MILITARY TECHNICAL COLLEGE

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ANALYSIS OF BARREL VIBRATION DURING FIRE

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ABSTRACT

The study of barrel vibration is important for the performance of firing weapons .In this paper the finite element method is used for modelling the barrel and determining its characteristics .A complete analysis of the course of affecting forces on barrel during the whole period of action is carried out for defining them.The calculation procedure is programed for easy analysis of barrel response. The influence of barrel vibration on successive uency analysis of the recorded details is carried out.The comparison between muzzle trajectory at different modes of fire. A real time analysis and a freq- frequency analysis of the recorded d tails carried out.The comparison between both theoretical and experimental results proved the accuracy of the proposed model .

1-INTRODUCTION

The barrel is the most important weapon component ,it gives the projectile required velocity direction and stabilization .Most available references discuss the barrel design as a thick-walled cylinder stressed by the internal pressure of powder gases neglecting the effect of vibration on barrel design. On the other hand, barrel vibrations largely affect the hitting accuracy of a weapon.

The problem of barrel vibrations has been discussed in its general case

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facilitating its application to any type of small arm and gun barrels under its own boundary conditions .For this reason, the one-sided clamped barrel using hand held Automatic Rifle 7,62 x 39 mm A K M is used to verify the agreement between theoretical and experimental results .

2-FORCES ACTING ON BARREL

Generally, the barrel affected by many forces which cause its vibrations. These forces vary in thier amplitudes,directions and points of application . according to the type of weapon .All these forces can be summarized in the following items :

a) Forces due to Resistance to Projectile Motion :

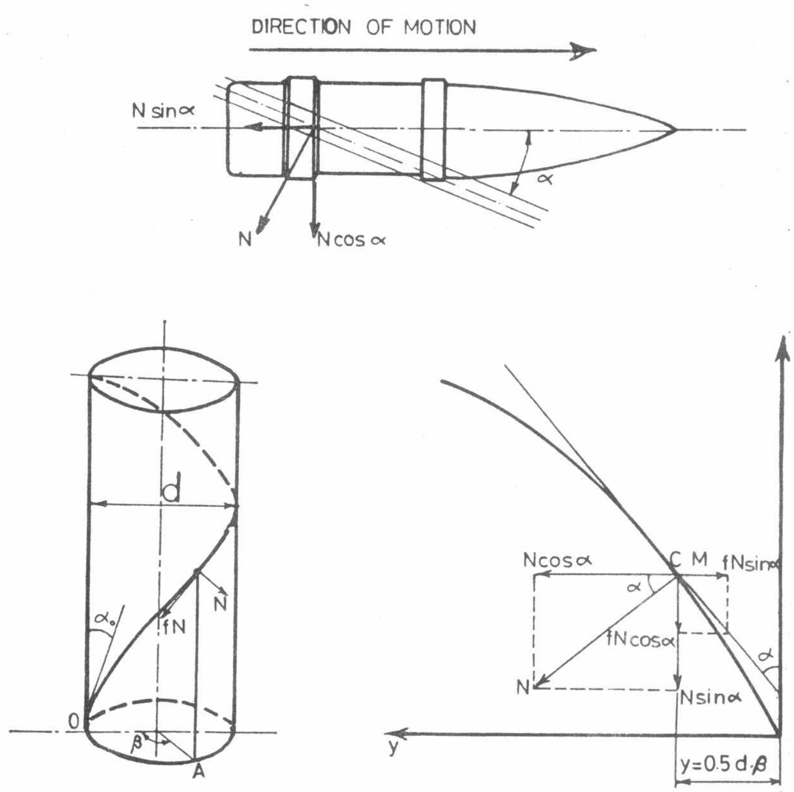

Figure (1)Components of resisting force to projectile motion

From figure (1) we can conclude that the resistance to projectile motion inside the barrel bore affect the barrel by an axial force (F_a)and torsional moment (M_t)according to the following relations :

$$F_a = n \frac{A\,(\sin\alpha + f\,\cos\alpha)}{B\cdot(1 + Bl)} P_B \qquad (1)$$

$$M_t = n \frac{A(\cos\alpha + f\,\sin\alpha)}{B\cdot(1 + Bl)} P_B \qquad (2)$$

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where

$$A = \left(\frac{2\rho}{d}\right)^2 . \tan\alpha$$

$$B = n.(\cos\alpha - f\sin\alpha) - W_{db}\sin\alpha . \frac{d}{2}$$

$$B1 = n.(\sin\alpha + f\cos\alpha) + W_{db}\cos\alpha . d/2$$

b) Forces Due to Projectile Unbalance :

