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KINEMATICS AND DYNAMICS OF GATLING WEAPONS

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A b s t r a c t :

The paper deal with basic kinematic and dynamic characteristics of Gatling weapons. This contribution is ongoing of topics published in [2]. Input values from technical experiments are used for calculations. Design results are compared with measured on the 12.7 mm machine gun 9-A-624.

1. Introduction

Nowadays when small arms with external drive are used their detailed analysis is very important. The aim of this paper is to show possibilities of Gatling weapon solution with an optional drive.

In the Czech Republic there are not suitable dynamic model simulating the behaviour of a weapon with external drive. We have only an action statement of an individual period certain weapons. The doctoral thesis [10] dealt with modelling the Gatling weapon with electric drive.

The weapon basic arrangement is shown in Figure 1. The weapon has got electric drive and breeches for every barrel are in phase shifted positions. Barrels are connected into a barrel group. The barrel group is created by given number of barrels connected by sleeve pieces into one assembly. In Fig. 2 there is the scheme example of four barrel weapon which was used for our analysis.

Individual breeches are meshing by a guiding roller with a fixed functional curve. During one revolution of the barrel group every breech makes distance forward and backward. Barrel number is from three to seven. A attainable rate of fire depends on barrel number and is

$$k_{\mathrm{G}} = \left(1 \div 2\right) i_{\mathrm{B}} k_{\mathrm{CLAS}}\,, \tag{1}$$

where i_{B} – barrel number,

k_{CLAS} – rate of fire for weapon with classical functional cycle (for weapon using same cartridge).

Let us note the maximal breech displacement is a little shorter than for a small arm with classical functional cycle. It is given above all that breech movement is determined by the functional curve and during cartridge feeding the breech does not move and a breech rebound does not denounce in the front position. The increasing of breech displacement is not necessary as at conventional small arms.

