Computation of In-bore Velocity-time and Travel-time profiles from Breech Pressure Measurements

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ABSTRACT

The paper describes breech pressure measurement and also discusses the computation of velocity-time and travel-time profiles in the barrel from the instantaneous breech pressure values. The computed value of velocity at the shot out instant is obtained as the muzzle velocity. A close correlation is observed between the muzzle velocities measured by a radar and those computed from pressure-time data by this method.

Keywords: Breech pressure measurement, gun propellant, breech pressure, gun system design, internal ballistics, gun

1. INTRODUCTION

Performance of a gun propellant is assessed by carrying out dynamic trials or actual gun firings. During these trials, two important parameters, viz., development of pressure in the barrel and velocity of shot at the muzzle are measured using electronic instrumentation. Copper crusher gauges or piezo-electric transducers are used to measure the pressure. The former can record only maximum pressure, whereas the latter provides pressure-time data, which gives a clearer picture of the burning of the propellant. The muzzle velocity is measured either using a radar or by putting two optical or wire screens in the path of the shot for measuring the time taken for travel between these screens.

Pressure-distance and velocity-time curves are important in gun system design. These curves show violation of maximum pressure limits of the gun system, if any, and the velocity buildup of the projectile up to the muzzle velocity. The prediction of relationships among pressure, velocity, and travel-time by computer simulations has been reported by Ludwig Stiefel[1]. The simulations were tried with ballistic data of representative small arms. A small arms ballistic simulation program, which takes charge weight, projectile weight, peak pressure, and expansion ratio as input and relates these to muzzle velocity, was used for this purpose. Zeitz[2] has generated pressure-travel profile from empirical data of small arms to generate velocity-time profile. In case of large caliber gun, velocity-time profile has been generated by a different program based on the lumped parameter model which is based on peak pressure and muzzle velocity as input.

2. THEORY

When the projectile gains velocity, a pressure gradient exists in the gun barrel due to hot gases, acceleration of unburnt propellant and fricton at

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the bore surface. The ratio of breech pressure to base pressure is a function of projectile velocity and is given by Kent[3]. If pressure at the projectile base causing the motion is known, then velocity-time profile of the projectile can be obtained by applying Newton's equation of motion. Kent's Eqn (1) has been used to compute the instantaneous base pressures from actually measured instantaneous breech pressure values. The relationship between P_{br} and P_b comes as hydrodynamic problem of the gun. The ratio of P_{br}/P_b derived by Kent is:

$$\frac{P_{br}}{P_b} = 1 + \frac{1}{2}\left(\frac{C}{W}\right) - \frac{1}{24\gamma}\left(\frac{C}{W}\right)^2 + \left(\frac{1}{80\gamma} + \frac{1}{360\gamma^2}\right)\left(\frac{C}{W}\right)^3 + \ldots. \qquad (1)$$

where C is the charge weight, W is the shot weight and y is the ratio of specific heats. The value of y is calculated from chemical composition of the propellant. A software for this calculation has been developed at the High Energy Materials Research Laboratory (HEMRL), Pune. The value of y for LOVA propellant is 1.2616 and for NQ/M propellant is 1.2508.

Applying these values to the instantaneous breech pressure values, instantaneous base pressure values are calculated. The base pressure values then lead to calculate the projectile velocity using the relation:

$$P_b . A = m.a \qquad (2)$$

Equation (2) on integration leads to the relation:

$$MV = \frac{A}{m} . \int_{t_{ss}}^{t_{so}} P_b . dt \qquad (3)$$

where m is the mass of the projectile, a is the acceleration of projectile, P_b is the base pressure of the projectile, A is the area of the base of the projectile, t_{so} is the shot out time, t_{ss} is the shot-start time, and MV is the muzzle velocity.

The integration of base pressure for different intervals of time, starting from t_{ss} gives instantaneous velocity of the shot in the barrel, and integration of base pressure up to t_{so} results in the muzzle velocity. The calculation of velocity needs consideration of force (or pressure) spent in engraving of driving band and overcoming the friction. A weight penalty[4] on the shot weight can be applied for this correction, giving the effective shot weight which comprises true shot weight plus resistance to the motion represented as additional weight.