Inaccuracy of ammunition production causes its rocking motion inside the barrel .This motion affects the barrel with a force perpendicular to barrel axis (C_{f1}) and bending moment (M_{b1}) where their values and directions vary with the projectile revolution and its position inside the barrel according to the follwing relations :

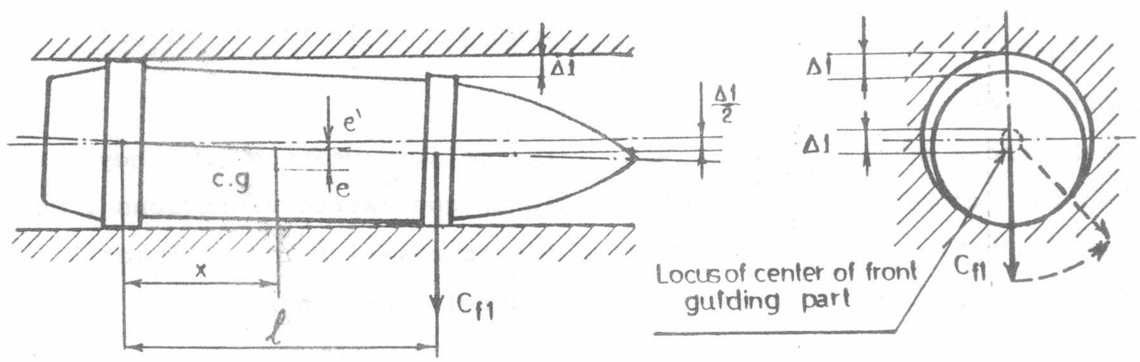


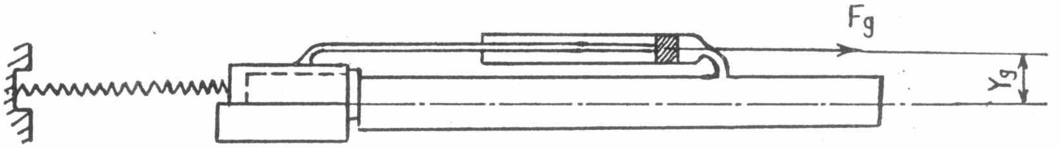
Figure (2) Scheme of acting forces on projectile due to its rocking motion inside the barrel.

$$C_{f1} = M.(e + \frac{x}{l}.\frac{\Delta l}{2}).\left(\frac{2\,v_x\,.\tan\alpha}{d}\right)^2 \qquad (3)$$

$$M_{b1} = C_{f1} . X_{tr} \qquad (4)$$

c) Force due to Gas Branching :

Specially, with automatic small arms, the gases used to complete the automatic function of the weapon act on the barrel by an axial force (F_g) and bending moment (M_{b2}) their values vary with the variation of pressure inside the gas unit chamber but their point of application is always the same as shown in figure (3):



Figure(3)Closed type gas unit

$$F_g = P_k \cdot S_p \qquad (5)$$

$$M_{b2} = F_g \cdot y_g \qquad (6)$$

d)Forces due to Existence of Muzzle Device :

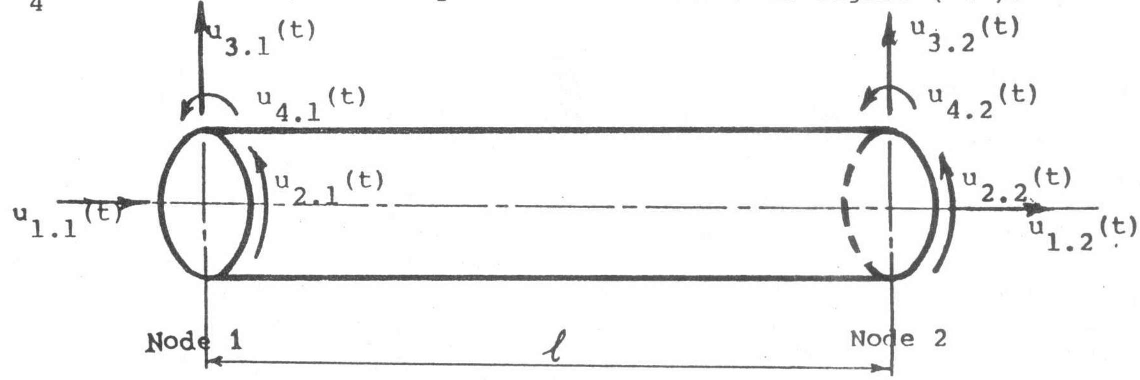
Existence of any muzzle device attached to the barrel muzzle influences the conditions of discharge from barrel . The study of gas process in the muzzle device and its modelization is a complex problem which must be treated separately In this paper such forces are neglected to simplify the problem .

