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FINAL REPORT NO. 61

ITEM NOS. 9 and 2

WEAPONS SECTION OF THE LFA, VOLKENRODE

with notes on

PHOTOGRAPHIC METHODS USED IN GERMAN BALLISTICS

BRITISH INTELLIGENCE OBJECTIVES
SUB-COMMITTEE

BIOS INVESTIGATION REPORT

on

WEAPONS SECTION OF LUFTFAHRTFORSCHUNGSANSTALT, VOLKENRODE.

with notes on

PHOTOGRAPHIC METHODS USED IN GERMAN BALLISTIC INVESTIGATIONS.

Reported by

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BIOS Target Nos.
C 9/469, C 2/662

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BALLISTIC MEASUREMENTS AT THE L.F.A.

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I. Introduction.

The Luftfahrtforschungsanstalt (L.F.A.) at Volkenrode has been subjected to several investigations. A general description may, for example, be found in a report by Col.Simon (C.I.O.S.Target No. 25/71). Features of interest to the Armaments Research Department are described in the report on C.I.O.S.trip No.462 by Col.Hinds, Capt.Illingworth and Capt.Wiseman. As a result of the information obtained by these investigators a team was constituted to make further and more specific investigation of some aspects concerned with ballistics and related subjects.

The membership of the team was:-

Dr.Maccoll (A.R.D.), Dr.Hankins (N.P.L.), Mr.Illingworth(A.R.D) and Mr.Adams (A.R.D.).

The first three members of this party started their investigations about ten days before the last named. The present report should therefore be read in conjunction with the reports issued by those members. Nevertheless an attempt has been made to include below a self-contained report on the apparatus and methods in use in the Weapons Section of L.F.A. more especially in relation to high speed photographic methods and precise ballistic measurements.

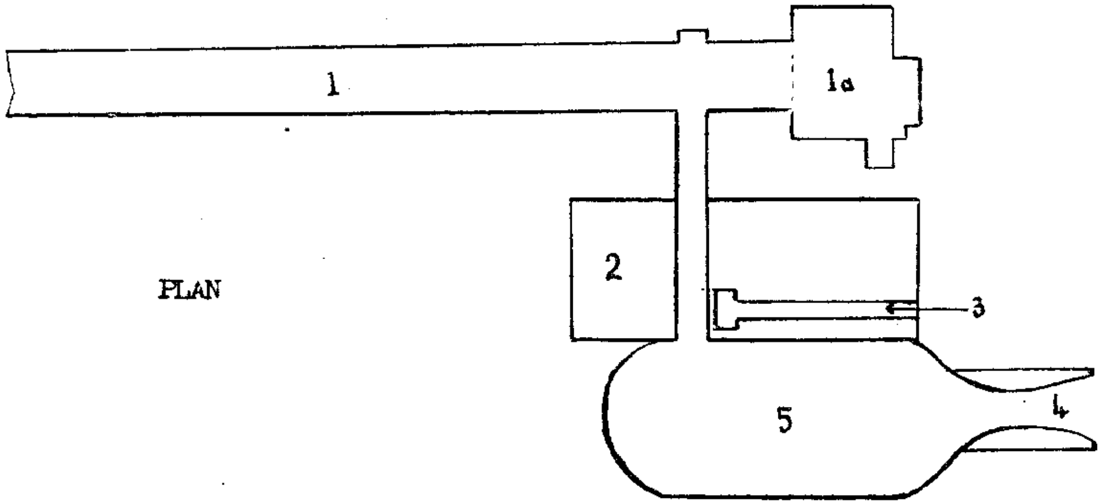
II. Organisation of L.F.A and personnel interviewed.

The L.F.A. was divided into four Institutes, all under the general direction of Prof.Blenek. The names of the Institutes and of their Heads were as follows:-

Aerodynamics Institute	Head,	Prof.Blenck.
Statics "	"	Prof.Dirksen.
Engines "	"	Prof.Schmidt.
Weapons "	"	Prof.Rossman.

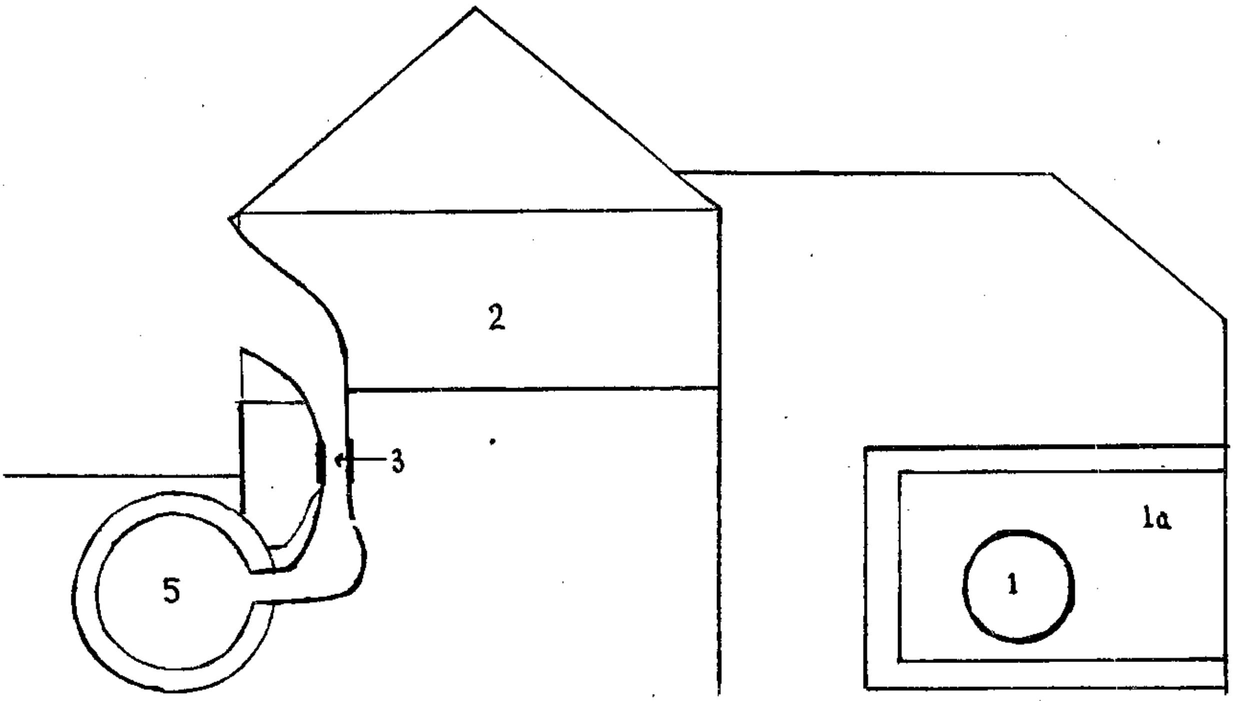
The Weapons Institute, with which this report is mainly concerned was sub-divided under Prof.Rossman, as follows:-

Ballistics	-	Dr.Schüssler.
Functioning of Weapons	-	Dr.Hackemann.
Bomb Sights	-	Dr.Schught



PLAN

1. Reduced pressure tunnel, recesses not shown.
1a. Firing point for the tunnel.
2. Machine house for pumps and controls.
3. Cross wind tunnel.
4. 'Bomb vibration' channel.
5. 3,000 cubic metres concrete vessel associated with 3 and 4.



ELEVATION

Figure 1.

Access to these rooms is possible from the tunnel through locks, thus enabling work to be performed in the tunnel between rounds without the necessity for re-evacuation. Supply cables and leads for measuring devices are run under the concrete floor and are accessible at intervals through floor plates, and there is also a plentiful supply of distribution boards protected by armour plate. Large guns, or guns mounted in aeroplanes can be brought to the outside of the firing point, which can be opened to allow firing in these conditions at atmosphere pressure. When sealed a pressure of .02 atm. can be reached and it was stated that further reduction to .01 atm. was planned.

The cross wind tunnel is associated with the low pressure tunnel to the extent that (1) the same pumps are used either to evacuate the low pressure tunnel or to evacuate the large chamber into which the air flows from the cross wind tunnel, and (2) the timing of the photographs in the cross wind tunnel is effected by simultaneous firing of similar equipment in the low pressure tunnel where screens are located which trigger the photographic apparatus viewing the cross wind tunnel. The method by which the cross wind is produced can be seen by reference to Figure 1. The concrete vessel (5) is sealed at the entry to the cross wind tunnel by a series of ten soft aluminium sheets (approx 1 mm. in thickness and 1 x 2.7 metres in area). Detonating cord is pasted round the borders of the plates and is fused immediately before firing. The sheets are thus blown into the vessel, exposing a cross section of 27 square metres through which atmospheric air rushes from the top of the tunnel. It is claimed that the opening process occupies a time only of the order of a millisecond and that a blast at 200 metres/sec. lasting for .5 second can be produced. These latter conditions can be varied by the insertion of cylindrical obstructions below the line of fire.

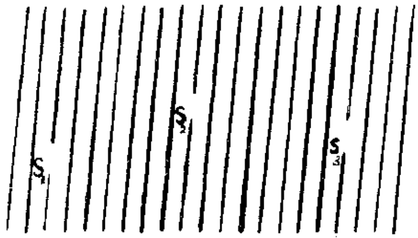
Details of the construction of the tunnel and the nature of the pumps were not considered important in the present connection. They may be found in 'Die ballistischen Versuchs und Messanlagen der Luftfahrtforschungsanstalt Herman Göring', by Karl Schüssler, Schriften der Deutschen Akademie der Luftfahrtforschung 1942. (Available in the library at L.F.A. A copy is also believed to exist at A.R.D. Fort Halstead).

V. General description of apparatus used in W-1.

The measurements taken in the tunnel are entirely concerned with External Ballistics. For this purpose there are two types of record taken.

