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MATERIALS RESEARCH LABORATORY

MELBOURNE, VICTORIA

TECHNICAL NOTE

MRL-TN-541

A PRESSURE BAR TEST FREE OF ASBESTOS FOR DETERMINATION OF DETONATOR PERFORMANCE

O.L. Fullinfaw, L.L. Heathcote, T.E.F. Symes and R.C. Nicholls

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ABSTRACT

The Pressure Bar equipment for testing detonators was developed from the Hopkinson Pressure Bar. Detonators were tested at Materials Research Laboratory (MRL) till 1969 on the Pressure Bar using an "asbestos-magnesium carbonate" degrading and protection pellet to transmit the detonation wave from the detonator to the pressure bar. In 1969, the use of asbestos was banned at MRL for health reasons. It thus became necessary to find an alternative test material and to suitably modify the Pressure Bar equipment to accept this alternative. This report details the search for such a material and the establishment of modified Pressure Bar equipment. Data for a wide range of Service and commercial detonators are described.

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A PRESSURE BAR TEST FREE OF ASBESTOS FOR DETERMINATION OF DETONATOR PERFORMANCE

1. INTRODUCTION

In November 1913, Professor Bertram Hopkinson, FRS, read a paper before the Royal Society entitled " A Method of Measuring the Pressure Produced in the Detonation of High Explosives or by the Impact of Bullets" [1]. His paper presented a method to analyse experimentally the results of violent blows and impacts in steel spheres or rods, and to measure the duration of the blow and the pressure developed.

The pressure bar machine was first elaborated as a Service test at the Research Department, Woolwich (UK). Diagrams of such pre-1945 instruments are detailed in Figures 1-5. During world war 2 the "Hopkinson Pressure Bar" was used extensively for the testing of explosives, detonators, fuzes, gaines and other similar items. This was subsequently developed into a method for testing the pressures produced by detonators using various types of pressure bars.

Australia also adopted this equipment as a Service test. The Pressure Bar equipment at (then) Defence Standards Laboratory (now MRL) utilised an "asbestos-magnesium carbonate" pellet for the testing of detonators. These pellets were pressed from a mixture of asbestos (30%) and granulated magnesium carbonate ponderous (70%) to various sizes and shapes. Because the pellets degraded rapidly, they had to be pressed immediately prior to testing, necessitating the storage and handling of large stocks of asbestos. The pellets were blown apart by the detonation creating a dust laden atmosphere within the explosion box. An extraction system then removed the dust from the box.

In 1953, work commenced at MRL to develop a rubber pellet to replace the existing pellets. Before this decision to use rubber was taken, various materials such as Dainite and other plastics were tried. The development was abandoned in 1956 because the Inspection Services here and in the United Kingdom did not see a need for it, although in that year MRL recommended the elimination of asbestos from this test.

In 1969 a revival of interest in the rubber pellet system was created because the use of asbestos (which generated asbestos dust) was banned at MRL and it was recommended that its use for the pressure bar test be eliminated in all Australian Proof

Establishments. In mid 1969 an interim rubber specification (for local MRL use) was prepared. Modifications to the Pressure Bar Machines (both Radial and Terminal) were carried out in order to accept and utilise the rubber pellet system. The preliminary work was completed by the end of 1971 and further modifications to the equipment periodically carried out.

The work described in this report details establishment of an optimised system to utilise rubber pellets, and subsequent testing to confirm the suitability of these pellets.

2. PRINCIPLE OF THE HOPKINSON PRESSURE BAR

The principle of the pressure bar as expressed by Hopkinson [1] is indicated in the following paragraphs.

If an explosive is detonated against or in the neighbourhood of the end of a tapered or cylindrical shaft, a wave of compression is transmitted along the rod with the velocity of sound in steel. Further, if the shaft is divided at a short distance from the end furthest from the charge, the opposed faces of the cut being carefully surfaced and held in firm contact, the compression wave passes this joint unaltered. Reaching the end of the shaft beyond the joint, the wave is reflected as a wave of tension, and the pressure at any section of the rod is the algebraic sum of the effects of the compression wave and the tension wave. When the front of the reflected wave has passed the surfaced joint, the conditions are such that the entering tension wave tends to separate the small portion of the shaft (known as the time-piece - See Fig 1) from the main shaft, while the tail of the compression wave tends to hold the time-piece on. As soon as the amplitude of the tension wave exceeds that of the compression wave, the time-piece is free to separate, the momentum trapped in it being the integral of the pressure-time curve which has passed the joint.

The test then depends essentially on the experimental determination of this momentum and its separation into two factors, pressure and time. Since the rate of transmission of the disturbance through steel is known, the time taken for the wave to traverse twice the length of the time-piece is known. The momentum in the time-piece was directly measured by the ballistic pendulum in pre-1945 equipment (Figures 1 and 2), and the mean pressure over the time interval was obtained by calculation. The time-piece is caught in the ballistic pendulum, the deflection of which measures the momentum. Since momentum per unit area of bar is proportional to the product of time and pressure, and as the time is fixed by the length of the time-piece, the average pressure during this time can be calculated.

The method differs from the ordinary ballistic pendulum since the latter evaluates the momentum of the blow without indication of its duration, whereas by determining the time integral of the pressure wave over a small period of time (eg. 2.5 μs) on either side of the maximum pressure, a measure of the brisance of the explosion is obtained. It is necessary to measure duration since the efficiency of a detonator depends not on the total energy, but on the exceedingly rapid rate with which its power is developed.

For the "time-piece" to separate the time is in the order of 3 to 5 μs and normally the detonator functions in a shorter time. However, in the case of a detonator which reacts more slowly, the total firing time would exceed 3 to 5 μs and then the "time-piece" would separate before the total energy of the detonator was absorbed. This can occur in practice with poor quality detonators and the test is designed to detect such shortcomings. Detonators which were slow to detonate, or did not build up to detonation, would record low energy and this would make the lot suspect.

An alternative consideration of the mechanism of the pressure bar as postulated by Thomas [2] is described below.

Considering the mechanism on an energy basis, when an explosive charge is fired at one end of a steel bar a vibration is set up which travels along the bar at the velocity of sound in steel, viz. 5180 m/s. When the vibration reaches the time-piece end a plane normal to the axis of the bar vibrates in the direction of the axis. The lapped face to which the time-piece is attached vibrates at an amplitude dependent on the energy which was applied to the face of the firing end. The attached time-piece follows the displacement of the lapped face from the zero position until maximum velocity has been reached, the time-piece having accelerated to the maximum velocity of that face. The bar face decelerates and eventually reverses in direction and, the time-piece having separated, continues on at the above maximum velocity. The time-piece energy is determined from measurement of its velocity:

$$E = 1/2\ mv^2.10^{-7}$$

where E = energy, J
v = velocity of the time-piece, cm/s
m = mass of the time-piece, g

The above concept is now used in the calculation of the time piece energy.

3. DESCRIPTION OF PRESSURE BARS AND TIME PIECES

The Pressure Bars and Time-Pieces are constructed from bars of nickel chrome steel, conforming to British Standard STA 5V/10, and heat treated to hardness 450-500 VPN throughout. Composition of the steel and dimensions of both the radial and cylindrical pressure bars are listed in Table 1 (page 4). The radial pressure bar is used for testing tubular detonators of varying sizes used typically in hand grenades, torpedoes etc whereas the cylindrical pressure bar is used for small cylindrical detonators generally used in service fuzes for shells and similar stores.

4. DEVELOPMENT OF THE PRESSURE BAR IN AUSTRALIA

4.1 Early Pressure Bar Equipment (pre 1945)

Figures 1 to 4 show the method adopted for the firing of detonators in the 18 mm Terminal Pressure Bar Apparatus.

The detonator was inserted in a brass collar with the bezel turned over. The collar was fitted into a steel slide then placed in a firing block which carried the striker. The position of the firing block assured that the striker, detonator and pressure bar were co-axial. The time-piece was attached using a slight smear of vaseline to secure a firm contact. A protective pellet, consisting of a mixture of asbestos (30%) and granulated magnesium carbonate ponderous (70%), was placed between the detonator base and the face of the bar.

TABLE 1

Specifications for the Radial and Cylindrical Pressure Bars

Bar Composition (%)		Dimensions
Carbon	0.35 to 0.43	RADIAL PRESSURE BAR
Silicon	0.10 to 0.35	**Shaft:**
Manganese	0.50 to 0.70	Diameter: 50.0 mm ± 0.05 mm at the firing end. A short parallel section is provided at the firing end tapering to 15.0 mm ± 0.015 mm at the time-piece end.The taper is approximately 2 degree angle
Nickel	1.30 to 1.80	
Chromium	0.90 to 1.40	
Molybdenum	0.20 to 0.35	
Sulphur	≤ 0.05	
Phosphorous	≤ 0.05	
Iron	Balance	
		Length: 500 mm ± 1.25 mm
		Time-Piece:
		Diameter: 15.0 mm ± 0.015 mm Length: 15.0 mm ± 0.015 mm Weight: 20.7 g
		CYLINDRICAL BAR
		Diameter: 17.8 mm ± 0.05 mm at the firing end. ± 0.025 mm at the lapped time-piece end
		Length: 660 mm ± 0.25 mm
		Time-Piece:
		Diameter: 17.8 mm ± 0.025 mm Length: 12.7 mm ± 0.025 mm Weight: 24.5 g

An electromagnetically released hammer gave a blow on the striker which in turn fired the detonator. The method for firing flash receptive detonators is shown in Figure 4. The pellet was pulverized by the detonation, transmitting a "fraction" of the force applied; the atmosphere became laden with asbestos-containing dust which was removed by an extraction system.

The movement of the ballistic pendulum, in which the time-piece was arrested, was recorded on a smoked glass plate by means of a steel needle attached to the pendulum by a spring. An example of a record by the ballistic pendulum is shown in Figure 6.

In the radial pressure bar apparatus (Fig. 5) the tubular detonators were tested by holding them vertically in a magnesium carbonate-asbestos protective pellet at a suitable distance from one end of a tapered steel shaft (the pressure bar). The detonator and bar being arranged perpendicularly, with the centre of the filling being placed at the centre of the base of the tapered bar. The detonators were fired either electrically or in the case of stab initiated (or delay detonators) by means of a falling weight impacting on to a steel firing pin placed above the detonator cap. The pendulum recording was similar to that of the 18 mm terminal pressure bar apparatus.

The method of calculation of the pressure using this system is given in Appendix A using units in vogue at that time.

4.2 Instrumentation to replace the Ballistic Pendulum

The equipment used in Australia until 1945 measured the momentum of the time-piece by means of the ballistic pendulum. This method was very cumbersome; some parts of the equipment had to be weighed regularly, records had to be kept of all changes and the reduction factor (or constant) of the instruments needed to be calculated with every change in weight. There was a tendency for damage to the time-piece and this required resurfacing and reweighing. The method of providing smoked glass plates and their preservation after recording and prior to calculation was tedious. The ballistic pendulum had to be protected from draughts and the opening and closing of the cabinet during tests prolonged testing time. The difficulties can be clearly visualised when the method of calculation in Appendix A is noted.

As the use of the pendulum gives rise to a loss of sensitivity, a photo-electric system was considered which could assure a greater degree of sensitivity. In 1945 the Ballistic Pendulum was replaced by the direct measurement of the velocity of the time-piece by means of a counter chronograph with a mechanical system of triggering using strips of tin foil as start and stop contacts. After experience with this mechanical system it was considered that further improvements would result from the use of a photocell triggering device, which came to be known as the Velocity Measuring Device (VMD).

The first VMD had the following features. During flight , the time-piece (15-18 mm in diameter) intercepted two parallel light beams which were 250 mm apart in a tunnel 75 mm square. Each light beam was formed by slits 0.5 mm wide and 10 mm long perpendicular to the trajectory. A separate exciting lamp, photocell and amplifier were used for each interceptor. When the light beams were intercepted, pulses were produced which operated the trigger circuits at the counter chronometer input. The absolute accuracy of the instrument was limited by the accuracy with which the slits

were set out. In the first generation VMD, the distance was known to within 1 part in 10,000; the errors in velocity would rarely be worse than 0.2% and would usually be about 0.1%.

Through the years to follow, further development progressed to transistorisation, duplicate reading facilities, elimination of slow changing light levels, elimination of background noise efffects, MRL designed Microsecond Counter Chronometers with the elimination of false triggering, the ability to record detonators with more power, a daylight recording technique and shock resistant equipment. Figure 7 shows the final circuit diagram for the VMD.

The method of calculation of the pressures using the asbestos pellets, VMD and Microsecond Counters is given in Appendix B.

4.3 Development of the Rubber Pellet

As explained in the Introduction, a considerable effort had been expended to replace the asbestos-magnesium carbonate pellet used on the pressure bars. In some early experiments (1953-1956) for the 10 mm (0.4 inch) Pressure Bar some of the following materials were tried:

Dainite	Butyl Rubber
Perspex	Butyl Rubber and Kaolin
Various Other Plastics	Polyurethane foam
Plaster of Paris	30 and 50 Microcell Rubber
Natural Rubber	Polystyrene foam

Most of the materials tested were rejected because they gave poor reproducibility of results. Polyurethane and polystyrene foam were damaging to the apparatus and very dusty. The best performing material was found to be natural rubber. In 1969, when use of asbestos was banned at MRL, it was decided to proceed with further experimentation. In order to accept the rubber pellet a modified Pressure Bar was required in which the moulded rubber was used in conjunction with a steel confining collar. Fresh experiments commenced especially with the Radial Pressure Bar pellet as no previous work had been done for this bar. New formulations were devised and mouldings of pellets with different sizes and shapes were tested. The final established shapes of the Rubber Pellet, both Radial and Terminal, are shown in Figures 8 to 11. Comparative firings with asbestos pellets were carried out.

However, due to difficulties of local supply and toxicity of some of the rubber ingredients, and for various other reasons, further formulations had to be tested. By 1975 several formulations were tried and tested and a specification written for a suitable formulation. A summary of formulations devised and tested is shown in Appendix C. A 25 cavity mould for the 18 mm Pressure Bar pellets and a 9 cavity mould for the Radial Pressure Bar pellets were designed at MRL and their manufacture completed by December 1980. Test mouldings and firings were conducted and during this process it became apparent that critical temperature control of rubber curing was required as low hardness and variable resilience could affect detonator performance results. In August 1983 an order was placed for pre-production. Testing confirmed reproducibility with small standard deviations. The final specification is attached as Appendix D.

