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18 February 1946

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From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Ordnance Research, Article 2 - Experimental Research on Super High Velocity Guns and Projectiles.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, dealing with Target O-39 of Fascicle O-1 of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Lt. Comdr. L.N. Peabody, USNR.

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31058

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O-39-2

JAPANESE ORDNANCE RESEARCH - ARTICLE 2
EXPERIMENTAL RESEARCH ON SUPER HIGH VELOCITY GUNS AND PROJECTILES

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945

FASCICLE O-1, TARGET O-39

FEBRUARY 1946

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SUMMARY

ORDNANCE TARGETS

JAPANESE ORDNANCE RESEARCH - ARTICLE 2
EXPERIMENTAL RESEARCH ON SUPER HIGH VELOCITY GUNS AND PROJECTILES

The following paragraphs, quoted from a translation of a Japanese document upon which this report is based, present the opinions of the Japanese technicians who conducted experimental research on super high velocity guns and projectiles:

Research was successful on a rifling process for barrels having a tapered section. Two experimental guns constructed on the basis of 'Gerlick's principle' were used. A projectile with a satisfactory trajectory at a muzzle velocity of 1300 m/sec was designed, but bore pressures encountered were too high. Further experimentation is necessary on the length of the barrel, since it has been proved that the bore space is too small in relation to the cartridge case volume in the present experimental guns.

It was found that the rate of burning of the propellant was slow, and because of excessive muzzle pressure, it was shown to be disadvantageous to make full use of the effective propellant gas.

The present propellant is 5.0 or 6.0 cord propellant. However, the firing results obtained by mixing this with a small amount of fine grain powder were found to be slightly better. There is need for a continuance of research for a more suitable propellant.

The static pressure feed drag of the projectile in the barrel was measured and the energy consumed in the bore due to frictional drag determined. When these results were compared with the muzzle energy, it was found that the problem was not as important as it had first appeared to be.

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INTRODUCTION

The material used in this report was obtained almost entirely from translations of parts of a Japanese document entitled "Study on Super Initial High Velocity Machine Gun and Projectiles for Its Use", dated September 1940, which has been forwarded to the Washington Document Center under NavTechJap Document No. ND50-3221. No attempt was made to prove or disprove any of the results recorded. No Japanese personnel were interviewed, as no one who worked directly or indirectly on this problem could be located. More specific details as to method and procedure may be obtained by a complete translation of the document.

THE REPORT

A. PURPOSE OF TESTS

The purpose of these tests was to carry out fundamental research on 13mm machine gun with the object of producing a super high muzzle velocity gun and projectile, based on Gerlick's conception of increasing the propulsion receiving surface of the projectile in the bore, as well as to carry out research on the decrease of air resistance after the projectile leaves the muzzle in order to shorten the time of flight and to approach as nearly as possible a flat trajectory.

B. RESULTS AND OPINIONS

1. Projectile. Tests were conducted with a 13mm experimental round. Mainly as a result of various improvements made on the fins of the round, it was found that the trajectory was satisfactory at a 1300 m/sec muzzle velocity. The body of this experimental projectile was made of steel, hardened to Shore 50. Two copper guide rings (or fins) are pressed onto the projectile. See Figures 1 and 2.

The trajectory of this round gradually will become unsatisfactory, if too high a muzzle velocity and excessive bore pressures are attained. The guide rings also are subject to peeling under these conditions. Need for further research on the design of the projectile and guide rings is apparent from results obtained.

2. Barrel. The barrel of the experimental gun differs from the standard barrel. It has a tapered section within the bore. To machine this required research for the development of a new rifling technique. For this reason the Mark 1 gun was designed with a smooth bore. This barrel consisted of the No. 1 flat section, a middle tapered section and the No. 2 flat section. Upon completion, this gun was used in the firing tests of the first experimental projectiles. Firing tests of the Mark 1 gun revealed the trajectory to be unsatisfactory, owing to the absence of rifling. The projectile also was still in the experimental stage. About this time a successful rifling process was developed, and the Mark 2 gun was produced. Shortly thereafter a Mark 3 gun was completed. Both of these guns had eight left hand spiral lands (one revolution in 400mm). The powder chamber of the barrels was of the built-up type.

After firing tests made with both new guns, a study of the bullet holes in a target showed the trajectory of the Mark 3 gun to be much better than that of the Mark 2 gun. The reason for the superior performance of the Mark 3 gun was thought to be the longer No. 1 flat section and the shorter No. 2 flat section, as compared to the Mark 2 gun. The tapered section of both was approximately equal.

Though a round with a generally satisfactory trajectory was obtained at a 1300 m/sec M.V., there was an excess of propellant charge, and the maximum bore pressure reached 47 kg/mm^2. When the bore pressure curve was photographed on the cathode ray oscillograph, the maximum bore pressure point appeared near the muzzle. After the projectile reached the maximum bore pressure point of the propellant gas, it showed that the projectile was leaving the muzzle when the bore pressure had dropped slightly. Consequently, it was considered that the muzzle pressure also was too high and that the use of this propellant gas was disadvantageous. This condition necessitated modification of the barrel and further research for a more suitable propellant.

When the frictional drag was measured in the Mark 2 gun barrel, by the static pressure feeding of a projectile, the results showed a maximum of 4000 kg (8800 lbs) to 5000 kg (11,000 lbs) load for the No. 17 experimental projectile, and about 9000 kg (19,800 lbs) load for the No. 19 experimental round. The drag at the No. 1 flat section for the No. 17 projectile was 100 kg (220 lbs) to 200 kg (440 lbs) and 459 kg (990 lbs) to 600 kg (1320 lbs) for the No. 19 projectile. Thus it was shown that the frictional drag of the No. 19 projectile was roughly three times that for the No. 17 projectile. Drag at the No. 1 flat section during the final phase showed plastic state drag (fins being engraved by the rifling). Thereafter the drag became more uniform, increasing sharply as the projectile entered the tapered section, and attaining the maximum drag just before entering the No. 2 flat section. As the projectile passed the tapered section and entered the No. 2 flat section, it advanced slowly, and began to increase speed slightly as it passed the center and dropped suddenly just as it reached the muzzle. In the case of a dynamic test, that is, converting the result of the static test into the frictional value of a fired round, it was found that the energy of the No. 17 projectile at the muzzle was about 4% and the energy of the No. 19 projectile was about 9%, when the consumed energy within the bore due to friction was compared with the energy of the projectile at the muzzle. Considering these results, the consumed energy within the bore due to friction appears to be a negligible problem. Because instances where actual tests, in which the static frictional drag must be converted into that for high velocities, such as for fired projectiles, are seldom found, the results obtained in these tests cannot be absolute. However, it can be safely assumed that there is a radical decrease of the frictional drag for high velocities.

3. <u>Propellant</u>. Basic research on the propellant to be used has not as yet been undertaken. A supply of cord propellant used in machine guns, mainly 5.0 special K and 6.0 special K obtained from the Naval Powder Factory, were used.

In trials made to increase the burning rate of the propellant, it was found that a mixture of a small percentage of rifle propellant (strip) and mortar ammunition propellant would give a slight improvement. However, fully satisfactory results were not obtained. Further research for a suitable propellant is recommended.

C. <u>FACTS ON RESEARCH</u>

1. <u>Projectile</u>. Research relative to the Gerlick Gun and ammunition is being conducted in various foreign countries. Recently this has been especially discussed as an anti-tank gun. Gerlick's material has been used as reference for this research on the construction and design of a finned projectile. The current model 13mm machine gun and ammunition are used as the basis for this research. The diameter of the projectile has been designed so as to be the same as that for the 13mm projectile. The cross-sectional surface of the guide ring of the projectile at the end of the rifling (No. 1 flat section) was designed to have twice the shock-receiving surface at the time of leaving the muzzle. There is an annular groove around the projectile aft of the guide ring. When the projectile passes the No. 2 flat section the guide ring is pushed into this groove.

A copper projectile was constructed as shown in Figure 3. Test results of projectiles fired underwater with the Mark 1 gun (see Figure 4) at an angle of 27° showed the following: The guide ring did not fit snugly into the groove but rolled up. The trajectory was bad, and the projectiles were bent. Two of the projectiles broke in two pieces. Because of these unsatisfactory results, various modifications in the construction of the annular groove were necessary. Since then about 19 modifications have been made, with the No. 19 projectile shown in Figures 2 and

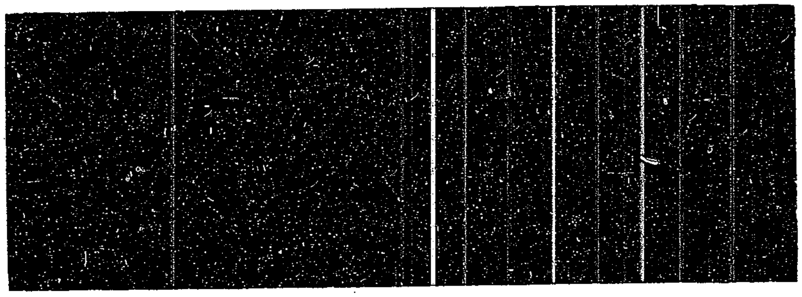
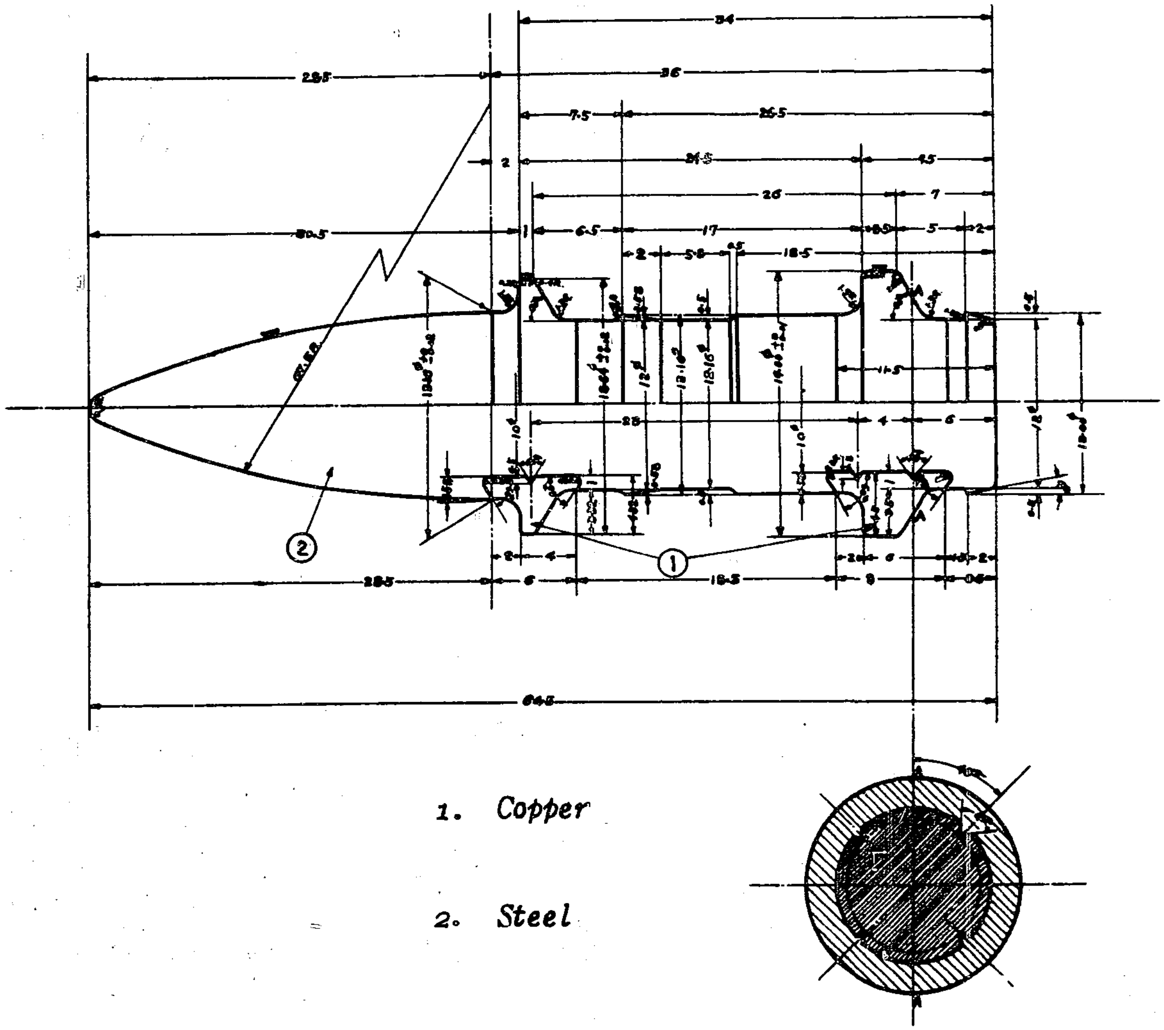