(1) Space time measurements.

The space time curve is obtained from the passage of the projectile through Al.foil screens. These are stated to have a negligible effect on the velocity of the shot. Check firings to establish this result have been carried out and it was found that many more screens than the number normally used were necessary to produce a measurable change of velocity. Recording is by cathode ray oscillograph with the beam oscillating at 1000 cycles/sec. and interrupted by each screen. The record is taken on a drum moving comparatively slowly, 1 to 2 m/sec., and the record is thus of the type shown in Figure 2.



Each complete line ≡ 1 fork period.

S_1, S_2, S_3 etc. ≡ instants at which screens are triggered.

Facilities were available for measuring the extent of the non linearity of the sweep (with time) by means of a high speed oscillograph. The accuracy claimed in time measurements by this method is 10^{-5} sec.

Ancillary apparatus used in connection with this system included, (a) transformers to burn away tatters of Al.foil after a shot has been fired to prevent shorting which might otherwise be caused by air waves preceding low velocity projectiles;
(b) facilities for shifting the screens by remote control+).

The object of (a) and (b) was to reduce the number of occasions on which it was necessary to enter the tunnel at reduced pressure.

The accuracy claimed for space measurements along the tunnel was ± 1 cm. (Further reference to this claim is made in Section IV).

A full description of the methods of space-time measurement is given in 'U.M.2062 (3)' by J.Schmidt of L.F.A. Only one copy of this document was found; it was therefore left in the L.F.A. library with a request that a copy should be made and sent to the A.R.D.

+) Only four of these were developed and it is doubtful whether any are now available. They were not found on inspection of the W buildings.

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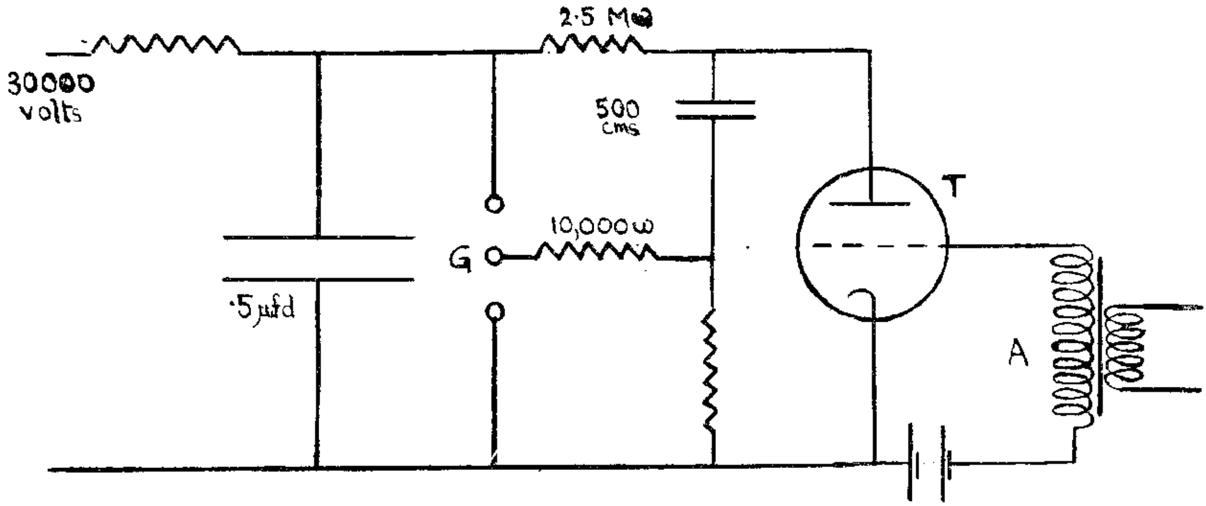
(2) Photographic measurements.

The main feature as regards the study of External Ballistics is the system for shot photography and its associated devices. The units used are called 'Blitzgeber'. Their purpose is to provide the light for a sequence of photographs (in two perpendicular directions) at intervals separated by an integral number of milliseconds (or other small unit time dependent on the fork used to control the sparks). The immediate control of the spark discharge is shown in the diagram below:-



The discharge will clearly occur across the gaps G (if they are correctly set) when the thyratron T is made conducting by a pulse from A. The thyratrons were specially designed and made by A.E.G. (Nickel-plated iron electrodes were used for the gaps G. Once they had been adjusted resetting was unnecessary). The pulse is not given directly from the screens. The output from the screens passes into a 'control unit' whose function is to raise the mean potential of an oscillating circuit controlled from the fork by about 100 volts. The transformer A therefore communicates a pulse to the grid of T (of a sufficient magnitude to trigger it) on the second peak after the passage of the projectile through the screens. A description of the operation of the control unit is given in Section V(3) below.

The main discharge is oscillatory but it is claimed that light emission is negligible after the first 10^{-6} sec. (about a full period of the discharge. No damping resistance is put in the discharge circuit). Photographs I have seen throw some doubt on this claim. The background is visible through the rear part of the projectile: Nevertheless the photographs are in general of

/good

good quality and it is likely that the effective exposure is only of the order 10^{-6} sec., the remaining exposure being weak and spread over a relatively long time.

The cameras had a field of view of about 3 metres diameter in the plane of fire. Sufficient light was obtained for +) direct photographs but there is also a diffuse shadow on the white background. More light would have been desirable and would be given by the substitution of discharge tubes containing Argon under pressure. These were under manufacture by "Geräte Entwicklung" at Danzig.

Use of the Argontubes would have two other advantages: (a) it would be unnecessary to confine the Blitzgeber in air tight vessels to maintain atmospheric pressure for the sparks when the tunnel is at reduced pressure. (b) There would be no products from the discharge to disturb the discharge potential. At present ozone and NO_2 are produced and must be cleared after firing by an air blast through the units. A compressor working at 15 atm. for this purpose is available and is housed at the 200 metre station.

The original units were triple, i.e. each container had three spark gaps in which the discharges followed with an interval equal to the period of the fork. No screening existed between the gaps and condensers of one spark system and the others in the sameunit. It was stated that this caused no interference, with the condensers originally supplied (made by the firm Hydra of Berlin). Condensers of later date had more internal inductance and interference occurred. Some units were therefore made with two spark gaps only and this allows space for screening, but the screening has not yet been introduced.

The development in contemplation was to use a large number of single Blitzgeber and 50 were on order in Hann.-Münden X.

When the photographs had been taken the position of the shot was reconstructed by replacing the negative in the camera and projecting the image into the tunnel on a screen capable of rotation and displacement in all directions. This apparatus is

/described

+) The shot were not always specially painted. In general they were used in the "as received" condition, but sometimes they were painted black.

X Firms: Hochspannungs-Gesellschaft, Köln, Zollestock, for the Blitzgeber.
D.W.M. (Director Herr Dinner) Lübeck, for the control units.

described in the report of Dr. Schüssler. The accuracy claimed for the angular position is about half a degree. The quality of the photograph from the vertical camera is inferior to that from the horizontal one owing to the direction of the light from the spark but scattered light from the white background assists the vertical camera. The mounting for the movable screen which I saw, is comparatively small. For projectiles of length greater than about 10 cms. the whole profile cannot be seen on the screen. The direction of the axis can still be estimated but a larger mounting was under construction.

A development was in progress to use cameras whose plates could be shifted automatically, allowing ten rounds to be fired without the necessity to re-enter the tunnel. These were not in operation.

Another development in contemplation was the use of photo-electric light screens. These were built by Siemens-Halske, of Berlin but only one was delivered. The mirrors, with their sections of spherical lenses are still mounted in the tunnel but the associated apparatus has been removed. The principal advantage of this method is the elimination of the necessity to shift screens between rounds, and a subsidiary advantage that the effect of the screens on the shot motion is zero. (This seems unimportant in view of the previous statement about the Al. screens). The system gave a region in the centre of the tunnel, about 5 metres width, continuously filled with light. It was stated that the cell was triggered at a head penetration into the beam of about 1 cm ± .4 cm. No difficulty was experienced with scattered light although the tunnel is painted white. It was not thought that the Blitzgeber cameras would have been affected if photoelectric screens of this type had been fitted at all stations. +)

VI. Details of triggering arrangements.

(1) Control units.

In addition to the information obtained by inspection and interview a written account of the operation of the control units was requested from Dr. Siekman. For the translation of his statement I am indebted to Dr. Calvert of the A.R.D. The following description is based on this document and amplified by the information obtained on the site.

/The

+) The cameras were fitted with auxiliary Compur shutters, worked electrically from the control unit, so that the lenses were open only for a short period bracketing the time of flight of the projectile.

The circuit diagram is shown in Figure 3.