A number of conditions for production of the rubber pellets are critical:

a. The temperature and time for curing should be controlled within tight limits.

b. Rubber hardness is to be treated as a major factor and should be between IRHD 62 to 68.

c. Resilience is a major factor and should be controlled between 40% and 50%.

d. Formulations may be varied slightly. Although MRL-H-756 has been specified, formulations similar to those marked with an asterisk in Appendix C are considered acceptable alternatives.

e. High limits for pellet dimensions must not be exceeded. Low limits are less critical.

f. The load defined in the specification to be exerted on the mould by the press should never be exceeded.

g. The production acceptance of the moulded pellets should be based on the physical tests as prescribed in the specification as well as on the firing results on the Pressure Bar.

h. For acceptance of production for all pellets (Radial Pressure Bar-Front Types A, B and Back; and the 18 mm Pressure Bar Types 1, 2 and 3) the firings are to be conducted using Pellet Type B, on the Radial Pressure Bar with an ICI No. 8 electric detonator.
Results must conform to:

Sample	20
Mean time-piece energy	16.0 ± 1.5 J
Standard deviation	Not greater than 0.75 J
Minimum individual energy	Not less than 13.05 J

i. If only 18 mm Pressure Bar pellets are to be manufactured, then the following acceptance criteria using detonator 5.5 Grain L/Z are applicable:

Sample	20
Mean time-piece energy	5.0 ± 0.5 J
Standard deviation	Not greater than 0.75 J
Minimum individual energy	Not less than 3.60 J

The rubber pellet system is suitable for testing all detonators, whereas in the past each detonator had to have its own special brass holder, necessitating large stocks of components. The detonator performance as recorded by the "time-piece" energy ($1/2\ mv^2$) with the rubber pellet system, is shown to give a good correlation with the calculated energy of decomposition. The kinetic energy transmitted to the "time-piece" is about six times greater for the rubber pellet holder system than for the asbetos-magnesium carbonate pellet, but is still only about one hundredth of the energy of decomposition. In order to cater for this increase of energy transmission and hence "time-piece" velocity, a more sophisticated VMD and Microsecond Counter Chronograph had to be devised. The design of the VMD was changed, making the instrument lighter, compact and more reliable together with the advantage of recording under normal lighting conditions. The drawings for the standardised MRL system using the rubber pellet are listed in Appendices E and F. Figures 12 and 13 show photographs of the final version of the equipment. Figures 14 to 17 depict the assembly methods of testing

detonators using this system. The method for calculation of the energy using this system (rubber pellet, VMD and Counter chronograph) is given in Appendix H.

5. DISCUSSION

The function of the Pressure Bar Apparatus is that of a comparator to assess detonator performance in relation to the performance of detonators carefully filled to design charge weights and for which specification limits have been established. Because of less efficient energy transmission and poorer reproducibility, the earlier version of the apparatus could not adequately measure the performance of small detonators. The change to the modified rubber pellet system gives improved reproducibility and reduced coefficient of variation. The two major factors in achieving this are more accurate measurement of the time-piece velocity and uniform confinement of the detonators.

The accuracy and reproducibility of the pressure bars using the rubber pellet was assessed using detonators filled accurately with a range of explosives of known decomposition energies. The complete range of materials and formulations are listed, with decomposition energies, in Table 2. In all cases a linear relationship was found between time-piece energy and decomposition energy. Results for a series of service detonators are plotted in Figs 18 and 19 for the radial and 18 mm terminal pressure bar respectively.

TABLE 2

Table of Decomposition Energies of Explosives
used in Initiating Devices

		Cal/g	kJ/g
A.	SINGLE COMPOUNDS:		
	Lead 2,4-Dinitroresorcinate (RD 1337)	270	1.13
	Lead Azide (Service)	385	1.61
	Mercury Fulminate	420	1.76
	Lead Styphnate (Normal)	450	1.88
	CE, density 1.35 to 1.45 Mg/m^3	910	3.81
	CE, density 1.65 Mg/m^3	1020	4.27
	CE, max. pressing density	1110	4.65
	RDX	1355	5.67
	PETN	1420	5.94
	Diazodinitrophenol (DDNP)	820	3.43
	Tetrazene	660	2.76
B.	MIXED COMPOSITIONS:		
	A Mixture (FM 37.5%)	158	0.66
	L Mixture (RD 1337 50%; Tet. 5%)	168	0.70
	NOL 130	280	1.17
	ASA Det. Composition (65/32.5/2.5)	396	1.66

Some typical experimental results comparing the two methods are tabulated in Table 3. These results indicate that the Rubber Pellet imparts a higher velocity to the time-piece and hence transmits more energy from these detonators. However, they also show that the increase in energy obtained with the rubber pellet is dependent on the type of detonator. It is therefore necessary to re-establish acceptance limits for each type of detonator by firings in the new system, as described in Appendix G.

The energy limits established for selected types of detonators are given in Table 4 (page 10).

TABLE 3

Comparison of Rubber Pellets/Magnesium Carbonate-Asbestos Pellets
Some Typical Mean Velocities of the Time-piece

Detonator Type	Time-Piece Time (ms)		Pressure (tsi)	Time-Piece Energy (J)
	MCA	RP	MCA	RP
ICI LE N6 Mks 1 & 2	58.28	12.42	5.67	4.19
Det No. 5 Mk 1	50.38	15.22	6.50	2.79
Det No. 33	29.94	8.28	10.9	9.44
Det Percussion W/T No. 28	20.38	5.08	15.56	25.06
Det No. 79	21.73	5.84	15.01	18.96
Det No. 80	23.99	6.60	13.66	14.85
Det 5.7 gr AZ	35.98	12.47	9.13	4.94

Notes: MCA = Magnesium Carbonate-Asbestos pellets
RP = Rubber Pellets

All times recorded using the velocity measuring device.

TABLE 4

Recommended Energy Limits for Testing Detonators
using the Rubber Pellet System

Detonator Type	Pressure Bar	Limit			See Note
		Time-Piece Energy (J)			
		Sample	Minimum (Not less than)		
			Mean	Individual	
Det. Percn. N5 Mks 1 & 2	Radial	10	6.25	4.80	1
		5	6.00	4.80	
Dets. L2A1 & L1A1	Radial	10	22.50	16.00	1
		5	21.0	16.00	
DBR 2 sec (Ikara)	Radial	10	2.62	2.12	1
		5	2.55	2.12	
DBR 4 sec (Ikara)	Radial	10	4.18	3.48	1
		5	4.09	3.48	
ICI Det. Electric No. 8	Radial	10	15.10	12.83	4
		5	14.80	12.83	
Det. Plain No. 8 Strength	Radial	10	12.70	10.30	4
		5	12.35	10.30	
Det. Electric No. 79 Mk 1	Radial			13.50	2
Det No. 80 Mk 1	Radial			13.50	2
Det. No. 82)					
Det. No. 101)	Radial	As for Det. Percn. N5 Mks 1 & 2			2
Det. LE N6 Mk 1)					
Det. Percn. W/T Mk N8	Radial	10	23.00	18.00	3
Det. 5.5 GRN L/Z	18 mm	20	4.30	3.60	1
Det. 5.7 GRN A/Z	18 mm			4.00	3
Det. 2.0 GRN R/Z/Y	18 mm	20	2.65	1.90	1
Det. 1.5 GRN R/Z/Y *	10 mm	20	1.90	1.45	1,5

Notes:

1. Based on the firing of detonators specially filled to MRL requirements.
2. Limits suggested on the basis of these detonators having similar fillings.
3. Provisional limits based on data of pooled firings of detonators fired at various times.
4. Limit based on the firing of a selected production lot.
5. A new limit should be established using the 18 mm bar.

The modified apparatus has many advantages over the earlier systems.

a. The asbestos hazard is eliminated.

b. Similarly filled detonators produce more uniform and reproducible energies than the asbestos-magnesium carbonate method, due to a more uniform transfer of energy to the face of the bar.

c. Utilisation of approximately six times more energy increases the sensitivity to changes in filling mass and composition.

d. Debris is retained in the rubber pellet cavity and can be examined for any abnormalities.

e. The whole range of production detonators can be tested using the same testing conditions.

f. Operational costs are reduced substantially as follows.

   i Little or no damage is incurred by the face of the bar, hence the life of the bar is indefinite.

   ii Pressing of the asbestos-magnesium carbonate pellets is eliminated. These pellets had a usable life of only 24 hours due to moisture uptake. This also avoids the holding of large stocks of asbestos and magnesium carbonate and the associated large press and moulds, rams, moulding components and the mixing machine.

   iii The need to hold large stocks of a variety of brass holders (18 mm pressure bar) is avoided.

   iv Time for turning over the bezel on the brass holder during detonator assembly is saved with the 18 mm pressure bar.

   v The cost per test of expendible components is reduced.

   vi Cleaning time is reduced.

6. CONCLUSIONS

The method developed at MRL for assessing detonator performance is considered to be very satisfactory as it is easy to operate and maintain the equipment, and test results can be given on the same day. The results are reproducible and any poor quality detonators are easily detectable. The detonator performance with the rubber pellet system (recorded as "time-piece" energy) gives a good correlation with the calculated energy of decomposition. The method can be used on all current production detonators.

7. ACKNOWLEDGEMENTS

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APPENDIX A

PRE 1945 EQUIPMENT

METHOD OF CALCULATION OF THE PRESSURE
(using Units in vogue at that time)

Calculation of the Constant of the Instrument
(also known as the Reduction Factor)

Let:

M =	mass (in slugs) of:	a)	pendulum + sprag + rod + counterpoise
	+	b)	bag + carrier + cotton wool
	+	c)	1/3 weight of suspension wires
	+	d)	bottom knife edge
	+	e)	time-piece

T = period of oscillation (in seconds) of the ballistic pendulum (including time-piece), as measured
D = diameter of the shaft (in inches)
d = diameter of the time-piece (in inches)
m = mass of the time-piece (in slugs)
L = length of the time-piece (in inches)
V = maximum velocity of the oscillation of the pendulum recording needle (ft/s)
v = velocity of the time-piece (ft/s)
f = mean force on the time-piece over time t
p = mean pressure over time t (in tons/square inch) over the cross sectional area of the time-piece and shaft end
S = length of the record (in inches)
t = the time (in seconds) taken by the impulse to traverse twice the length of the time-piece

1. Imparting momentum to the time-piece

$$ft = mv \qquad \text{but } f = p.\ \frac{\pi d^2}{4}$$

Therefore: $$p.\ \frac{\pi d^2}{4}\ .\ t = mv$$

2. Measurement of the Momentum of the time-piece by the ballistic pendulum

Assumptions: Simple harmonic motion of the recording needle.
(since amplitude of the vibration is small compared to the length of the suspension)

Therefore: $$V = \frac{2\pi S}{T} \quad \text{and} \quad MV = \frac{2\pi M}{T}\ .\ S$$

The momentum acquired by the time-piece is imparted to the pendulum.

$$mv = MV$$

$$p \cdot \frac{\pi d^2}{4} \cdot t = \frac{2\pi M}{T} \cdot S$$

Therefore: $$p = \frac{2\pi M}{T} \cdot S \frac{4}{\pi d^2} \cdot \frac{1}{t} = \frac{8M}{d^2 \cdot T \cdot t} \cdot S$$

Note: $$\frac{8M}{d^2 \cdot T \cdot t}$$

is known as the Reduction Factor or Constant of the Instrument. This will vary with changing mass M and the length of the time-piece and pendulum.

3. Calculation of Reduction Factors

For a mass of M measured in pounds, and pressures calculated in tons/square inch, the above equation becomes:

$$p = \frac{8 \times \frac{M}{32.2 \times 12}}{d^2 \times T \times t \times 2240} \cdot S \text{ tons/square inch.}$$

For a velocity of the impulse in steel of 17,000 feet/second:

$$t = \frac{2 \cdot L}{12 \times 17{,}000} = 9.80 \times 10^{-6} \cdot L$$

Therefore $$p = \frac{\frac{8M}{32.2 \times 12}}{d^2 \times T \times 9.80 \times 10^{-6} \times L \times 2240} \cdot S$$

For the 18 mm Terminal Pressure Bar

$L = 0.5"$
$d = 0.7"$
$t = 9.80 \times 10^{-6} \times 0.50 = 4.90 \times 10^{-6}$ seconds
and $p = 3.85\,(M/T).S$

For a typical value of M of 2 lb 9 oz 7 dr (2.59 lb), and a measured value of T (taken by

timing 100 swings with an accuracy of 0.02 seconds) of 2.00 seconds,

$$p = 5.S \text{ tons/square inch}$$

For the Radial Pressure Bar

$L = 0.5906"$
$d = 0.5906"$
$t = 9.80 \times 10^{-6} \times 0.5906 = 5.79 \times 10^{-6}$ seconds
$p = 4.58\ (M/T).S$

Taking values for M = 4 lb 0 oz 12 1/2 dr (4.048 lb) and T = 2.00 seconds,

$$p = 9.303\ .\ S \text{ tons/square inch}$$

These factors, also known as the Constants of the Instruments, represent the pressure corresponding to a record of one inch. By altering M, the value of the pressure corresponding to one inch of the record may be varied. Thus, in order to minimise the labour of calculating the pressure, the weight of the pendulum can be adjusted so that the pressure per inch of record is some convenient number, e.g. 5 or 10 or 20 tons/square inch.

4. Measurement of records and the resulting pressure

A smoked glass plate is used to record the tracing of the length of the swing of the pendulum. Figure 6 shows an example of records on the smoked glass plate. The reading is taken from the zero mark to the furthest point of travel of the stylus in the direction of the first throw. Accuracy of reading is 0.01 inch.

The record thus obtained must be suitably corrected for friction. The appropriate correction for friction is determined by measuring the difference between the first and second displacements from the zero line in the same direction. The correction is made by adding one quarter of this difference to the uncorrected record. This correction having once been determined may be applied for subsequent testing provided that the conditions of testing remain unaltered, but should preferably be checked at frequent intervals. It is desirable that the friction between the stylus point and the plate should not be excessive, and the equipment should be adjusted so that the difference between successive displacements in the same direction does not exceed 0.2 inch, i.e. the correction for damping should not be much greater than 0.05 inch.

Example of pressure determination

Uncorrected record:	1.98 inch (say)
Corrected record: (corrected for damping due to friction)	1.98 + 0.04 = 2.02 inch
Pressure (Record x Reduction Factor)	2.02 x 5 = 10.1 tons/square inch

APPENDIX B

1945 TO 1970 EQUIPMENT

METHOD OF CALCULATING THE PRESSURE USING THE VMD, COUNTER CHRONOGRAPH AND ASBESTOS-MAGNESIUM CARBONATE PELLETS

(Using units in vogue at that time)

Let:

- m = mass of the time-piece (in gram)
- v = velocity of the time-piece (in feet/second)
- d = diameter of the time-piece (in inches)
- T = the time (in seconds) for the time-piece to travel over 25cm (i.e. the standard distance in the VMD)
- t = the time (in seconds) taken by the vibrational energy to travel twice the length of the time-piece
- L = length of the time-piece (in inches)
- f = mean force on the time-piece over time t (lb)
- p = mean pressure over time t (in tons/square inch) over the cross sectional area of the time-piece and the shaft end.