e)Body Forces :

Such forces appear clearly with large calibre weapons ,so they must be taken into consideration when dealing with gun barrel vibrations . But in small arm barrel they may be neglected due to relative low effect compared with the other forces affecting barrel vibrations .

3-MATHEMATICAL MODEL

In this work , finite element technique is used to construct the mathematical model for the barrel . In order to represent the vibrations in the shape of barrel and its boundary conditions the element taken has a cylinderical tubular form possessing four degrees of freedom per node such as $u_1(t)$ for axial displacement ; $u_2(t)$ for torsional displacement and $u_3(t)$, $u_4(t)$ for lateral displacements as shown in figure (4):



Figure(4)One dimensional element .

6 In this work the barrel of Automatic Rifle 7,62 X 39 mm AKM has been divided to four elments according to variation in barrel shape or boundary conditions as shown in figure (5) :

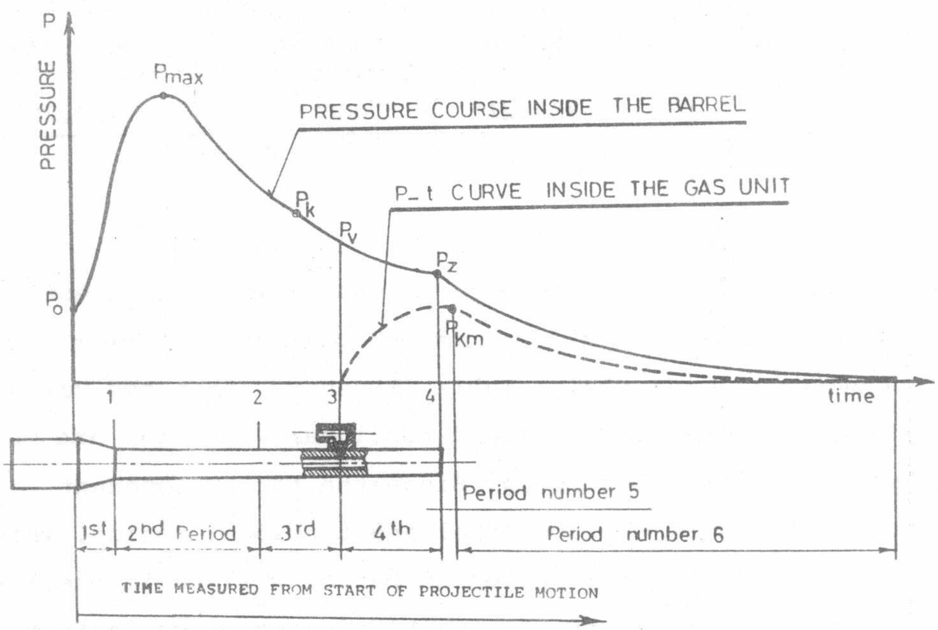


Figure (5) Periods of calculations (During forces action).