The base pressure data, in turn, results in velocity-time profile in the bore up to shot out time or muzzle end. The final value of velocity in the velocity-time curve is the muzzle velocity.

3. BREECH PRESSURE MEASUREMENTS

HEMRL has developed piezoelectric transducers or cartridge case gauges for pressure measurements during gun trials. A tourmaline crystal is used for the pressure sensing. The sensitivity of the gauge is determined accurately prior to the measurements. A dead weight tester of 250 MPa maximum pressure is used for dynamic calibration of the gauge. A typical calibration curve is shown in Fig. 1. The accuracy of pressure measurements is better than 1 per cent.

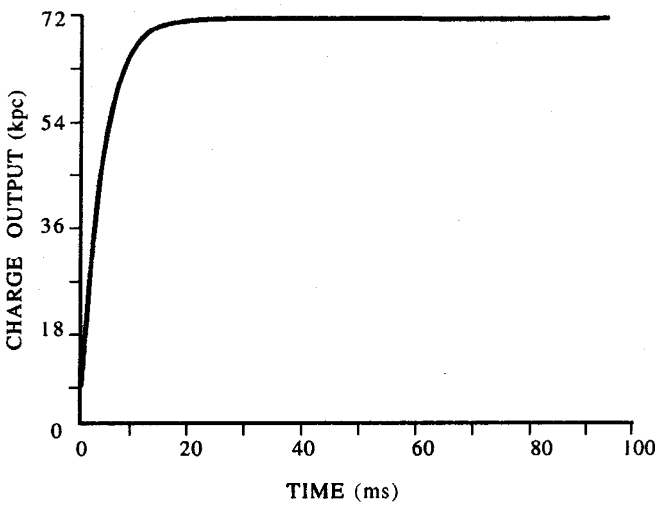

Figure 1. Charge output versus time graph of dynamic calibration of pressure transducer.

The gauge is fitted in the end cap and the pressure signal is brought out from the breech end, for recording. As the gauge is located at the breech end, it records the breech pressure. The shot out time is recorded by a pulse generated by breaking of a wire at the muzzle end. The breech pressure profile and shot out pulse is recorded on a high speed digital storage oscilloscope. Time reference for event start is taken from a trigger pulse derived from firing current of the shot. Figure 2 shows the breech pressure measurement setup and Fig. 3 shows a typical pressure-time graph, ignition and shot out pulses. In these trials, the muzzle velocity of the shot is measured by a radar.

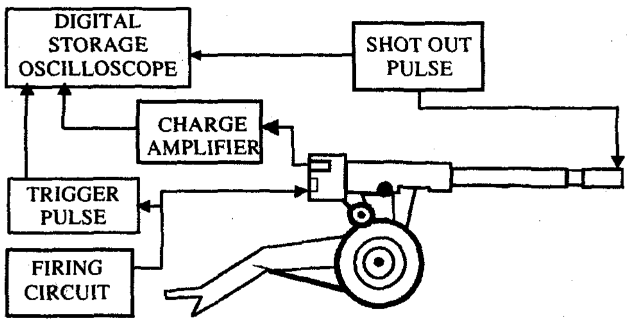

Figure 2. Schematic of breech pressure measurement setup.

Buildup of some initial pressure on the base of the shot is required to start its motion. This initial pressure is called as the shot-start pressure. Projectile is then further accelerated with the pressure acting on its base. The muzzle velocity can be predicted based on the propellant's chemical composition and burning rate found out from the closed vessel test. Another important parameter for muzzle velocity prediction is the shot-start pressure. The shot-start pressure can not be measured easily, so its value is assumed for muzzle velocity calculations. The experimentally measured breech pressure (P_{br}) is the resultant of all the losses, such as heat, strain, recoil, gas leakage, etc. occurring in the gun. There is always a difference in pressure value at the breech and base of the shot. The breech pressure is normally higher than the base pressure (P_b).