1. Imparting momentum to the time-piece

$$ft = mv \qquad \text{but } f = p \cdot \frac{\pi d^2}{4}$$

Therefore:

$$p \cdot \frac{\pi d^2}{4} \cdot t = m.v$$

2. Calculation of Pressure

From $$p \cdot \frac{\pi d^2}{4} \cdot t = mv$$

$$p = mv \cdot \frac{4}{\pi d^2} \cdot \frac{1}{t}$$

But $$v = \frac{25}{2.54 \times 12 \times T} \text{ ft/second}$$

and $t = \frac{2L}{12 \times 17{,}000}$ seconds

Substituting:

$$p = m \cdot \frac{25}{2.54 \times 12 \times T} \cdot \frac{4}{\pi d^2} \cdot \frac{12 \times 17{,}000}{2L}$$

Converting to tons/square inch

$$p = \frac{m}{453.6 \times 32.2} \cdot \frac{25}{2.54 \times 12 \times T} \cdot \frac{4}{\pi d^2} \cdot \frac{12 \times 17{,}000}{2L} \cdot \frac{1}{2240}$$

$$= 0.003256 \frac{m}{T \cdot L \cdot d^2}$$

Using the above equation, the typical simplified formulae for the pressure bars are:

A. Radial Pressure Bar: $p = \frac{0.3264}{T}$ tons/square inch

B. 18 mm Terminal Pressure Bar: $p = \frac{0.3269}{T}$ tons/square inch

C. 10 mm Terminal Pressure Bar: $p = \frac{0.3280}{T}$ tons/square inch

where "T" is in seconds

APPENDIX C

MRL FORMULATIONS FOR RUBBER PELLETS

Ingredient	Parts by Weight (PHR)			
	Early Experimentation - Original Formulation			
	Formulation Number MRL - H -			
	460	754	755	756
Natural Rubber SMR 5	100	-	-	-
Natural Rubber SMR 10 Grade	-	100	100	100
BR 1220	-	-	-	-
Lamp Black (Magicol 888) (1)	70	-	-	-
FEF Carbon Black	-	37.5	37.5	37.5
FEF Master Batch (Including Mobisol K & Stearic Acid)	-	-	-	-
SRF Black	-	-	-	-
Nonox B (acetone diphenylamine) (2) (condensation product)	1	-	-	-
Octamine (Octylated diphenylamine)	-	1	1	1
Processing Oil (Shell Diala B)	2	-	-	-
Mobisol K	-	2	2	2
Aromatic Oil	-	-	-	-
Clay C 10 (or approved equivalent)	-	-	-	32.5
Whiting (in lieu of Clay C 10)	-	-	-	-
Paraffin Wax	1	-	-	-
Microcrystalline Wax	-	1	1	1
Stearic Acid	1	1	1	1
Tetramethyl Thiuram Disulphide	3	3	3	3
Zinc Oxide	30	30	40	30
TOTAL	208	175.5	185.5	208

Notes: (1) Not available in Australia at the time of formulation.

(2) Originally Phenyl-B-Napthylamine (PBN). As it was a health hazard it was replaced by Nonox B.

MRL FORMULATIONS FOR RUBBER PELLETS

Ingredient	Parts by Weight (PHR)			
	Original Formulation modified to suit Master Batches			
	Formulation Number MRL - H -			
	754	755	756	782
Natural Rubber SMR 5	-	-	-	-
Natural Rubber SMR 10 Grade	50	50	50	50
BR 1220	-	-	-	-
Lamp Black (Magicol 888) (1)	-	-	-	-
FEF Carbon Black	-	-	-	-
FEF Master Batch (Including Mobisol K & Stearic Acid)	90.5	90.5	90.5	90.5
SRF Black	-	-	-	-
Nonox B (acetone diphenylamine) (2) (condensation product)	-	-	-	-
Octamine (Octylated diphenylamine)	1	1	1	1
Processing Oil (Shell Diala B)	-	-	-	-
Mobisol K	-	-	-	-
Aromatic Oil	-	-	-	-
Clay C 10 (or approved equivalent)	-	-	32.5	-
Whiting (in lieu of Clay C 10)	-	-	-	27.5
Paraffin Wax	-	-	-	-
Microcrystalline Wax	1	1	1	1
Stearic Acid	-	-	-	-
Tetramethyl Thiuram Disulphide	3	3	3	3
Zinc Oxide	30	40	30	30
TOTAL	175.5	185.5	208	203

Notes: (1) Not available in Australia at the time of formulation.

(2) Originally Phenyl-B-Napthylamine (PBN). As it was a health hazard it was replaced by Nonox B.

MRL FORMULATIONS FOR RUBBER PELLETS

Ingredient	Parts by Weight (PHR)	
	MRL Specification Formulation	
	Formulation Number (1)	MRL - H - 756 (2)*
Natural Rubber SMR 5	-	-
Natural Rubber SMR 10 Grade	100	100
BR 1220	-	-
Lamp Black (Magicol 888) (1)	-	-
FEF Carbon Black	37.5	37.5
FEF Master Batch (Including Mobisol K & Stearic Acid)	-	-
SRF Black	-	-
Nonox B (acetone diphenylamine) (2) (condensation product)	-	-
Octamine (Octylated diphenylamine)	1	1
Processing Oil (Shell Diala B)	-	-
Mobisol K	2	-
Aromatic Oil	-	2
Clay C 10 (or approved equivalent)	32.5	32.5
Whiting (in lieu of Clay C 10)	-	-
Paraffin Wax	-	-
Microcrystalline Wax	1	1
Stearic Acid	1	1
Tetramethyl Thiuram Disulphide	3	3
Zinc Oxide	30	30
TOTAL	208	208

Notes: * Indicates suitable formulation.

(1) To specification ETG/PB-1; Issue 1; dated 2-12-1974 and 1-75.

(2) To specification ETG/PB-1; Issue 2; dated 3-1979.

MRL FORMULATIONS FOR RUBBER PELLETS

Ingredient	Parts by Weight (PHR)		
	Experimental Formulations		
	Formulation Number MRL - 1366 /		
	1	2	3
Natural Rubber SMR 5	-	-	-
Natural Rubber SMR 10 Grade	100	100	100
BR 1220	-	-	-
Lamp Black (Magicol 888) (1)	-	-	-
FEF Carbon Black	40	45	30
FEF Master Batch (Including Mobisol K & Stearic Acid)	-	-	-
SRF Black	-	-	-
Nonox B (acetone diphenylamine) (2) (condensation product)	-	-	-
Octamine (Octylated diphenylamine)	1	1	1
Processing Oil (Shell Diala B)	-	-	-
Mobisol K	-	-	-
Aromatic Oil	2	2	2
Clay C 10 (or approved equivalent)	32.5	32.5	32.5
Whiting (in lieu of Clay C 10)	-	-	-
Paraffin Wax	-	-	-
Microcrystalline Wax	1	1	1
Stearic Acid	1	1	1
Tetramethyl Thiuram Disulphide	3	3	3
Zinc Oxide	30	30	30
TOTAL	213	218	203

MRL FORMULATIONS FOR RUBBER PELLETS

Ingredient	Parts by Weight (PHR)		
	Experimental Formulations		
	Formulation Number MRL - 1378 /		
	1	2	3
Natural Rubber SMR 5	-	-	-
Natural Rubber SMR 10 Grade	100	100	100
BR 1220	-	-	-
Lamp Black (Magicol 888) (1)	-	-	-
FEF Carbon Black	30	37.5	40
FEF Master Batch (Including Mobisol K & Stearic Acid)	-	-	-
SRF Black	-	-	-
Nonox B (acetone diphenylamine) (2) (condensation product)	-	-	-
Octamine (Octylated diphenylamine)	1	1	1
Processing Oil (Shell Diala B)	-	-	-
Mobisol K	-	-	-
Aromatic Oil	2	2	2
Clay C 10 (or approved equivalent)	32.5	32.5	32.5
Whiting (in lieu of Clay C 10)	-	-	-
Paraffin Wax	-	-	-
Microcrystalline Wax	1	1	1
Stearic Acid	1	1	1
Tetramethyl Thiuram Disulphide	3	3	3
Zinc Oxide	30	30	30
TOTAL	205.5	213	215.5

MRL FORMULATIONS FOR RUBBER PELLETS HOLDERS

Ingredient	Experimental Formulations Parts by Weight (PHR)				
	Formulation Number MRL - 1430 /				
	1*	2*	3	4	5
Natural Rubber SMR 5	-	-	-	-	-
Natural Rubber SMR 10 Grade	100	70	100	100	70
BR 1220	-	30	-	-	30
Lamp Black (Magicol 888) (1)	-	-	-	-	-
FEF Carbon Black	37.5	37.5	55	-	-
FEF Master Batch (Including Mobisol K & Stearic Acid)	-	-	-	-	-
SRF Black	-	-	-	70	70
Nonox B (acetone diphenylamine) (2) (condensation product)	-	-	-	-	-
Octamine (Octylated diphenylamine)	1	1	1	1	1
Processing Oil (Shell Diala B)	-	-	-	-	-
Mobisol K	2	2	2	2	2
Aromatic Oil	-	-	-	-	-
Clay C 10 (or approved equivalent)	32.5	32.5	-	-	-
Whiting (in lieu of Clay C 10)	-	-	-	-	-
Paraffin Wax	-	-	-	-	-
Microcrystalline Wax	1	1	1	1	1
Stearic Acid	1	1	1	1	1
Tetramethyl Thiuram Disulphide	3	3	3	3	3
Zinc Oxide	30	30	30	30	30
TOTAL	208	208	193	208	208

Notes: * Indicates suitable formulation.

APPENDIX D

SPECIFICATION FOR RUBBER PELLETS USED ON THE PRESSURE BAR APPARATUS

1. Scope

This specification is applicable to two types of rubber pellet used for the testing of detonators on pressure bar systems.

1.1 Rubber pellet, Types 1,2 and 3 for the 18 mm Terminal Pressure Bar.

1.2 Rubber pellet, Front - Types A and B, and Back for the Radial Pressure Bar.

2. Applicable Documents

Reference to the following British Standards is required:

BS 3106 : Non-Silver-Staining Natural Rubber Compounds.
BS 903 : Methods of Testing Vucanised Rubbers.

3. Requirements

3.1 The components are described and dimensionally detailed in Materials Research Laboratory (MRL) drawings:

3.1.1 MRL 59/1882/2 Sheet 1, Issue 5 - Items 11, 19 and 20. Rubber Pellets (Types 1, 2 and 3), 18 mm Pressure Bar Assembly.

3.1.2 MRL-2877-01, Sheet 7; Radial Pressure Bar:
Part Number 53 Type A : Rubber Pellet Front - Type A.
Part Number 53 Type B : Rubber Pellet Front - Type B.
Part Number 54 : Rubber Pellet - Back.

3.2 The components shall be compression moulded from a formulated natural rubber compound of approved composition. The approved formulation is known as MRL-H-756.

3.2.1 **Formulation MRL-H-756**

Material	Parts by Weight (PHR)
Natural Rubber, SMR 10 Grade	100
Zinc Oxide	30
FEF Carbon Black	37.5
Stearic Acid	1
Aromatic Oil	2
Microcrystalline Wax	1
Octylated Diphenylamine	1
Clay C 10 (or approved equivalent)	32.5
Tetramethylthiuram disulphide	3
TOTAL	208.0

3.2.2 The natural rubber shall be SMR 10 Grade, and no reclaimed rubber, factice, vulcanised waste or any other organic extender shall be used. All ingredients used shall be free from grit and extraneous materials. The selection of the ingredients and process conditions shall be such that the vulcanisates will be free from surface imperfections, blisters, lamination or porosity and will not show excessive bloom. The items shall be press cured. Advice on curing conditions can be obtained from the Rubber Section, Materials Division (MRL), DSTO Melbourne.

3.3 **Physical Properties**

The moulded components shall conform to the following requirements:

3.3.1 **Hardness**

When determined using the method described in BS 903 Part A 26 the hardness shall be in the range 65 ± 3 IRHD.

3.3.2 **Specific Gravity**

When determined using the method described in BS 903 Part A 1 the specific gravity shall be in the range 1.29 ± 0.02.

3.3.3 **Compression Deflection**

3.3.3.1 **Rubber pellet, 18 mm Pressure Bar**

a. Deflection after 0.9 kN compression load applied for 2 minutes 6 to 9 mm

b. Compression Set (1 hour after removal of 0.9 kN load applied for 2 minutes) 1.0% max.

3.3.3.2 **Rubber pellet, Front, Radial Pressure Bar**

a. Deflection after 4.5 kN compression load applied for 2 minutes 9 to 12 mm

b. Compression Set (1 hour after removal of 4.5 kN load applied for 5 minutes) 1.5% max.

3.3.3.3 **Rubber pellet, Back, Radial Pressure Bar**

a. Deflection after 4.5 kN compression load applied for 5 minutes 2.8 to 4 mm

b. Compression Set (1 hour after removal of 4.5 kN load applied for 5 minutes) 1.0% max.

4. Quality Control

4.1 For type approval of unvulcanised compound a sample of 0.5 kg shall be submitted to MRL for determination of curing characteristics.

4.2 Initial test mouldings shall be produced and submitted to MRL for the determination of dimensions, physical properties and performance test compliance.

4.3 During the production run a representative sample of not less than 20 Rubber pellets will be supplied by the contractor, free of charge, for further laboratory examination.

4.4 The moulds supplied by MRL shall not be used in Presses of greater than 100 ton. (Note: Material used for the mould is Steel - Welten 80 C for the Radial Pressure Bar and MCV Vibrac, NCV for the 18 mm Terminal Pressure Bar).