Figure 1
NO. 19 PROJECTILE



1. *Copper*

2. *Steel*

Figure 2
SKETCH OF NO. 19 PROJECTILE

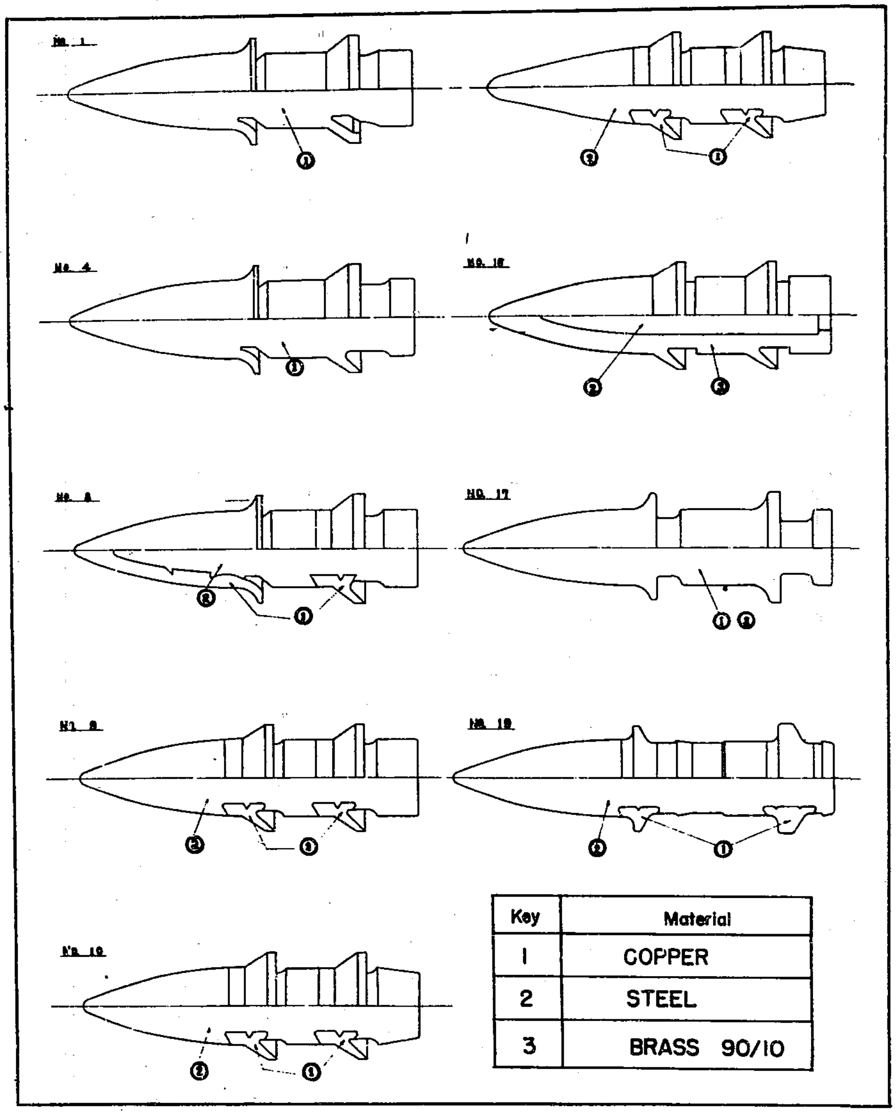


Figure 3

SKETCHES OF PROJECTILE IMPROVEMENTS

3. In test firing conducted with the Mark 2 and Mark 3 guns firing this projectile, the trajectories were found to be satisfactory. The No. 19 projectile is made of tempered steel hardened to Shore 50. Two guide rings are constructed almost vertically with the axis slightly inclined toward the nose. When the guide rings were inclined aft, as in the projectile designed in the first stage, the propellant gas pressure within the bore caused the guide rings to loosen from the projectile body. As a result, the guide rings were either unstable or came off while advancing through the base, thus causing erratic flight of the projectile. When the face of the after guide ring was slightly inclined toward the nose of the projectile, the resultant force of the propellant gas acting upon its rear surface tended to push the guide ring toward the axis of the projectile. This action prevented the guide ring from being separated from the projectile body. Upon inspecting a projectile which had been fired in sand, the groove aft of the guide ring was found to be too

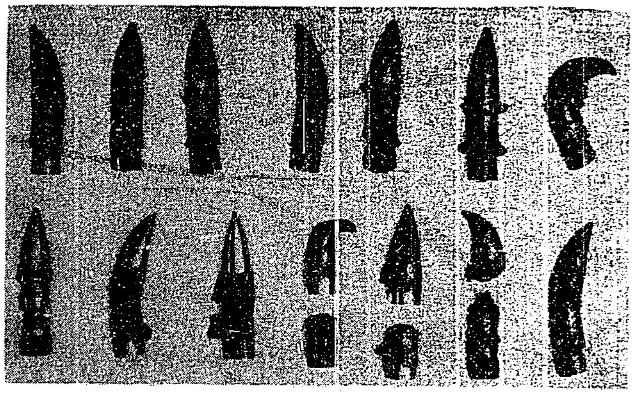


Figure 4

PROJECTILES FIRED UNDERWATER FROM MARK 1 GUN

large. The guide ring was not fully pushed into the groove and there was a space between it and the edge of the groove. Because of the need for more modification, new projectiles are now in the design stage. Figure 5 shows the shapes of various experimental rounds before and after firing.

2. Barrel

(a) Mark 1 Experimental Gun. Barrel Material: Ni-Cr Steel G. Because of the tapered section of the bore, the rifling process is very difficult, requiring experimental research for a suitable method. The Mark 1 gun with a smooth bore was first constructed in order to conduct the research. The barrel consisted of the tapered and flat sections, and the powder chamber was designed so that an HO Type 25mm machine gun cartridge case (193.3mm long) could be used. The mount and the barrel are of the fixed type with no recoil system installed on the barrel. This gun was used to carry out the underwater firing tests of the first experimental rounds (No. 1 to No. 10). These were mainly of copper construction, in order to test the sticking propensities of the guide rings.

The gun was fired eleven times, totaling 86 rounds. However, because of the smooth bore the results were unsatisfactory. In the initial stage of the tests the Abajin M.V. Chronograph was used to measure muzzle velocity, but this was later changed to the shipborne type because of inaccuracies encountered in the former type. Bore pressure was first measured with a small model pressure gauge placed in the cartridge case. However, due to firing, the gauge would frequently become stuck in the bore, so thereafter a hole was drilled in the breech and this was aligned with another hole (5mm in diameter) drilled in the cartridge case. It was found that the smaller the size of the propellant charge the better the results. A muzzle velocity close to 1500 m/sec was measured but the trajectory was poor, and a considerable number of projectiles were broken in two parts.

(b) Mark 2 Experimental Gun. Material: Special Japanese tungsten steel. A successful rifling process was developed for the construction of this gun. The rifling was designed with eight spiral lands and grooves, left hand, with one turn in 400mm. Compared with the Mark 1 gun, the No. 2 flat section is 50mm longer, but the No. 1