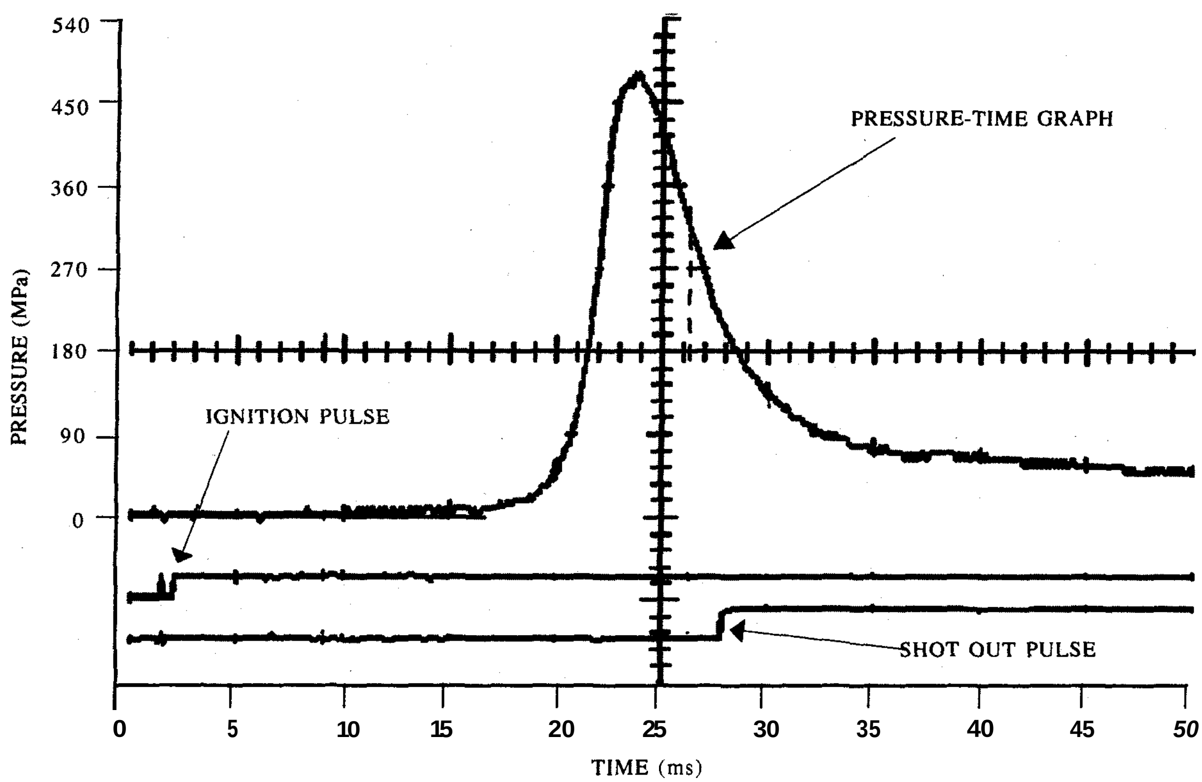

Figure 3. Typical record of breech pressure measurement

4. RESULTS & DISCUSSION

The pressure-time and the muzzle velocity data is taken from gun trials of LOVA propellant. The trials were conducted on 120 mm gun using FSAPDS proof shots. The muzzle velocity from P_{br} has been computed with the following assumptions:

(a) The shot-start pressure of 100 MPa is assumed for all the firings

(b) Frictional losses for all the firings are same and are incorporated as penalty in the weight of the projectile

(c) Breaking of wire instant is recorded electronically in synchronisation with the pressure-time measurements. The wire breaks due to the front-end of the projectile but the projectile accelerates till its rear end comes out of the barrel. Actual shot out instance is computed considering the velocity of the projectile at breaking of wire and its length.

(d) The charge weight, C in Eqn (1) is considered to be constant, although it decreases continuously during burning of the propellant.