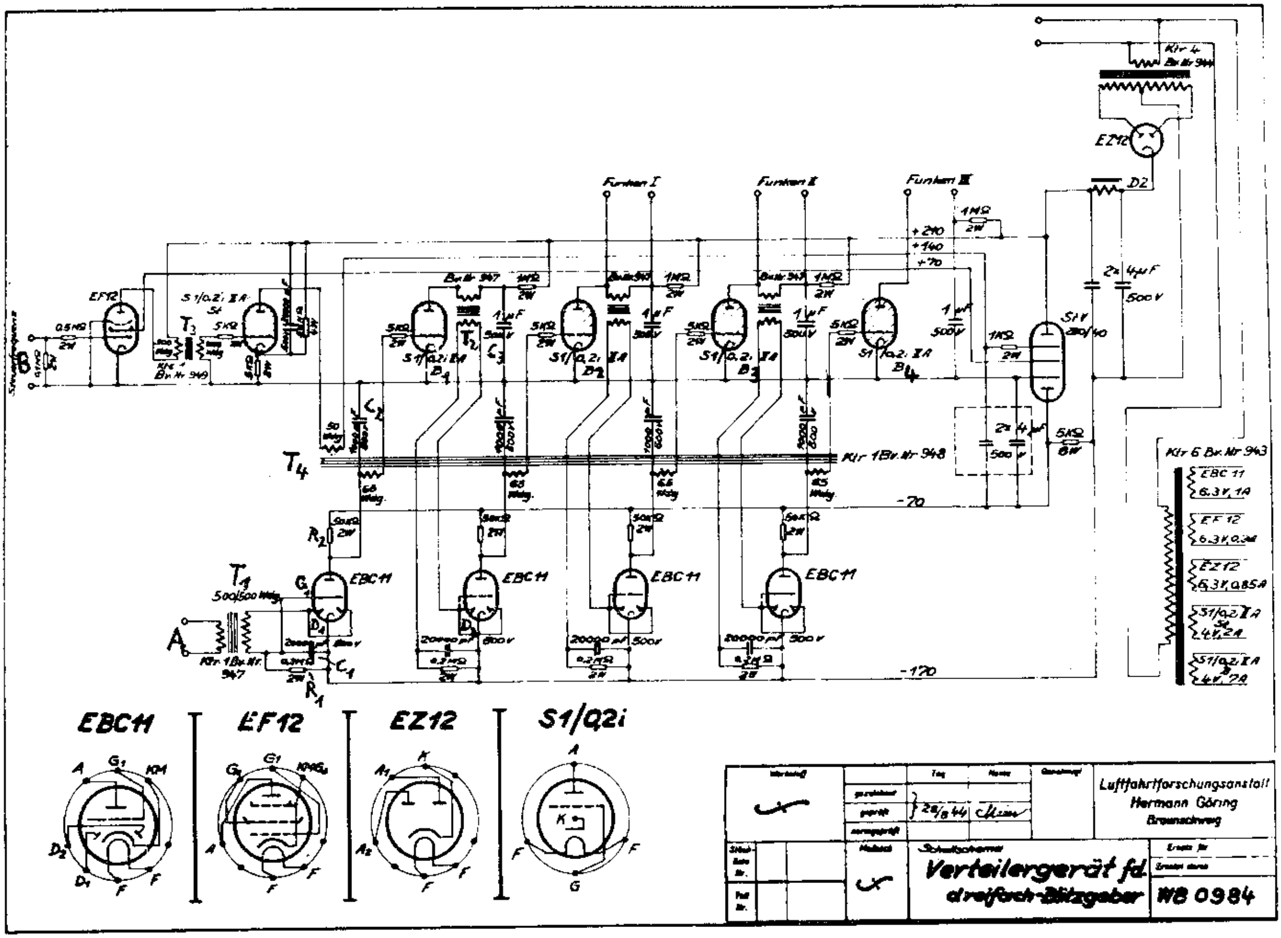


Figure 3.
(Reproduced from German circuit diagram).

A thyratron circuit (not shown in Figure 3) is actuated by each aluminium foil contact screen and provides an impulse to the primary terminals A of the transformer T_1 (K tr.1. Bv.Nr 947, 500/500 windings A.E.G). The secondary current of the transformer charges the condenser C_1 through the diode component of the diode-triode G_1 and this charge brings a negative potential to the grid of G_1. In the steady state the grid and cathode of G_1 are at the same potential and current is therefore flowing from the triode anode. The negative potential applied to the grid stops this anode current. The period for which the current is stopped depends primarily on the magnitude of the condenser C_1 and of the resistance R_1 which shunts it and through which it will eventually discharge. The values are $C_1 = 20{,}000\ \mu\mu fd$, $R_1 = 0.2$ megohms, giving a time constant of 4 milliseconds. For a time of this order, therefore, the only current flowing through the anode resistance R_2 (50,000 ohms) is that due to the partial discharge of the condenser C_2 (1000 $\mu\mu fd$). The time constant of this circuit is 5.10^{-5} seconds. The lower plate of C_2 is connected through a secondary winding of the transformer T_4 to the grid of thyratron B_1 (Type S 1/0 2 i, II A (Helium) or I A (Argon)). The mean potential of the grid of this thyratron therefore rises exponentially (with time constant 5.10^{-5} seconds) from its previous value of about -150 volts to the limiting value of -70 volts. The initial value of -150 volts for the mean bias is sufficient to prevent the thyratron from striking as a result of the periodic potential fluctuations applied from T_4. The rise in mean bias is sufficient to ensure that the next peak from T_4 will raise the grid potential above the critical control voltage and hence fire the thyratron.

The periodic voltage applied by the secondary of T_4 is controlled by a tuning fork and associated distorting circuits as shown in the top left of Figure 3. The fork output is applied at B to the grid of a pentode (Type E.F.12 Telefunken) with zero mean bias. For most of the positive half period the valve is therefore saturated and in these intervals the anode current is nearly of rectangular form. This current passes through the primary of the transformer T_3 (Type K.tr.1. Bv.949 A.E.G) and its secondary therefore gives an output with a sharp front to its wave form. The sharp front triggers the thyratron to whose grid the secondary of T_3 is connected. Since rapid extinction is required in this thyratron it is of the helium filled type (S 1/0 2i, IIA (He)A.E.G). The anode circuit of the thyratron includes the primary (50 turns) of the transformer T_4 (Type K.tr.1. Br. Nr.948) which has four

/secondaries

secondaries each of 65 turns. The first of these secondaries is connected as described above, to the grid of B_1 which is thus triggered at the first peak after contact at the alumirium foil. The first spark is not triggered by B_1 because the phase of the fork frequency might be such that a peak occurred immediately after contact and a photograph of the projectile just projecting through the screen would not be useful. B_1 is therefore, in effect, a priming stage whose function is to provide to the diode-triode D_2 an impulse similar to that provided by T_1 to D_1. This equivalence is arranged by including a transformer T_2 (Type K tr 1. Bv. Nr.947. A.E.G.) in the anode circuit of B_1. T_2 thus communicates to D_2 a pulse of the same nature as that communicated to D_1 by T_1, the whole circuit being duplicated. Hence B_2 is triggered at the next pulse from the fork after that which triggered B_1, i.e. at least one and at most two periods after contact is made at the screen. The process is repeated twice so that B_3 functions one period later than $B_2$and B_4 one period later than B_3. It is claimed that the converted fork impulses are sufficiently sharp to ensure that the intervals between successive triggering of the thyratrons B_1, B_2, etc. are subject to a mean error of less than 2 microseconds. The fork frequency commonly used was 1000cycles/sec. Forks of frequency 250, 500 and 2000 were also available and could be used without any changes in the control unit. (The choice of C_1R_1 = 4 millseconds appears to have been made to allow the comparatively low frequency of 250 to be used if required).

As shown in Figure 3, the output to the spark units is taken from the primaries of the transformers in the anode circuits of the thyratrons B_1, B_2, B_3. The output is applied, through a transformer to the grid of the high voltage thyratron controlling the triple gap in the manner described in (2) of Section V. Each triple unit thus provides three photographs, with light provided by three separate spark gaps all in the same housing, superposed on the same plate. The merit of this rather complicated system of control was stated to lie in the greater ease of analysis of results when the time intervals between photographs are multiples of a single period. It was stated that, to the accuracy required, the sparks occurred with the correct intervals. Nevertheless an arrangement existed to record the time of occurrence of the sparks. This consisted simply in a wire stretched along the range above the spark units and connected to the space-time oscillograph. Each 'earth' electrode of the spark units was connected to the wire and the pulse occurring in it was of sufficient magnitude to deflect the beam and so to record the time on the cathode ray record.

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(2) The photo-electric screen.

A diagram of the optical arrangement of the photo-electric system is shown in Figure 4, in which only the axial ray has been drawn.

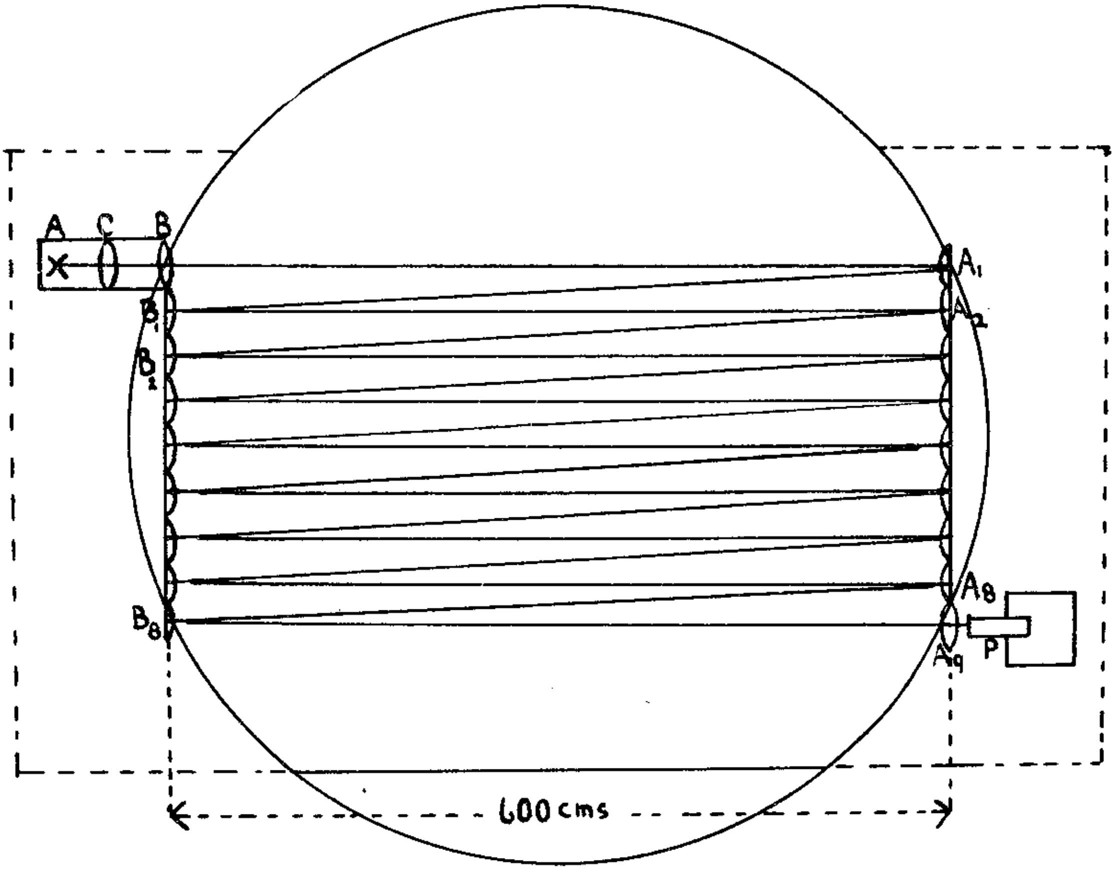

Figure 4.

