AD/A-003 350

DEVELOPMENT OF A REVOLUTION-COUNTER DISTANCE MEASURING ARTILLERY FUZE

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Bulova Watch Company, Incorporated

Prepared for:

Picatinny Arsenal

December 1974

BULOVA WATCH COMPANY, INC.,

SUMMARY REPORT

Development of a Revolution-Counter Distance Measuring Artillery Fuze

December 1974

Contract No. DAAA21-73-C-0317

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1.0 NARRATIVE

1.1 Principle of Operation

The basic principle and the advantages of its use as an artillery fuze are discussed for certain applications.

As background information, it is a well-known principle that a centrifugal force operated device, such as an artillery arming delay mechanism, will count the turns imparted by the rifling; always arming at the same number of shell revolutions, independent of the shell velocity. These devices are ordinarily limited to a range of about 200 ft. and their accuracy, though sufficient for safety and arming purposes, would not be great enough for use as a distance-measuring fuze (DMF) mechanism.

The pendulum mechanism as conceived by Picatinny Arsenal engineers is shown diagramatically in Figure 1. The axis Z-Z is the spin axis and flight path. X-X is perpendicular to Z-Z and is the pendulum axis. Y-Y is perpendicular to X-X and Z-Z and is the neutral position of the Pendulum. The amplitudes are measured from this line as shown in the diagram. (L) is the length of the Pendulum, assuming all of its mass concentrated in the points labeled (m), (r) is the perpendicular distance from (m) to the spin axis.

The diagram of Figure 1 is an idealization which is useful in understanding the geometry and principle of the pendulum mechanism alone.

There are complications which are treated in paragraphs 1.4 and 1.5.3 dealing with spin about an axis parallel to Z-Z but displaced from it (eccentric spin); with precession, whereby the spin axis itself rotates about the principal axis;

and nutation, whereby the spin axis rotates about an axis which in turn revolves about the principle axis. These phenomena will not be brought into the narrative at this time.

If the mechanism of Figure 1 is now assumed to be rotating around axis Z-Z and the Pendulum is released from the angle as shown, then centrifugal forces F will result and the Pendulum will oscillate with constant amplitude in the absence of friction.

The periods of one pendulum cycle and of one rotational cycle are related. At small displacements, the periods are theoretically equal. If the amplitude is appreciable, the Pendulum period will be greater than the rotational period.

If a real pendulum is constructed, the amplitude would decay due to frictional energy loss, thereby changing the ratio between the periods of rotation and the pendulum and adversely affecting the capability of using the mechanism as an accurate DMF.

However, if an energy source were connected to the pendulum, which could supply energy at the same rate at which it is lost, where a constant amplitude would be maintained, and which would also advance incrementally with each period, this combination of mechanical elements would be capable of constituting the heart of a potential distance - measuring instrument.

Note that a limitation is apparent at this point. A DMF would have a setting mechanism which would indicate distance, which in turn is proportional to the twist. The same DMF would require a setting mechanism with a different scale if used in a gun with a different twist. Thus, a universal fuze would require a setting mechanism with a scale for each twist (weapon) or a separate fuze would be required for each weapon. This should not be a problem since the largest DMF application would most probably be an AP weapon such as a 105 mm gun.

1.2 First Model

A model demonstrating the operation of a free pendulum was constructed by Picatinny Arsenal technicians and is shown in Fig. 2. High-speed motion pictures at various spin rates verify the results of the analyses made in paragraph 1.4 of this report. These films are available from Picatinny Arsenal.

1.3 Field Test of a Prototype

A field test of three prototypes of a pendulum mechanism was reported in June 1971, entitled "Artillery Projectile Revolution Counting Prototype Fuze Field Test," TSD TR 194-71 by Picatinny Arsenal. This mechanism used a single-ended pendulum released from a deflected position and oscillated freely to interrupt a light beam regularly. These interruptions were counted electronically to a pre-set value which caused shell function. Two out of three functioned accurately and the test was considered successful.

1.4 The Stanisic Report

The report "On the Dynamical Responses of a Projectile Revolution Counter in a Force Field" concerns the analytical mechanics study made by Dr. M. Stanisic of Purdue University. The scope of the report is evident from its "conclusion," reproduced below.

1.4.1 Conclusion (Extracted from the Stanisic Report). "A study concerning the motion of a gyro pendulum used as a revolution counter has been made. The theory developed in this study is based on the fundamental equations of the motion of a rigid body. The motion is described in the Eulerian sense of three angular rotations. However, due to the degrees of freedom of the pendulum, only two angles are needed to completely specify the motion.