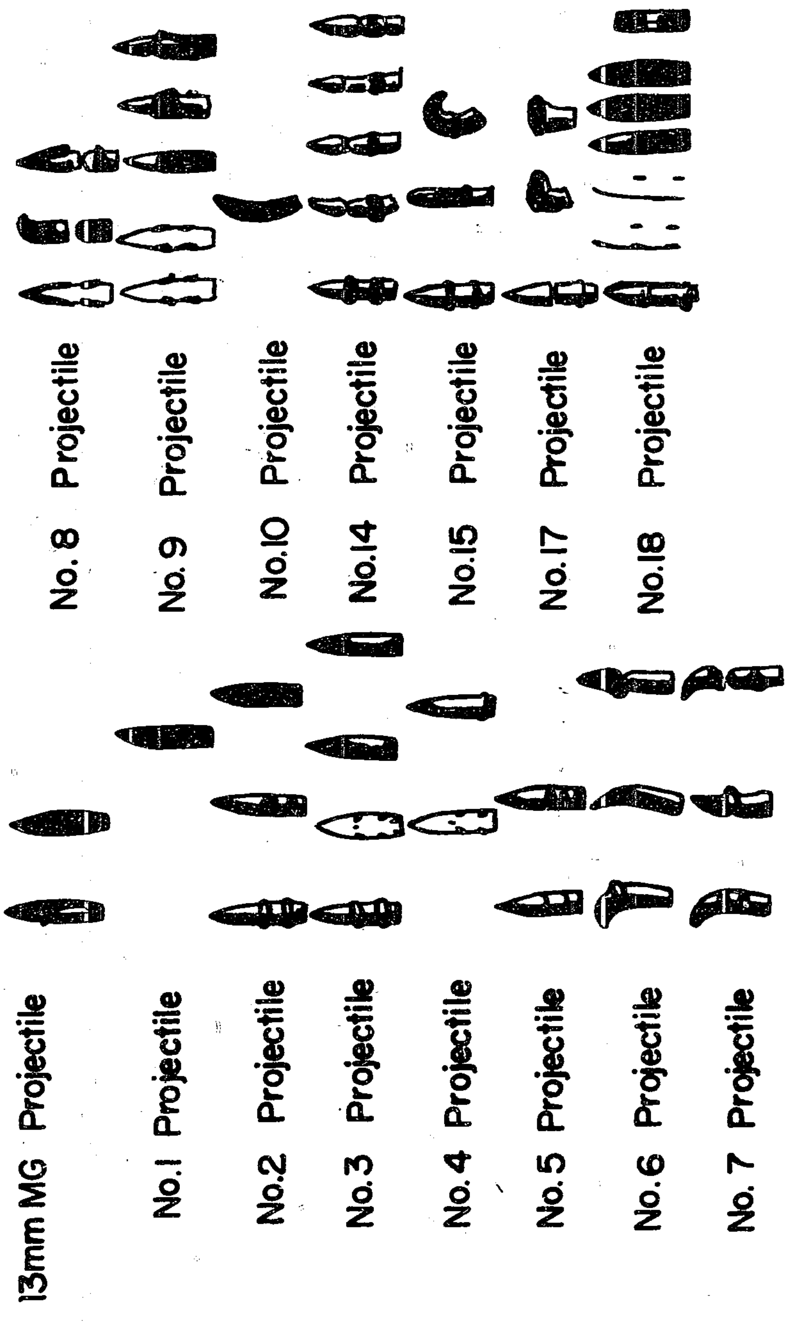


Figure 5

PROJECTILES BEFORE AND AFTER TEST FIRING

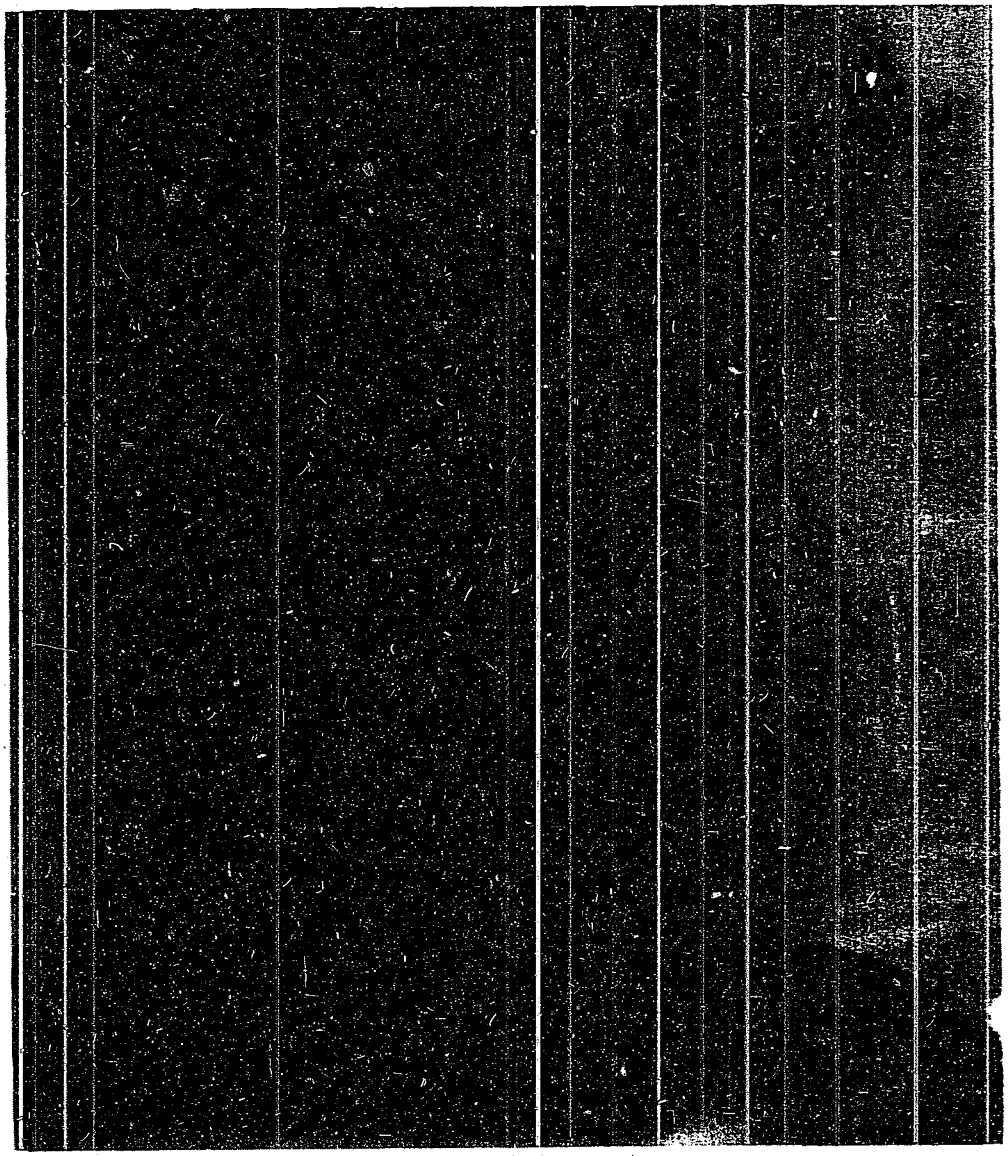


Figure 6
MARK 2 GUN

flat section and the tapered section are of the same length. The barrel may be elevated and traversed freely. A good quality (5mm thick) rubber strip was inserted between the fixed mount and the recoil mechanism to absorb the shock of recoil. Projectiles No. 14 to No. 16 fired up to the sixth firing test were modified, but the trajectory was unsatisfactory. Results were not available (recorded), but the rifled bore produced deviation of shots, and dispersion was great. Rifling marks were clearly engraved on the guide rings of rounds fired into sand and underwater.

From a study of these rounds it was determined that the axis of the projectile had become inclined to the axis of the barrel, indicating that the strength of the guide ring was insufficient. Since then the No. 19 was produced, and from the results of the seventh firing test, it was found that the trajectory was satisfactory, and the dispersion area was smaller. The bullets had directly penetrated three targets set up at 20 meter intervals, leaving circular holes.

Measuring of the bore pressure up to the seventh firing test was conducted with a pressure gauge (4.50mm diameter rod, using 5/7 copper bar) installed on the breech of the gun (see Figure 13). For this reason, only the maximum bore pressure was obtained. The pressure variation within the bore could not be measured. To obtain more informative bore pressure data, the use of the crystal pressure gauge and cathode ray oscillograph was planned. This was put into use in the eighth firing test with the Mark 3 Gun.

Upon viewing the pressure condition within the bore on the oscillograph recording, it was seen that the propellant burned slowly and that the maximum bore pressure point was very close to the muzzle. Consequently, the muzzle pressure was excessive, indicating that the rate of burn and expansion moment of the present powder were improper. Therefore, various mixtures of powders were used in an attempt to increase the burning rate of the propellant. Though there were no marked changes, a slight improvement was made. Furthermore, because the bore area of the experimental gun used in this research was small in relation to the powder chamber capacity, it was thought that the burning of the propellant would be unsatisfactory.

Total rounds fired up to the eighth firing test were 102. When the bore was inspected, considerable erosion was found near the lead of the rifling and at the muzzle. There were several narrow cracks down the axis of the bore. From these findings it appears that special research is required in modifying the shape around the lead of the rifling in this type of gun. Figures 12 and 13 show the firing results for the No. 19 projectiles using various propellant charges in the Mark 2 gun. Figures 14 and 15 show the same for the Mark 3 gun. The trajectories were generally satisfactory, but, many shots were still off target because of the poor fitting of the rings. Further study and development are recommended.

(c) <u>Mark 3 Experimental Gun</u>. Material: Japanese tungsten steel. The rifling process used for the Mark 2 gun also was employed in the construction of the Mark 3 gun. The powder chamber and rifling of this gun are identical with those of the Mark 2 gun. Only the specifications for the barrel differ as follows: The No. 1 flat section is longer, the tapered section is the same, and the No. 2 flat section is much shorter. The overall length of the bore is roughly equal to that of the Mark 1 gun. Specifications appear in Figure 16. Compared to the firing results of the No. 19 projectile