APPENDIX E

DRAWING LIST FOR RADIAL PRESSURE BAR

Drawing Number	Sheet No.	Issue No.	Date	Item
MRL 2877-01 (10 sheets)	1	1	29-07-'80	Radial Pressure Bar: Assembly.
	2	1	13-06-'80	Details 1-3, 5-7 and 12.
	3	1	13-06-'80	Details 13,14,16,18-21,23,24.
	4	1	13-06-'80	Details 25-27 and 30-32.
	5	1	13-06-'80	Details 34,35 and 37-39.
	6	1	13-06-'80	Details 40-46.
	7	1	13-06-'80	Details 47 and 50-54.
	8	1	13-06-'80	Detail 50
	9	1	13-06-'80	Details 56,59,62,63 and 68.
	10	1	13-06-'80	Details 69,72,74,75,77,78,83 and 87.
MRL 2877-02 (2 sheets)	1	1	13-06-'80	Radial Pressure Bar: Lock Sub-Assembly; Arrangement and Details 1,4 and 13.
	2	1	3-06-'80	Details 5,6,14,15,18,20,21 and 25.
MRL 2877-03 (2 sheets)	1	1	13-06-'80	Radial Pressure Bar: Exhaust Chamber; Sub-assembly - Arrangement.
	2	1	13-06-'80	Details 1 - 3.
SLIDES AND SUB-ASSEMBLIES				
Slides				**Slide Testing**
DSL 2230/2	1	1	28-10-'71	Torpedo, Electric No.1 Mk 2.
DSL 2230/3	1	1	28-10-'71	Grenade No. 75 & Percussion N3 and N5.
DSL 2230/4	1	1	22-11-'71	Detonator Percussion Watertight.
DSL 2230/5	1	1	28-10-'71	Detonator Band Release 2 second and 4 second (Ikara) and Break-up Fairing (Ikara).
DSL 2230/6	1	1	28-10-'71	Demolition Detonators.
DSL 2230/8	1	1	22-11-'71	Detonator Electric No.28 Mk 2.
MRL 2547-01	1	2	05-03-'75	Detonator Percussion N5 Mk2. (DSL 22?0/3 added to)
DSL 63/1613/1	1	1	23-12-'63	Detonator Electric No. 21.
DSL 63/1613/2	1	1	23-12-'63	Detonator LEN6, and Nos. 6,8 79, 80, 82, 108, 109 & similar types

Drawing Number	Sheet No.	Issue No.	Date	Item
Sub-Assemblies				**Terminal Outlets Sub-Assembly:**
MRL 2877-01*	1	1	29-07-'80	See Drawings Below
DSL 58/2535/2	1	1	11-03-'59	Terminal Outlets Assembly.
(2 sheets)	2	1	11-03-'59	Details 1,2 and 3.
DSL 58/2635/1	1	1	10-12-'58	Terminal Sub-assembly and Details 1 to 4.
DSL 58/2635/2 (2 sheets)	1	1	10-12-'58	Terminal Socket Sub-assembly and Details 1,2,4,5 and 7.
	2	1	10-12-'58	Details 3,6 and 8.
MRL 2877-01*	1	1	29-07-'80	**Control Box Sub-Assembly**
DSL 58/2602	1	2	05-10-'79	Sub-Assembly and Detail 8.
MRL 2877-01*	1	1	29-07-'80	**Stop Sub-Assembly**
DSL 58/2636 (2 sheets)	1	1	03-02-'59	**Stop Percussion Firing Assembly**
	2	1	25-02-'59	Details 1,4 to 10.
MISCELLANEOUS				
MRL 2877-04	1	1	20-01-'80	Slides and Explosion Chamber Assemblies for various detonators.
DSL 2230/7	1	1	28-10-'71	Assembly and Details: Striker, Detonator, Percussion Water-tight.
MOULDS - RUBBER PELLETS:				
Pellets Front Types A & B				
MRL 2817-01 (5 sheets)	1	2	02-12-'80	Mould: Rubber Pellet - Front; Types A and B (Radial Pressure Bar) - Assembly.
	2	2	10-02-'80	Details -Guide Pin, Groove Insert Type A, Groove Insert Type B, Half Groove Insert Type A Half Groove Insert Type B, Guide Bush.
	3	2	02-12-'80	Top Pressure Plate.
	4	3	02-12-'80	Bottom Pressure Plate.
	5	2	11-12-'78	Detail - Cavity Plate.

Drawing Number	Sheet No.	Issue No.	Date	Item
Pellet Back				
MRL 2817-02 (5 sheets)	1	3	02-12-'80	Mould: Rubber Pellet - Back (Radial Pressure Bar) - Assembly.
	2	2	02-12-'80	Details - Guide Pin, Groove Insert, Guide Bush.
	3	3	02-12-'80	Top Pressure Plate.
	4	3	02-12-'80	Bottom Pressure Plate.
	5	2	21-08-'80	Detail - Cavity Plate.
ASSOCIATED EQUIPMENT:				
Velocity Measuring Equipment				
MRL 2872-01 (12 sheets)	1,2	2	03-'81	Velocity Measuring Device: Assembly and Details.
	3	2	15-10-'79	Details.
	4 to 8	2	28-08-'79	Details.
	9	3	28-08-'79	Details.
	10	2	28-08-'79	Details.
	11	2	10-10-'79	Details.
	12	1	03-'81	Details.
Microsecond Counter Chronometer - Mk 3				
MRL 2764-01 (4 sheets)	1	6	05-'82	Assembly.
	2	6	05-'82	Details.
	3	5	01-'81	Details.
	4	9	05-'83	Circuit Diagram and Power Supply Board.

* Indicates repeat of drawing for reference to tree assemblies.

APPENDIX F

DRAWING LIST FOR 18 mm TERMINAL PRESSURE BAR

Drawing Number	Sheet No.	Issue No.	Date	Item
MRL 59/1882	1	3	23-07-'80	18 mm Terminal Pressure Bar: General Arrangement.
MRL 59/1882/1 (2 sheets)	1	3	23-07-'80	Explosion Chamber and Pendulum Release Support: Arrangement and Details 1,6 and 11.
	2	3	23-07-'80	Details 2 to 4, 8 and 14.
MRL 59/1882/2	1	5	23-07-'80	Firing Block Assemblies and Details 1, 2, 4 to 20.
MRL 59/1882/3 (3 sheets)	1	4	21-07-'64	18 mm Pressure Bar Apparatus: Pressure Bar Assembly and Details 1 to 7, 11 to 16, and 19.
	2	2	21-07-'64	Part No. 9 - Bracket with Roller Sub-assembly and Details 2 to 4. Part No. 10 - Spring Loading Device Sub-assembly and Details 1, 2, 4, 5 and 8. Part No. 20 - Bracket for Spring Support Sub-assembly and Details 1, 2 and 4.
	3	2	22-07-'64	Part No. 8 - Roller Sub-assembly and Details 1 to 4.
DSL 59/1882/4	1	2	21—7-'64	Bed and Details 1 to 3.
DSL 66/1718 (2 sheets)	1	1	20-01-'67	Chamber Interlock - Arrangement and Details 2,4,7 and 15 to 17.
	2	1	20-01-'67	Details 1,5 and 20-22.
DSL 63/2419/1	1	1	17-02-'64	Electromagnetic Pendulum Release - Arrangement and Details 1-3, 6-9, 11, 14, 15, 18-24, 26 & 28-30.
UK IA(MISC) 2207 *	1	4	29-09-'66	18 mm Pressure Bar: Detail - Bar.
UK IA(MISC) 2208 †	1	4	23-09-'66	18 mm Pressure Bar: Detail - Time-piece.
-	-	-	-	Exhaust Cover.

* Traced: MRL 3420-01 Sheet 1 Issue 1 Dated 30-05-1986.
† Traced: MRL 3420-01 Sheet 2 Issue 1 Dated 30-05-1986.

Drawing Number	Sheet No.	Issue No.	Date	Item
MOULD - RUBBER PELLET				
MRL 2742-01	1	1	11-07-'77	4 Cavity Mould - Arrangement and Details.
MRL 2821-01 (8 sheets)	1	4	12-'83	25 Cavity Mould - Arrangement and Details.
	2	4	11-'83	Mould Centre
	3	4	11-'83	Platen Lower
	4	4	11-'83	Details - Pin; Plate
	5	1	11-'83	Adapter - Lower Platen
	6	1	11-'83	Adapter - Lower Platen
	7	3	11-'83	Adapter - Pin platen
	8	1	12-'83	Adapter - Pin plate
MRL 2821-02	1	1	04-02-'80	Lever.
ASSOCIATED EQUIPMENT:				
Velocity Measuring Equipment				
MRL 2872-01 (12 sheets)	1,2	2	03-'81	Velocity Measuring Device: Assembly and Details.
	3	2	15-10-'79	Details.
	4 to 8	2	28-08-'79	Details.
	9	3	28-08-'79	Details.
	10	2	28-08-'79	Details.
	11	2	10-10-'79	Details.
	12	1	03-'81	Details.
Microsecond Counter Chronometer - Mk 3				
MRL 2764-01 (4 sheets)	1	6	05-'82	Assembly.
	2	6	05-'82	Details.
	3	5	01-'81	Details.
	4	9	05-'83	Circuit Diagram and Power Supply Board.

APPENDIX G

METHOD FOR ESTABLISHING LIMITS

For establishing specification limits it is required that detonators be specially filled. The basis of fillings and typical quantities are as follows:

METHOD 1: (Drawing gives Nominal filling with tolerances)

Group A filling:	Mean Filling ± 1.5% of Mean or ± .005 g or .05 gr
Group B filling:	90% of Mean ± 1.5% of Mean or ± .005 g or .05 gr

Note: In the case of multiple pellets use ± .01 g instead of .005 g.

Example: Detonator L2A1

Filling	Drawing Limits (g)	Group "A" (g)	Group "B" (g)
ASA	0.35 ± .025	0.35 ± .005	0.32 ± .005
CE Granules	0.30 ± .005	0.30 ± .005	0.27 ± .005
CE Pellets (3 x .25 g)	0.75 ± .01	0.75 ± .01	0.68 ± .01
Number Required		25	15

Method 2: (Drawing gives Upper and Lower Limits)

Group "A" Upper Limit ± .005 g Number Required 25
Group "B" Lower Limit ± .005 g Number Required 15

Method 3: (Drawing gives Nominal Filling with + tolerance and NIL - tolerance)

Group "A" Nominal Filling + (+ tolerance)
Group "B" Nominal Filling
Group "C" 90% of Nominal Filling + 0.005 g

Example: Detonator DBR 2 second

Filling	Drawing Limits (g)	Group "A" (g)	Group "B" (g)	Group "C" (g)
RDX (RD 1347)	0.130 + 0.003 - 0.000	0.133	0.130	0.123
Lead Azide	0.065 + 0.003 - 0.000	0.068	0.065	0.058

Method 4: (18 mm Pressure Bar) Detonator 2.0 gr RZY

Filling	Drawing Limits (gr)	Group "A" (gr)	Group "B" (gr)	Group "C" (gr)
CE	0.40 ± .05	0.40	0.35	0.30
Lead Azide	1.25 Approx	1.25	1.10	1.00
RD 1336	0.30 ± .05	X_1	X_2	X_3
Number Required		25	15	15

Notes:
1. X_1, X_2 and X_3 to be selected to give a filling height that will enable closing to give an overall length of 0.75 ± .005 in.
2. A valued estimation of fillings should be made for the filling of stab initiated cylindrical detonators fired in the 18 mm Pressure Bar.

Quantities

Quantities should be sufficient for a proper estimate of limits. Generally quantities should not be less than the following:

	Radial Pressure Bar (typical)			18 mm Pressure Bar	
Group A	25	30	25	16	25
Group B	15	20	15	9	15
Group C	-	-	10	5	15

PROCEDURE FOR TESTING AND ESTABLISHING LIMITS

a. Prior to firing tabulate:
Det. No.; Component filling weight; Energy of Decomposition for each filling weight(s); and Overall Mean of Energy of Decomposition (for each Group).

b. Carefully conduct the firing of the detonators (preferably on different days) and tabulate the firing results.

c. Graph the grouped results of firings against energy of decomposition.

d. Assess any "Outliers" (using the Dixon Criteria).

Reference: Experimental Statistics Handbook 91
US Department of Commerce
National Bureau of Standards
Chapter 17 and Table 14

e. Accept or reject results in accordance with this method so that the calculation is based on the proper population and not on any outliers that are spurious for various reasons.

f. Calculate the Mean and Standard Deviation of the fired results of each Group (after discarding "outliers").

g. The specification limits are calculated for small sample sizes as follows:

i. Reference: British Standard BS 600R:1942 - Quality Control Charts
Table 10 - Control Chart Limits for Average ($\bar{x}$)
- For Outer Limits $A_{0.001}$

ii. Use the Outer Limits in the Lower Direction.

Example:

Specification Limit

Number in Sample	Calculation of Limit
10	Firing Mean of Group "A" minus 0.977 SD
5	Firing Mean of Group "A" minus 1.382 SD
20	Firing Mean of Group "A" minus 0.691 SD
Minimum Individual	Firing Mean of Group "A" minus 5% of Firing Mean of Group "A" minus 3 SD

Note: Usually for the radial pressure bar proof samples used are 10 and 5 whereas for the 18 mm pressure bar a sample of 20 is used.

Table 5 gives a typical example of such a calculation for establishing limits.

TABLE 5

Establishing Limits DBR 2 second

A. Results of Firing (in descending order of Time-Piece Energy)

Group "A"	Group "B"	Group "C"
3.226	2.837	2.585
2.914	2.771	2.348
2.887	2.648	2.228
2.867	2.595	2.137
2.863	2.536	1.938
2.860	2.524	1.779
2.807	2.477	1.498
2.785	2.396	1.191
2.774	1.632 R-DC	
2.760		
2.672		
2.648		
2.595		
2.420		
2.110 R-DC		
1.452 R-DC		

R-DC = Discarded for Limits - Outliers in accordance with Dixon Criteria (DC)

n = 14 (for calculation of limits)

$\bar{x}$ = 2.7913

SD = .177

B. Filling and Energy Data from Firings

Group	Filling (g)		Energy of Decomposition (cal)	Number for Mean	Time-Piece Energy (J)		
	RDX	Service Lead Azide			Mean	Standard Deviation	Range
A	0.133	0.068	206.395	14	2.791	0.177	0.806
B	0.130	0.065	201.175	8	2.598	0.140	0.441
C	0.123	0.058	188.995	8	1.963	0.185	1.394

C. Calculation of Limits

Sample of 10	Sample of 5	Minimum Individual (MI)
$\bar{x}$ = 2.971	$\bar{x}$ = 2.971	$\bar{x}$ = 2.971
SD = 0.177	SD = 0.177	SD = 0.177
Limit = 2.971 minus 0.977 (0.177) = 2.618	Limit = 2.971 minus 1.382 (0.177) = 2.546	Limit = 2.971 minus 5% (2.971) minus 3 (0.177) = 2.120

Established Limits

Sample of 10 : Not less than 2.618
Sample of 5 : Not less than 2.546
Minimum Individual : Not less than 2.120

Note: Groups B and C are used as indicators for sample level acceptance as to laid down means and the Minimum Individual must be above the Group C level (90% filling).