From a mathematical point of view, the motion of such a pendulum is non-linear in nature. Hence, in order to obtain the response of the pendulum, it requires a mathematical analysis of some complexity.

In this study, the equations of motion have been derived taking into account all influences of importance; gyro effects; bearing damping; eccentricity; aero-dynamic effect caused by the internal motion of the media in the projectile; transfer of energy due to the escape mechanism; nutation and precession of the projectile; thrust forces arising from the eccentricity, the escape mechanism and the nutation and precession. Each of these influences has been studied separately in order to clearly show the effect of each on the system under consideration.

In Chapter I the general equations of motion for illustrating the gyro effects of the system are obtained. It has been shown in this chapter that the spin rate of the projectile is approximately equal to the frequency of the pendulum.

Chapter II finds the bearing forces rising due to the gyroscopic effect of the pendulum. An exact solution, based on the assumptions made, is found for the maximum bearing force due to the gyroscopic effect, eq. (2.37). In addition, a study concerning the free vibration of the pendulum with bearing damping has been made. This study shows that the energy loss per cycle of the pendulum is proportional to the cube of the initial amplitude at the beginning of a cycle, see eq. (2.94).

Chapter III illustrates the influence of eccentricity on the motion of the pendulum. The important result of this chaper is that the effect of eccentricity does not change the frequency of the pendulum but increases the loss of energy of the pendulum due to an increase in the bearing forces, which in turn increases the frictional forces, see eq. (3.31).

Chaper IV contains a mathematical description of the aerodynamic effect caused by the internal medium of the projectile which surrounds the pendulum. It has been shown that the energy loss for one cycle due to this effect is initially proportional to the square of the initial amplitude and then approaches the cube of the amplitude. This development will occur over a relatively short time interval.

Chaper V describes the motion as well as the energy exchange between the pendulum and the escape mechanism. In this chapter each region of the motion has been treated in great detail with minimum assumptions, and all energy losses and gains have been examined. For the pendulum the energy gain is given by eq. (5.61) and the energy loss by eq. (5.75). In addition, a criteria is developed to enable the design of a pendulum system such that the pendulum will not impact with its surrounding walls.
See inequality (5.70).

Finally, in Chapter VI a study has been made of the motion of the pendulum in a projectile that is both nutating and precessing. The general equations of motion have been revised to include these two effects. See eqs. (6.9) and

(6.17). It has been shown that the complexity of the motion due to these two additional degress of freedom prevents a simple qualitative solution.

The individual analyses of the previous chapters show the feasibility of predicting certain parameters for the design of the system. However, for a complete description of the pendulum motion due to the combined effects considered in the previous chapters, a detailed numerical analysis must be carried out. Since the escape mechanism leads to discontinuities in the pendulum motion, a complete and accurate analysis can be achieved only with a thorough understanding of the physics and geometry of the system, which can be provided by a detailed study of this report."

1.5 Bulova Contract

A contract was awarded to the Bulova Watch Company in January 1973. The Scope of Work is reproduced below. Note that a principal advantage is that the M577 time fuze upon which the proposed fuze is based, is in current production at this facility and ensures the availability of components and test equipment.

1.5.1 Scope of Work

1.5.1.1 Objective. "The Contractor shall apply his efforts for a period of approximately six (6) months on design studies including the manufacture of parts and a model, as required, of a modified M577 Fuze which substitutes a revolution counter for the timekeeping module but other wise contains as many as possible of the specific parts and features of the M577 Fuze.

1.5.1.2 Procedure. To attain this objective the Contractor shall perform the following:

a. Review all pertinent work conducted to date on the theory of revolution counting as an analog to distance measuring and related to the mathematical study provided by Picatinny Arsenal to be supplemented with an appropriate computer programming which may be subcontracted.

b. Conduct detailed design studies of all moving components and the main spring in such a way as insure an energy equilibrium over as wide a range as possible of spin variations around the median value of 16,000 rpm.

c. Construct pendula, escapements and other components to bench test as required.

d. Fabricate an operational display model for delivery to Picatinny Arsenal.

e. In his final report include to detail all work performed under the contract and compare the accuracy of revolution counter with a time fuze such as the M577 to ranges up to 5,000 meters.

1.5.1.3 Background and Requirements

1.5.1.4 Background Information. The standard M125 Booster for artillery fuzes, as well as other devices, makes use of the principle that, for any given weapon, distance from the muzzle is proportional to the number of turns of the projectile in flight. Various approaches have been proposed to apply this principle further to a fuze which would use spin counting for measurement of substantial distance down range. These efforts have generally been hampered by lack of precision of the device or complexity of the resulting mechanism.