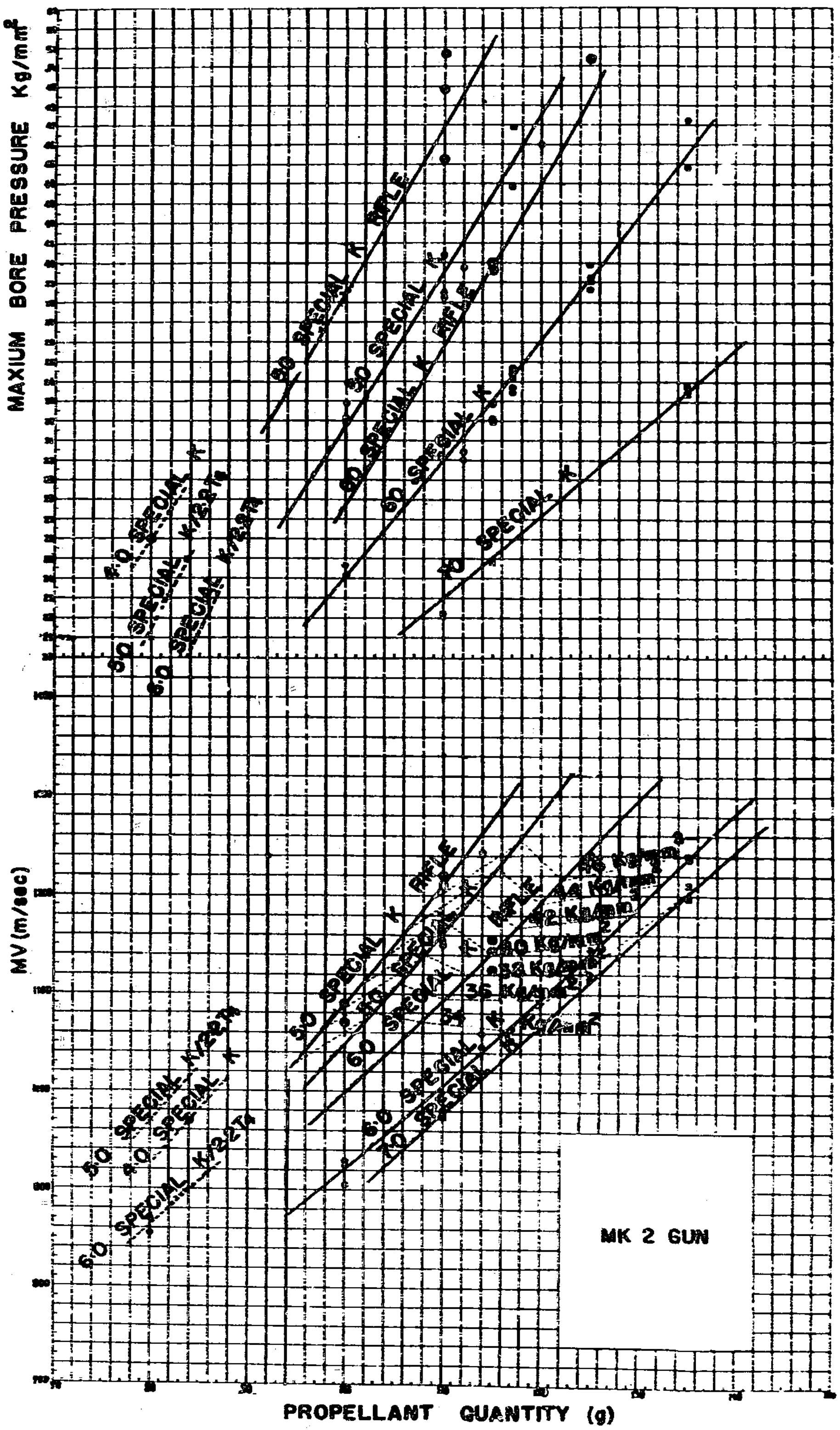


Figure 7
FIRING RESULTS FOR NO. 19 PROJECTILE USING VARIOUS PROPELLANT CHARGES - MARK 2 GUN

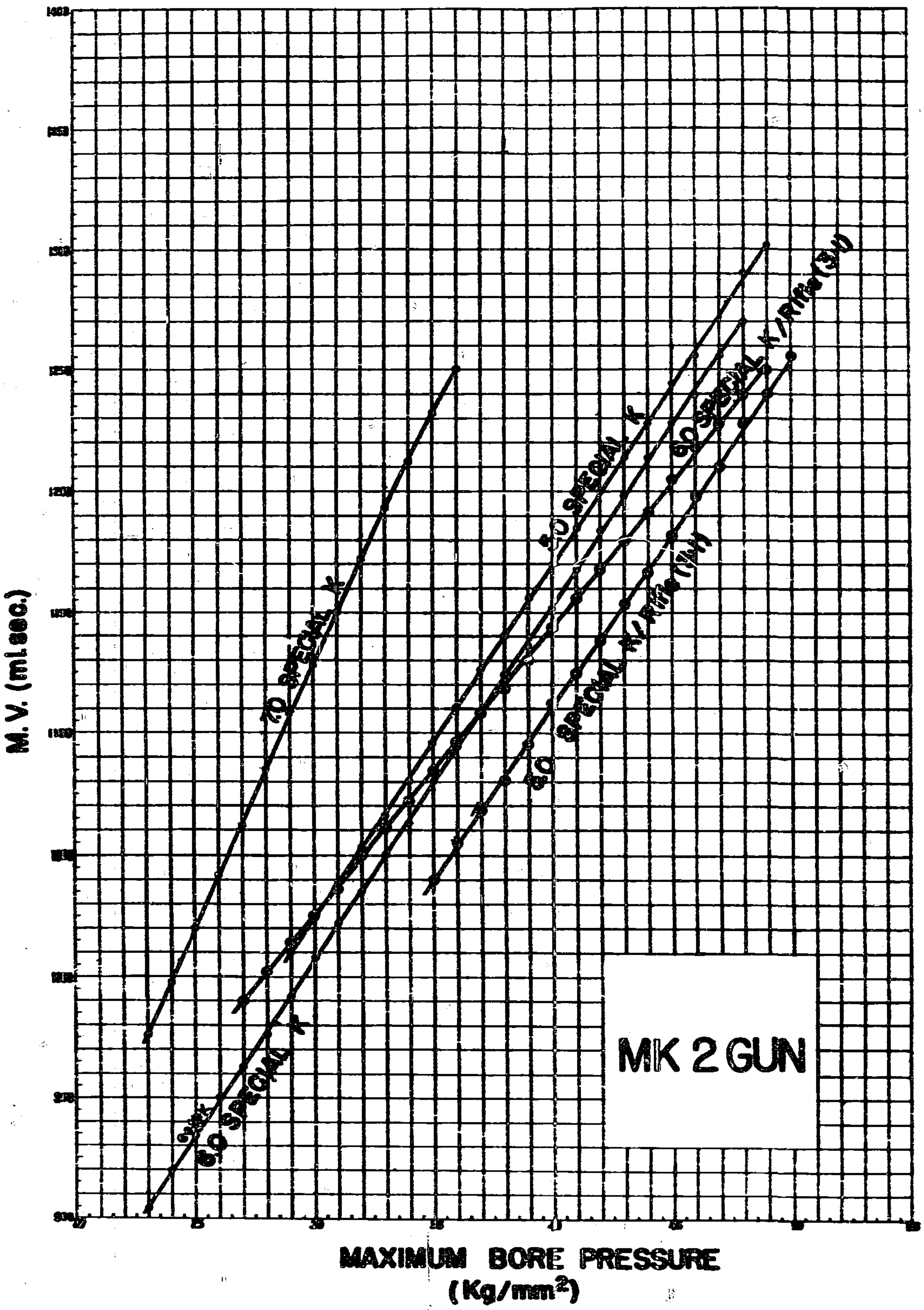


Figure 8
MAXIMUM BORE PRESSURES FOR MARK 2 GUN

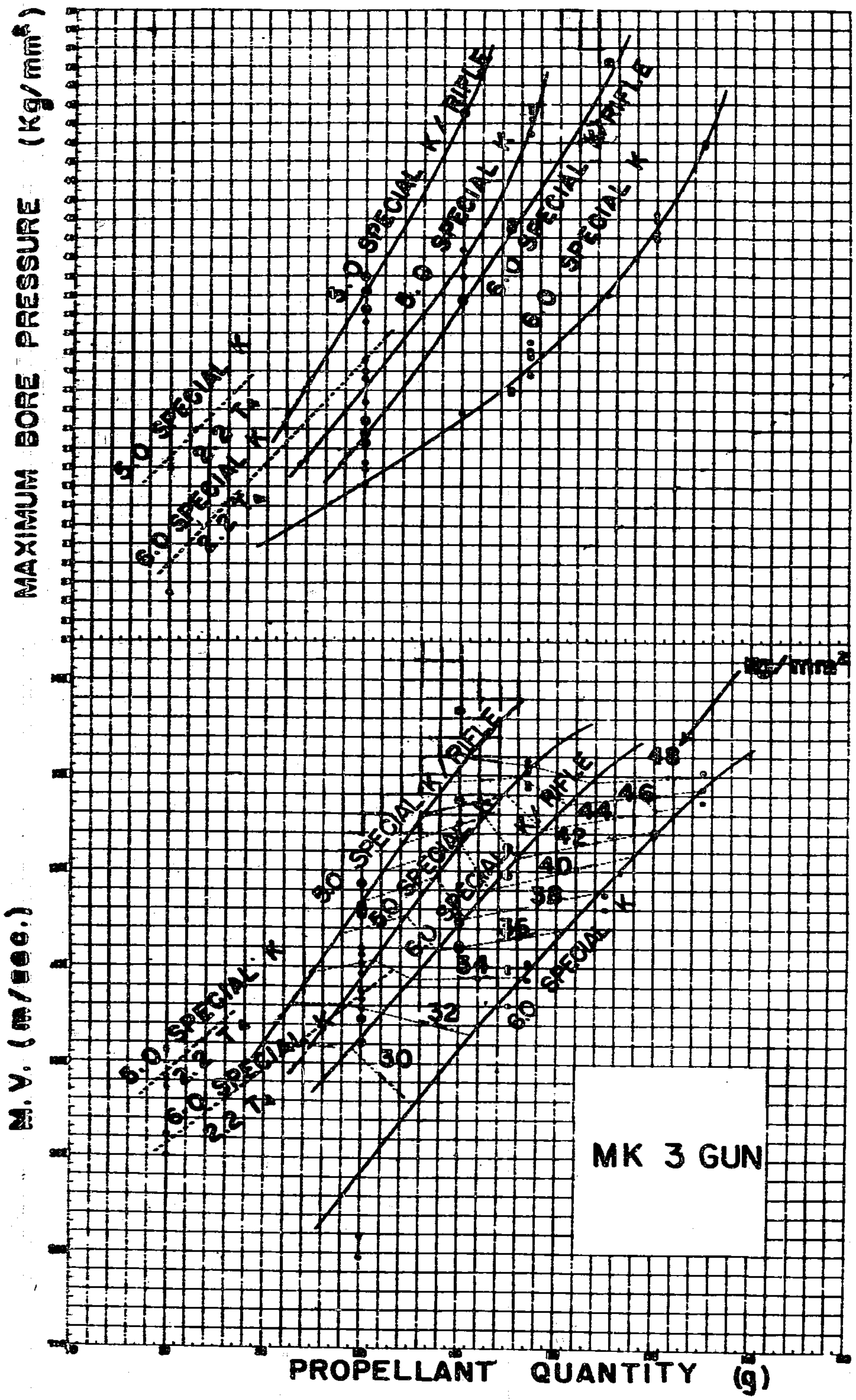


Figure 9

FIRING RESULTS FOR NO. 19 PROJECTILE USING VARIOUS PROPELLANT CHARGES - MARK 3 GUN

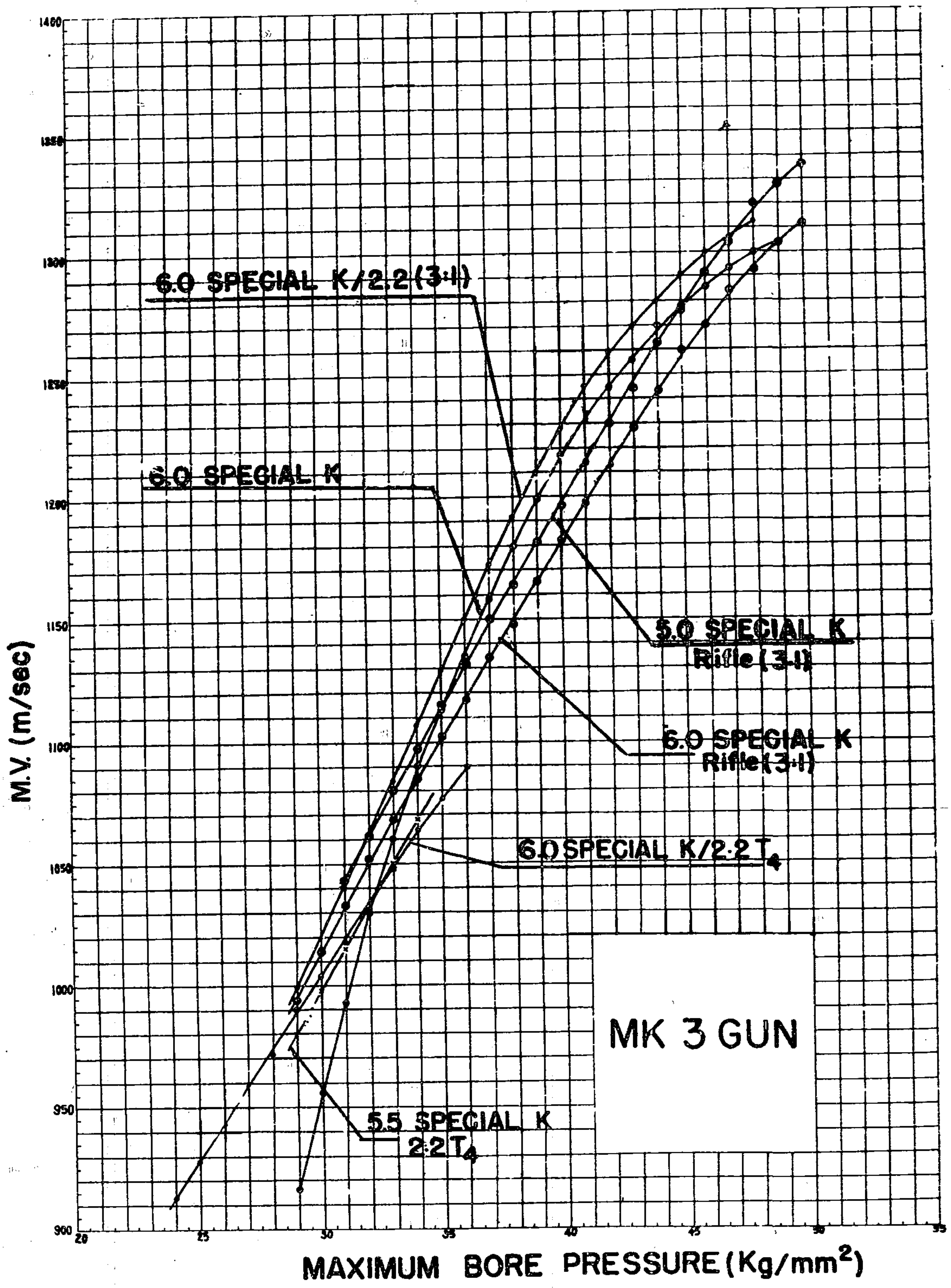


Figure 10

MAXIMUM BORE PRESSURES FOR MARK 3 GUN

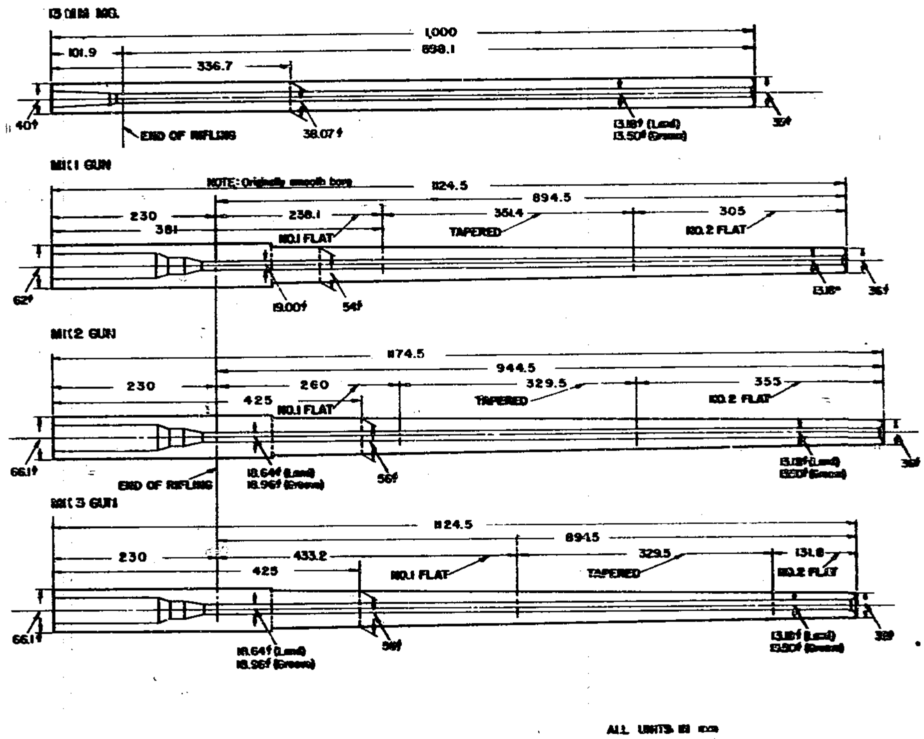


Figure 11

COMPARISON BETWEEN PRESENTLY USED 13mm GUN BARREL AND EXPERIMENTAL GUN BARREL

with the Mark 2 gun, the trajectory was, on the whole, better, the reason being the longer No. 1 flat section and the shorter No. 2 flat section of the Mark 3 gun. That is, the lengthening of the No. 1 flat section results in a better trajectory, and it seems that the shortening of the No. 2 flat section does not produce unfavorable trajectory characteristics.

Firing of the No. 17 copper projectile in the first firing test with the Mark 3 gun showed the trajectory to be fairly satisfactory. It was thought that constructing the guide rings almost perpendicular to the axis of the projectile would improve the trajectory, so the modified No. 19 projectile was constructed. Results of firing this projectile proved the trajectory to be more satisfactory. Therefore, firing tests were conducted with various propellants, and muzzle velocities and bore pressures were measured. Upon examining the computed bore pressure curve, the maximum bore pressure point was found near the muzzle, and the muzzle pressure appeared to be excessively high. This same condition existed in the Mark 2 gun. It appears to be necessary to lengthen the No. 1 flat section in order that the maximum bore pressure point should be within the No. 1 flat section. For this reason, a Mark 4 gun was being designed when the war ended.

Four firing tests were conducted with the Mark 3 gun. A total of 118 rounds were fired, mostly No. 19 projectiles. The erosion within the bore was found to be the same as that of the Mark 2 gun. Because of the unsystematic firing conducted with various powders, no determinations were made in connection with erosion. Figures 9 and 10 show the firing results of this gun. Figure 12 shows a projectile fired into sand.