Table (1) indicates the results of 16 firings and parameters like charge weight (C), shot weight (W), P_{max}, base pressure at the shot out instant (P_{so}) along with the muzzle velocity from a radar and that calculated by the method described above.

Table 1. Muzzle velocity values recorded by radar

Charge Wt (kg)	Y	Shot Wt (kg)	Base area (cm^2)	P_{max} (MPa)	P_{so} (MPa)	$MV_{recorded}$ (m/s)	MV_{calc} (m/s)	Accuracy (%)
6.50	1.2616	6.86	113.1	201	81	1180	1126	4.58
6.50	1.2616	6.87	113.1	210	103	1180	1136	3.73
6.50	1.2616	6.86	113.1	218	88	1273	1175	7.70
7.00	1.2616	6.86	113.1	223	99	1263	1195	5.38
7.00	1.2616	6.86	113.1	282	92	1336	1356	-1.50
7.50	1.2616	6.86	113.1	265	113	1353	1397	-3.25
7.50	1.2616	6.86	113.1	323	112	1443	1398	3.12
7.50	1.2616	6.86	113.1	375	110	1537	1436	6.57
8.00	1.2616	6.86	113.1	338	115	1500	1446	3.60
8.00	1.2616	6.86	113.1	362	115	1559	1473	5.52
8.00	1.2616	6.86	113.1	456	106	1619	1568	3.15
8.40	1.2616	6.86	113.1	464	122	1604	1614	-0.62
8.20	1.2616	6.86	113.1	399	116	1572	1510	3.94
8.30	1.2616	6.86	113.1	411	128	1579	1487	5.83
8.40	1.2616	6.89	113.1	510	97	1632	1732	-6.13
8.45	1.2508	6.86	113.1	490	141	1637	1636	0.06
				Mean deviation				4.00

Last column shows percentage deviation in computed muzzle velocity, considering muzzle velocity measured by radar as standard. The mean deviation between the calculated and the measured muzzle velocity is of the order of 4 per cent. The graphs in Fig. 4 depict development of P_{br}, P„, and velocity versus time and Fig. 5 shows the graph for chamber pressure and projectile velocity versus travel distance.