Design studies conducted at Picatinny Arsenal, and culminating in three successful firings, indicate that a simple pendulum can be used to measure spin as its frequency is directly proportional to the spin rate. The Scope of Work provides for the mechanization of the principle in an existing standard artillery fuze by the substitution of a timekeeping module with the spin counting module and various corresponding changes in the setting mechanism.

1.5.1.5 Requirements. Work will be conducted in two phases, the first requiring approximately four (4) months and culminating in preliminary designs and bench tests for proposed fuzes with an undriven pendulum. The second phase, which completes the contract, will consist of bench tests of a full escapement including mainspring and the fabrication of a model of a base line fuze employing as many as possible parts from the M577.

No firing or environmental tests are to be included in the work performed under this contract nor is any work with explosives. However, in conducting his design studies, the Contractor is to bear in mind the fact that any fuze which ultimately would result from a continuation of this program would be required to function in the normal artillery and tank cannon environments after the typical preconditioning covered by MIL-STD-331."

1.5.2 Spin Fixture. A spin fixture, Tool #645-60001, was designed and built to study the performance of a free pendulum under various spins and with pendulums of varying characteristics.

These characteristics are pivot friction, as determined by bearing size and material, release angle and ratio of moment of inertia to mass.

One pendulum, part #KC-87751, was constructed.

The instrumentation and technique for measuring the amplitude, and the fixture and pendulum drawings are found in "Monthly Progress Report #1."

1.5.3 Alternative Escapement Designs. The operational requirements of the escapement in this pendulum mechanism are:

a. To maintain an energy balance between energy added and that lost to friction.

b. To enable a mechanical motion whose angular displacement is proportional to the number of pendulum cycles.

Some functional requirements which became apparent early in the study are:

(1) The escapement must be capable of functioning over a wide range of amplitudes. It is desirable to maintain a constant amplitude, but to permit operation throughout its range.

(2) It must be capable of being released from a displaced position.

(3) It must be capable of surviving the gun environment.

(4) It must be contained within the space available in the M577 mechanical time fuze.

(5) It must be readily manufacturable with automation techniques.

The following possibilities were investigated:

a. The M577 detached lever, escape wheel and balance (modified into a centrifugal pendulum), rotated 90° into the Y-Z plane of Figure 1. This would meet all of the requirements except that of complexity. It was felt the extra mechanical elements such as the right angled drive, lever and supporting structure which would not be required in most of the other designs, would be best not considered at this time.

b. A similar arrangement, but using the Junghans mechanism. This was also rejected for reasons similar to the above. In addition, the Junghans (or any other cylindrical escapement mechanism) pallet and escape wheel is difficult to manufacture. Moreover, the minimum amplitude required for operation of this class of mechanism was felt to be too great.

c. A crown escape design, originated by Picatinny and upon which the Stanisic 1972 analysis was based. This escapement arrangement met most of the requirements. Investigation of this concept revealed some undesirable characteristics which led to slight modifications, resulting in the final design with a flat, or conventional, escape wheel. The undesirable characteristics referred to are in three areas:

(1) Structural. The pendulum, requiring some elements to pass through the crown teeth, became complex, fragile and difficult to assemble.

(2) Functional. The crown wheel design favored a fixed amplitude. If the crown wheel were designed for amplitudes greater than about 15°, the

clearance required would result in a long, fragile tooth form. This configuration also yields an undesirably high inertia, thereby imposing problems at high spin rates.

(3) Manufacturability. Neither the crown wheel nor its pendulum lends itself to stamping.

d. The final prototype design, using a conventional escape wheel with slotted sectors on the pendulum, was decided upon as meeting all of the requirements.

A set of drawings of this escapement is found in Monthly Progress Report #2, a sketch of the assembled escapement in Figure #3 and a general fuze arrangement in Figure #4.

The design is felt to be the simplest possible. Flexibility of parameters is great. For example, the impulse angle of the sector and its location may be readily varied to provide a minimum working amplitude of one or two degrees, and impulses to suit various dynamic conditions by slight dimensional changes. No exotic manufacturing techniques are required to produce and assemble units. The analytical studies of Drs. Stanisic and Euler, although using the crown wheel model, are equally applicable to this design, with some modification.