A is a light source consisting of a 75 watts 12 volts lamp having a filament consisting of a narrow spiral with vertical axis. It is placed at the focus of the condensing lens C (focal length 10 cms.) and the neighbouring lens B therefore forms an image at its focal distance (600 cms.) of the source A. This image completely fills the lens A_1 which is a rectangular section (10 cms. height, 2.5 cms. breadth) of a spherical lens of focal length 600 cms. A mirror is situated immediately behind A_1. (It was not stated whether the mirror and lens were separate components or whether the lens was plano-convex with the plane surface silvered). The effective focal length of the lens-mirror combination is thus 300 cms. A_1 therefore forms an image of B on B_1 with unit

/magnification

APPENDIX 1.

High speed Schlieren photography in the Engines Institute.

Apparatus is installed in the Engines Institute for investigating, under the direction of Prof. Schmidt, the phenomena occurring during the combustion of gaseous mixtures (e.g. propane and air) in 'cylinders' similar to those of internal combustion engines. For this purpose the 'cylinder' is mounted with its long axis horizontal and its vertical walls are made of plane glass. The usual Schlieren optical system employing a concave mirror is used. Owing to the length of the cylinder, in which propagation effects are studied, four mirrors are used each covering neighbouring sections of the cylinder and each with its own associated spark source. The four spark gaps are in series and are housed in a glass walled tube containing hydrogen at 2 to 3 atmospheres. Across the extreme electrodes there is a condenser of capacity .03 μfd . This is fed, through an inductance, by a reservoir capacity of 3 μfd. For most of the work the inductance was chosen to give a maximum spark frequency of approximately 25,000 per second. Other inductances, to give different speeds, were available and it was intended to make some applications at 50,000 per second.

Synchronisation of the beginning of the spark discharges with the initiation of the explosion was arranged by a pendulum. The condensers were charged to 30,000 - 40,000 volts and the pendulum closed a circuit which, though a thyratron relay, applied a field from an induction coil to the spark tube, breaking down the gaps and thus initiating the discharges.

The pictures were recorded on continuously moving film with a linear speed of approximately 7.5 cms/millisecond, the picture width being about 3 mm. Hence at 25,000 frames/sec. the boundaries of one picture and the next were nearly touching. Examination of some of the original records showed that the frequency in any one sequence was very variable. The intervals were long at the start, then became progressively shorter, and subsequently expanded again. This effect would be expected to follow from the initial increase in ionisation consequent on the earlier discharges, and the reduction in voltage due to exhaustion of the reservoir condenser in the later stages. It was considered unimportant in view of the fact that the spacing of the frames on the film provided a measure of the individual intervals.

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The installation calls for no special comment as regards technique, the principles used being well known. All the components were excellently designed and made, and, as far as could be seen, in a state fit for immediate application. The method and results of its applications are described in: 'Probleme der Verbrennung', Prof.Schmidt, Deutschen Akademie der Luftfahrtforschung.

APPENDIX 2.

Work on Terminal Ballistics at Krupps, Essen, up to 1943. (Information derived from interviews with Prof.Rossmann).

(1) From 1930 to 1942 Prof.Rossman directed scientific research at Krupps, Essen. He had previously been chief assistant to C.Cranz at the Institute for Technical Physics and Ballistics and continued his contact with Cranz from Essen. He appears to have continued the direction of research work at Krupps from the time he left in 1942 to take up his post at L.F.A. until July,1943, when research at Krupps was brought to an end by bombing. The following account should therefore include all the Terminal Ballistics research undertaken at Krupps from 1930 onwards. It is difficult to believe that these rather meagre results cover the German research activities in Terminal Ballistics for that period. The statement frequently made by Prof.Rossmann and others that research in Germany was in 'watertight' compartments and that jealousy existed between firms, institutes and Ministries is therefore probably correct. An examination of all possible sources of information would therefore be necessary to ensure that no development of technique has been missed.

(2) The well known optical system of Cranz and Schardin was used in conjunction with the usual capacity-inductance circuit to produce 24 spark shadowgraphs of armour plate penetration at frequencies from 200,000 to 60,000 per sec. The electrodes used were nickel plated iron, the array was 6 x 4 and the spacing between neighbouring sparks 6 cms. Voltages used were 50 - 100 kV. No electrical screening was included, but the range was heated to counteract humidity effects. Sparks sometimes occurred out of their proper time sequence but in general the regularity of repetition of time intervals was about 10%. No independent record of the times of the sparks was made but it was contemplated to use a drum camera with a film speed of 10 cms/millisec. for this purpose. Such cameras had been in use by Schardin.

/Only

Only qualitative facts now well known in the U.K., were established by these researches which were carried out in 20 mm. calibre. Transverse rotation of the shot in oblique impacts, and the behaviour of soft caps were observed. The targets used were soft for armour plate (120 - 150 kg/mm^2)*. An attempt was made to obtain the force-time curve through armour plate by double differentiation of the space-time curve. No allowance was made for shot elasticity, and times were taken from the head wave motion. It is therefore unlikely that the results have sufficient accuracy to provide any reliable information on plate resistance.

A sketch of a proposed method for extending the observations to 10 cm. projectiles, by the use of mirrors was provided. The range had been built but the installation had not been made.

For photography of target impacts giving considerable light emission (e.g. tungsten carbide cores with aluminium envelopes) the target was confined in a box with two glass walls, filled with carbon dioxide. Flash was successfully eliminated by this method.

The peak force occurring during the penetration of armour plate had been measured by a gauge housed in the shot (20 mm. calibre). The gauge consisted of a hardened steel plate, coated with soot and bearing against the curved surface of a segment of a sphere. The latter was also of hardened steel. Only elastic distortions occurred at the region of contact. The extent was measured from the impression on the soot and a static calibration then gave the force.

(3) Experiments were made to find whether a scale effect in armour penetration could be observed. These experiments appear to have been very restricted in scope. Bracketing critical velocities were determined in 20 mm. shot made as exact scale models, including hardness distribution, of 150 mm. shell. The results were compared with the records available at Krupps of the performance of the 150 mm. shell and the conclusion was that no scale factor existed. No attempt was made to fit a formula to the results, and no static tests were made. The target hardnesses were again very low (120 to 150 kg/mm^2)*. It is unlikely that these results can contribute any new information to the more exhaustive and accurate trial results known in the U.K.

/(4)

* This figure was quoted by Prof. Rossmann in response to a question on hardness. I interpreted his answer to refer to refer to an indentation test. Dr. Baines has since pointed out that the figures may give the range of yield strengths. This is probably the correct interpretation since the hardness would then be in the expected range.

(4) It was stated that a large increase in energy absorption during penetration occurred as velocity was increased. No figures could be quoted by Prof.Rossmann at the interview.

(5) All the above information, and some additional lectures (total 10) are stated to be contained in "Bericht 166 of the Lilienthal-Gesellschaft für Luftfahrforschung". Approx. date: May 1943. No copy could be found at LFA but it was stated that a copy has been taken to U.K.

Conclusion

It is unlikely that any addition to British knowledge regarding Terminal Ballistics can be obtained from the results described by Prof.Rossmann. As suggested in (1) above further examination of other personnel (e.g. Schardin) might yield more information and also lead to more profitable directions for investigation.

APPENDIX 3.

Kerr Cell Photography.

I. Introduction.

There was no evidence of any work on Kerr cell photography at Volkenrode, but two documents referring to work at another Institution on this subject were found in the W buildings by Mr. Illingworth, who kindly put them at my disposal. For their translation I am again indebted to Dr. Calvert. The titles are:-
'Bericht über funkenkinematographische Aufnahmen von Panzerplattenbeschüssen auf einem Schiessplatz bei Tageslicht', Dr. Funfer, Physikalisches und Ballistisches Institut der Luftkriegsakademie Berlin-Gatow 2. 7/40.
'Entwicklung und Erprobung einer fahrbaren Funkenanlage', Dr. Fünfer.
Ballistisches Institut der Luftkriegsakademie. Berlin-Gatow 2.