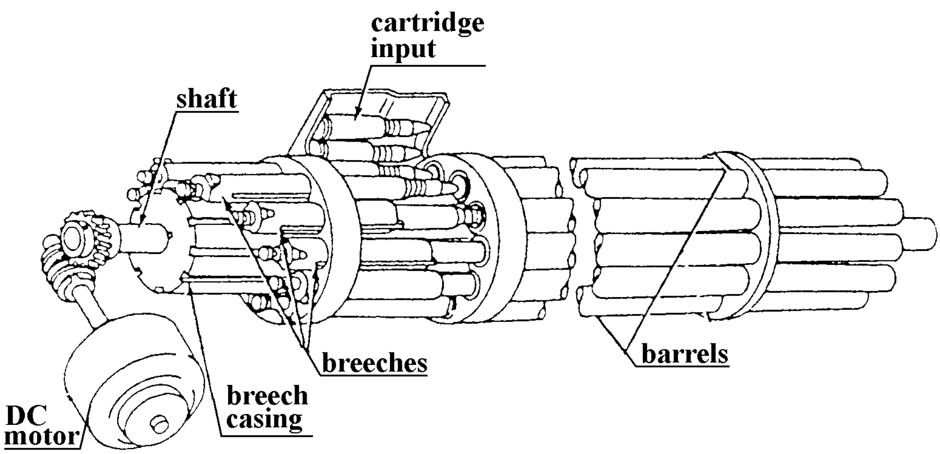

Fig. 1 Gatling weapon arrangement

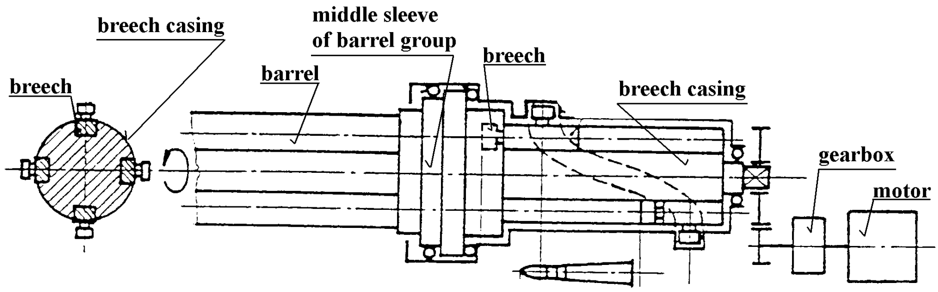

Fig. 2 Four barrel weapon arrangement

2. Kinematic and dynamic analysis of Gatling weapon

In [9] there is a procedure of Gatling weapon calculation roughly designate with the basic analysis of kinematics and dynamics. The influence of the cartridge feeding on an operation is not discussed. Altered angular acceleration of the system is not considered and the level of the modelling is corresponding to ways and means of the sixtieth.

In the research report [14] there is solved a start up of the Gatling weapon VKP – G3A with 23mm calibre by an actuation of a spring starting torque and the gas operation follows.

Weapon acceleration is solved by the FORTRAN language procedure until the barrel group angle 540°.

From the eighties the research works were not published in the area of the Gatling principle weapons. Not before in the thesis [10] context some results were presented, see references at the end of this paper.

The presented dynamic model permits detailed operation analysis of the Gatling weapon particular parts. Geometric and mechanical parameters can be modified for the purpose of their influence assessment on final weapon behaviour. These parameters are dimensions, mass, inertia mass moments etc of individual parts. External drive is defined by torque-speed characteristics.

With respect to weapon design we have chosen the angular displacement of the barrel group as the independent variable instead of the time. It was given in consideration of adaption simplicity of the weapon geometry. The chosen solution is suitable because all operations are running on direct dependence of the barrel group angle as well. Then results were converted from angular displacement domain into the time domain.

This procedure is different regarding modelling of the weapon operation with the time argument, see [3], [9], [13] or [14].

For an initial model checkout was used an auxiliary model of a single-barrelled weapon. The barrel group contains only one barrel and the related breech. The weapon casing remains no change.

All barrels and breeches are regularly distributed around of a barrel group axis and their functions are only phase shifted. This dynamic model is possible to apply on a given number of the barrel in the barrel group. During modelling one barrel group revolution was divided on elements with constant length

$$\Delta j = 2\pi/n,$$

where n – number of path legs 2π.

The number of path legs depends on required calculation accuracy. The procedure divides one revolution onto 4 000 elementary sections, then $\Delta j = 1.5707.10^{-3}$ rad. The input data were determined in the 400 sections. During calculations data were considered constant for the given section.

The breech motion was divided into the following sections, see Fig. 3.