APPENDIX H

FINAL EQUIPMENT

METHOD OF CALCULATION OF THE ENERGY USING THE VMD, COUNTER CHRONOGRAPH AND RUBBER PELLETS

Let:

M = mass of the time-piece, kg

L = projectile flight timing distance, metres

t = time of flight over L , milliseconds, (time-piece flight)

$\bar{t}$ = average time, milliseconds, (time-piece flight)
(duplicate readings of time of flight t, averaged)

T = average time, seconds, (time-piece flight)

V = velocity of time-piece, metres/second

E = energy of time-piece, joule,
(reported to 3 significant figures)

Calculation of Energy

$$E = 1/2\ MV^2 \qquad \text{but:} \quad V = \frac{L}{T}$$

Now: L = standard distance of 25 cm = 0.25 m

$$T = \frac{\bar{t}}{1{,}000} = \frac{\bar{t}}{10^3} \text{ seconds}$$

$$M = 20.7 \text{ gram} = \frac{20.7}{10^3} \text{ kg (in the case of the Radial Pressure Bar)}$$

$$M = 24.6 \text{ gram} = \frac{24.6}{10^3} \text{ kg (in the case of the 18 mm Terminal Pressure Bar)}$$

Radial Pressure Bar

$$E = 1/2 \times \frac{20.7}{10^3} \times \{0.25/(\bar{t}/10^3)\}^2 = 1/2 \times 20.7 \times (0.25/\bar{t})^2 \times 10^3 \text{ joule}$$

$$= \frac{646.875}{(\bar{t})^2} \text{ joule where } \bar{t} \text{ is measured in milliseconds)}$$

18 mm Terminal Pressure Bar

$$E = 1/2 \times \frac{24.6}{10^3} \times \{0.25/(\bar{t}/10^3)\}^2 = 1/2 \times 24.6 \times (0.25/\bar{t})^2 \times 10^3 \text{ joule}$$

$$= \frac{768.750}{(\bar{t})^2} \text{ joule (where } \bar{t} \text{ is measured in milliseconds)}$$

Example of Calculation:

Radial Pressure Bar:

$$E = \frac{646.875}{(\bar{t})^2} \text{ joule}$$

t_1 = 6.35 milliseconds

t_2 = 6.33 milliseconds

$\bar{t}$ = 6.34 milliseconds

M = 20.7 gram
(**Note:** A correction is required if there is a significant change in weight after re-surfacing)

$$E = \frac{646.875}{6.34^2} = 16.093 \text{ joule}$$

18 mm Terminal Pressure Bar

$$E = \frac{768.750}{(\bar{t})^2} \text{ joule}$$

t_1 = 12.36 milliseconds M = 24.6 gram

t_2 = 12.34 milliseconds (**Note:** As above)

$\bar{t}$ = 12.35 milliseconds

$$E = \frac{768.750}{12.35^2} = 5.040 \text{ joule}$$

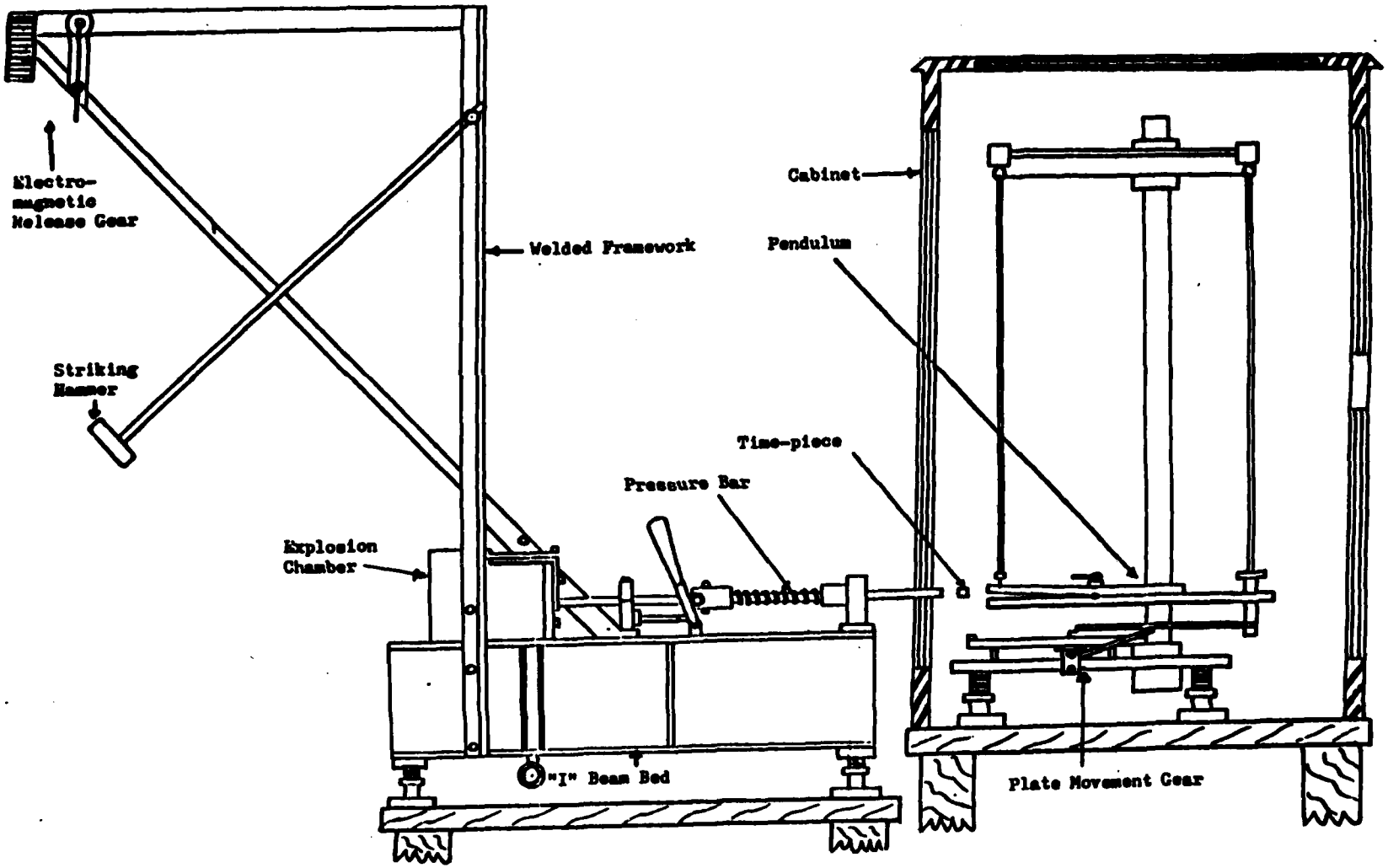


FIGURE 1 General arrangement of the 18 mm terminal pressure bar - pre 1945 equipment.

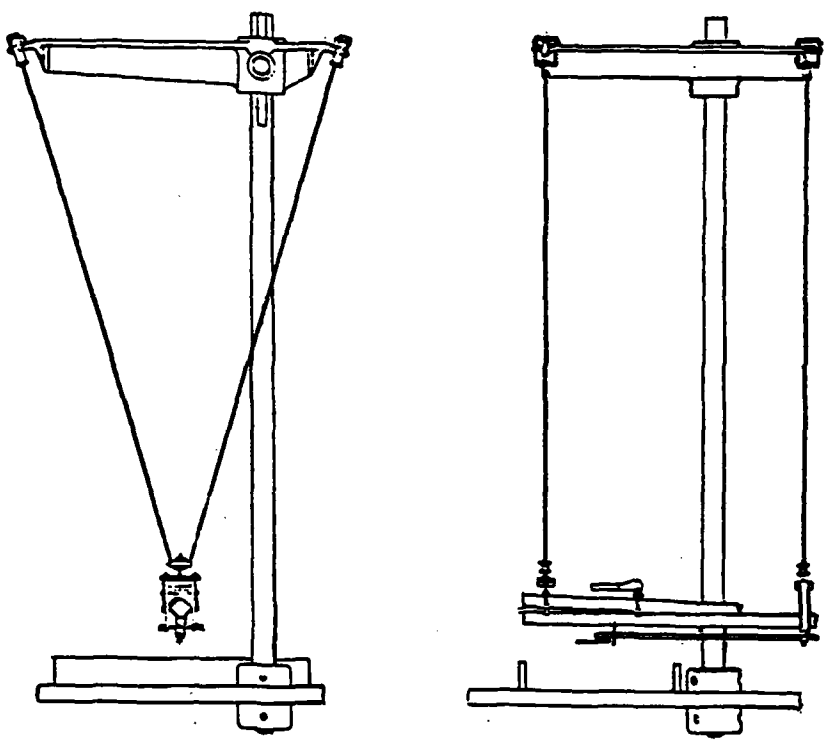


FIGURE 2 **Pendulum arrangement for the radial and 18 mm terminal pressure bars - pre 1945 equipment.**

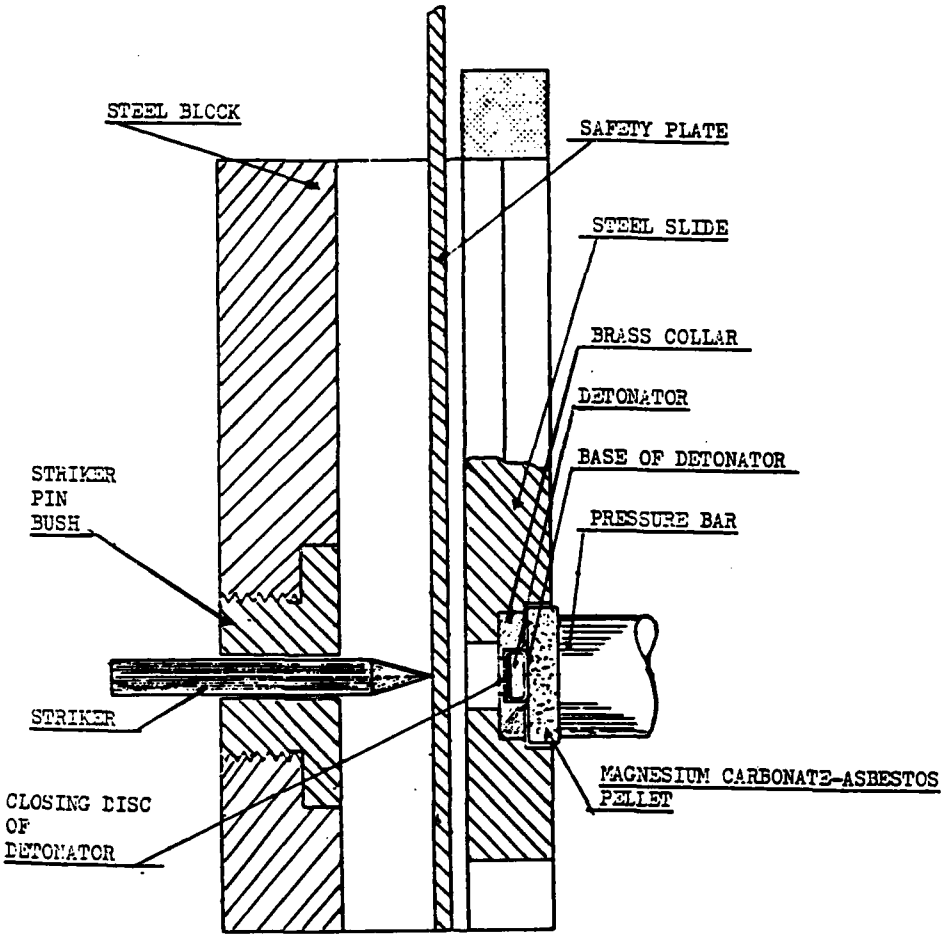


FIGURE 8 **18 mm terminal pressure bar - pre 1945 equipment; method of testing stab initiated detonators - firing block assembly.**

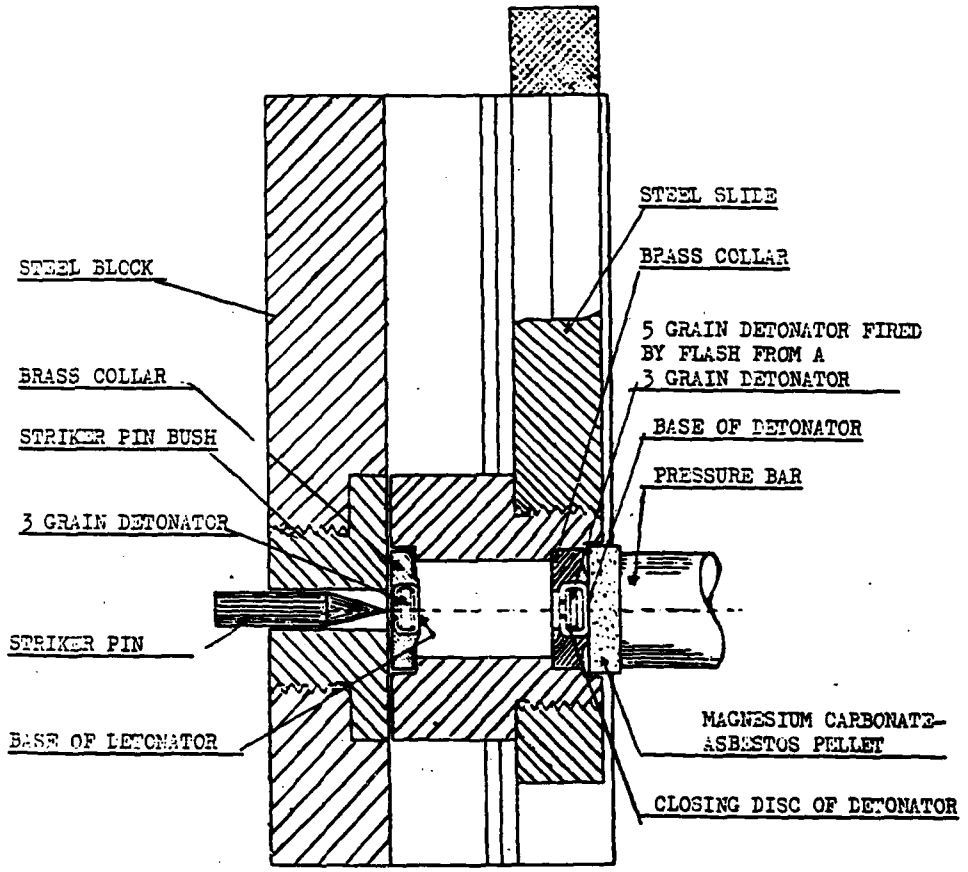


FIGURE 4 **18 mm terminal pressure bar - pre 1945 equipment; method of testing flash initiated detonators - firing block assembly.**