Assuming constant mass per unit length and uniform stiffness ,the mass and stiffness matrices per element [7] are known.Comparison of the theoretical results obtained by using the consistent mass matrix with the experimental results show that the diagonal mass matrix gives more accurate results with high rate of convergence .Afterward ,the global matrices representing the mass and stiffness matrices for the whole barrel are formed according to the boundary conditions. Since all elements have the same direction,there is no coupling between the axial ,torsion and bending modes.So,we are able to study each case separately. Substituting the obtained matrices in the free undamped equation of motion in the form :

$$[M]\{\ddot{x}\} + [K]\{x\} = \{0\} \qquad (7)$$

Then , by solving the characteristic equation by sweeping iteration technique the natural frequencies and corresponding mode shapes in each case are obtained .A well prepared computer program is constructed for this purpose.The natural frequencies of the system are obtained as in the following table :

case \ mode no.	1	2	3	4
Axial (Hz)	2531.986	7033.860	12285.632	15273.607
Torsion (Hz)	1837.739	4714.181	7914.691	9657.993
Bending (Hz)	76.61	364.215	1006.829	1492.707

Table (1)

The natural frequencies are calculated to ensure that the theoretical model represents the actual barrel by comparing them with the natural frequencies obtained experimentaly .Table (1) show that the values of the natural frequencies due to axial and torsional vibration are very high compared with those due to bending, Since the force component causing bending is larger than that causing axial and torsional motion. Therefore we can conclude that the main vibration of barrel will be in the lateral direction,presenting the most important vibration component affecting the accuracy of fire which is the main spot of this work .

The force vector is constructed according to the studied type of barrel and is substituted in the general form of the differential equation of motion of the system :

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \{f\} \qquad (8)$$

Since the force has a general form, we use Wilson-Teta method [5] for solving the system response which is given by :

$$\left[\frac{6M}{\Delta t^2} + \frac{3C}{\Delta t} + K\right]\{x(t)\} = \{F(t)\} + [M]\{A_2(t)\} + [C]\{A_1(t)\} \qquad (9)$$

where

$$A_1(t) = \frac{3}{\Delta t}\cdot x(t-\Delta t) + 2\dot{x}(t-\Delta t) + \frac{\Delta t}{2}\ddot{x}(t-\Delta t)$$

$$A_2(t) = \frac{6}{\Delta t^2}\cdot x(t-\Delta t) + \frac{6}{\Delta t}\dot{x}(t-\Delta t) + 2\ddot{x}(t-\Delta t)$$

Taking the initial conditions $\{x\}_0 = \{\dot{x}\}_0 = \{\ddot{x}\}_0 = \{0\}$,a computer program is prepared for solving equation (9) .

we use an Aut.Rifle 7,62 x 39 mm AKM to find the response of the barrel due to fire in case of lateral vibration . This response is shown in the

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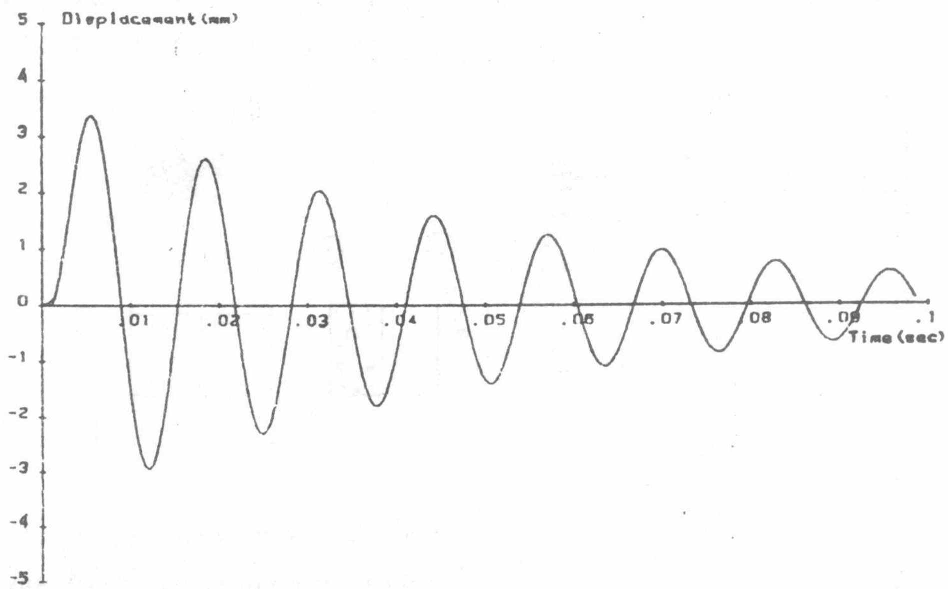
following figure :



Figure(6)Response of barrel due to its acting forces

Theoretical results determining barrel response due to fire present the maximum displacement of muzzle point (3 : 3,4 mm) while the the same point is deflected by about 1 mm at the moment of initiation of the second shot when firing in bursts .