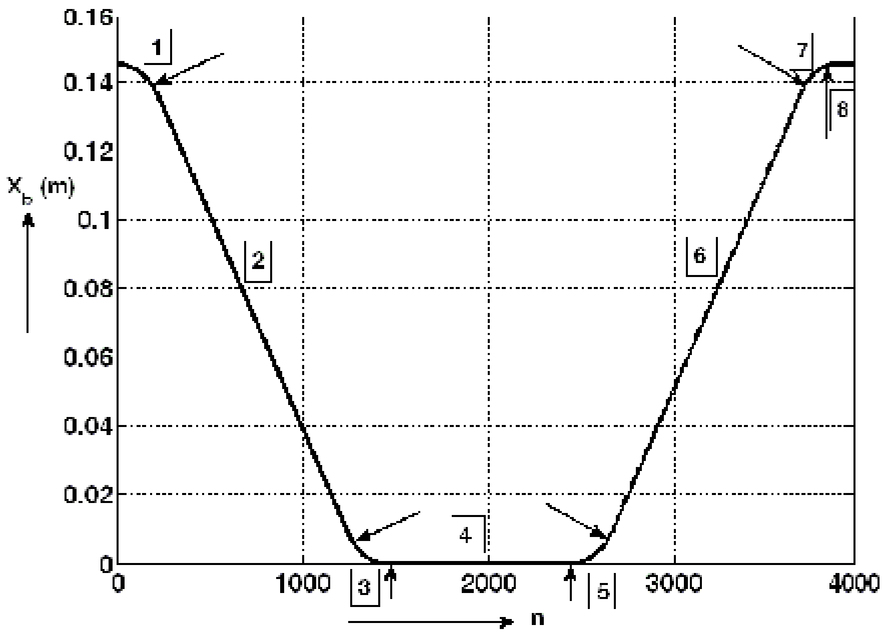

Fig. 3 Sections of breech displacement

Section 1– forward breech acceleration from rear position,

Section 2 – forward breech uniform motion (cartridge ramming),

Section 3 – breech deceleration before the front position,

Section 4 – breech in the front position (locking, shot, unlocking),

Section 5 – backward breech acceleration from front position,

Section 6 – backward breech uniform motion (case extraction, ejection),

Section 7 – breech deceleration before the rear position,

Section 8 – breech in the rear position (cartridge feeding).

Input data are given as the EXCEL table defining courses individual functioning of the breech during one revolution of the barrel group. Ramming force, moments for breech locking and unlocking, case extraction, etc are included as well.

The motion equation is written for a reduction of masses onto the barrel group, see [10]:

$$I_{\mathrm{BG}}\ddot{\varphi}_{\mathrm{BG}} = M_{\mathrm{T}} - M_{\mathrm{FEED}} - M_{\mathrm{D}} - M_{\mathrm{KIN}} - M_{\mathrm{I}} - M_{\mathrm{EX}} - M_{\mathrm{UL}}, \qquad (2)$$

where:

I_{BG} - inertia mass moment of system [kg.m^2],

$\ddot{\varphi}_{\mathrm{BG}}$ - angular acceleration of the barrel group [rad.s^{-2}],

M_{T} - torque of drive [N.m],

M_{FEED} - feeding moment [N.m],

M_{D} - damping moment [N.m],

M_{I} - iniciation moment [N.m],

M_{EX} - case (or misfire cartridge) extraction and ejection moment [N.m],

M_{UL} - unlocking and locking moment [N.m],

M_{KIN} - breech kinematic moment [N.m].

The permanent magnet DC motor ATAS P2ZX527 was connected via the MTC22 gearbox (transmission ratio 10) with the barrel group. The motor power is 1.1 kW, maximal revolution 2800 /min.

The drive characteristics is described by the relation

$$M_{\mathrm{T}} = 170 - 0.436w$$

and is depending on the supply voltage.

Torque drive of the barrel group is given by the characteristics on the Fig. 4.

The feeding moment M_{FEED} depends on a cartridge husking force from the belt at best. In the thesis [10] there were determined the course of this force.