1.5.4 Analytical Computer Study. The Stanisic Report of Section 1.4 was a qualitative analytical study of the dynamics of the subject mechanism. A second and third report of subsequent studies was generated under the Bulova Contract. The second is entitled "On the Numerical Analysis of the Dynamical

Responses of a Projectile Revolution Counter" by Dr. James Euler, and is a summary of the applicable equations and an outline of a computer program designed to simulate the response of the mechanism to values assigned to parameters such as impulse tooth angle, shell angular velocity, aerodynamic drag, etc.

The third report entitled "On the Utilization of a Computer Program to Analyze Dynamical Responses of a Projectile Revolution Counter," by L. Popovitch, is a report of a computer runs and results in tabular and graphic form, of the programs developed in the second report.

In the approach to the synthesis of the subject mechanism, it was found helpful to use computer-assisted design techniques. The chart shown in Figure 5, using a program called "PEND" was generated in this way to establish a range of values for pendulum parameters versus shell spins. Columns 1 & 2 show shell spins ranging from 3,000 to 60,000 rev./min.; column 3 the rotational period, col. 4 the generating circle velocity associated with the calculation for pendulum maximum angular velocity of column 5; col. 6 shows maximum linear velocity of an impulse pin at an assumed .1 in. radius. The last column assumes that the pendulum has been designed to operate at 15,000 rev./min. and at an amplitude of 15°. The values shown are the range of amplitudes which result in a constant maximum impulse pin velocity associated with the col. 1 spins.

Another very useful program called "PEMB" is used to generate trajectories of pendulum vs. escape wheel starting at the instant of unlocking. Figure 6 shows a typical plot where the ordinate is pendulum displacement and the abscissa is escape wheel displacement. The "line of contact" is so labeled; note the value of .025 inches (abscissa) which is the thickness of the pendulum sector. The family of curves is for 30,000 rev./minute at amplitudes of 10°, 15° and 30°. The plotted points are increments of 1/10,000 second. The "line of contact" is intersected only by the 10° curve. It is evident that for these parameters, the pendulum amplitude will decay until this line is intersected, at which amplitude an impulse will occur, transferring energy to the pendulum and maintaining an equilibrium amplitude. It may be mentioned that it has been deduced from this and other analytic data plus observed behavior of the prototype that the amplitude is self-limiting. If enough energy is imparted to the pendulum to increase its amplitude beyond the point at which impulse can take place, the amplitude will decay until impulse takes place.

1.5.5 Prototype Model of Driven Pendulum. A model was made, with the escapement described in 1.5.3 (d), with the remaining elements being M577 Clock Ass'y. parts. The unit was not fitted with inertial safety and launching devices. A set of drawings appears in Progress Report #2.

The model was tested by spinning in a lathe. The unit proved to be self-starting at angular velocities above 2,000 rev./min. Stroboscopic studies indicated that overbanking occurs at the high range of mainspring torque. The unit proved easy to assemble and accurately repetitive. Quantitative test results are shown in paragraph 2. The escapement performed equally well with a steel and an aluminum pendulum, except that the steel one was self-starting at lower velocities.

1.5.6 Setting Mechanism. A setting mechanism was designed and constructed to replace the M577 counter. The Pendulum mechanism is geared down to a ratio of 1/9 of the setting knob turns. A pinion and sprocket arrangement transports a thin steel tape upon which appears distances to function. The tape leaves one spool and winds up on another, passing the ogive window through which the settings are visible. Figure 4 shows the setting mechanism in an overall fuze configuration. The drawings may be found in Progress Report #6.

A Demonstration model of the setting mechanism was constructed & mounted on a dummy mechanism. As constructed within the limitations of the contract, in which commercial components were used for gears and tape, the operating parameters are as follows. Pendulum cycles per scroll revolution 830; resolution in scroll degrees per pendulum cycle, .411°; setting tape resolution 27 inches per setting knob turn; for the 105mm M103 gun, 200 ft of travel per inch of setting tape.

This would permit settings of up to 11,000 meters in the 155 mm M126 howitzer. Maximum range may be readily increased by appropriate gear ratio changes or by increasing the number of escape wheel teeth.

1.5.7 Bench Centrifuge Demonstrator. A contract requirement was to furnish an operational display model. A bench centrifuge was also included to supply the centrifugal force required to operate the model. In use, the Pendulum mechanism is illuminated by a stroboscope synchronized with the rotation.