Since these reports show that development of Kerr cell photography had been initiated earlier and taken further, than similar work in the U.K. a summary of the essentials of the German method, as described in these reports, is given below.[x] Before giving the summary a few general considerations regarding this type of photography should be stated:-

The objects to be photographed in many ballistic studies move with such rapidity that the exposure time which can be tolerated is only about one microsecond. By using spark-shadow photography, either direct or via a field lens (or mirror) and cameras, these exposure times can be arranged without serious difficulty in a darkened range. There are two disadvantages to these methods, (1) Where impacts are concerned, e.g. armour piercing projectiles attacking armour plate, there is a limit to the size of projectile which can be used owing to the risk of damage to the equipment, some of which is necessarily very close to the target. (2) It is sometimes inconvenient with relatively small calibres, and almost impossible with larger calibres, to arrange the impact in a darkened range. The extension of photographic methods to larger calibres therefore involves the abandonment of shadow photography in favour of reflected-light photography, and of darkened ranges in favour of natural conditions on an open range. The short exposure required still makes it necessary to provide artificial illumination, the brightest sunlight being quite inadequate for photography at a microsecond exposure. Moreover, the use of reflected light requires that the source shall be very

/much

x A description of a system of Kerr cell photography developed in the Armaments Research Dept. may be found in A.R.D. T.B. Report 9/45.

much brighter than that which suffices for a silhouette, and the larger field of view also entails a more powerful light source. These considerations are in principle independent of the problems associated with the shutter. Assuming the light to be available it is still necessary that the exposure time shall be confined to about one microsecond. The Kerr cell deals only with this aspect, but in any practical application the means of providing the required light must also be considered. The two German reports 7/40 and 2/42, like the British report A.R.D.T.B.9/45, treat the two problems together. Circuits are devised for triggering the light source and the Kerr cell shutter nearly simultaneously. The Kerr cell presents a means of obtaining a very rapid acting shutter in the following way. The effect discovered by Kerr, and named after him, is that some media become doubly refracting when an electric field is applied across them. If plane polarised light passes through these media the plane of polarisation can therefore be rotated by the application of an electric field perpendicular to the direction of transmission. If the medium is bounded by parallel polarising screens where the light enters, and where it leaves, and if the axes of the screens are perpendicular, the amount of light transmitted will be nearly zero when no field is applied, but can be increased almost to the limit of the light passing through the entry screen if the applied field is sufficiently large. The combination can, therefore, be made to act as a shutter, and the problem of producing a short exposure time at the right instant reduces to that of producing a short voltage pulse (of sufficient magnitude) synchronised with the event and the illuminating flash. Either the flash, or the Kerr cell exposure, must be of the necessary short duration. Since there is inevitably some residual transmission in the Kerr cell even when there is no rotation of the plane of polarisation it is necessary to supplement the Kerr shutter with another shutter whose function is to ensure that the camera is 'open' when the exposure is required, but not for a sufficiently long time to allow the plate to record an image by residual transmission. The liquid showing the largest Kerr effect is nitrobenzene.

II. Summary of 7/40.

A Leica camera with a Summitar f/2 lens was chosen. It was taken as a condition that the distance between the cell plates should equal the diameter of the lens, 2.5 cms. For 90° rotation, corresponding with maximum transmission, the following relation must hold -

$$kV = .3a \left(\frac{0.5}{Bl.}\right)^{\frac{1}{2}}$$

/where

where kV (called the 'Brightvoltage') is the applied potential in kilovolts, and

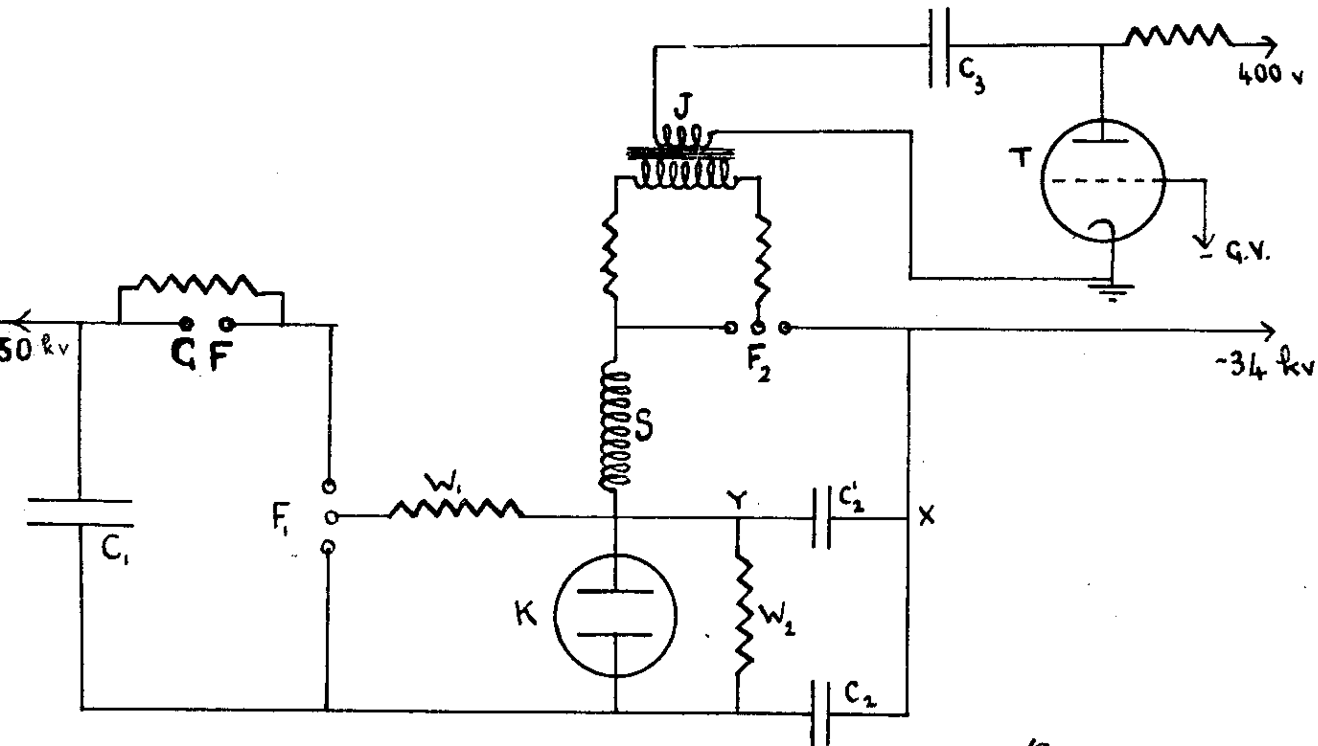
a = electrode separation in cms (= 2.5cms)
B = Kerr constant (= 3.10^{-5} approx. for nitrobenzene)
l = length of path through medium (= $2.^{0}$ cms).

Hence 68 kV would be required for full transmission.

The polarising material was 'Herotares', made by Zeiss and available in large thin sheets, but suffering from two disadvantages: some absorption in the blue region, and strong transmission in the crossed position in the red region. The transmission was sufficiently countered by the use of an auxiliary Compur shutter operating at 1/10 second.

For the illumination 'Guided sparks' were used. The necessary combination of high energy and short duration was not obtainable with air sparks. Discharges in gases at increased pressure were tried and could have been used but the guided spark was simpler. The guided spark consists of a condenser discharge along the surface of a partial conducter. Effective durations of 4 microseconds were obtained in this way.

The circuit used to control the guided spark and the Kerr cell is shown in Figure 1 (Fig.2 of 7/40).



/01

C_1 = condenser providing light discharge (magnitude not quoted)
GF = guided spark, F_1 = control spark for GF.
K = Kerr cell. F_2 = " " " K.
C_2, C_2^1 = Condensers applying high voltage to K. ($C_2 = C_2^1$ = .05 microfarads?).
S = inductance, W_1 = high resistance (magnitudes not quoted).
W_2 = high resistance (0.1 megohms approx?)
T = thyratron, C_3 = capacity, J = transformer.

Figure 1 (Fig.2 of 7/40).

The principle of the circuit is clear from Fig.1. The impulse from the event is applied at GV to the grid of the thyratron T, causing C_3 to discharge through J and hence producing a triggering spark in F_2. Regarding the time constant of the circuit C_2^1 F_2 S as small compared with C_2W_2, it is a close approximation to assume that the voltage at the point X rises exponentially from -34kV to zero with time constant C_2W_2, and that the potential difference across C_2^1 oscillates with an amplitude 34kV and a period proportional to $\sqrt{SC_2^1}$. Hence the first peak potential at Y is nearly -68kV. This is applied both to the cell K and to the control gap F_1, which therefore triggers the discharge of C_1 through GF and F_1. During the discharge through GF the voltage across the cell is oscillating with a mean value of approximately -34kV.

Details are given of various oscillograph measurements of voltage both with the above circuit and with aperiodic damping in C_2F_2S and of measurements of ligh transmission. Some description is also given of the extension of the arrangement to provide three units and the measures adopted to prevent one unit from interfering with the next. Methods of restricting the time for which the Kerr cell is open are given a very brief discussion, but since they follow fairly obvious lines and are dealt with more fully in the later report their description is omitted from this summary. The report concludes with a discussion of photographs (reproduced in the report, but not here) taken with the apparatus at Unterlüss.

III. Summary of 2/42.

The principal difference between the basic circuit described in 1942 compared with the earlier circuit is that the later arrangement, shown in Fig.2. includes a subsidiary circuit to give early closure of the shutter. (Apart from this subsidiary circuit the arrangement now resembles that of T.B.9/45).