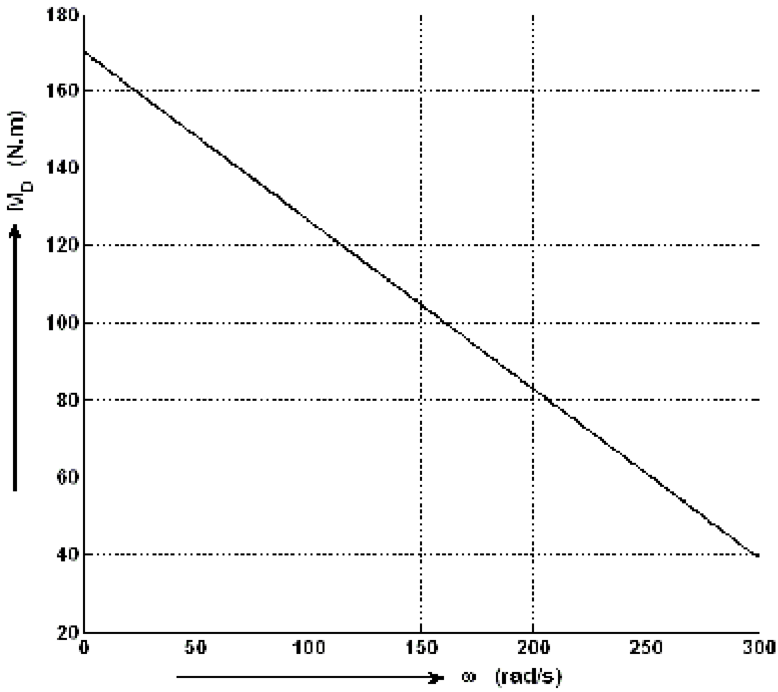

Fig. 4 Characteristics of drive

After the Rudnev formula incorporation the final feeding moment (during 1/4 of revolution of the barrel group) with respect to the barrel group was approximated by the curve from Fig. 5.

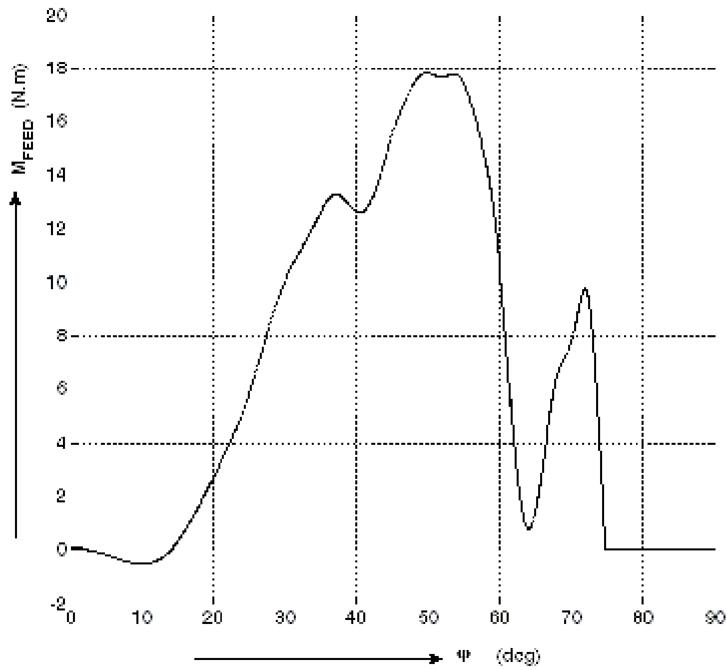

Fig. 5 Feeding moment

Unlocking and locking moment M_{UL} acts during the breech unlocking when the clearance takes up in the course of the breech angular displacement. After the shot the breech angular displacement comes again and the friction forces between the breech head and the cartridge base are overcame including the friction in the lucking lugs. This moment is given as constant value on the angular displacement Δj . The unlocking moment is set similarly. The moment M_{UL} is determined as the mean value in the interval Δj . New cartridges (real state) have this moment in the range from 28Nm until 56Nm as it is published in [10]. The influence of the cartridge ramming during the breech locking is an argument for twice increase of the moment M_{UL} in consideration of the breech unlocking.

The initiation moment M_I is included by the energy E_I necessary for the primer initiation. After the primer initiation the barrel group angular velocity decreases to the value w_E :

$$w_E = \sqrt{\left({w_B}^2 - 2\frac{E_I}{I_{BG}} \right)}, \tag{3}$$

where w_B - barrel group angular velocity before initiation.

The damping moment M_{D} contains all resistances against the barrel group rotation without cartridges and breeches. The approaching values of this moment were determined - equation (4) - by the way measuring of the 12.7mm 9–A–624 machine gun, see [10] and Fig. 6:

$$M_{\mathrm{D}} = 0.0004w^2 - 0.005w + 1.266 \tag{4}$$

It is necessary to note that the mentioned course is applicable for the given velocities range and an eventual approximation will have to interpret carefully.

The extraction and ejection moment M_{EX} were determined by the energy way as the moment M_{I}. In the thesis [10] there were developed a formula for the extraction velocity calculation and the moment M_{EX}, whose value depends on the friction factor between the case and the ejection surface and between the case and an edge of an ejection window.