If the Pendulum is then observed, its behavior under the stroboscopic illumination can readily be interpreted. If the pendulum and the escape wheel appear stationary, the Pendulum and the rotational periods are equal. Several such tests were run and videotapes made. When these tapes were replayed, it was noticed that there seemed to be two distinct types of motion. The first was characterized by an erratic pendulum motion, the second by a smooth pendulum motion. The escape wheel in the first case appeared to rotate in a forward direction, indicating that the Pendulum period is shorter than the rotational period. In the second case, the escape wheel appeared to rotate backward. The second case is the behavior predicted by analysis.

The mainspring torque was evidently too great at full wind, causing the Pendulum amplitude to exceed the space available, and resulting in an elastic collision between itself and the housing. The discontinuity in the motion resulted in the apparent anomaly. The preliminary analysis of accuracy prediction was based upon these videotapes and appears in "Monthly Progress Report No. 5". The Mainspring was replaced with one having half as much torque, and the test rerun.

2.0 LABORATORY SIMULATION

a. The proposed pendulum mechanism appears to function as predicted, judging by the testing described below. In addition, a comparison with a MTF, used in the same gun and zone, indicates that the pendulum mechanism has superior accuracy.

b. The following test conditions and assumptions governed a comparison test between PDMF and MTF made in the laboratory.

c. Fixtures and Instrumentation used for the PDMF test are, the desktop centrifuge and fixture, a source of stroboscopic illumination, and a video recorder.

2.1 Parameters and Assumptions

The gear train of the MTF was used for the PDMF as well, and has a ratio of 113.7 between the scroll cam and the escape wheel. The PDMF escape wheel has 7 teeth. This results in a ratio of 830 pendulum cycles per scroll revolution, or 2.306 pendulum cycles per scroll degree. The setting error associated with the MTF is .36 degrees or .415 pendulum cycles. It is assumed that the parameters of the PDMF and MTF are applied to a 105mm M103 gun at zone 7; velocity of 1621 ft/sec., constant. The resultant setting error is ± 2.5 feet.

2.2 Test Method

Test method consists of operating the prototype in the centrifuge fixture at 3,450 rev./min. The stroboscope is synchronized so that the pendulum and the escape wheel image is clearly discernable. A TV camera and tape equipment is used to record the events. When the tape is replayed, it can be noted that the pendulum amplitude is at a maximum, with contact between the pendulum and the structure. In this mode, where excessive energy reaches the pendulum, the escape wheel appears to be rotating forward. This indicates that the pendulum period is shorter than the rotational period. However, as the mainspring runs down, the predicted mode occurs. This is manifested by an escape wheel image apparently rotating in reverse, indicating a pendulum period greater than the rotational period. To obtain values, the pendulum cycles are counted and compared to the number of revolutions. Several runs are made. The observed number of cycles at each check point (incremental no. of revolutions) is recorded. A standard deviation is calculated for each group of similar values for all runs. These values are then plotted on the same axes as known MTF values. Figure 7 is such a comparison of 5 pendulum runs.

Figure 7 shows the overall accuracy of the PDMF and MTF on axes which display dispersion in ft. versus range to 28,000 ft. It is evident that the most significant difference between them is the setting accuracy. The dispersions are .002 ft/ft for the MTF and .00275 ft/ft for the PDMF. The sum of the setting and dispersion ordinates meet at 100,000 ft. This estimated PDMF accuracy is 5 times better than the earlier one made in "Report #5." Note that the calculation for dispersion implies that the necessary correction between rotation and pendulum periods exist. In the real fuze this would be the case. The firing table data would also influence the graduations of the tape in the setting mechanism.

The succession of efforts starting with the analytical mechanics and numerical analysis which predicted the PDMF performance and the more recent field and laboratory tests all tend to reinforce the validity of Picatinny Arsenal's original concept of a Pendulum Revolution Counter.

The stage of development at the conclusion of this contract consists of two groups of mechanical elements; The ones based upon the M577 MTF, and the newly developed mechanisms. The elements of the first group are now in production and are used without change. They are:

1. The outer housing consisting of the Ogive, the Body and Plug.
2. The explosive train, except the Point Detonator which is not used.
3. The Safe & Arm system.
4. The Trigger.
5. The inner structure from the base to the gear train including the timing cam, sleeve, Mainspring Housing and all clock plates except Plate #1.

The second group requires completion of development to produce a fuze which can be fired. These elements are:

1. The Pendulum. A system of spin and setback detents are required to release the pendulum when the gun environment is experienced.
2. The Setting Mechanism. A basic design has been made, using a metal reel-to-reel tape with a sprocket engaging teeth in the tape which are similar to motion picture film perforations. Some improvement in the transmission geometry is required for smooth operation. It is felt that this would be easily done. It is also necessary to convert data obtained from the firing tables and pendulum mechanism firing tests into calibrations on the tape.