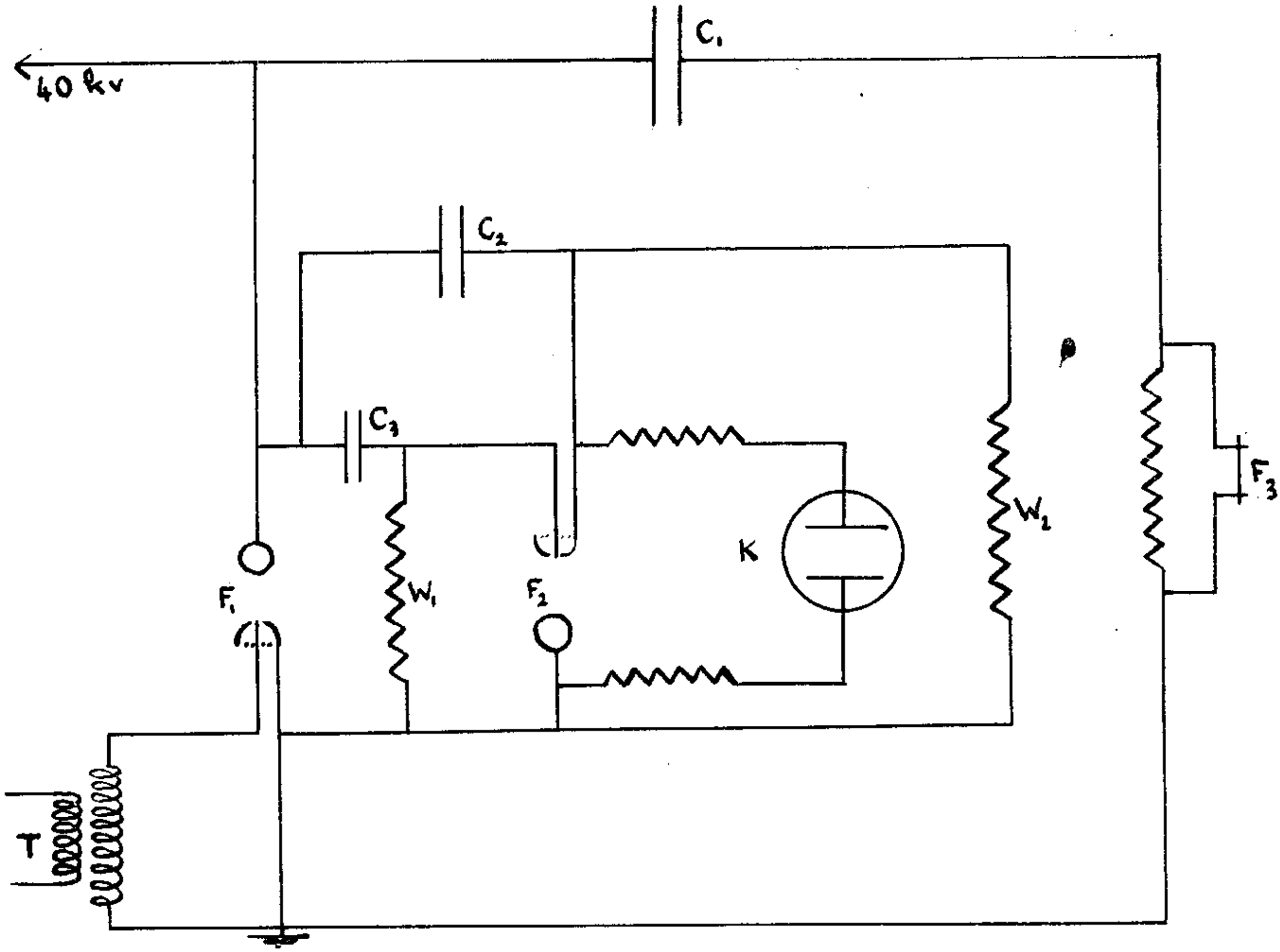


Figure 2 (Fig.1 of 2/42).

From the description of the circuit given later in the text the values of the components appear to be as follows:-

C_1 = 0.5 microfarad. (This is not definitely stated but seems to be implied in discussions of duration measurements).

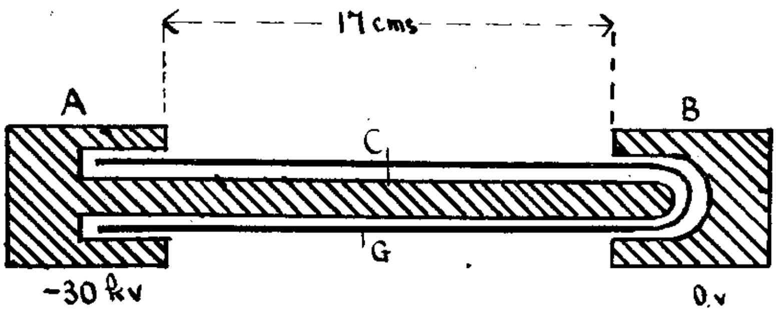
$C_2 = C_3$ = 10000 cms. (.01 microfarad).
W_1 = 1000 to 10000 ohms, W_2 = 1 meghohm
F_1 and F_2: 'slit' spark gaps respectively for initiation and cut-off.

F_3 illuminating spark gap.

/The

The 'slit' spark gaps are not described but the form of the diagrammatic representation suggests that they are three-electrode gaps in which the control electrode projects through a hole or slit in one of the main electrodes. The two 'slit' spark gaps F_1 and F_2 are set so that they will just withstand the applied voltage of 40kV. The triggering impulse is supplied by the coil T to the control electrode of F_1, causing a spark in the minor gap and so ionising the main gap. The breakdown of F_1 causes a potential of 40 kV to be applied to F_3 and the Kerr cell K. The voltage across the cell will be reduced to zero when F_2 breaks down. The time at which this breakdown occurs depends on the difference in the time constants $C_3 W_1$, C_2W_2 since the minor gap of F_2 is subjected to the difference between the potentials across C_2 and C_3. It is clear that the time constants can easily be varied and it is implied that the minor gap of F_2 will always break down at the same voltage, thus giving a simple control of the time of closure of the shutter. The important point of the regularity of the minor gap is not dealt with in this report. Oscillograms are reproduced showing that an approximately rectangular voltage wave is thus applied to the cell. The duration is comparatively long (7.10^{-5} secs. approx) and when the guided sparks described in 7/40 were used the effective illumination from F_3 occupied approximately the last 3.10^{-5} secs. For the purposes envisaged these times are too long and a modified illuminant was therefore developed.

In the new guided-spark gaps the semi conductor was replaced by glass. Oscillograms showed that both initiation time and duration were thereby greatly reduced. The form evolved for use with a reflector is shown in Figure 3.



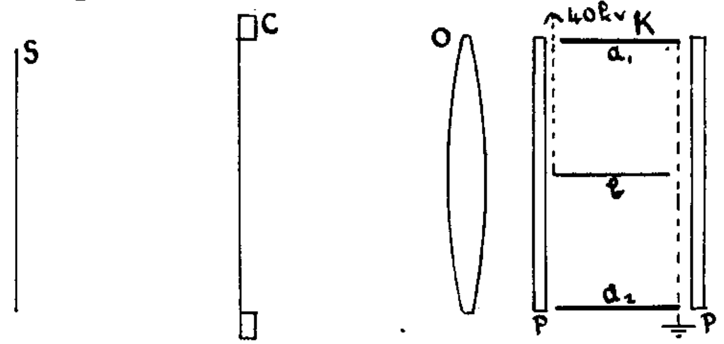
A,B = Electrodes, G = Glass tube, C = Copper rod.

Figure 3. (Figure 7 of 2/42).

/It

It is stated that A should be the negative pole and that although roughening of the glass surface occurs, a very large number of sparks may be discharged without reducing the effectiveness. From the oscillograms reproduced it appears that the illumination lasts for about 20 microseconds, and that in the particular case analysed, the Kerr cell was open for about 40 microseconds. These comparatively long times apear unsuitable for the majority of ballistic applications. A later part of the report, however, indicates that by variation of the control circuit of F_2 an exposure time of 3 microseconds was achieved on one occasion.

The design of the camera is indicated in Figure 4.



K = Kerr cell P = polarising screens.
O = Objective = Leitz Xenon lens, f = 5 cms, aperture = f/1.5
C = Compur shutter giving 1/10 sec. exposure.
S = Photographic plate.

Figure 4 (Fig.10 of 2/42).

The lens O had a coated surface to reduce reflection losses. Since its diameter was 34 mm. and the light path through the cell was only 18 mm. it would be estimated theoretically that a voltage of 88kV would be necessary to obtain maximum transmission. Increase of the voltage above 40kV was considered impracticable and the field was doubled without increasing this voltage by halving the plate separation. By duplicating the outer plates, i.e. using a_1 and a_2 as shown, no sacrifice of aperture was necessary and the small angular field prevented the centre electrode b from introducing any serious defect in the image. Photocell measurements showed that the distance 17 mm. between plates gave optimum transmission although the formula would predict 15 mm. The discrepancy is of course readily understandable in view of the uncertainty of the constant B, especially when the nitrobenzene is impure, and the inhomogeneity of the electric field.

/Details

Details are given of tests made with rotating mirrors to examine the timing of light intensity and Kerr cell operation and also of the auxiliary circuits required in connection with control and delay arrangements, extension to quadruple units, and high voltage supply. For these details reference should be made to the original report. Complete translations of both reports have been prepared by Dr.Calvert.

IV Comments.

These reports show good achievement in the following aspects -

(i) A compact and effective design of camera and Kerr shutter has been produced.

(ii) The control and auxiliary apparatus has been sufficiently reduced in bulk to make it easily mobile. This reduction was one of the objects of the work described in 2/42. Although the dimensions of the complete apparatus are not quotedit is apparent that it was in fact portable to the site of trials.

(iii) The problem of producing sufficient light appears to be only partially solved. The guided-sparks, when used with reflectors appear to provide adequate light over a field of perhaps 2 to 3 metres diameter with the energy from .5 micro-farad at 40kV. Both from the examples of photographs and from the text of the reports, however, it seems likely that the duration, by ballistic standards, is too long, possibly by a factor of 10 or more. The extent to which the available light will allow the exposure to be reduced is not made clear.

V. Recommendations.

Further investigation of the work done on this subject would be very desirable. While some information may already have been collected by other investigators it seems clear that it is likely to be incomplete unless the staff of the 'Ballistisches Institut der Luftkriegsakademie' formerly at Berlin-Gatow 2 have been interviewed specifically on this subject. The staff concerned appear to be:- Dr.Schardin, Dr.Fünfer, Dr.Elle, Dipl.Ing.Turetschek, Dipl.Ing.Weohl, Dipl.Ing.Struth, Dipl.Ing.Kling, Dr.Thomer, Dipl.Ing.Vollrath. It is not certain that all of these individuals were employed in the Institute, but they are quoted as having assisted in the development. Since the work of this Institute is also of the greatest interest in other connections, including multiple spark photography, it is strongly recommended

/that

that not only the director, Dr. Schardin, and the author of these reports, Dr. Fünfer, but also any other available senior members of the staff should be interviewed. It is further recommended that efforts should be made to obtain any publications issued by the Institute. These efforts might well include a request for search in the libraries of other institutions concerned with Ballistics.