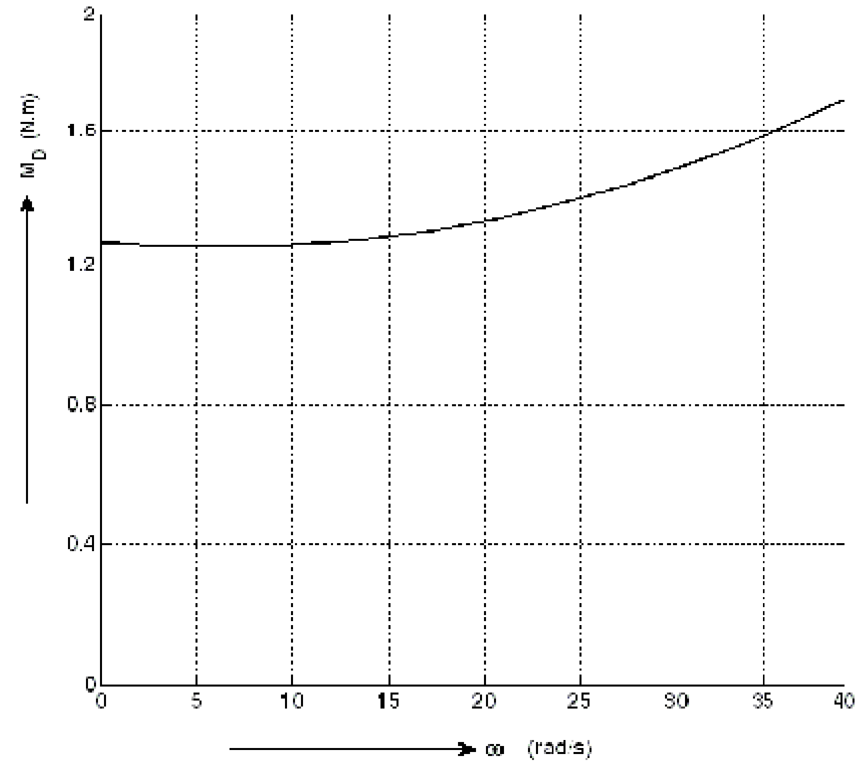

Fig. 6 Damping moment

The ejection comes within 0.05rad the rotation of the barrel group. The calculated moment M_{EX} (points) and its polynomial approximation 4[th] order are described by the following equation

$$M_{EX} = 43.97747553 j^{0} + 763.37688564 j^{1} + 10047.67291430 j^{2} + \\ + 11359.02204572 j^{3} + 1653720.98428524 j^{4} \quad . \tag{5}$$

The course of this moment is shown in the Fig. 7. The extraction energy is approx 3 J but the power is 1830 W regarding the very short extraction and ejection time, see [10].

Cartridge case (or cartridge) ejection is the same as for conventional rotating bolt breeches. The acceleration of the breech block in Gatling weapons during extraction is much lower than in conventional weapons so that the stresses in the extractor and the cartridge case are also lower.