It is felt that the logical conclusion of this development would be to institute a program to complete the design, build prototype fuzes and perform laboratory and field tests. The resulting weapon component will prove to be extremely useful.

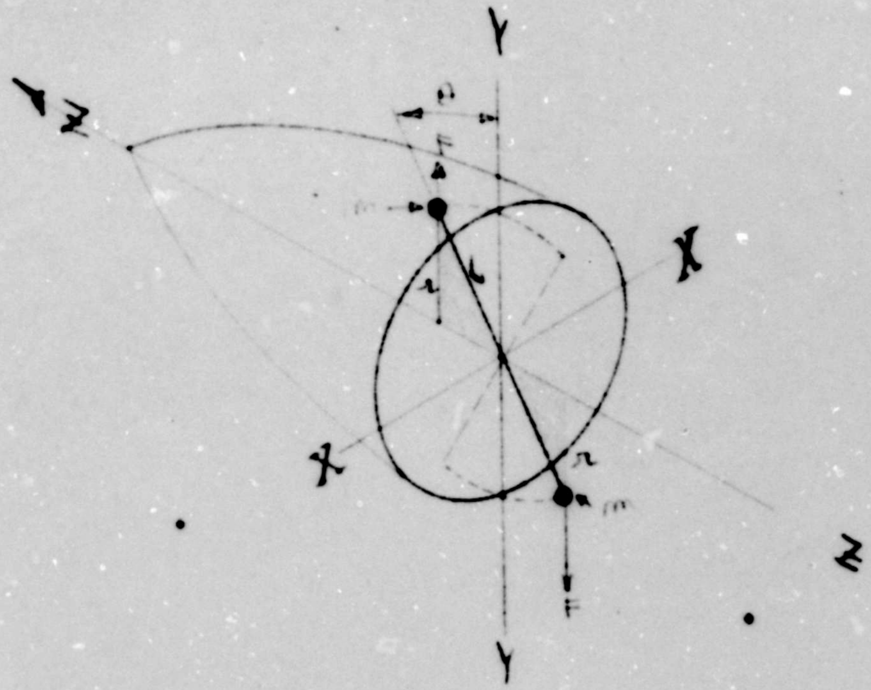


FIG. 1
CENTRIFUGAL PENDULUM DIAGRAM