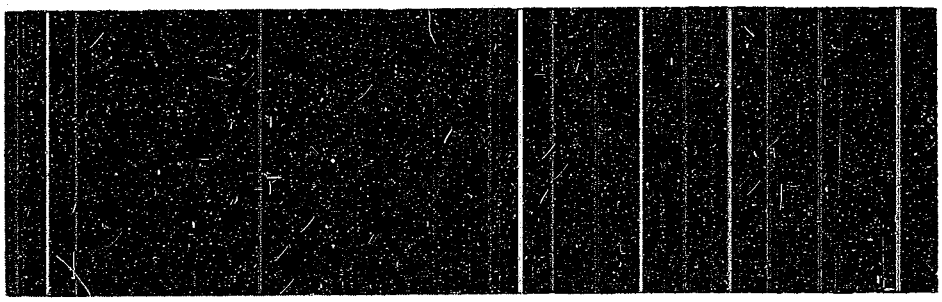


Figure 12

NO. 19 PROJECTILE RECOVERED FROM SAND

(d) Measuring Muzzle Velocity and Pressure within the Bore with the Crystal Pressure Gauge. Because changes in bore pressure occurring as the projectile advanced through the bore could not be determined with the copper bore gauge, a crystal pressure gauge was planned. It was constructed in the following manner (see Figure 14): Two crystal pieces 10mm in diameter and 4mm thick are placed at the position of the copper bar and connected to a Piezo Amplifier by a lead wire (tin-plated soft copper wire 0.23mm in diameter). The amplifier output voltage is connected to the terminal on the deflecting plate of the cathode ray oscillograph by a cord. After the various parts have been adjusted so that the cathode ray trace will be screened at a suitable position on the film, all the switches are closed and the cathode ray is deflected by the position deflecting coil so that the ray will not reach the film. Initially, when the trigger is pulled manually, the wire is cut before the primer is initiated. The position deflecting coil current is cut, and because the deflecting operation of the coil fades, the cathode ray is screened on the film. Following this, pressure from the propellant gas expanding applies negative voltage to the lower terminal of the deflecting plate, P, through the crystal and the Piezo Amplifier. The cathode ray is repelled and deflected, thus showing the increasing pressure on the film. Next, when the projectile reaches the muzzle it contacts Target No. 1 which is insulated and set up in front of the muzzle, thus closing the circuit of a 50-volt battery. At this instant, the negative voltage from the battery is cancelled, the cathode ray is deflected downward and registers the instant the projectile passes the muzzle on the film. The projectile advances to Target No. 2 and because it contacts an insulated wire, makes a mark similar to that which it made when it contacted Target 1. It then reaches Target No. 3 and when it cuts the wire, the current to the electric magnet is cut off, and the steel ball which thus far had been attracted to the magnet, drops, moving the relay to the after firing position. The current is again transmitted to the position deflecting coil, the cathode ray is deflected and fades from the face of the film, preventing distortion. Because this gun is fired manually, the automatic switch on the cathode ray oscillograph cannot be used, so the image is made to appear on the time base. The circuit for the time base is 100 volt 50 cycle AC. This is boosted to 1200 volts by a transformer and led to both terminals of the oscillograph time deflecting plates. The length of the oscillogram base line is one-half cycle, that is, it is equivalent to 0.01 second. By utilizing the remaining gas pressure within the bore after the projectile has left the muzzle, an image appears on the bore pressure curve, and the wires are distributed so that the measuring of the muzzle velocity may also be accomplished. Figures 15, 16 and 17 show the bore pressure oscillograms for the Mark 2 and Mark 3 guns, using various propellant charges. The Piezo Amplifier is constructed so that it may be used with the Matsuda Cathode Ray Oscillograph, Model BT-140V. The wiring diagram is illustrated in Figure 18 and Figure 19 shows the output curve. The lead wire from the crystal is connected to the input terminal of the Piezo Amplifier by way of the electric condenser (5000mm F plus variable 5000mm F). The distance between the crystal and the Piezo Amplifier is about two meters, and it is about 20 meters from the amplifier to the cathode ray oscillograph set.