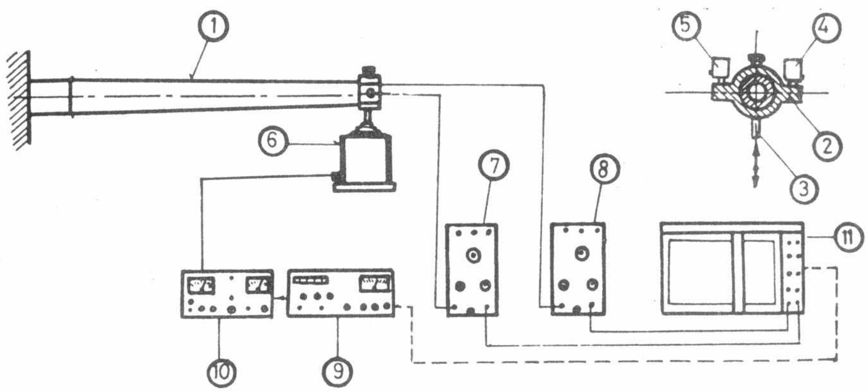
4-EXPERIMENTAL WORK

A special designed set-up is constructed to detect barrel vibrations . For safety requirements ;all measurements have been taken inside a closed shooting range using hand-held automatic rifle 7,62 x 39 mm AKM . The system of barrel fixation secures for the fixed end :

- -No displacements in axial,torsional and lateral directions .
- -Firing in individual shots and bursts .
- -Accelerometers are fixed in two perpendicular directions in one plane to detect lateral vibrations of muzzle point .

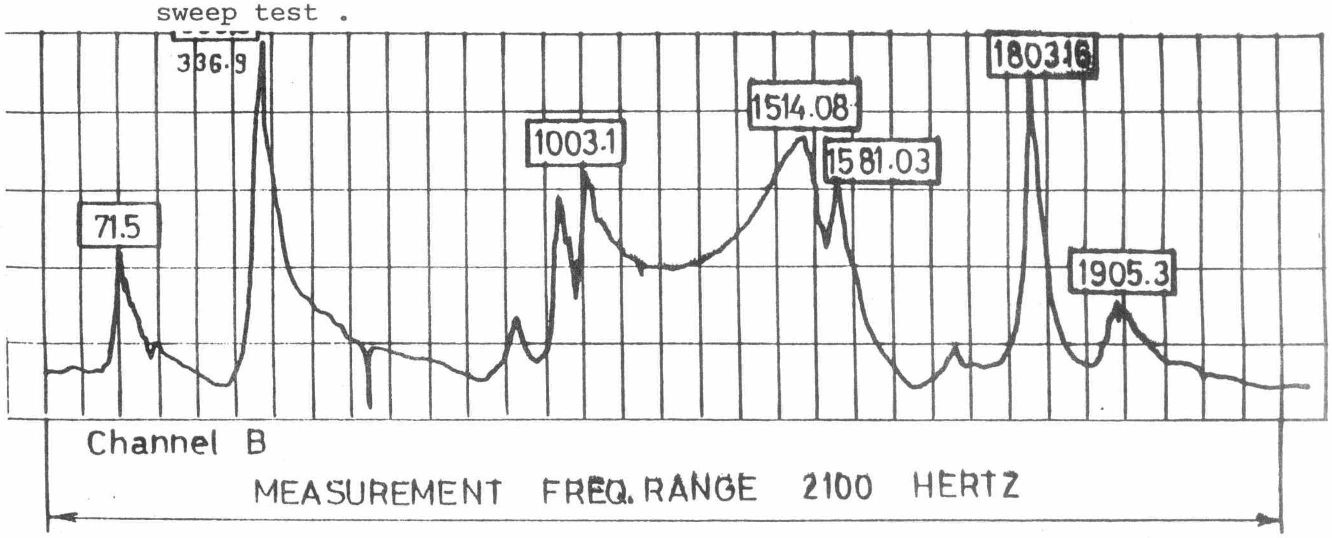
a)Free Vibration measurements :

An accelerometer has been fixed on a special manufactured muzzle nut such that its axis is eccentric to barrel axis in order to permit the detection of torsional and bending displacements.Then,making a frequency sweep test ,frequencies in case of axial and lateral vibrations are obtained.The block diagram of used apparatus and result are shown in figs (7 , 8) :



1-Fixed free test barrel
2-Special manufactured muzzle nut
3-Pushing rod
4-Accelerometer(type 4370 B&K)
5-Impedance head(type 8001 B&K)
6-vibration exciter .
7,8-Ch.amplifiers(2635 B&K)
9-exciter control(type 1047 B&K)
10-Power amplifier(2707 B&K)
11-Two chann.X-Y recorder(2308 B&K)

Figure(7)Block diagram used for measurements of free response by frequency sweep test .