A supply of the polarising screen material, which was produced by Zeiss-Ikon, would be of great value in the development of Kerr cell cameras in the A.R.D. and it is recommended that if any is available it should be obtained for this purpose.

APPENDIX 4.

High speed photography undertaken by the 'Reichs Anstalt für Film und Bild'.

On 31.7.45. Major White kindly supplied me at G(T) & C.W., 21st Army Main H.Q., with a list of reports obtained by him from Dr. Gottlard Wolff head of the 'Abteilung Technische Forschungsfilm' of the 'Reichs Anstalt für Film und Bild'. The list is given at the end of this Appendix. I am also indebted to Major White for the opportunity to examine these reports and for the information that he had obtained the draft of a book prepared by Dr. Wolff and had made arrangements that it, and also the reports, should be microfilmed and made available in the U.K.

A brief examination of the reports failed to show any applications in which abnormally high frame speeds had been used. There were frequent references to the 'Zeitlupe' but without any precise indications of its capabilities. In no instances of the reports examined x were speeds above 2000 frames per second used. Most applications appeared to have been made at 1000 frames per second or less. The general difficulty appeared to consist in weather conditions which usually failed to supply sufficient light to enable the cameras to be run at their maximum speeds. A reference was, however, found (Report 10 of the attached list) to a camera built by A.E.G. (Zeitdehner) with a speed of 48,000 frames per second.

On 12.8.45. I made contact with Dr. Wolff at Höckelhein (near Northeim) and questioned him on the above subjects. He stated that he was unaware of any high speed photographic developments in Germany other than those produced by the commercial firms. On the subject of the A.E.G. camera he gave the following details:- Continuously moving film is driven, through vertical guides from the drum on which it is wound, into a sack-like container. The drive is simply provided by a motor with a pulley connection to the film drum. The film passes, with a linear speed of 30 metres/second, behind a slit. On the other side of the slit a disc of lenses rotates with the same linear speed as the film, thus giving the succession of images on the film. This system was used up to 10,000 frames per second. For higher speeds the image formation was entirely performed by a stationary lens opposite the slit and the disc of lenses was replaced by a disc with a series of narrow slots. Picture size was very small (3 x 4 mm) and few subjects provided sufficient illumination to allow the use of

/the

x Insufficient time was available to read all the reports.

the very high speeds. Nevertheless construction had been undertaken of a camera acting on this principle with slit dimensions and film speed to give a maximum rate of 80,000 frames per second.

Dr. Wolff stated that his book would contain all the information he could provide on photographic methods used in Germany and that, apart from the firms (Zeiss and A.E.G) making the cameras, he could not suggest any further sources of information.

COPY OF DOCUMENT SUPPLIED BY MAJOR WHITE.

APPENDIX "A" TO C.A.F.T. GROUP 6 REPORT
No.202.

LIST OF DOCUMENTS REMOVED FROM HOCKELHEIM NEAR NORTHEIM

No.	Range	Date	Title
1.	Reinickendorf (Berlin)	21.10.45.	Quenching of M.G.42 blocking pieces.
2.	Brunn	Feb and Jul 44.	Cinematographic research of the working of parts of the 3 cm MK 303 Br.
3.	Cammin	1 to 2.8.44.	Research on ejection and deviation of cartridge cases on M.G.42.
4.	"	Feb/Mar 1944	Research on the safety delay of Fuze type AZ1
5.	"	17.3.44.	Locking process of MG 42 bolt.
6.	Felixdorf	22.11.43.	Movement of the S.P.mounting when firing 12cm mortar.
7.	Gottingen	8.3.41 to 8.9.41.	Report of trials to determine the reaction of propellers by flying against balloon wires.
8.	"	--	ditto
9.	Grafelfing	Aug.1941.	"Lichtenstein" (radar calibration).
10.	--	1942	Cinematographic research on the visible spreading out of explosion wave from the various weights of explosive.
11.	Hillersleben	19.6.42.	Research on 10.%cm long shells with folding and parallelogram lines.
12.	"	28.4.43 to 26.5.43.	Flight research on special purpose ammunition A.P.shell 10, 5/7, 5cm.

No.	Range	Date	Title
13.	Hillersleben	7.5.43.	Flight research on Minengranaten.
14.	"	23.5.43.	Bundle shot.
15.	"	10.6.43.	Flight research on Minengranaten.
16.	"	22.6.43.	Research on the muzzle flash of 15.5cm K-418(f) with different shells and charges.
17.	"	25.6.43.	Burying of armoured cupola by explosive methods.
18.	"	28.5.43.	Rifling research on arrow shell ppg 10.5cm.
19.	"	23.7.43.	Firing with 10.5cm UKP39/39 shell (arrow type).
20.	"	13.8.43.	Recoil research on the Pek 40
21.	"	31.8.43.	Firing with the 10.5cm UKP39/39 shell (arrow type)
22.	"	6.10.43.	Research on the movement of the L.F.H. 18/40 S.P. mounting on firing.
23.	"	3.11.43.	Research on the barrel movements of the 10.5cm, Flak 39 (smooth bore).
24.	"	18.8.43.	Trajectory research on sub-calibre projectiles 10.5 /8.8cm.
25.	"	12.12.44.	P.A.W. 8cm muzzle movement on firing.
27.	Hiboke	18.8.44.	Firing with 10cm shells, 39 ROT with spring extended fins.

No.	Range	Date	Title.
28.	Hiboke	Jul. & Aug. 1944.	Firing with fin stabilised rockets, 12, 15, 21cm, with fin stabilised shell 10.5 & 15cm and shells with discarding sabots 15cm.
29.	Karlshagen	Jul. & Sep. 1944.	Cinematographic research in the descending path of V2.
30.	"	Aug. 1944.	Photographs of speed of combustion.
31.	Kummersdorf	14.10.43.	R.W.43.
32.	"	23.11.44.	Tank gun shell I. To find the velocity of the shell by observation of the trajectory up to 6 metres from the muzzle.
33.	"	1942.	The parachute unfolding of a parachute flare.
34.	"	13 Oct - 3 Nov.43.	8.8cm grenade projector.
35.	"	1/3 Nov.44.	Twin pistol 42. Cinematographic research of the movement of M.G. 42 on the twin mounting.
36.	"	17.5.44.	To find the projectile velocity of R.W.58.
37.	"	22.3.44.	R.W.43 U. R.W.58 (Rocket projectile).
38.	"	4-5.4.44.	Tests to compare different high explosives.
39.	"	4/3-11.8.44.	Auto loading gear for K.W.K. 7.5cm.

No.	Range	Date	Title.
40.	Kummerdorf	19.4.44. 3.5.44. 10.5.44.	To find the projectile velocity of R.W.43 and R.W.58.
41.	"	27.4.44. 10.5.44. 17.5.44.	Research on Ofenrohr III
42.	"	31.3.43.	Flight research on 8cm Wurfgranten.
43.	"	3.11.43.	R.W. 43 II.
44.	"	28.6.44.	To find projectile velocity and stability of Marga I.
45.	"	1.7.43.	Movement research on closing cap and base plate of the 12cm mortar.
46.	"	21.6.44.	Research on muzzle flash with shortened Ofenrohr.
47.	Ohrdruf.	4.5.43. 12-23.5.43.	Explosion of G Wagons (Buttes).
48.	Reinsdorf	28.11.44.	Material 75(IV) To find projectile velocity with short burning ammunition with R-Pressling.
49.	"	14.11.44.	Material 75 III to find projectile velocity and wear with new quick burning ammunition.
50.	"	21.9.44 - 29/9.44.	Material II. To find the projectile velocity and the time of combustion at the moment of firing.
51.	"	6.9.44.	Gerät I. To find the projectile velocity and time of combustion using normal ammunition.

No.	Range	Date	Title.
52.	Rugenwalde	29-30.9.42.	Firing with elongated shells at water to ascertain time of impact.
53.	"	11.12.43.	Research on rifling with Peenemünder arrow shell.
54.	"	25.3.43.	Research on special purpose shells PPG 28/17cm subcalibre.
55.	"	17-19.8.43.	PPG Knüppel.
56.	Sennelager	7.12.44.	"ROTKAPPCHEN" shot ejection and velocity measurements.
57.	Suhl.	19.10.44.	Recoil time curve of a recoil-less gun.
58.	Swinemünde	17-18.1.44.	Movement of the SP gun chassis of the 12.8cm Flak 40M during firing.
59.	Unterlüss	22.9.43.	Bursting of a 3.7cm Flak C/36.
60.	"	29.4.43.	Measurement of movement on a Tank II.
61.	"	29.3.43. 3.4.43. 19-22.4.43.	Time and space research on the movements of the chain trunnion on the automatic FLAK C/36.
62.	"		Panzerpistole, Cinematographic research of the bent barrel part while firing in automatic.
63.	Zempin	5-6.9.44.	2 cm Flak twin carriage,Research in the deviation of cartridge cases.
64.	"	1943.	Research of carriage movements I.
65.		Sep.42.	Cartridge case jamming in MG 42.
66.		Jun 42.	Firing tests with spin stabilised discarding sabot.

