The maximum value of recoil force for forward period is upper limited by the elastic force of return spring.

These conclusions have a major practical importance because they allow the separation by calculus of elastic component in recoil force from the friction component. The friction component is important when study handgun dynamic behavior during fire, because it points out the effort done in different moments of functional cycle.

$$F_{rf} = F_r - F_{re} = F_r - K_e x. \quad (12)$$

The $F_{rf}(x)$ diagram is typical for each weapon – ammunition system. The most important requirement for this diagram is to be recurrent, no matter firing conditions. If this condition is fulfilled, the weapon – ammunition system is not subjected to firing incidents.

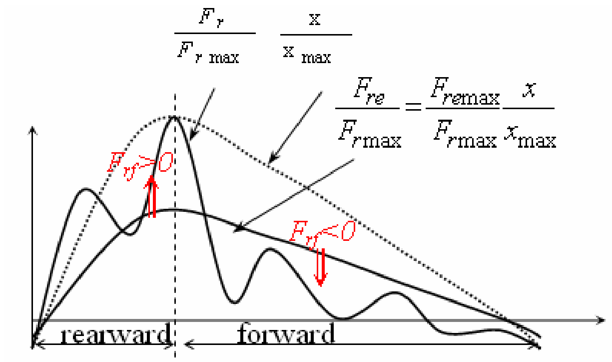

Fig.12 The measured values normalized as function of time

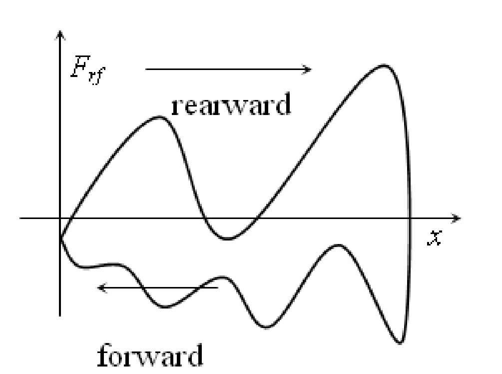

Fig.13 Typical diagram of friction force

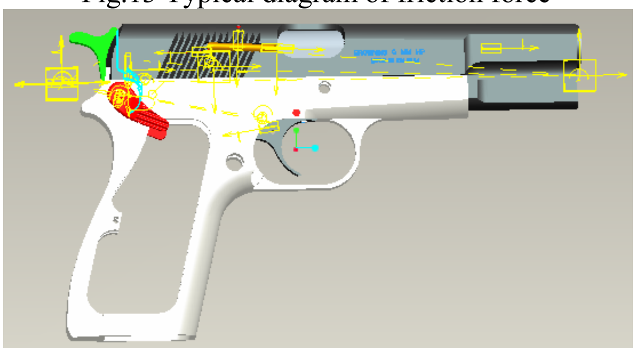
Fig.14 Handgun assembly with kinematic joints

4 Conclusions

Very accurate design and a very good organizing of joints system are determinant in the quality of simulation. Also, a lot of experimental work must be done to carry out the parameters which are involved in the simulated model.

Even if, once build the model works, dangerous conditions which are just simulated should never be applied deliberately in practice. High temperature gradients, higher loading density or other abnormal shooting conditions could lead to serious damages and injuries to the personnel.

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