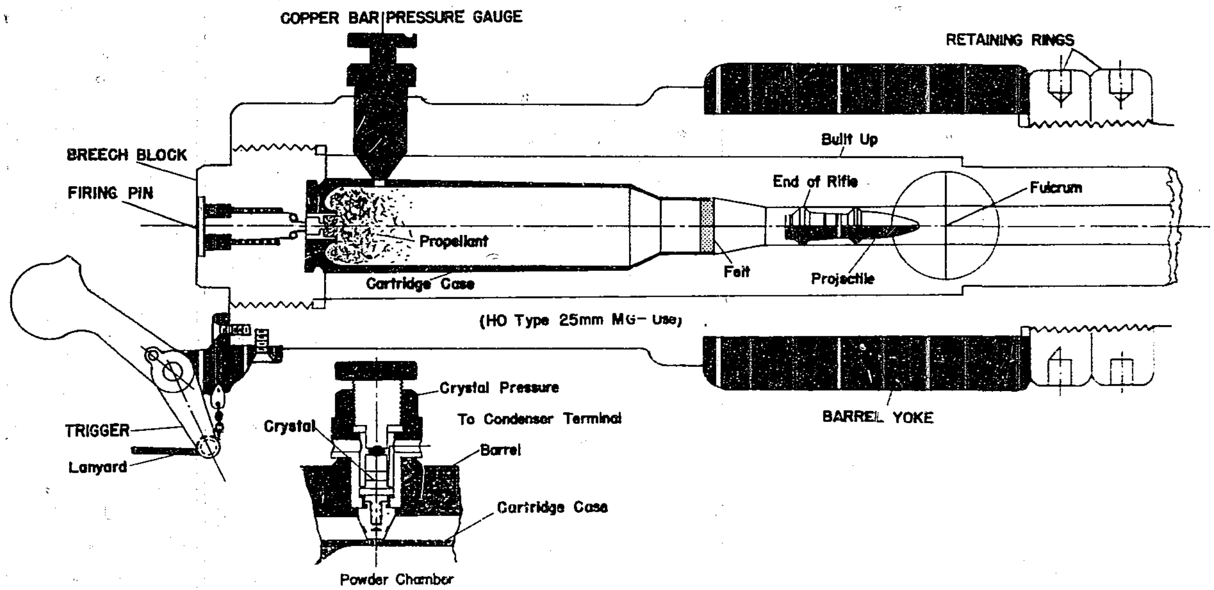


Figure 13

PRESSURE GAUGE

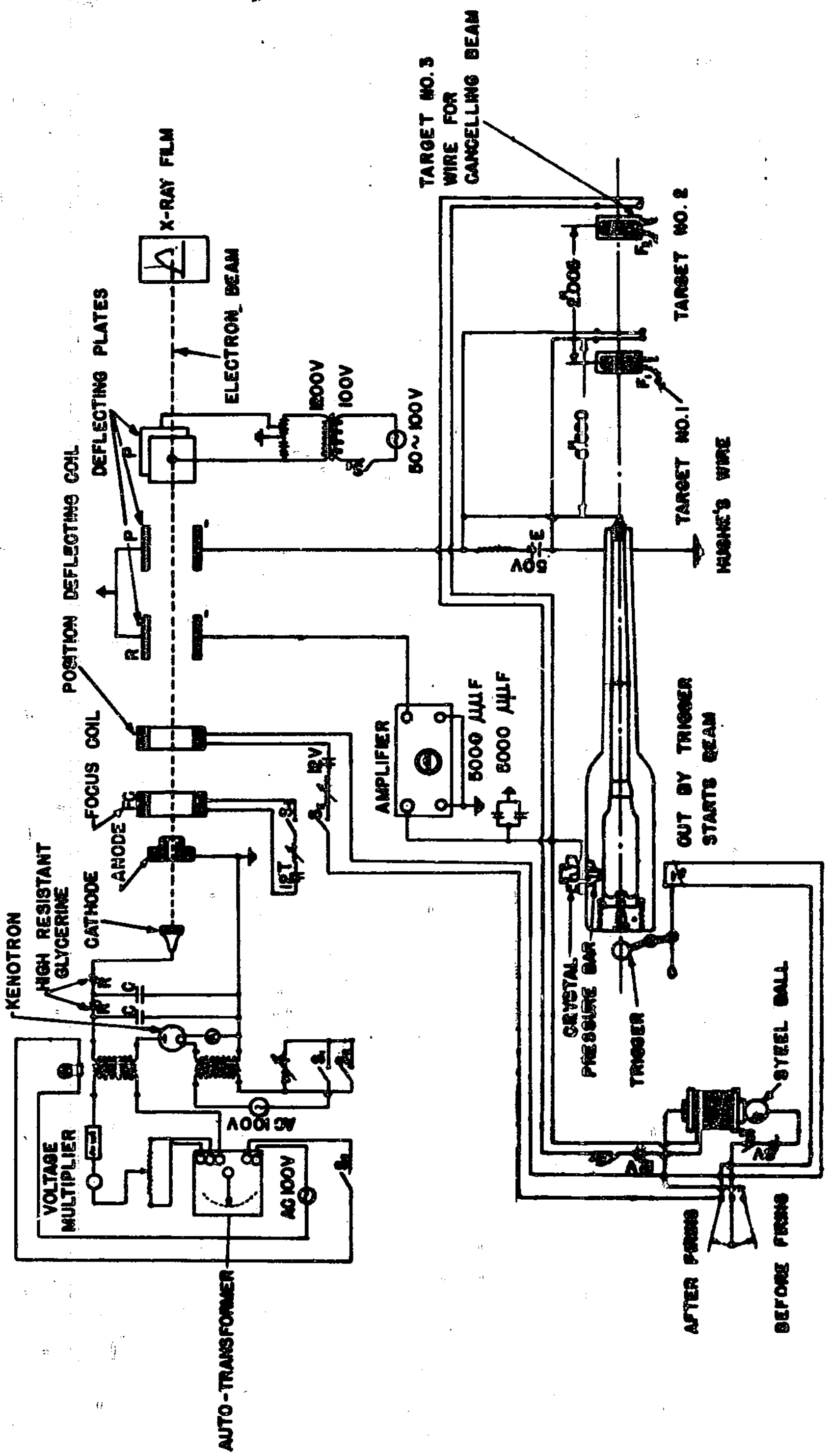


Figure 14

MEASURING BORE PRESSURE WITH CATHODE RAY OSCILLOGRAPH

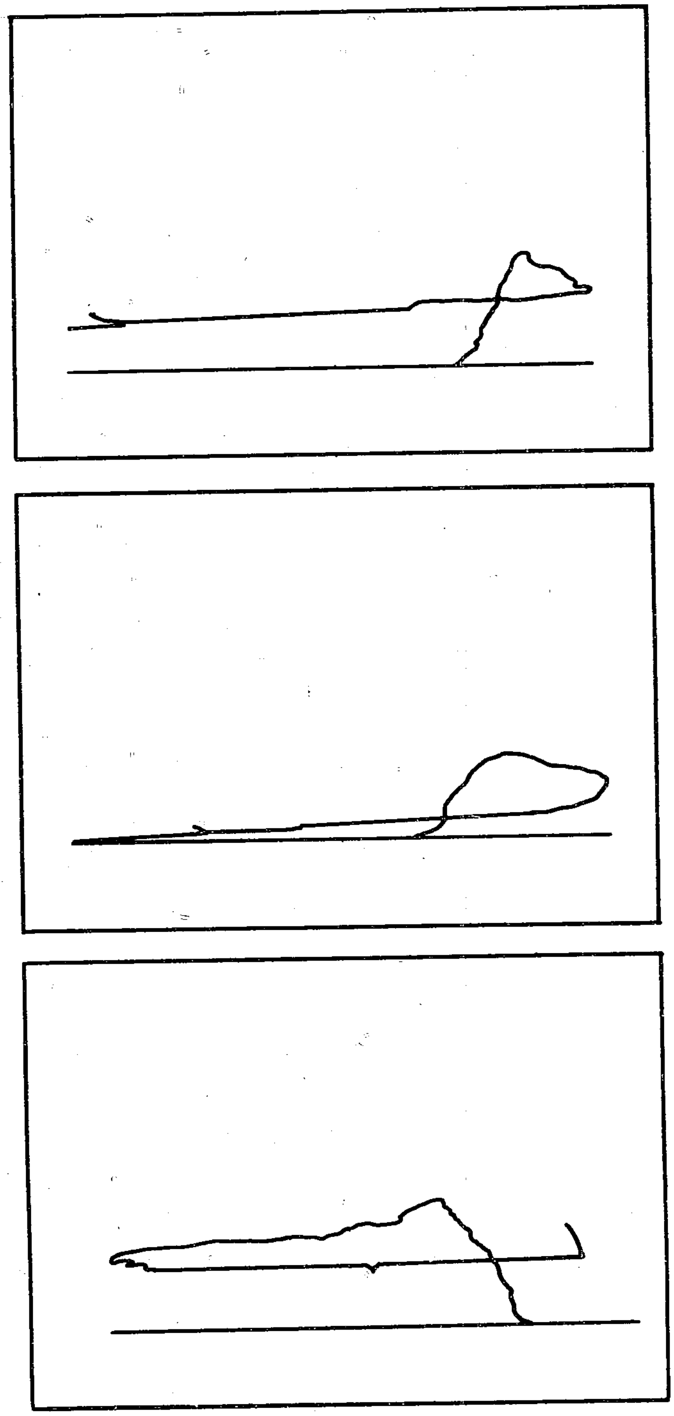


Figure 15

BORE PRESSURE OSCILLOGRAM FOR MARK 2 GUN

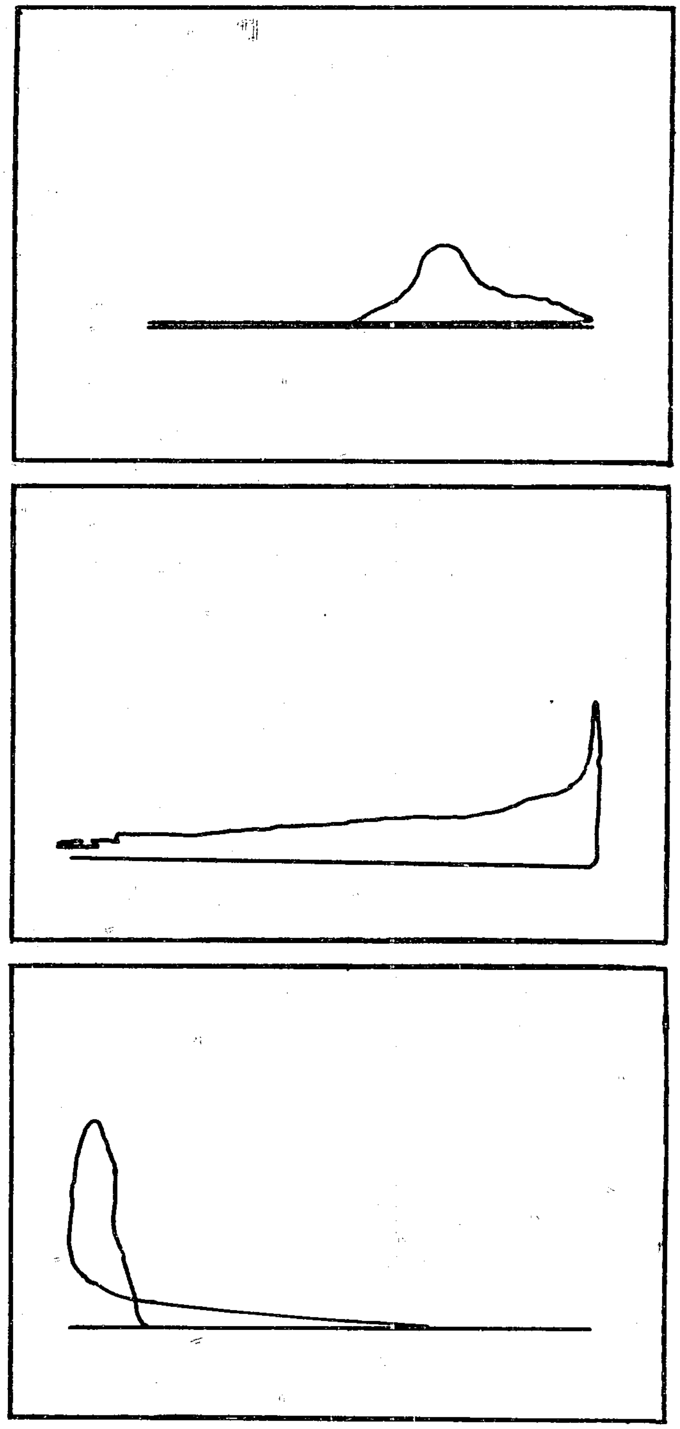


Figure 16

BORE PRESSURE OSCILLOGRAM FOR MARK 3 GUN

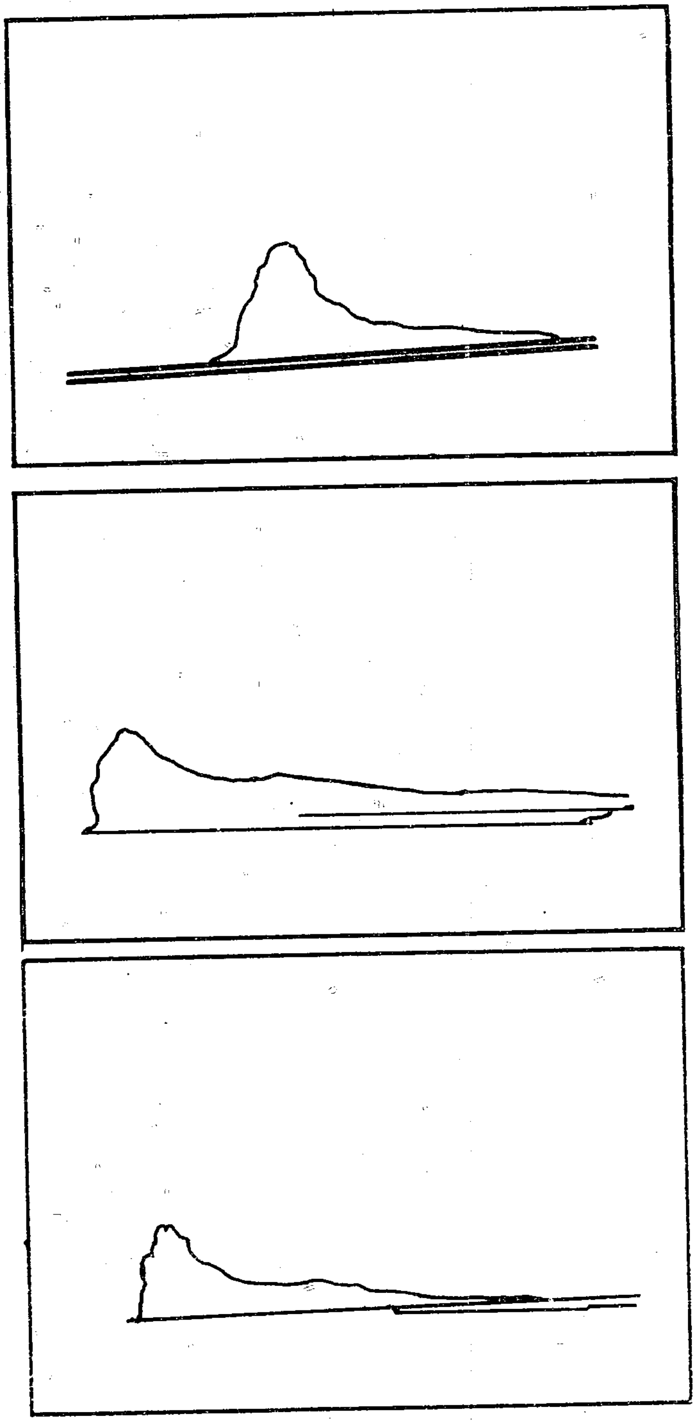


Figure 17

BORE PRESSURE OSCILLOGRAM FOR MARK 3 GUN

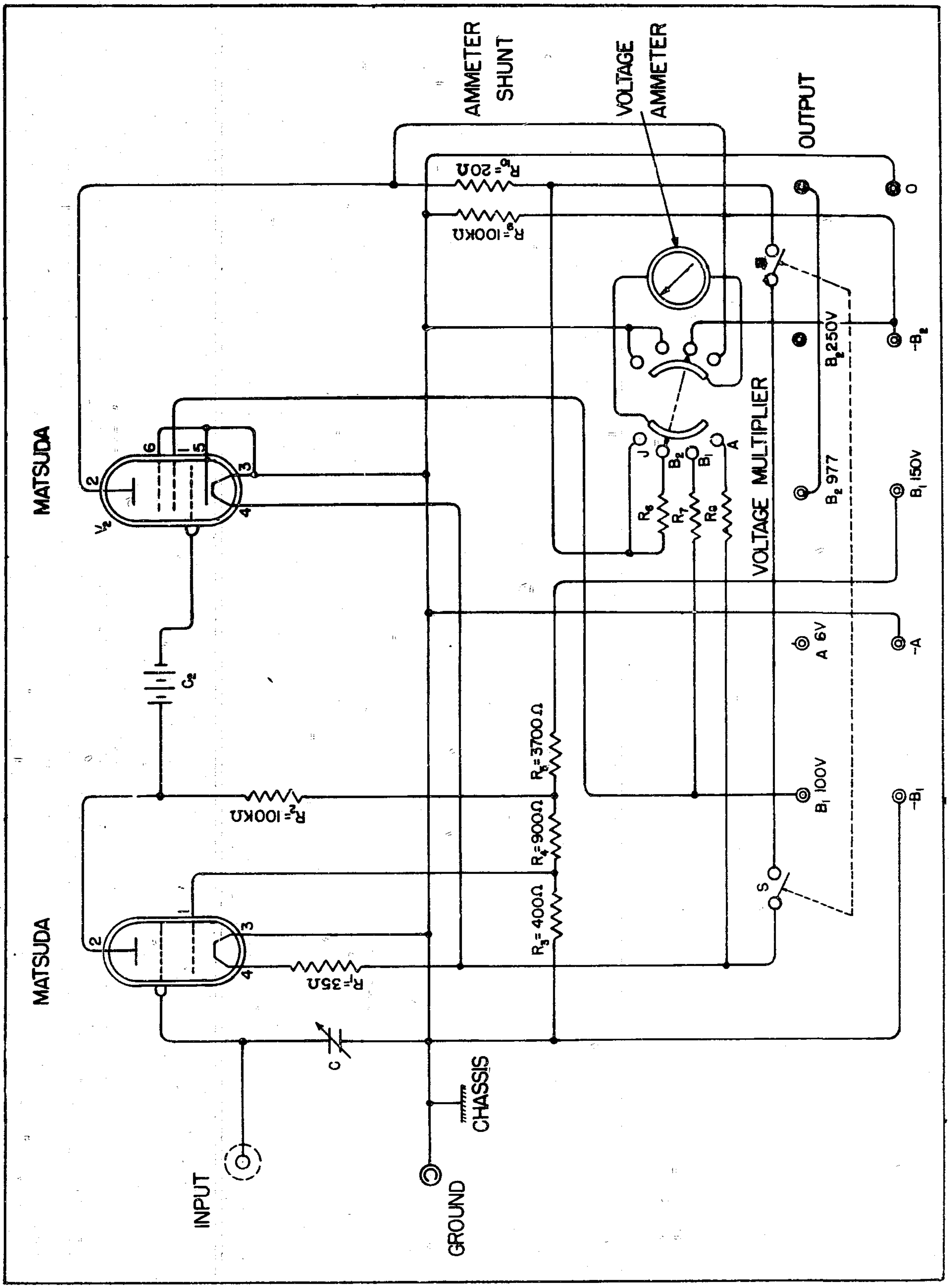


Figure 18

PIEZO AMPLIFIER CONNECTING DIAGRAM

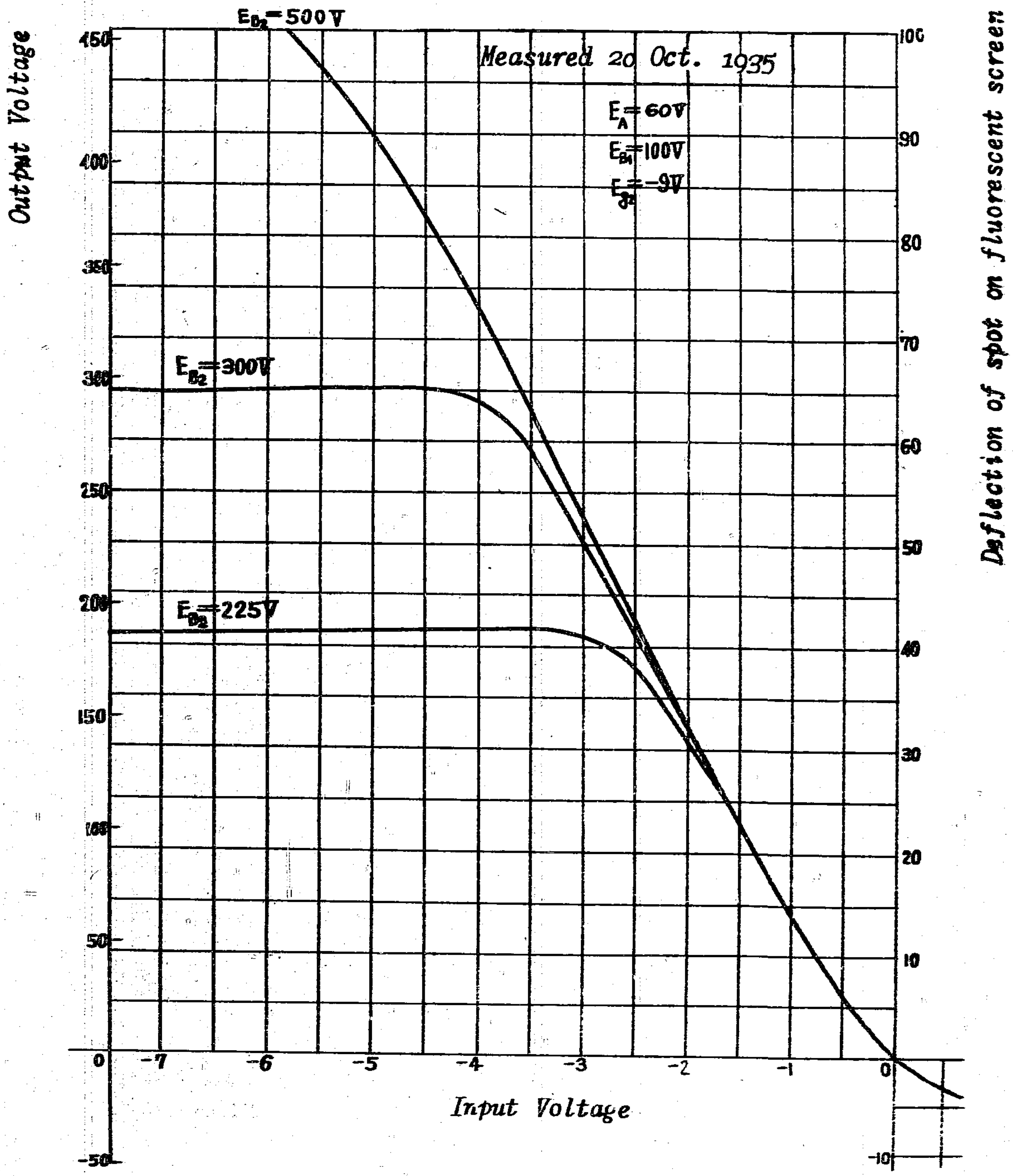


Figure 19

PIEZO AMPLIFIER FIDELITY CURVE

(e) Measuring Projectile Pressure Feed Drag (Measuring Equipment and Method).

1. Procedure A rod is vertically attached to the upper fixed block of a 25-ton Amusura Model Tester as shown in Figures 20 and 21. The breech of the experimental gun is positioned up-

Figure 20

PROJECTILE PRESSURE FEED ARRANGEMENT

ward and attached to the movable testing block. This block is slowly raised by oil pressure and the projectile which has been inserted in the barrel is pressure fed toward the muzzle. The rod is 13mm in diameter and 200mm long. It is of tempered steel and consists of several pieces screwed together. Measuring is commenced when the rifling engages the first fin. The barrel is raised slowly (about 1 cm/min). The pressure is recorded each 1cm of feed. This test was conducted with a dry bore. Fifty-seven rounds had been fired from the barrel in which the No. 17 projectile was tested, and sixty-three rounds fired from the barrel used for the No. 19 projectile.

2. <u>Results</u>. The computed frictional drag curve in Figure 22 shows the drag to be comparatively small at the No. 1 flat section, and to be fixed once the projectile begins to move. For the No. 17 projectile the drag was about 200 kg, and 450 kg to 600 kg for the No. 19 projectile. The drag at the No. 1 flat section consists of the plastic drag of the fins contacting the rifling and the frictional drag of the bearing portions. The pressure feed drag suddenly increases due to the force which tends to act upon the fins when the projectile enters the tapered section. For the No. 17 projectile the maximum load was 4000 kg to 5000 kg and about 9000 kg for the No. 19 projectile. At the No. 2 flat section, the fins were