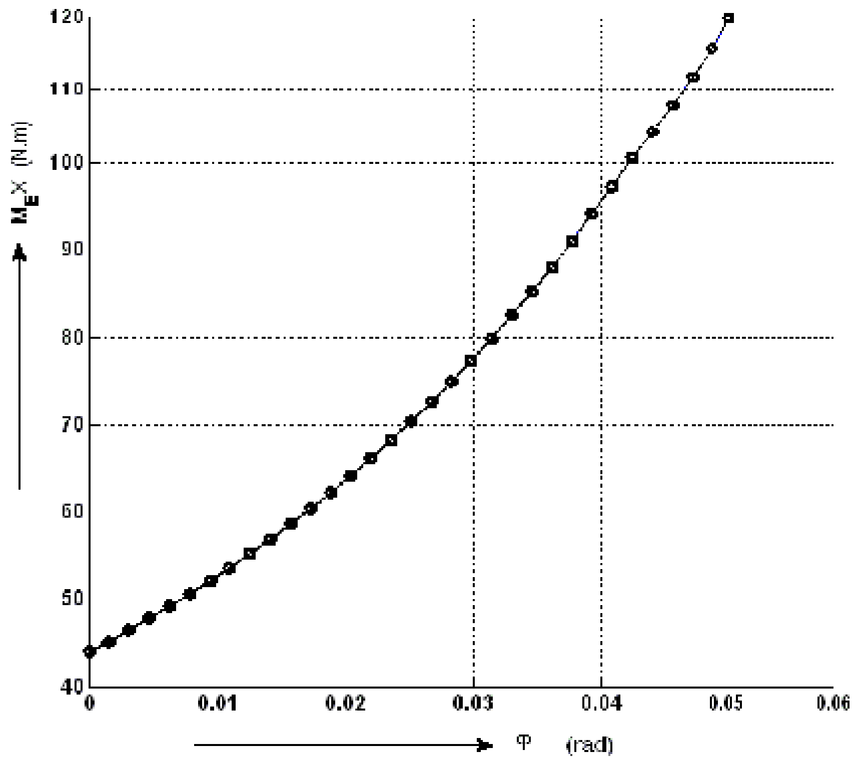

Fig. 7 Extraction and ejection moment

3. Results

The model verification was realized on the 12.7mm 9A-624 machine gun with the electric drive [4]. The detailed descriptions of the technical experiments were introduced in the publications for example [4], [10]. The computer program in the Microsoft Excel has 162 Mb, see [10].

The equation (2) was solved in the table form by way that the known values were the acceleration e . The new angular velocity w and the time stroke Δt were calculated via formulas with Δj step

$$w = \sqrt{w_0^{\,2} + 2e\Delta j} \tag{5}$$

and

$$\Delta t = \frac{-w_0 \pm \sqrt{w_0^{\,2} + 2e\Delta j}}{e}, \tag{6}$$

where w_0 - angular velocity in previous step,
e - angular acceleration in computed step.

In the Fig. 8 there are presented the barrel group angular velocities. The suffix M means measured values and suffix C calculated values. Apart from the initial level the course match is visual. The different is given using of an incremental gauge and in reference to input data precision. This comparison is published for the first time in known sources.

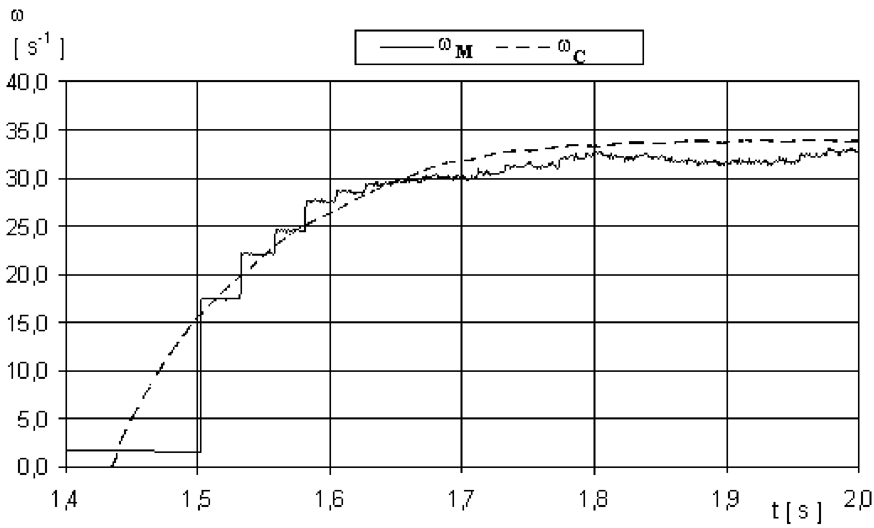

Fig. 8 Calculated and measured angular velocities

The kinematic values – displacement (x_b), velocity (v_b) and acceleration (a_b) – of all breeches versus time are drawn in the Fig. 9. The breeches courses correspond to barrel group rotation until three revolutions, it means 1080°. In the graph there is apparent successive growth of the velocities and accelerations which becomes evident shortening of the functional time then a rate of fire rises.