Figure(8)Results of frequency sweeping test

The obtained frequencies for lateral and torsional vibrations shown in figure(8)give six readings related to lateral vibrations and only one due to torsional vibration which appear at(1803.16 Hz).This record reveals the importance of study of lateral vibrations at low frequencies (0 up to 2000 Hz) which are accompanied by high displacements affecting the accuracy of target hitting.Also,the displacement at each node is measured for each natural frequency to identify the mode shape .

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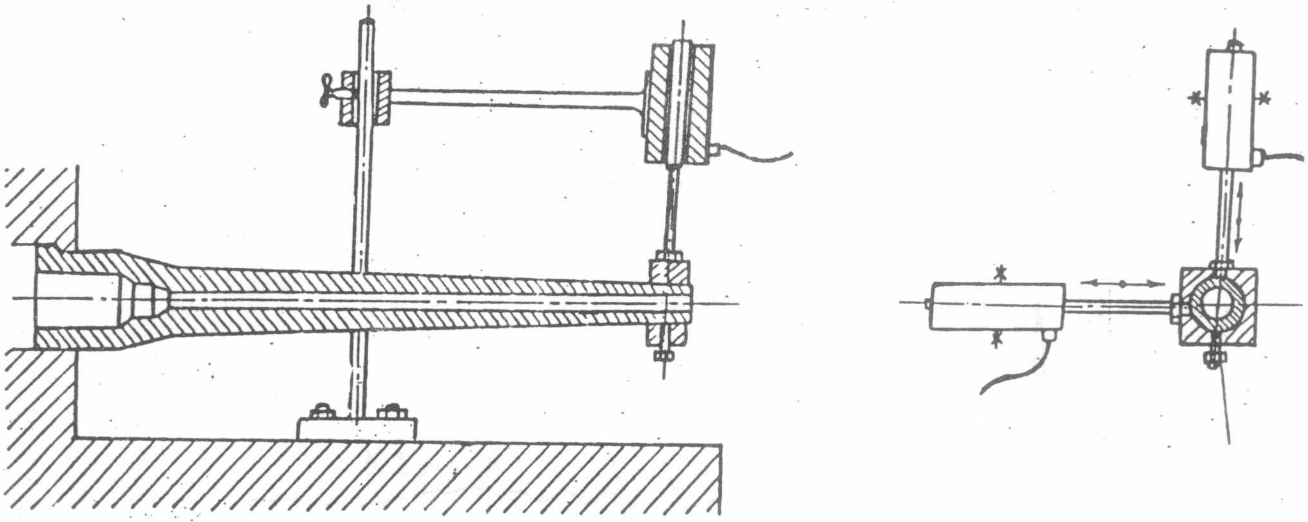
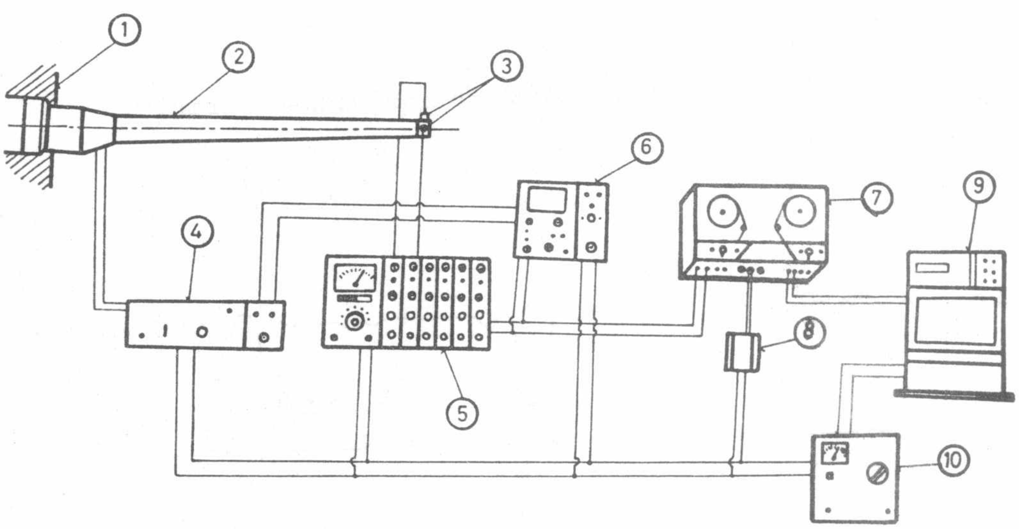
b)Forced Vibration measurements :