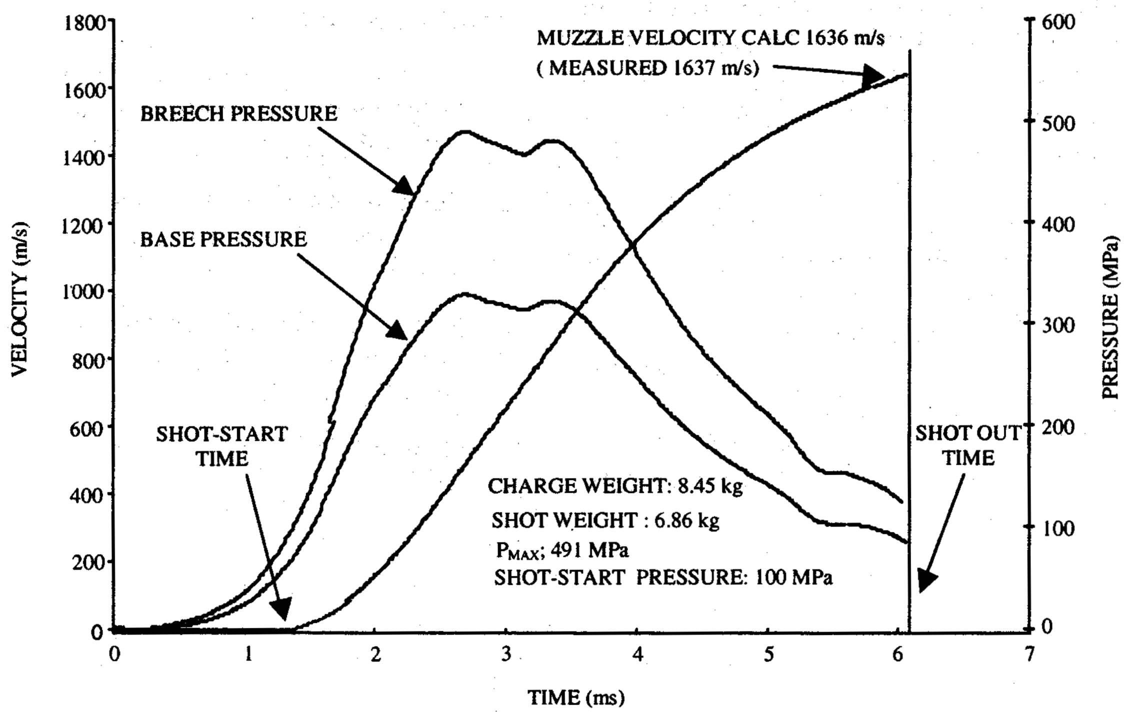

Figure 4. Development of velocity and pressure versus time

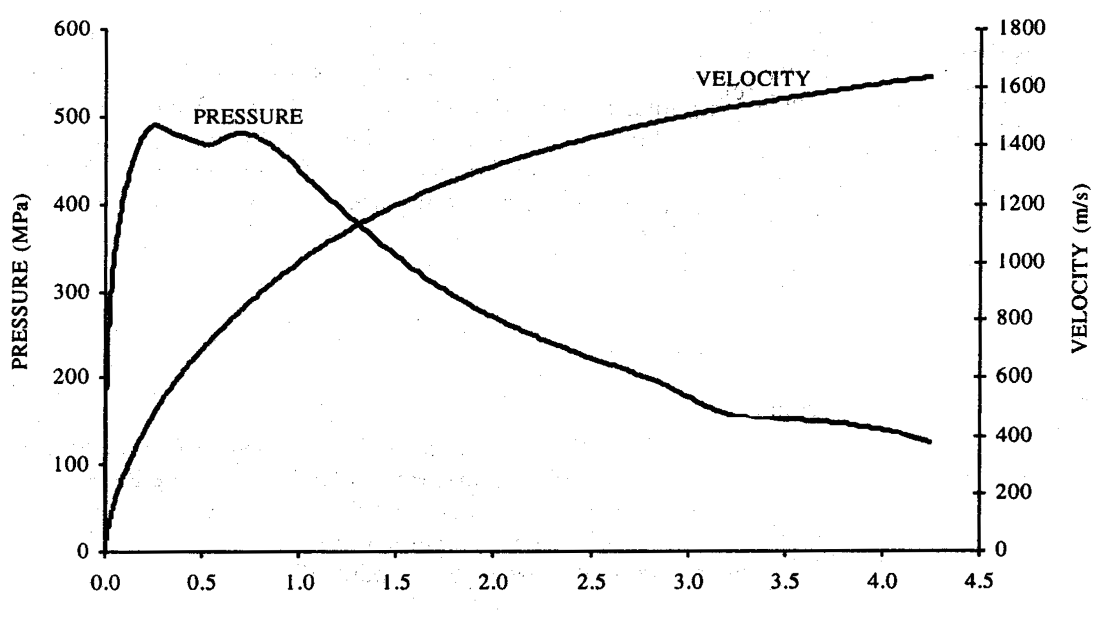

Figure 5. Development of pressure and velocity versus travelled distance

5. CONCLUSIONS

It is apparent that breech pressure measurements lead to computation of muzzle velocity with mean deviation of 4 per cent using Kent relation with charge weight C as constant. The accuracy can further be enhanced with the knowledge of shot-start pressure, which was assumed constant in these calculations. Possibility of measurement of shot-start pressure in the barrel is being explored.

The estimation of base pressure, instantaneous velocity, travel-time, and muzzle velocity is possible with the measurement of breech pressure, shot-start pressure and shot out time. With the knowledge of velocity in the bore, it will be possible to compute the change in the volume during combustion of the propellant. This may help in experimental assessment of the combustion of propellant in variable volume.

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