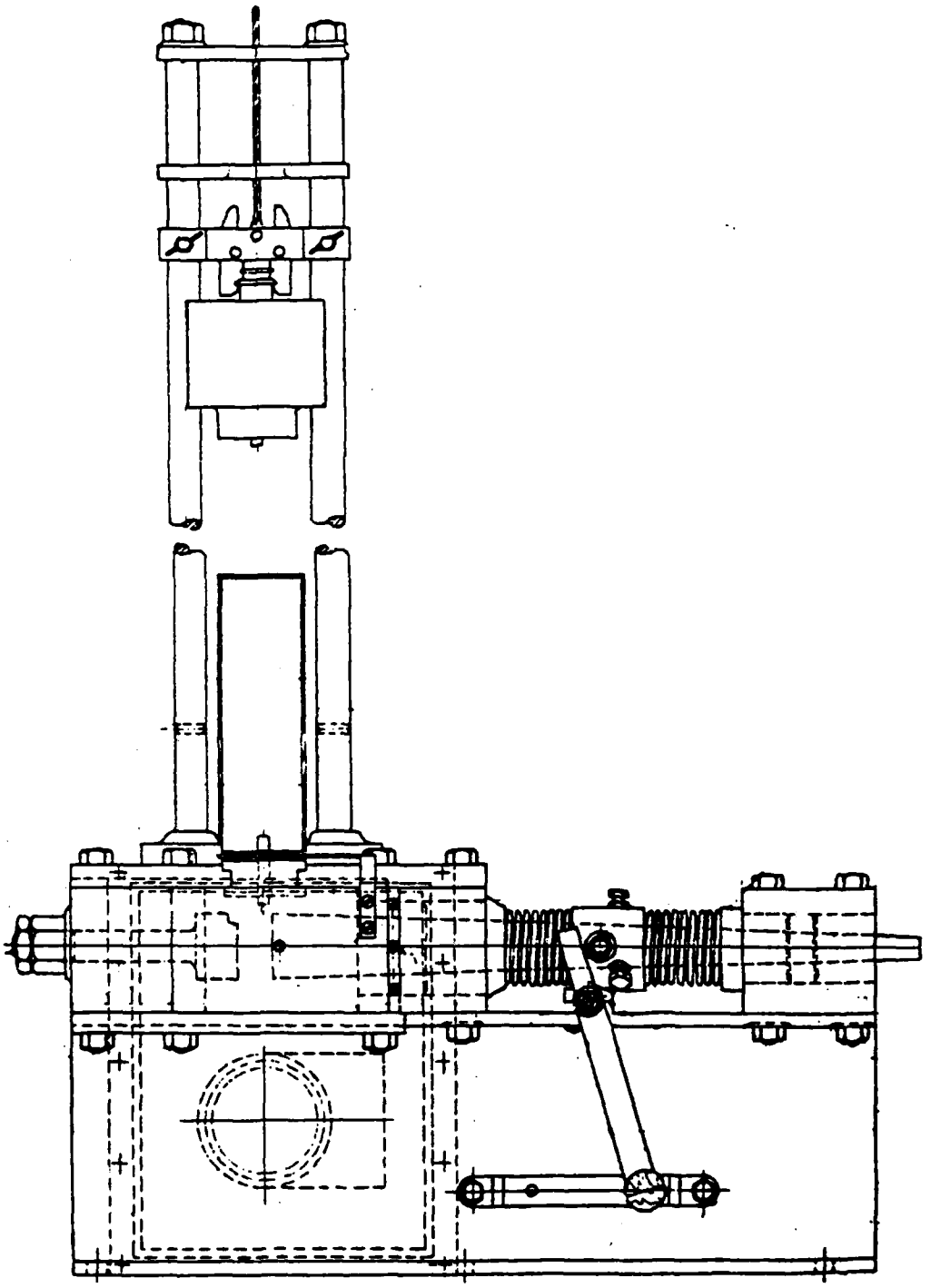


FIGURE 5 General assembly - radial pressure bar; pre 1945 equipment (pendulum not shown).

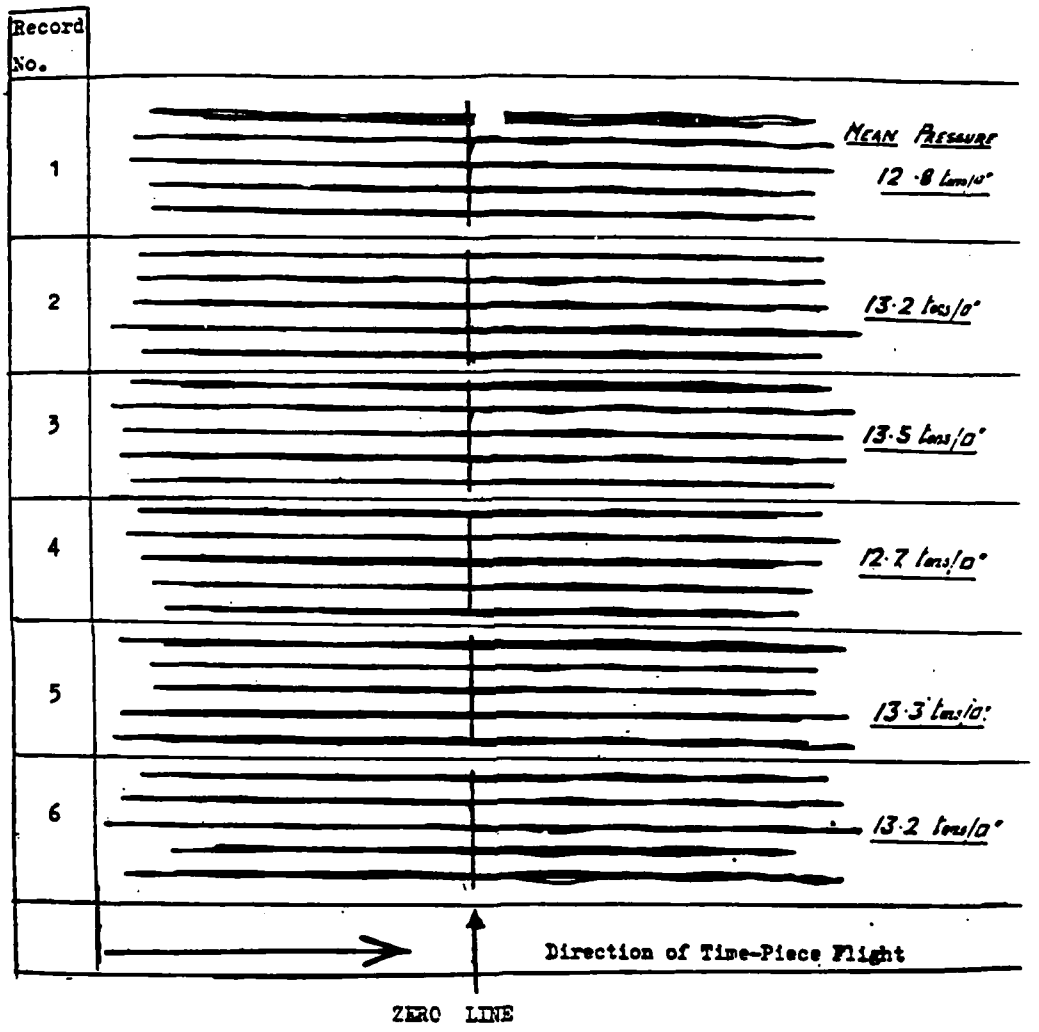


FIGURE 6 Example of pressure bar records on the smoked glass plate - pre 1945 equipment.

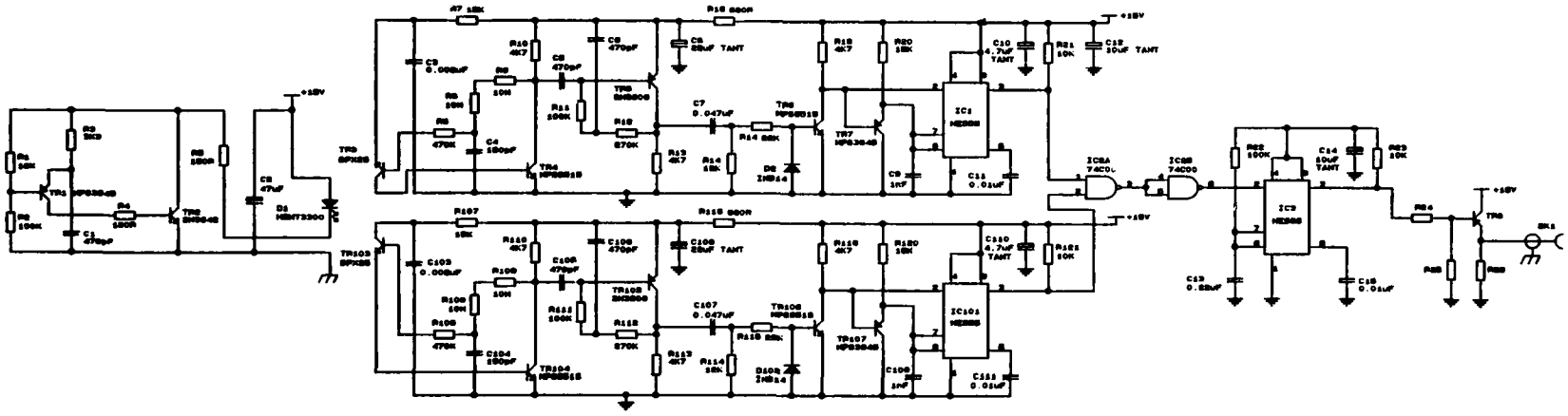


FIGURE 7 Final equipment (VMD) - Circuit diagram

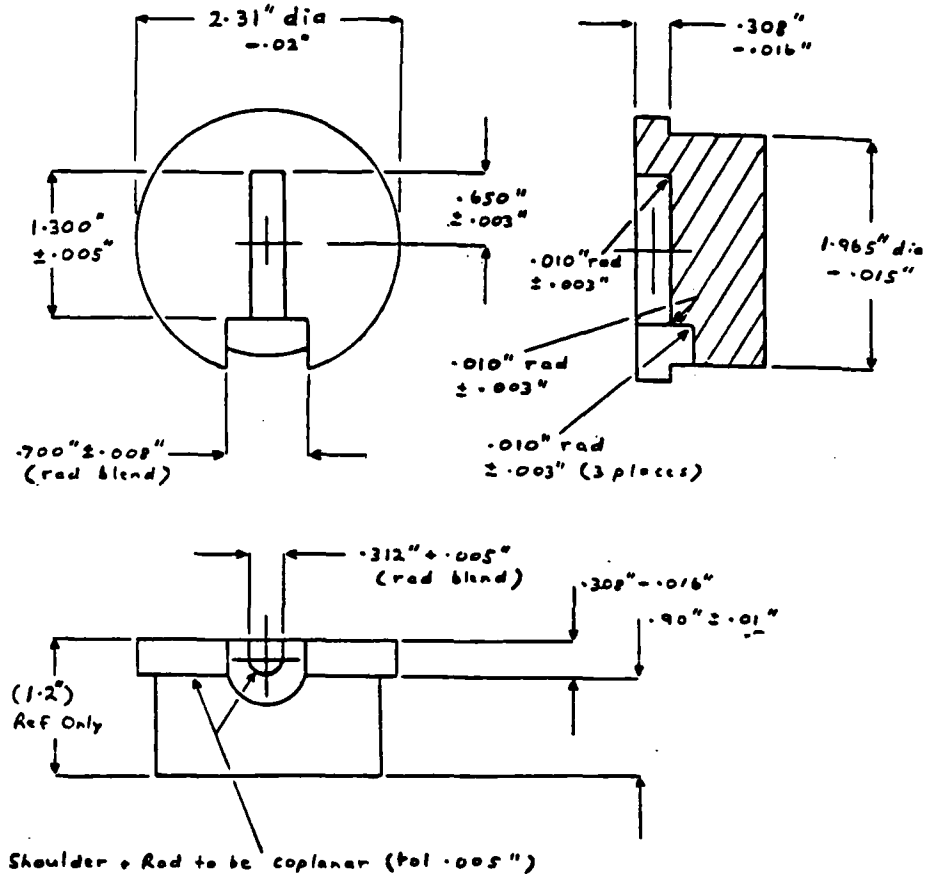


FIGURE 8 Radial pressure bar – pellet holder (front) Type A.

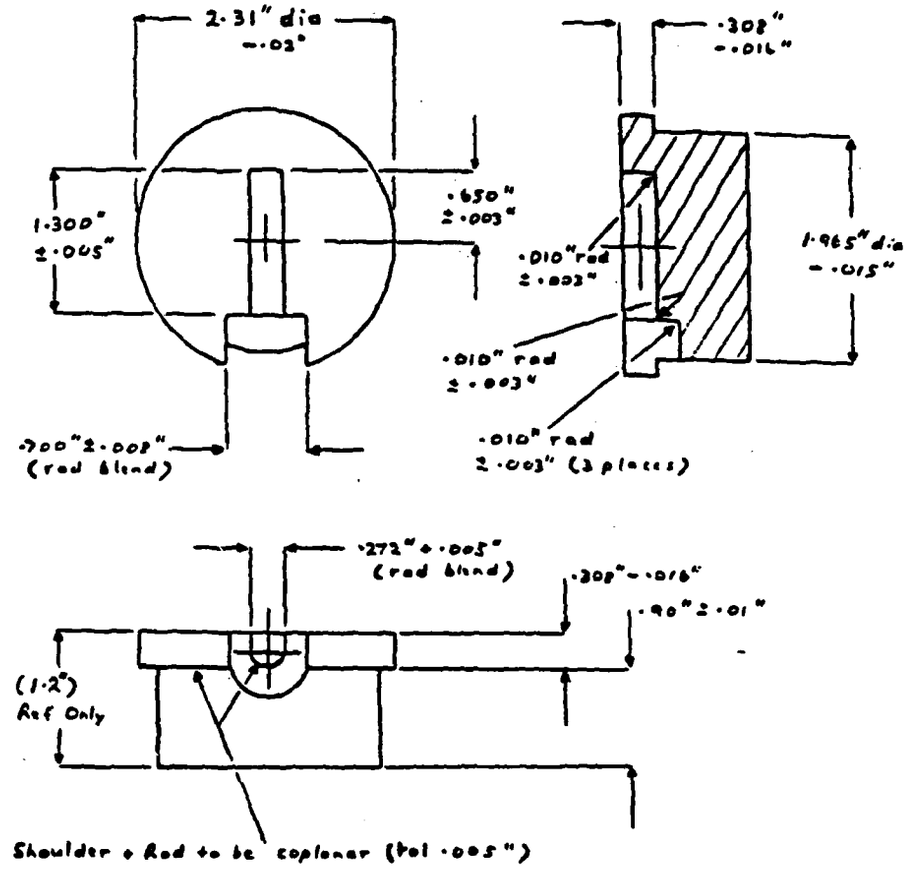


FIGURE 9 Radial pressure bar - pellet holder (front) Type B.