we use inductive displacement pick-ups which after calibration are maintained to measure barrel response for vertical and horizontal lateral displacements.Installation of detecting elements and measurement circuit diagram are shown in figs (9 , 10) respectively :



Figure(9)Installation of barrel and sensing elements(Ind.disp.pick-ups)



1-System of barrel fixation
2-Test weapon Aut.Rifle 7,62x39 mm AKM
3-Inductive displacement pick-ups(type Hottinger Balldwin Mestechnik.)
4-Aut.firing unit(211 c Drello)
5-Multi-channel amplifier(H.B.M.KWS/6T)
6-Tow channel st.oscill.
7-4 channel tape recorder(7003 B&K)
8-Tape rec.power supply
9-Dual Channel analyser(type 2032 B&K)
10-Mains;stab.power supply .

Figure(10)Block diagram for forced vibrations measurements and analysis .

Results of forced vibration measurements have been carried out during firing in single shots and bursts as shown in figure (11)and figure(12) respectively :

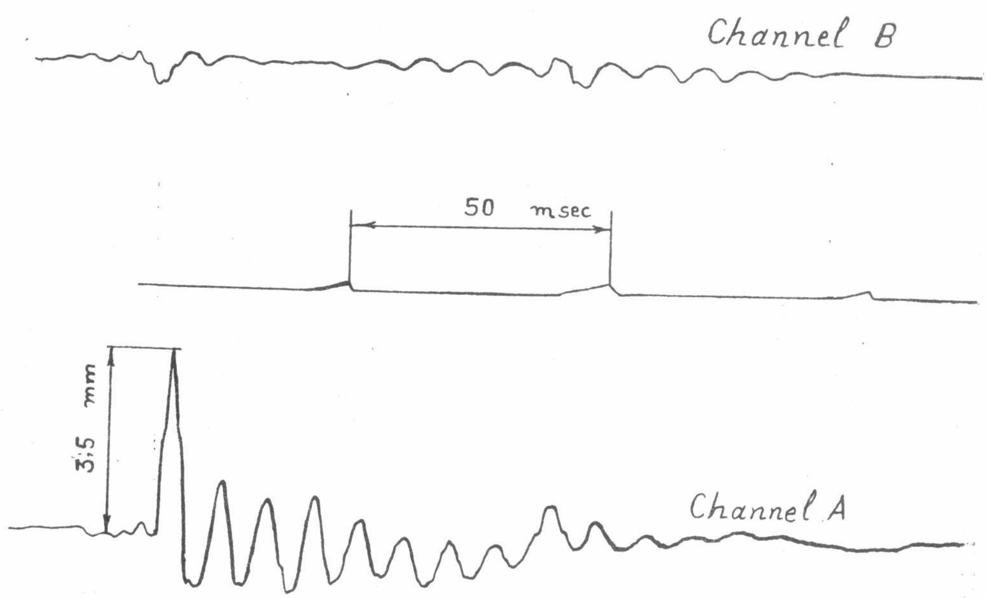
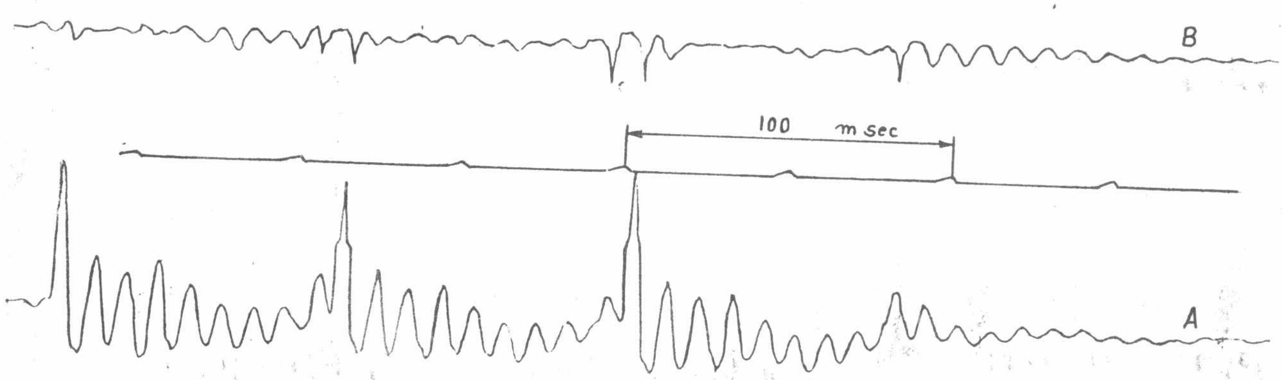