No.	Range	Date	Title.
67.		14.8.42- 15.8.42.	Discharge of a rotating winged bomb for load dropping from aircraft.
68.		Jun 43.	Research on the reaction of sections of the guiding fins of various types in a super-sonic wind tunnel.
69.		Sep.43.	Rotation research on base-fuzes type DOV.
70.		12-14.2.42.	Tests with discarding sabot projectiles calibre 27/17cm spin stabilised.
71.		22.-25.9.42.	Firing at concrete.
72.		Jun 42.	Research of elongated shells 7.62/5cm sub-calibre-unrotated fin stabilised.
73.		Dec 42.	Rifling research on elongated shells 21cm with folding fins (fin-stabilised).
74.		Sep.42.	The movements of the plain and the drilled breach spring on MG 42 - single shot firing.
75.		Oct 42.	The movements of an undrilled spring on the MG 37 on automatic firing.
76.		Feb 43.	Firing at concrete(penetration of concrete using SME ammunition calibre 7.9mm.
77.	Heimat Artillerie Park II.	Jun 43	Research into opening and closing fins in the jet of V2, in super-sonic wind tunnel with intermittent operation.

No.	Range	Date	Title.
78.		Mar 43	Pictures of the time-space curve of the oscillation of the breach block of MG 42.
79.		Jul 43	Firing at concrete with S.m.k.H. ammunition calibre 7.9mm.

APPENDIX 5.

Bore temperature, piezo electric, and low temperature gun functioning measurements in W-2 and W-3.

These researches were carried out in a building under the control of Dr.Hackemann, a member of Prof.Rossman's staff. It comprises two underground ranges, one of 100 metres length and the other 25 metres. The tunnels contain no measuring facilities other than accommodation for screens, either of the solenoid type for use with magnetised shot, or the ordinary aluminium foil type. No solenoid 'screens' could be found. The only reasons for using underground tunnels were:- (1) To provide safety when firing with larger calibre projectiles (75 mm. barrels firing 45 mm. shot had been used). Rebounds from the sand butts occurred. (2) To give camouflage. (3) To reduce the spread of noise.

The cross-section of the 100 metre tunnel is about 2 x 2.5 metres. It could be used for Terminal Ballistic trials and in fact a small amount of shooting against captured armour plate had been carried out in it. At the end of the tunnel near the butts there is a small room about 13 ft. x 21 ft.

At the 'gun' end of the tunnel there is a very rigid looking mounting to which barrels may be clamped. The laboratories at this end are designed for researches in the following subjects:-

(1) Measurement of pressure time curves in the gun chamber by piezo electric gauges.
(2) Measurement of the temperature in the chamber and bore of the gun by means of thermo couples.
(3) Examination of gun functioning at low temperatures.

(1) Pressure time measurements for Internal Ballistics.

Asked what special advantages, if any, the system had over others working on the same principle, Dr.Hackemann replied that in Germany the standard system is the Zeiss-Ikon which has serious disadvantages: (a) No provision is made for pre-compression of the quartzes. (b) The gauge is in three parts and unsuitable for mounting in a variety of weapons. (c) The amplifier is of poor design. The gauge used at L.F.A. is claimed to be of good design (a) because it has provision for pre-compression of the quartz elements, (b) because it is compact and can be screwed into small chambers. The amplifier, the first stage of which contains the 'electrometer type' valve is of good design and is made at L.F.A.

Some of the gauges and amplifiers are available in the building. The air condensers used to load the crystals were found. These are

/used

used to minimise absorption effects. It was stated that the long leads from crystal to amplifier did not introduce significant distortion. The cathode ray tube is probably available in A12. The recording drum had a speed giving 15 cms/millisec. It is not known whether this is still available in L.F.A. With this drum the film was mounted inside. The calibrating presses are available in W-11.

(2) Temperature measurements.

Some of the thermo couples were located in W2. They require a small diameter hole (.2 mm dia.) drilled in a rod and their production is a delicate piece of work since insulated wire must be threaded through this hole and sealed with nickel plating. If this work were resumed it would be necessary to arrange for the construction of a supply of the gauges since one is used on each round. A description of this work, and of other experimental methods designed by Dr.Hackemann is given in a lecture entitled x 'New Methods of Weapons Research' delivered before the Lilienthalgeselleshaft in December,1943. According to Prof. Rossman a copy of this lecture is available in the library of A-12. Since details of the methods will be obtainable from this publication I did not obtain particulars of the circuit but asked Dr.Hackemann whether he considered, from inspection of the buildings and contents, that the apparatus could be reconstructed. He thought reconstruction would not present great difficulties.

The accuracy of temperature measurement was quoted as about ± 20° C. Calibration was carried out in an oven against a platinum iridium thermometer.

(3) Examination of gun functioning at low temperatures.

In addition to the normal firing block there is provision for mounting the gun in a cold chamber behind the block ordinarily used. This chamber can give temperatures down to -60°C and can accommodate weapons up to 37 mm. The muzzles of the larger weapons project from the cold chamber but adequate provision is made for heat insulation in these circumstances by surrounding them with a tube and baffles. It was stated that no systematic scientific work had

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x The complete description of the temperature measuring scheme is given in Forschungsbericht No.1346. 'Ein Verfahren zur Messung schnellveründlicher Oberflächentemperaturen und seine Anwendung in Schusswaffenhaufen' P.Hackemann. (see Appendix 6).

been carried out using the cold chamber but that it was kept busy in testing the functioning of apparatus made by various manufacturers. This state of affairs seemed general to the Weapons Section. Most of the work was on ad hoc problems.

(4) General.

W-2 contained a number of well made barrel gauges for accurate measurement of land or groove diameter. These were made by Zeiss and depended on viewing reflections from split gauges, which could be sprung to different diameters and which had polished ends. The optical apparatus required in connection with these gauges was not available. Several sets of accept-reject gauges of high accuracy were still present.

A rate of fire meter for machine guns, operated acoustically, was found and also some well made instruments looking like long cleaning rods, for examining the bore under magnification.

Several projectiles for use in attack from aircraft against tanks (below) or bombers (above) were found. These were for use in a recoilless-type gun but the essential part of the scheme was the automatic control of fire. The pilot had only to fly directly above the tank or below the bomber to cause the guns to function. In the case of tanks the control was effected by magnetic or electrostatic effects and in the case of aircraft by photoelectric effect. These methods are described in Dr.Hackemann's lecture.

Some piezo electric gauges for use in accelerometers and also for the measurement of stresses in aircraft components were found, with some of their associated equipment. The piezo electric apparatus and associated amplifiers and recorders are being brought into order by Dr.Küsters.

Dr.Hackemann described some earlier work, now abandoned, on the recording of the flame in the barrel by using a longitudinal slit viewed by a camera with a film speed of 15cms/sec. This work was considered by the German Air Ministry to have no practical value but it could be resumed and used to give space-time curves up the bore. No serious difficulty was experienced with the slit. The calibre was 13 mm.

/Velocities

Velocities in the bore had been measured (but not at L.F.A), by making the shot bridge an air gap in the magnetic flux of an iron cored solenoid with an outer sheath which was not ferromagnetic (Fe. with 45% Ni). This had application to measurement of muzzle velocity aboard ship and it was believed it had been further elaborated for this purpose.

APPENDIX 6.

German documents relevant to the subjects investigated.

(1) The following reports were brought to the U.K. from Germany and have been forwarded to B.I.O.S. (Lt.Col. Mohring, Halstead Place).

'Ein Verfahren zur Messung schnellveränlicher Oberflächentemperaturen und seine Anwendung in Schusswaffenläufen' Dr.Hackemann.
Luftfahrtforschungsanstalt Hermann Göring. Forschungsbericht No.1346.

'Entwicklung der Funkenkinematographie' Carl Cranz)
'Physikalische Vorgänge bei hohen Belastungen und)
Belastungsgeschwindigeiten' Hubert Schardin)
Schriften der deutschen Akademie der Luftfahrtforschung.1940.

'Bericht über funkenkinematographische Aufnahmen von Panzerplattenbeschüssen auf einem Schussplatz bei Tageslicht'
Dr.Fünfer.
Physikalisches und Ballistisches Institut der Luftkriegsakademie.7/40.

'Entwicklung und Erprobung einer fahrbaren Funkenanlage'
Dr.Fünfer.
Ballistisches Institut der Luftkriegsakademie. 2/42.

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(2) Requests were made for copies of the following documents, only one copy of each being available at Volkenrode:-

'Die Bestimmung der Weg-Zeit-Kurve fliegender Geschosse über längere Messetrecken und ihre Anwendung zur Ermittlung des Luftwiderstandes' J.Schmidt.
Luftfahrtforschungsanstalt. U.M.2062(3).

'Die ballistischen Versuchs und Messanlagen der Luftfahrtforschungsanstalt Hermann Göring'.
K.Schüssler.
Berlin deutsche Akademie der Luftfahrtforschung. 1942.

'New methods in weapons research' Translation of a lecture delivered by Dr.Hackemann At Ainring in Dec.1943 before the Lilienthalgesellschaft.

/'Untersuchungen

'Untersuchungen zur Vermessung von Geschossbahren und pendelungen besonders in Schiesskanälen.' Henning und Schmidt. Forschungsbericht Nos. 980/1, 980/2, 980/3.

(3) From interviews and from the literature it appeared that the following documents, which were not found, would give useful information:-

Bericht 166 of the Lilienthal Gesellschaft fur Luftfahrtforschung May 1943 approx.

This report is stated by Prof. Rossmann to contain about ten lectures on armour penetration, giving a description of the work on Terminal Ballistics at Krupps (see Appendix 2) which includes 'Untersuchungen über die Vorgänge beim Beschuss von Panzerplatten' by H. Kratz.

Reports 1/41 and 3/42 of the Ballistisches Institut der Luftkriegsakademie. Reference is made to these reports in the description of the Kerr cell camera and they appear likely to contain valuable information on the 'guided-spark' technique.

Dr. Wolff's book dealing with high-speed photographic methods and applications. Arrangements have already been made by Major White to make this document available in U.K. (See Appendix 4).