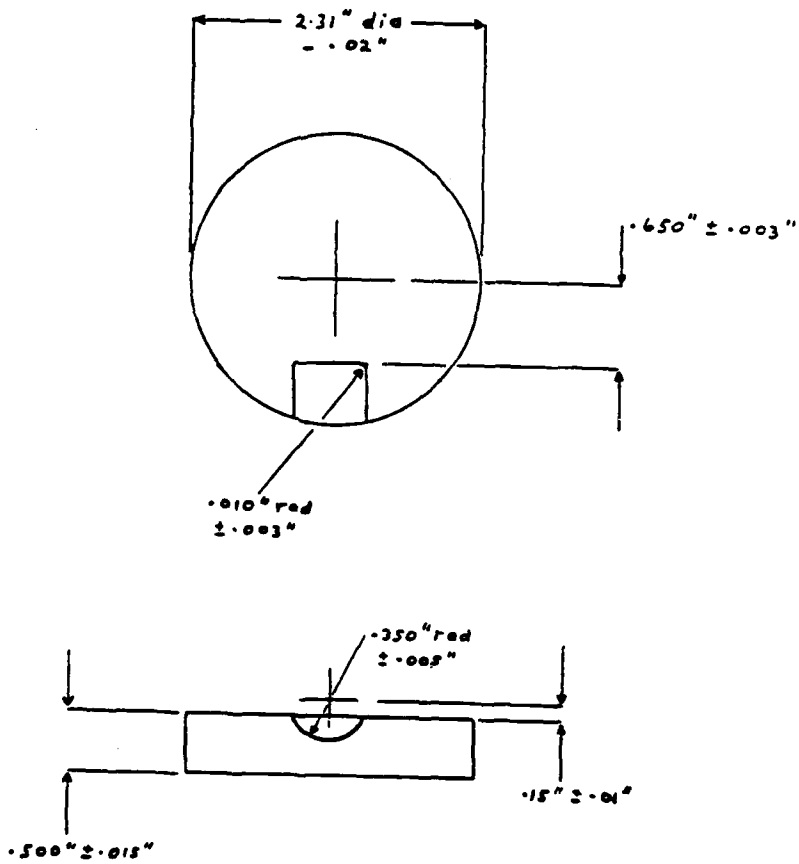
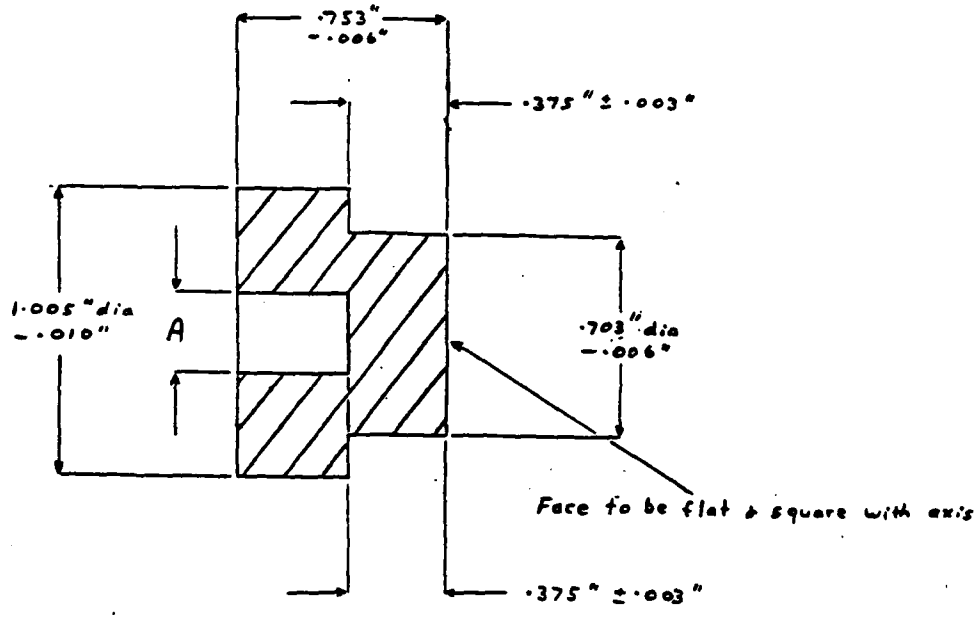


FIGURE 10 Radial pressure bar - pellet holder (back).



Pellet Type 1 - Hole Diameter A = .302 inch (6.67 mm)
Pellet Type 2 - Hole Diameter A = .190 inch (4.83 mm)
Pellet Type 3 - Hole Diameter A = .169 inch (4.29 mm)

FIGURE 11 18 mm terminal pressure bar - pellet holders types 1, 2 and 3.

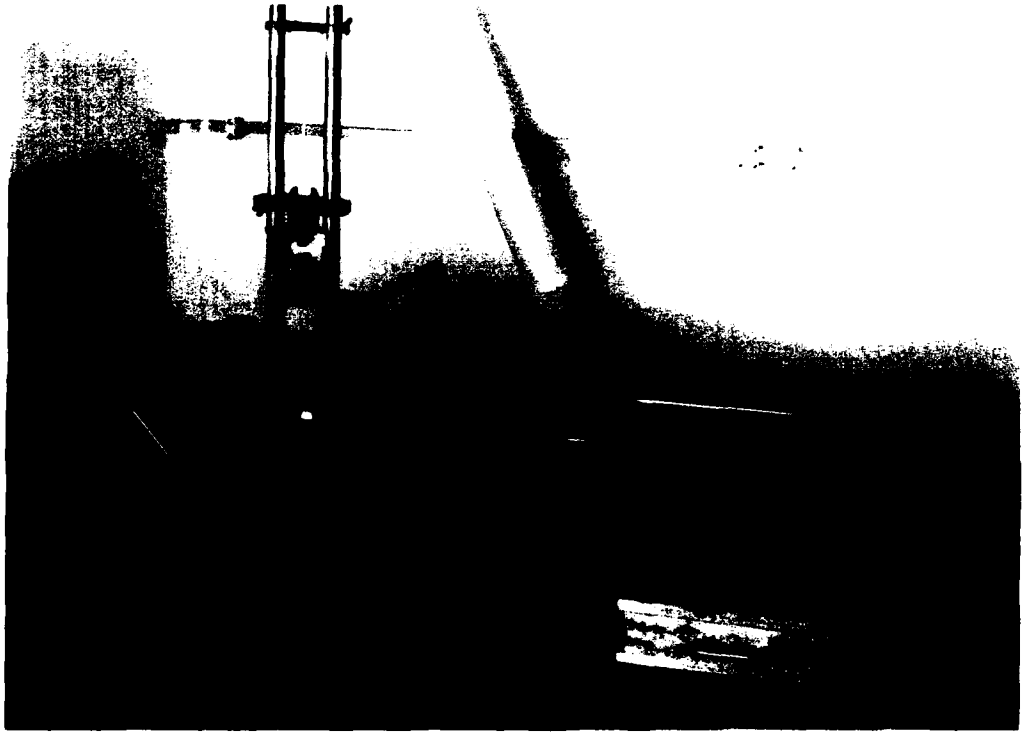


FIGURE 12 Current radial pressure bar (MRL Model) - utilises the rubber pellet system.

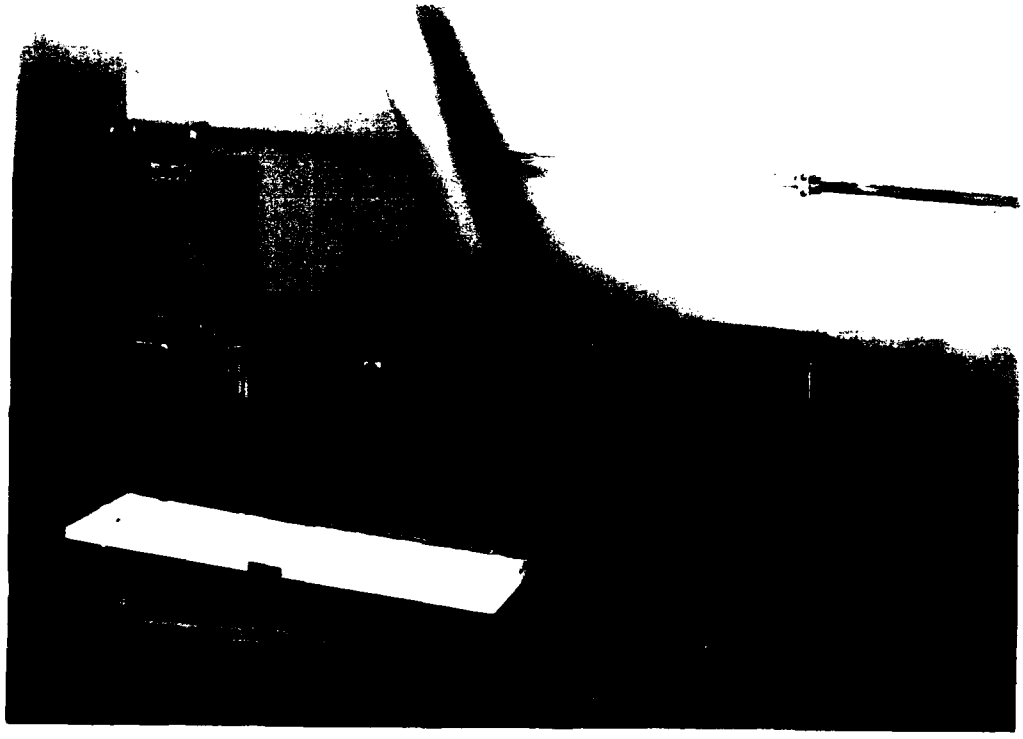


FIGURE 13 Current 18 mm (0.7 inch) terminal pressure bar (MPL Model) - utilises the rubber pellet system.

PARTS LIST

PART	TITLE
1	TERMINALS.ELECTRIC FIRING
2	SLIDE
3	HOLDER PELLET. BACK
4	HOLDER PELLET. FRONT TYPE B
5	CONFINING COLLAR

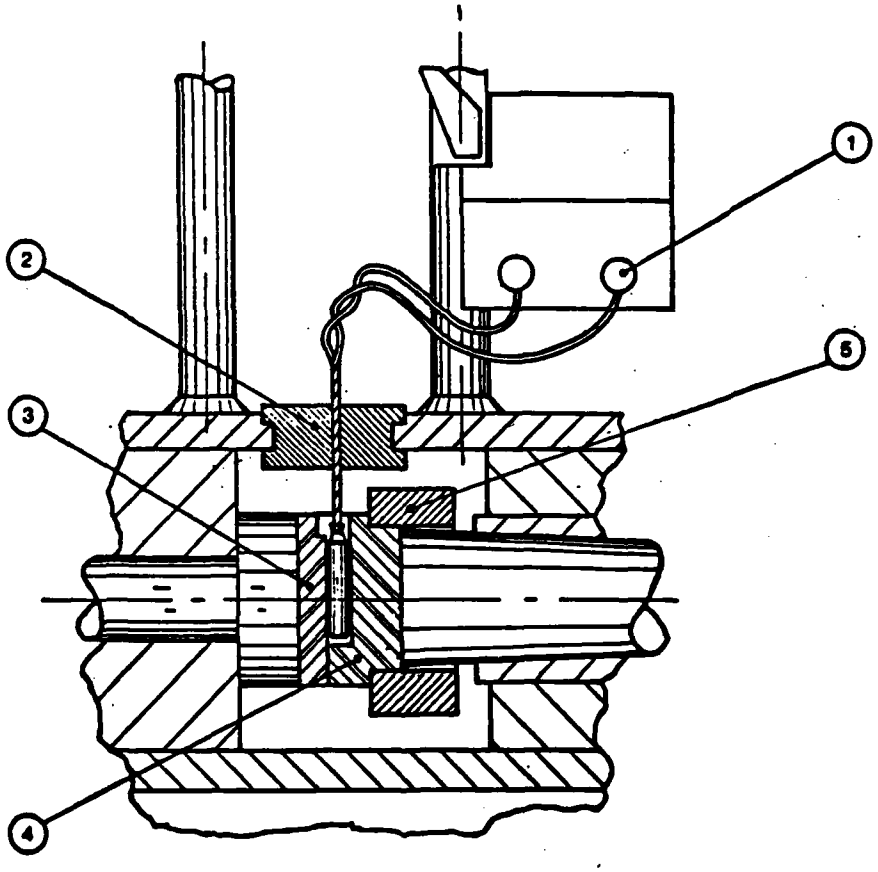


FIGURE 14 Radial pressure bar; rubber pellet holder system - assembly method for electrically fired detonators.