Figure (11)Barrel response due to individual firing .



Figure(12)Barrel response due to automatic firing (three contin.shots).
-Channel A presents lateral displacement of barrel in vertical direction .
-Channel B presents lateral displacement of barrel in horizontal direction .

Measurements of free and forced vibrations give the following important results :

-Damping coefficient of barrel material ξ =0.063

-Maximum lateral disp.of muzzle point =3,5 mm

While the theoretical results corresponding to these values are :

-Assumed damping coefficient ξ =0,0525

-Maximum lateral displacement of muzzle point=3,15 mm

This proves the accuracy of the constructed mathematical model .

5-DISCUSSION

Theoretical and experimental study of barrel vibration proves its great effect on muzzle displacements , consequently high effect on dispersion and accuracy of fire specially lateral one .On the other hand ,the study of barrel vibration leads to group of recommendations and guardianships for improving barrel design and accuracy of fire as :

-When studying the vibration of gun barrel elastic line must be considered .

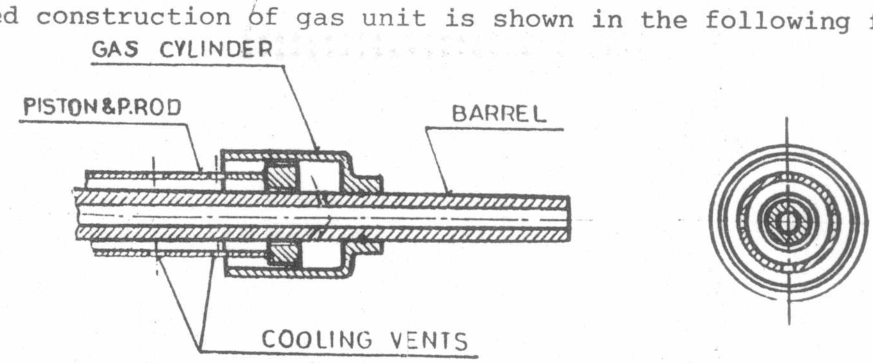
-When choosing barrel material ,we must take into consideration one which improves the rigidity of the barrel .

-Impacts of weapon components must be considered specially when dealing with the vibrations of small calibre automatic weapons .

-For automatic small arms , it is necessary to avoid successive impacts with frequency near to barrel natural one.Similarly,proper choice of the rate of fire is to be considered .

-For gas operated system weapons , gas unit design must avoid eccentric application of gas unit chamber pressure .

A suggested construction of gas unit is shown in the following figure :



Figure(13)Suggested construction of gas unit in gas operated sys.weapons.

NOMENCLATURE

d .... Calibre of barrel
e .... Eccentricity of projectile centre of gravity.
f .... Coefficient of friction between projectile and barrel bore.
n .... Number of riflighs.
P_B.... Pressure of gases behind the projectile base.
P_k.... Pressure of gases inside the gas unit chamber.
S_p.... Area of piston head.
v_x.... Instantaneous velocity of projectile at travelled distance (X_{tr}).
W_{bd} cos Resistance force due to driving band cutting.
α.... Angle of twist of rifling.
δ.... Damping constant of proportionality.
ρ.... Projectile radius of gyration.

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