forced back, so there was only the frictional drag between the fins and the rifling, practically the same as for an ordinary barrel. Drag was highest at the extremity of the tapered portion. It fell slightly upon entering the No. 2 flat section, but increased at one time after passing the center and fell suddenly at about 100mm from the muzzle. At the No. 2 flat section the drag was presumed to be about 3000 kg for the No. 17 projectile and about 8500 kg for the No. 19 projectile.

3. <u>Propellant</u>. Basic research on the propellant has not been conducted. Cord propellants supplied from the Navy Powder Factory chiefly were used for these tests. The special K propellant, which consists of the following ingredients, has been used in the main:

N/G	27.0%
M/C	64.8%
C/L	5.0%
OTU	3.0%
G/P	0.2%
	100 %

The main sizes of the propellant are 4.0, 5.0, 6.0 and 7.0 special K. Also 4.0, 5.0 and 6.5 special K2 were used. When these propellants were tested for suitability as to muzzle velocity and bore pressure, 5.0 special K, and 6.0 special K were found to give slightly better results. Therefore, these two chiefly were used in the actual firing tests. During the critical phase only one type of the various propellants was used. Mixed propellants were used after the computation of a bore pressure variation graph was begun with the cathode ray oscillograph. Mixtures of 5.0 special K and 6.0 special K, with rifle ammunition propellant and mortar ammunition propellant 2.2 T4, showed a slight increase in the rate of burning and a better disposition. However, the utilization of the propellant gas was still unsatisfactory.

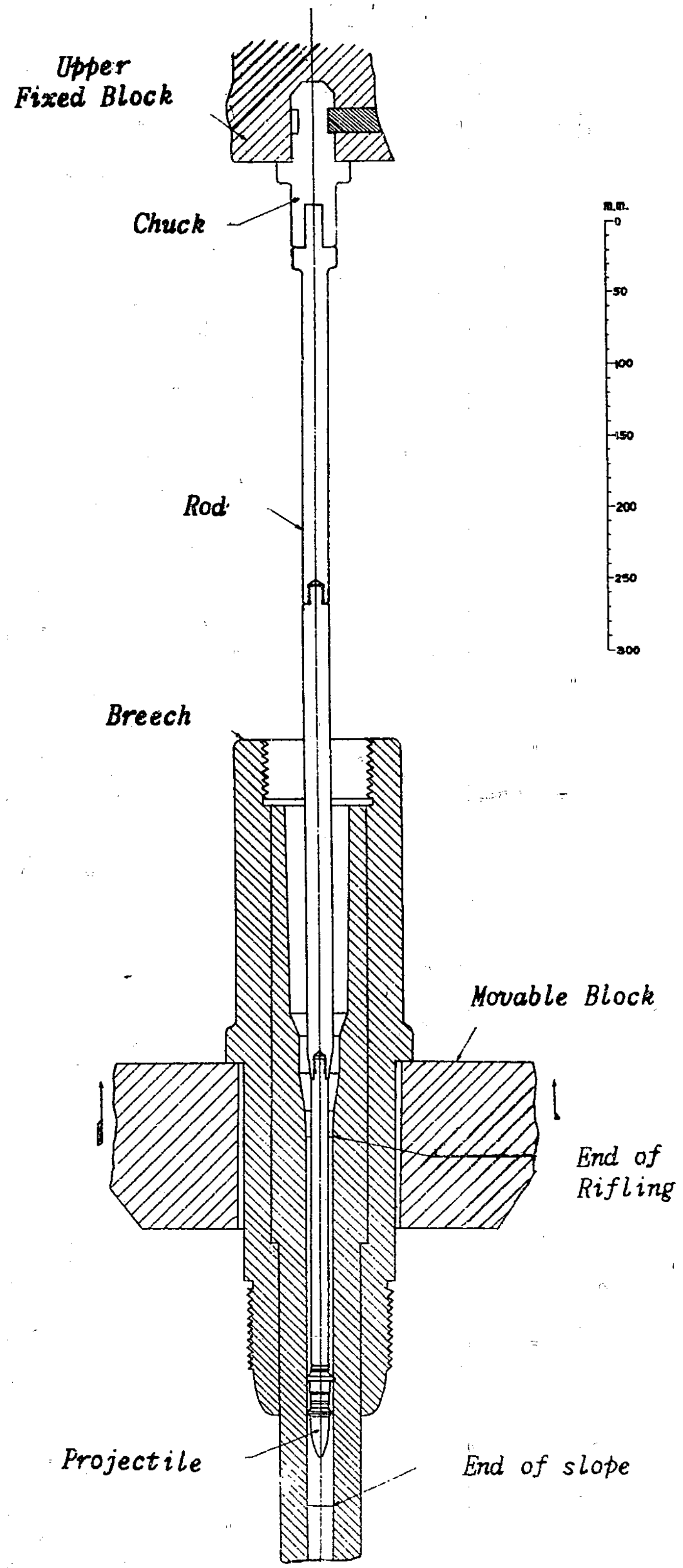


Figure 21

PROJECTILE PRESSURE FEED ARRANGEMENT

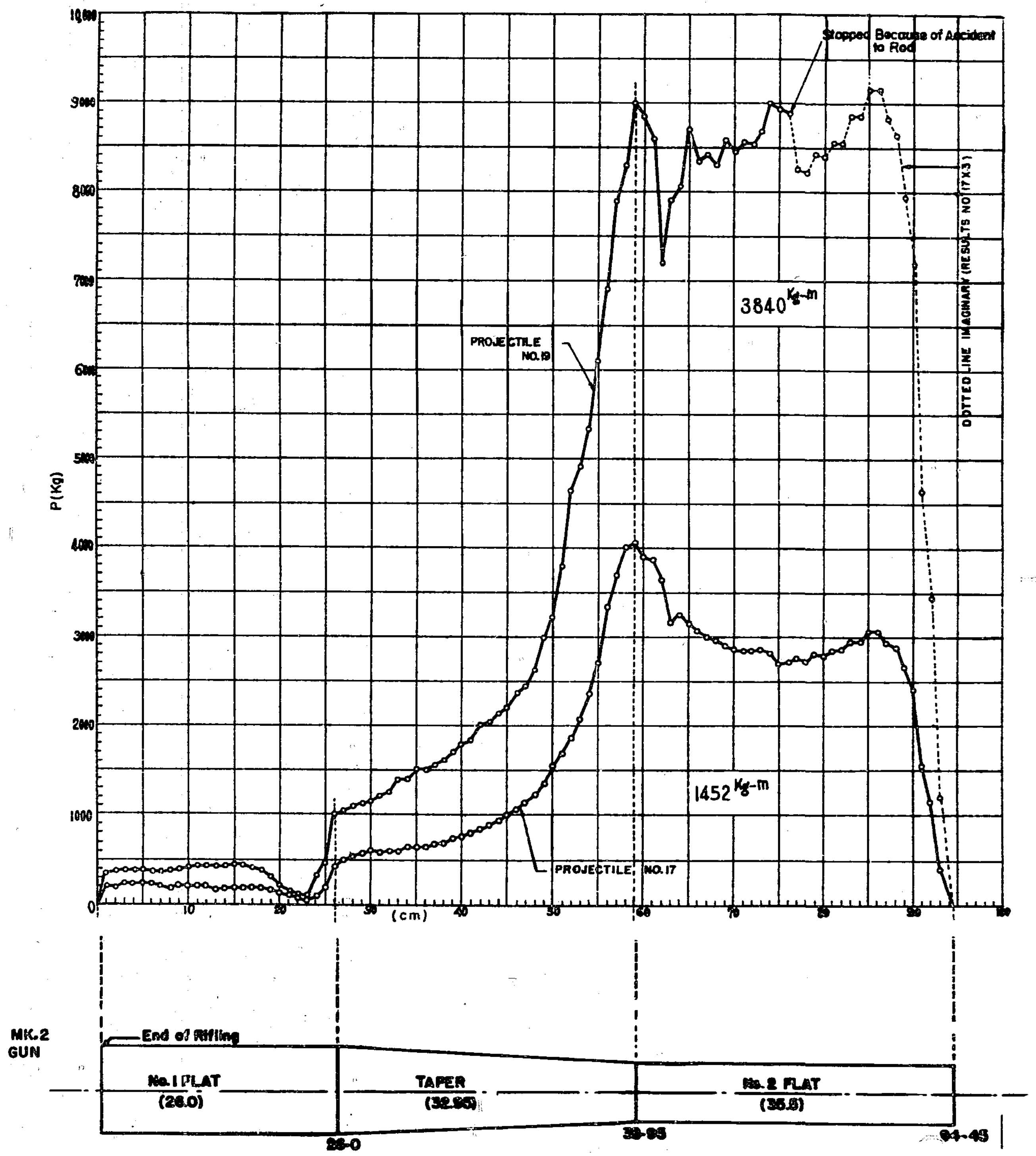


Figure 22

FRICTIONAL DRAG CURVE

Considering the relationship between the cartridge case volume and the bore space, the bore space of the Mark 2 gun is about 1.03 times the cartridge case volume of 179.5 cc and about 1.13 times for the Mark 3 gun. Compared to the five and six times ratio of the cartridge case volume of an ordinary gun barrel, this is very small. Because of the small expansion area for the propellant gas, the effective gas cannot be used sufficiently. Hereafter, research is necessary for a suitable propellant which will fulfill the requirements for this gun.