The Gatling weapons velocities and mainly accelerations are several times lower than for weapons with classical systems (gas operated, recoil and blowback). For example the velocity of this investigated system is four rimes lower than gas operated machine gun NSV or M2HB for the same rate of fire and same cartridges.

The nominal rate of fire was achieved at voltage supply 24 V during 0.25 s. It corresponds to three shots simulation. During voltage supply 32 V the obtained rate of fire was 1400 rds/min after 0.3 s. The maximal rate of fire 4000 rds/min can be reach using of the drive with the maximal power approx. 5.7 kW, see [10].

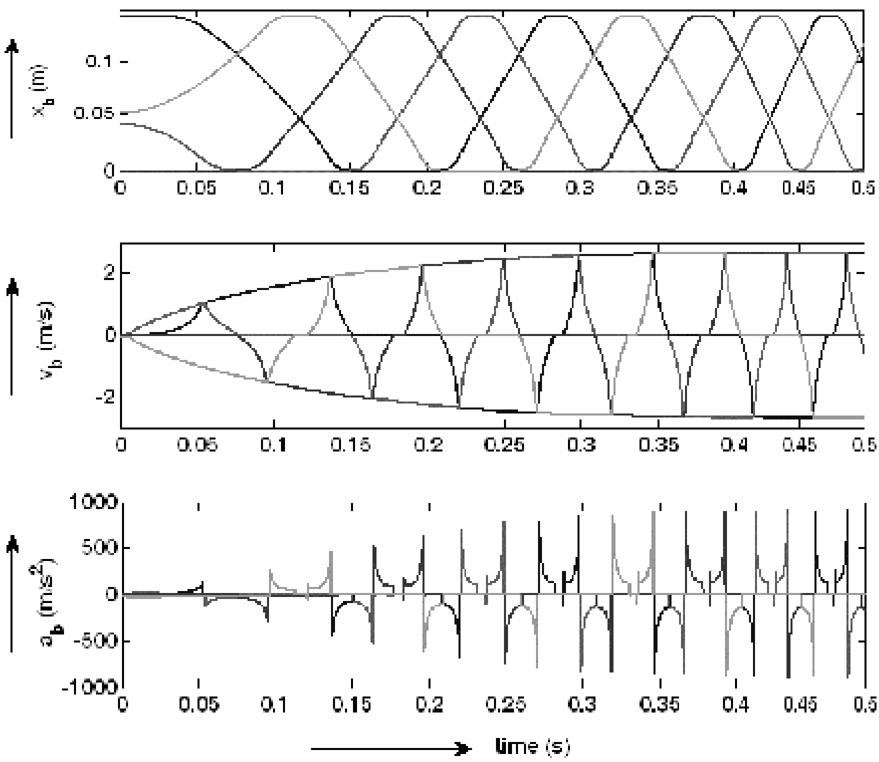

Fig. 9 Breeches kinematic characteristics

Other calculations have shown, see [10], the selected drive enables during tests short time mechanical and electrical overload. During supply voltage 32 V was attained rate of fire 1452 - 1489 rds/min with 0.3 s acceleration time.

4. Conclusions

The mathematical model published in [10] came true.

The dominant influence on torque peaks were found during cartridge ramming, locking and unlocking of the breech.

The energy intensiveness has shown to be evident for achievement of an acceptable acceleration time not only for a burst shooting during one barrel group revolution.

The new weapon design or some reconstruction have to make provision for the form and external drive characteristics with focusing on the torque course during one barrel group revolution. A weapon optimalization with the drive brings to drooping of energy consumption and a mass system saving.

We recommend other continuation of the studies in two areas.

In the theoretical area:
- to develop dynamic models of Gatling weapon locking assembly,
- to work out new feeding device models (for example conveyer brand).

In the experimental area:

- to consider a possibility to use hydraulic or pneumatic drives.

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