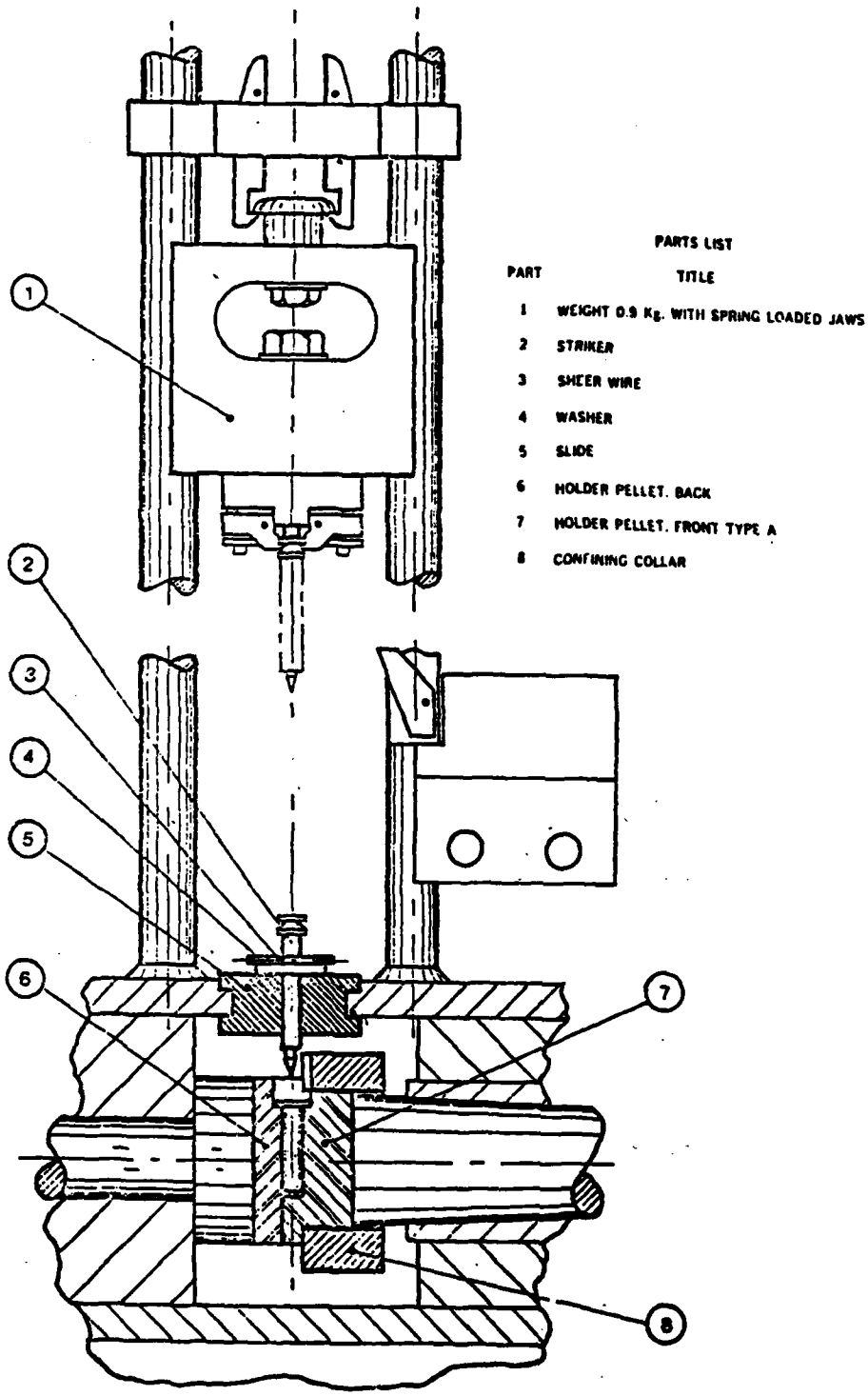
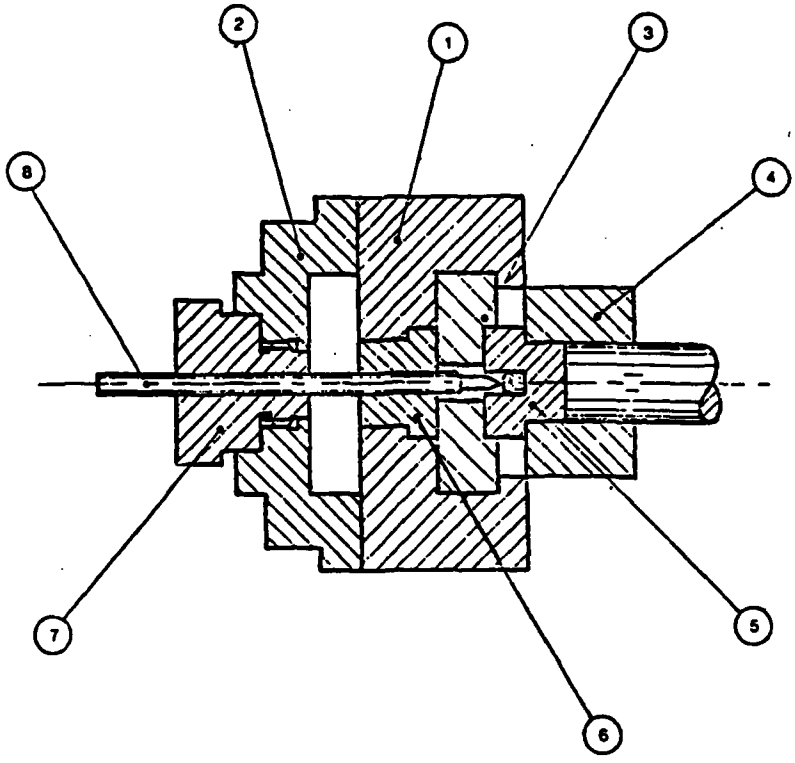


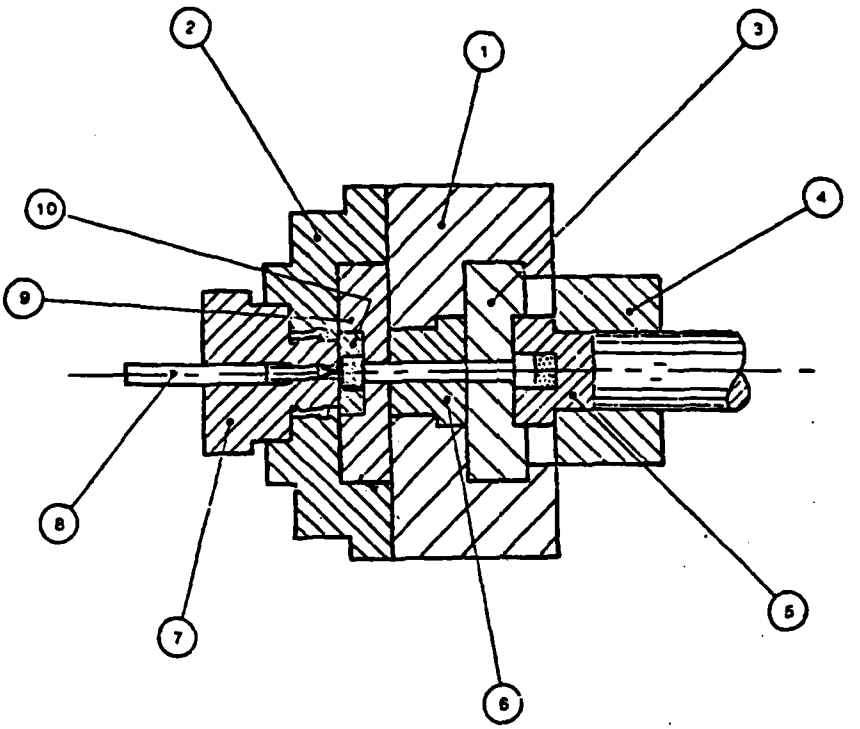
FIGURE 15 Radial pressure bar; rubber holder pellet system - assembly method for percussion fired detonators.



PARTS LIST

PART	TITLE
1	BODY
2	FRONT PLATE
3	SLIDE IN BODY
4	CONFINING COLLAR
5	HOLDER PELLET
6	GUIDE BUSH OR FLASH BUSH
7	STRIKER ADAPTER
8	FIRING PIN

FIGURE 16 **18 mm terminal pressure bar - rubber pellet holder system; method of assembly for firing stab initiated detonators.**



PARTS LIST

PART	TITLE
1	BODY
2	FRONT PLATE
3	SLIDE IN BODY
4	CONFINING COLLAR
5	HOLDER PELLET
6	GUIDE BUSH OR FLASH BUSH
7	STRIKER ADAPTER
8	FIRING PIN
9	SLIDE IN FRONT PLATE
10	COLLAR FOR FLASH DETONATOR

FIGURE 17 **18 mm terminal pressure bar - rubber pellet holder system; method of assembly for firing flash initiated detonators.**

RADIAL PRESSURE BAR: GRAPH OF TIME-PIECE ENERGY/DECOMPOSITION ENERGY

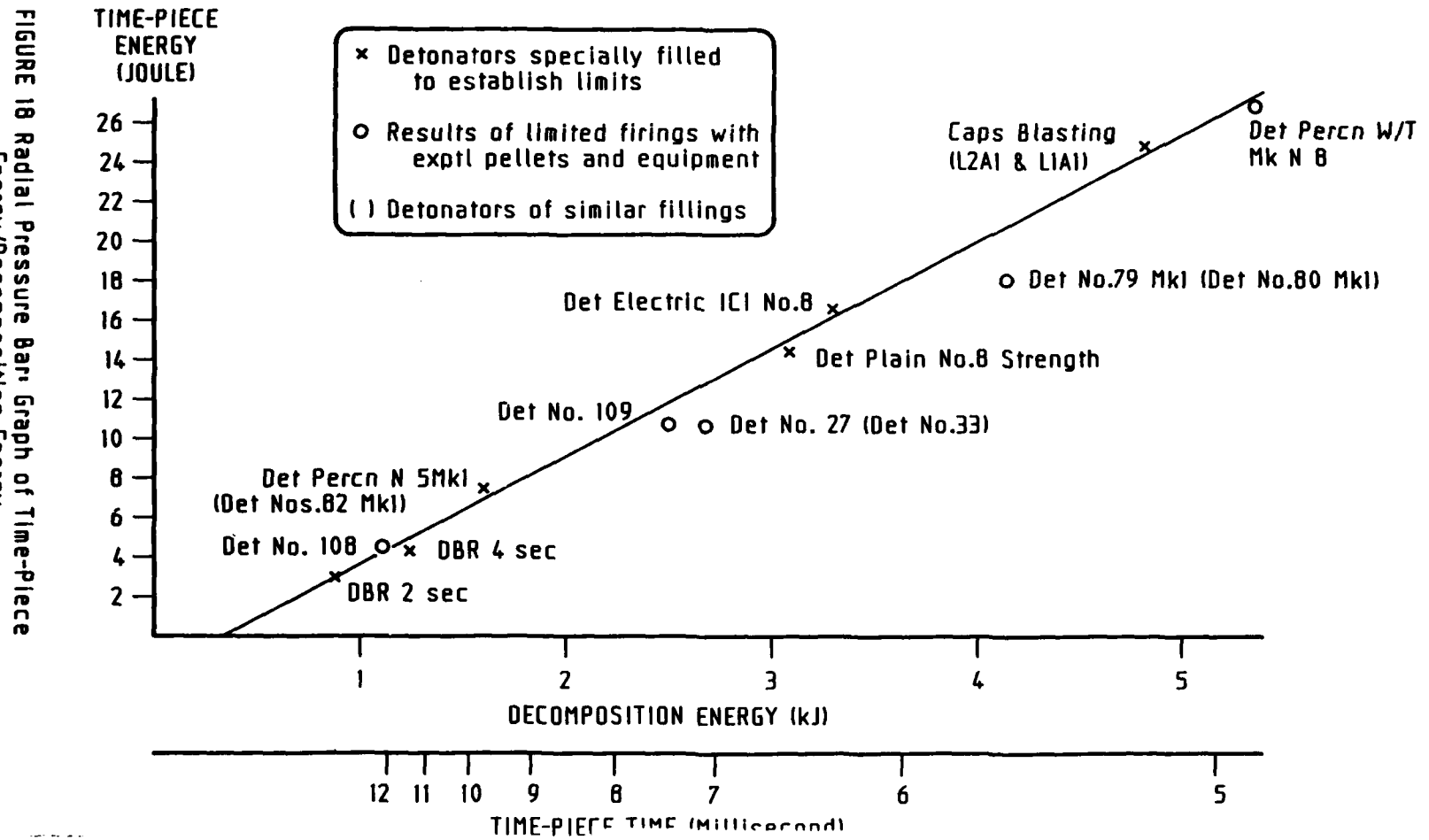


FIGURE 18 Radial Pressure Bar: Graph of Time-Piece Energy/Decomposition Energy

18mm TERMINAL PRESSURE BAR: GRAPH OF TIME-PIECE ENERGY/DECOMPOSITION ENERGY

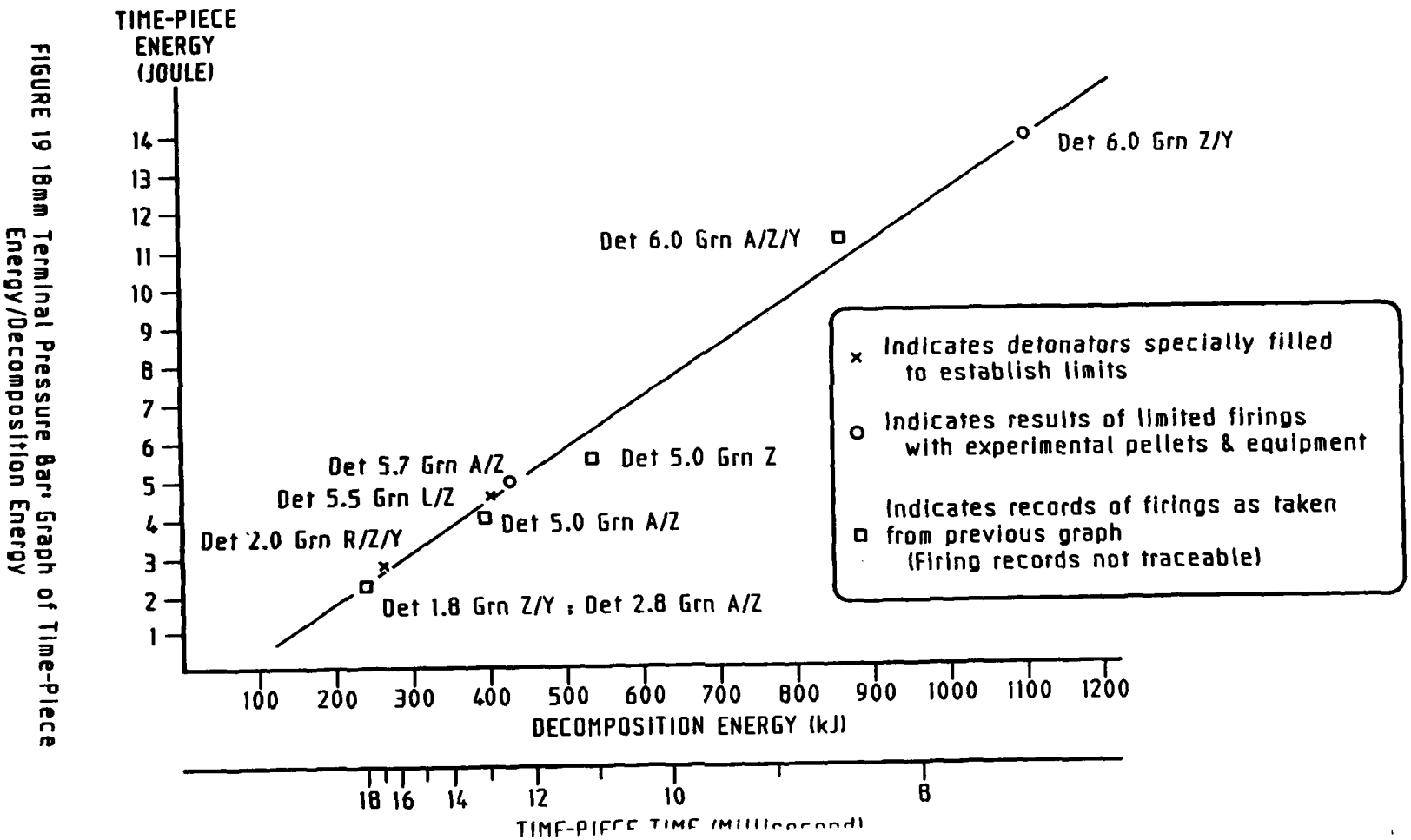


FIGURE 19 18mm Terminal Pressure Bar: Graph of Time-Piece Energy/Decomposition Energy

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A pressure bar test free of asbestos for determination of detonator performance

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Detonation wave

SUBJECT GROUPS 0079E

ABSTRACT

The Pressure Bar equipment for testing detonators was developed from the Hopkinson Pressure Bar. Detonators were tested at Materials Research Laboratory (MRL) till 1969 on the Pressure Bar using an "asbestos-magnesium carbonate" degrading and protection pellet to transmit the detonation wave from the detonator to the pressure bar. In 1969, the use of asbestos was banned at MRL for health reasons. It thus became necessary to find an alternative test material and to suitably modify the Pressure Bar equipment to accept this alternative. This report details the search for such a material and the establishment of modified Pressure Bar equipment. Data for a wide range of Service and commercial detonators are described.