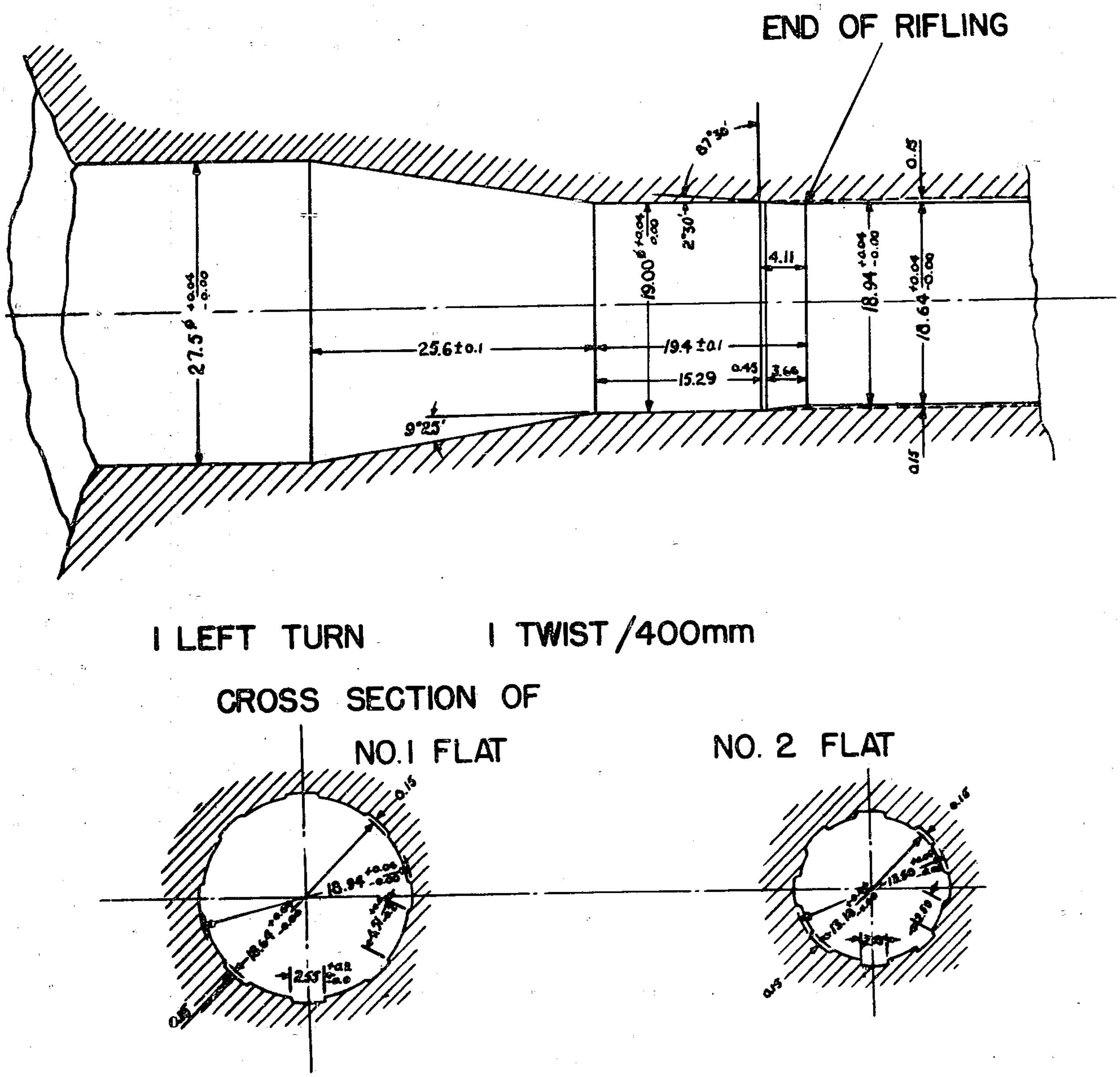


Figure 23

END OF RIFLING AND DETAILS OF RIFLING

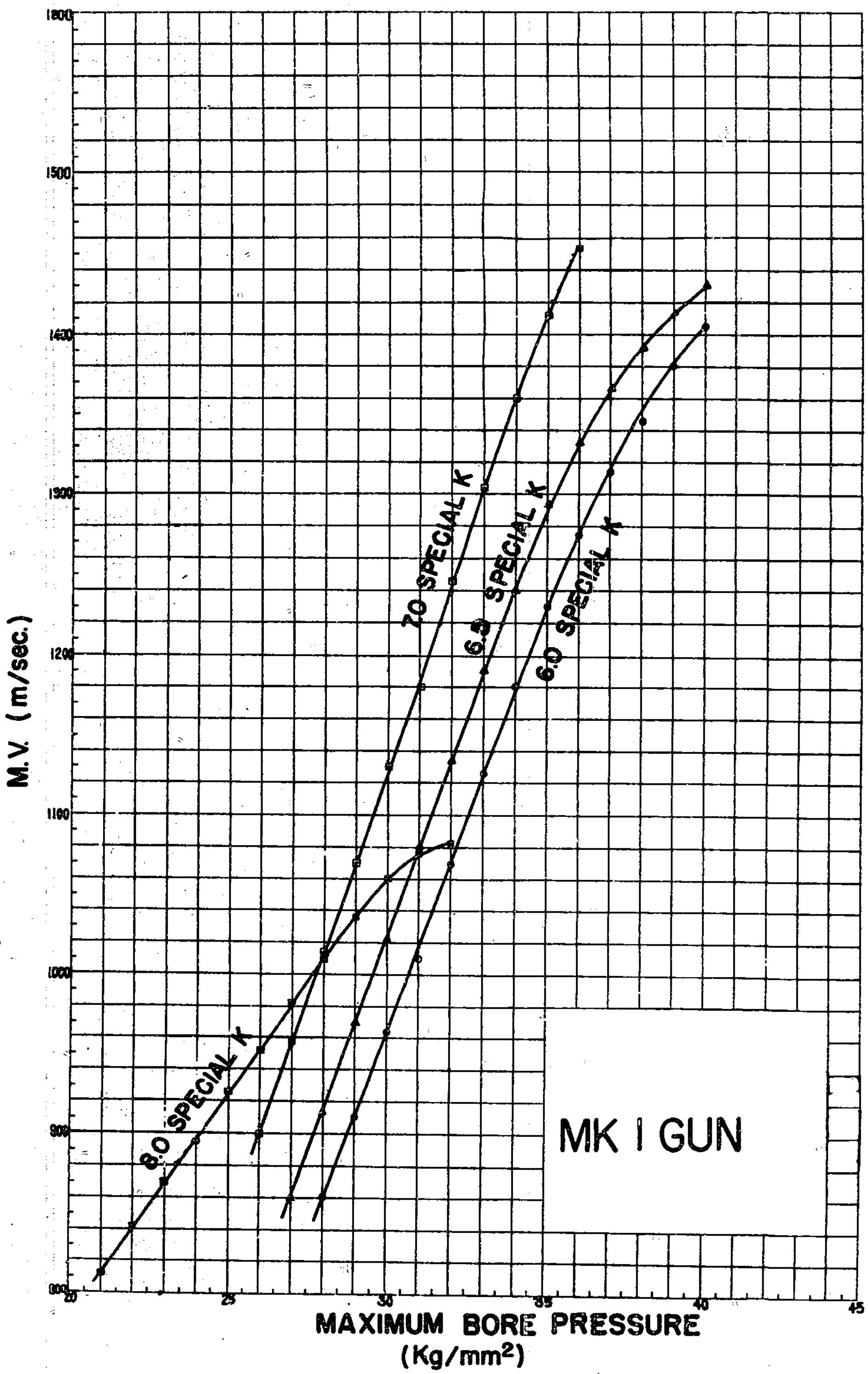


Figure 24

BORE PRESSURE CURVES WITH RELATION TO PROPELLANT QUANTITIES - MARK 1 GUN

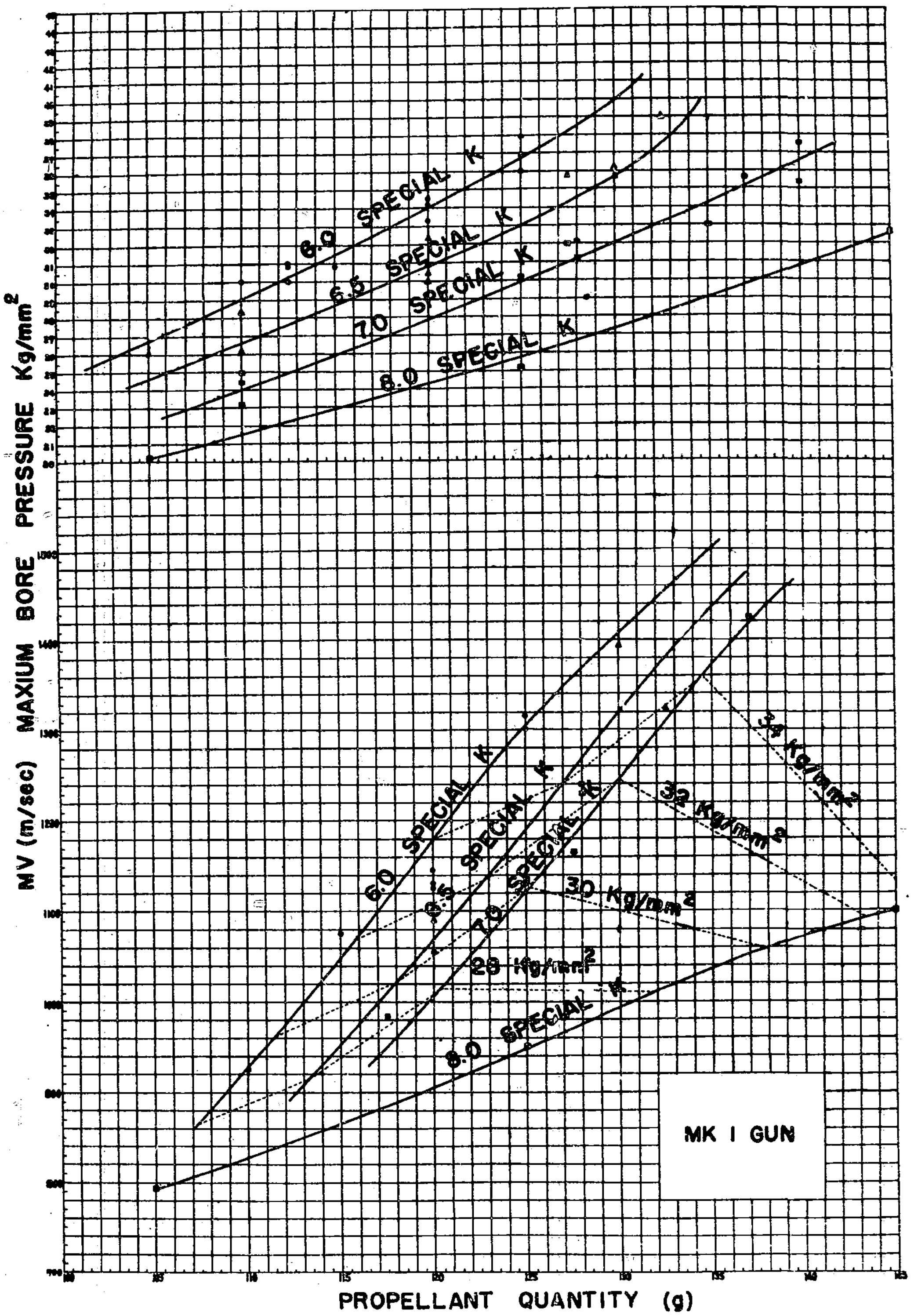


Figure 25

MAXIMUM BORE PRESSURE CURVE – MARK 1 GUN