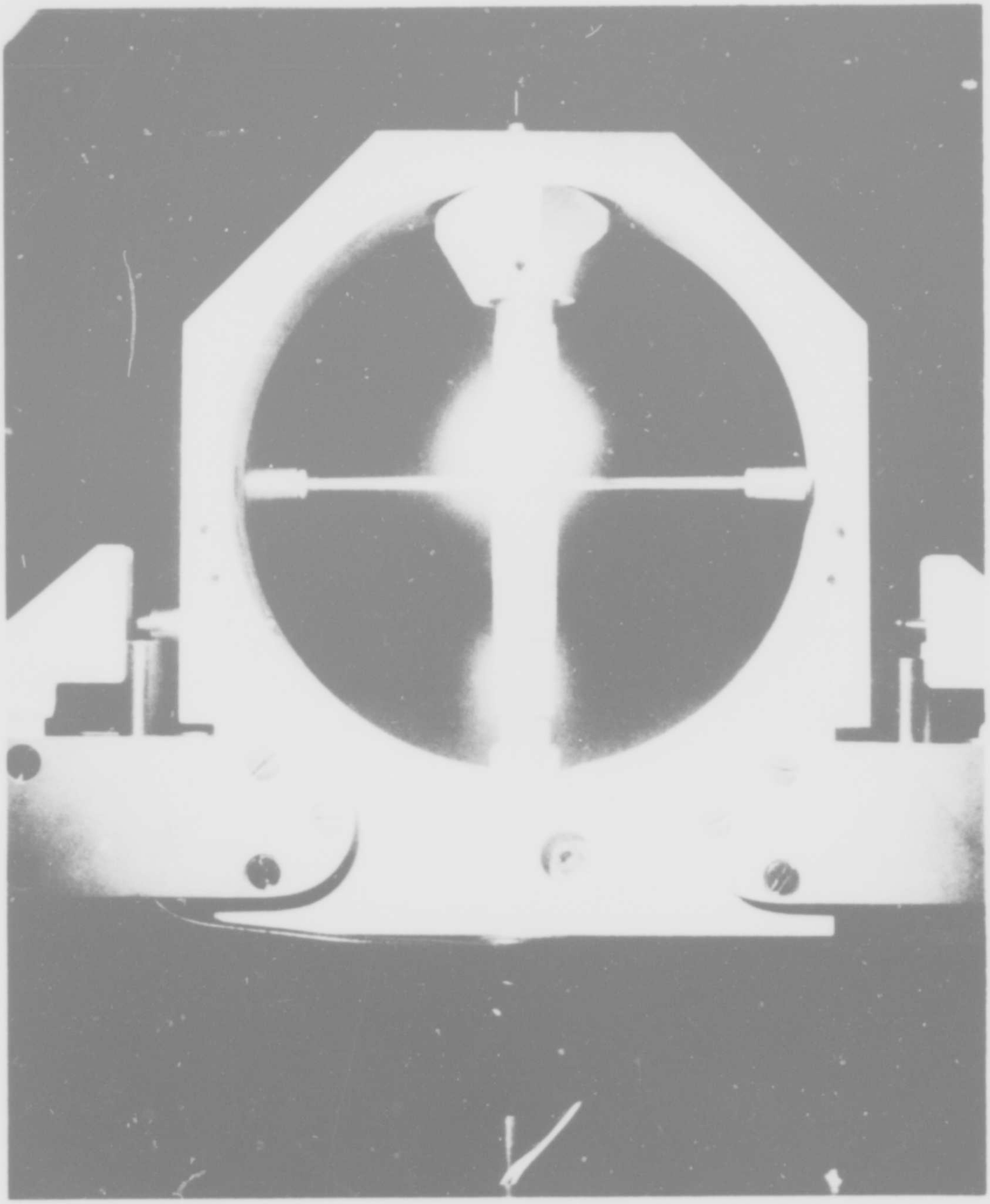
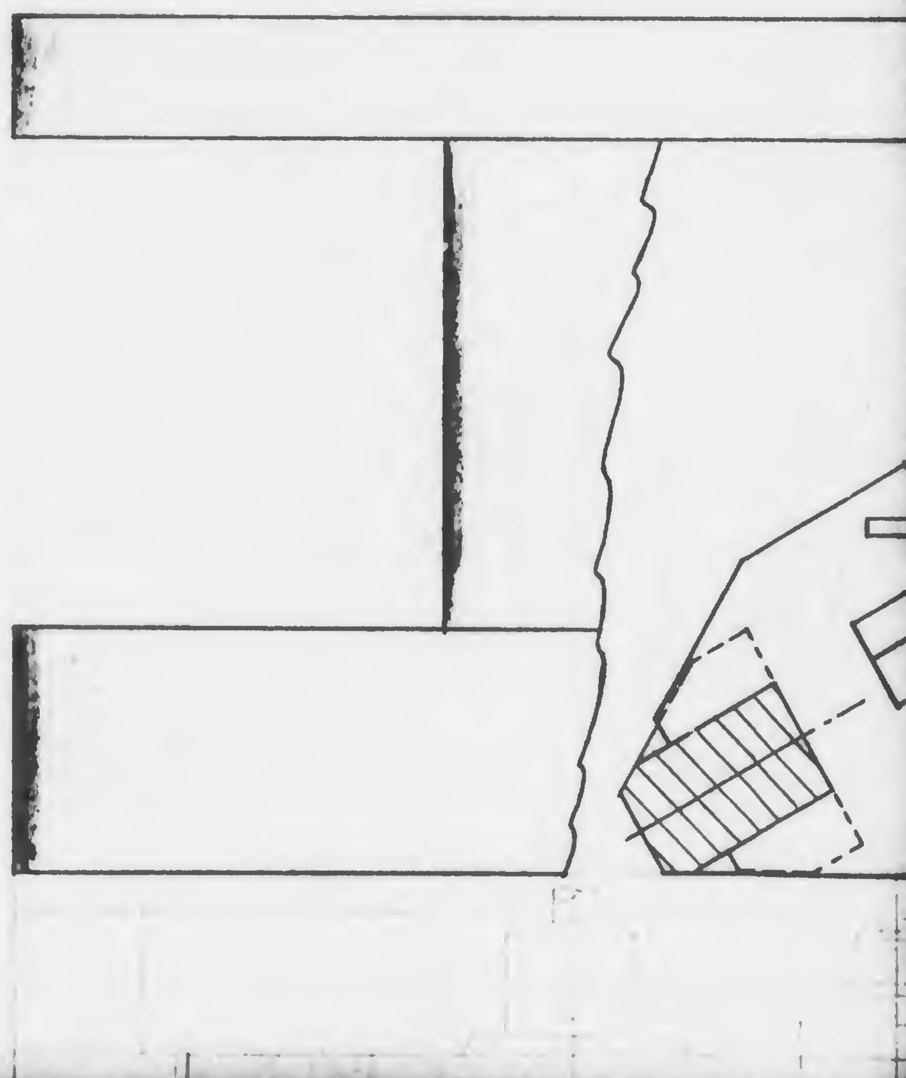
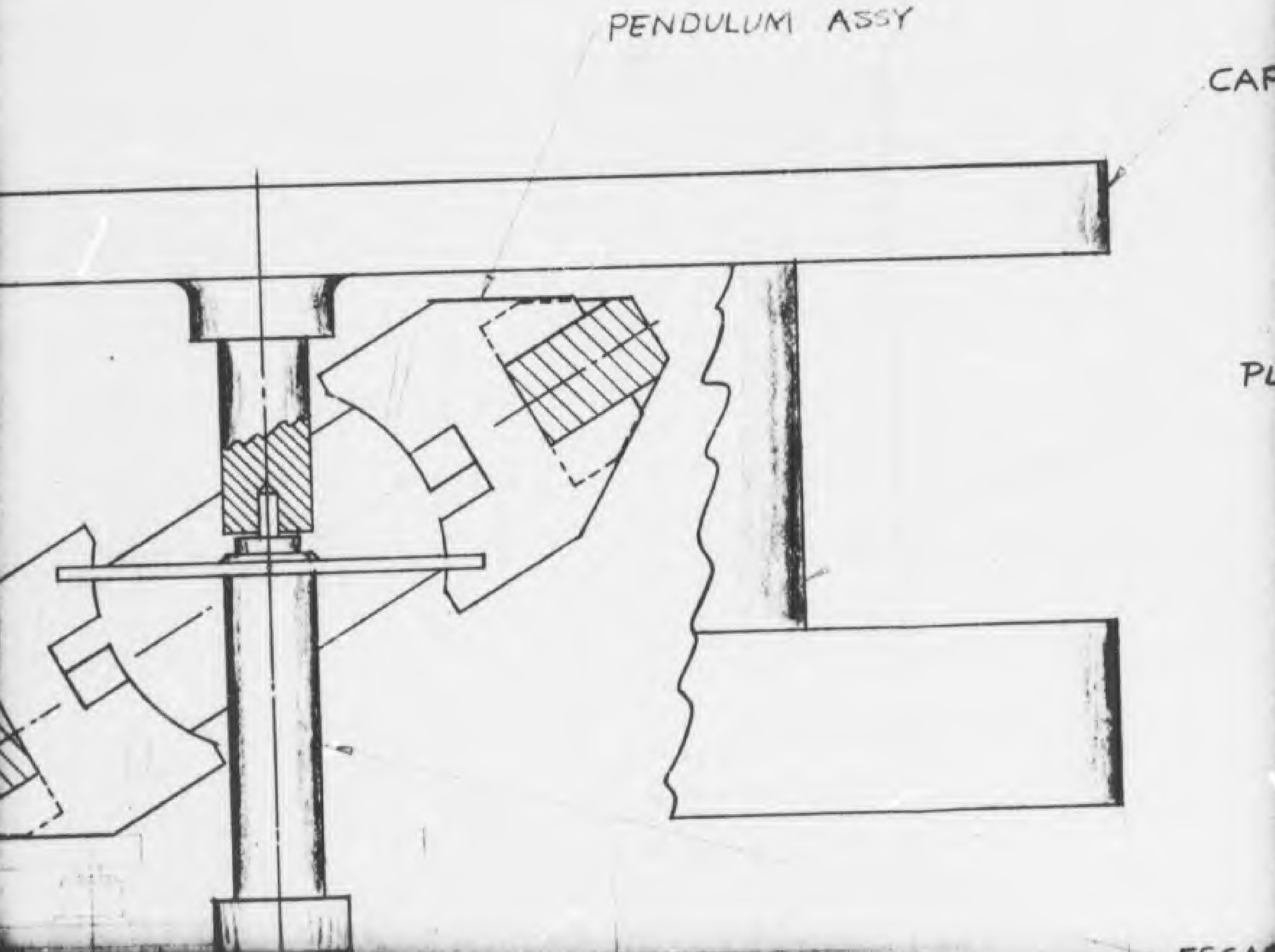


Figure 2. Model of a Free Pendulum



M577 POWER TRAIN ASSY.

B



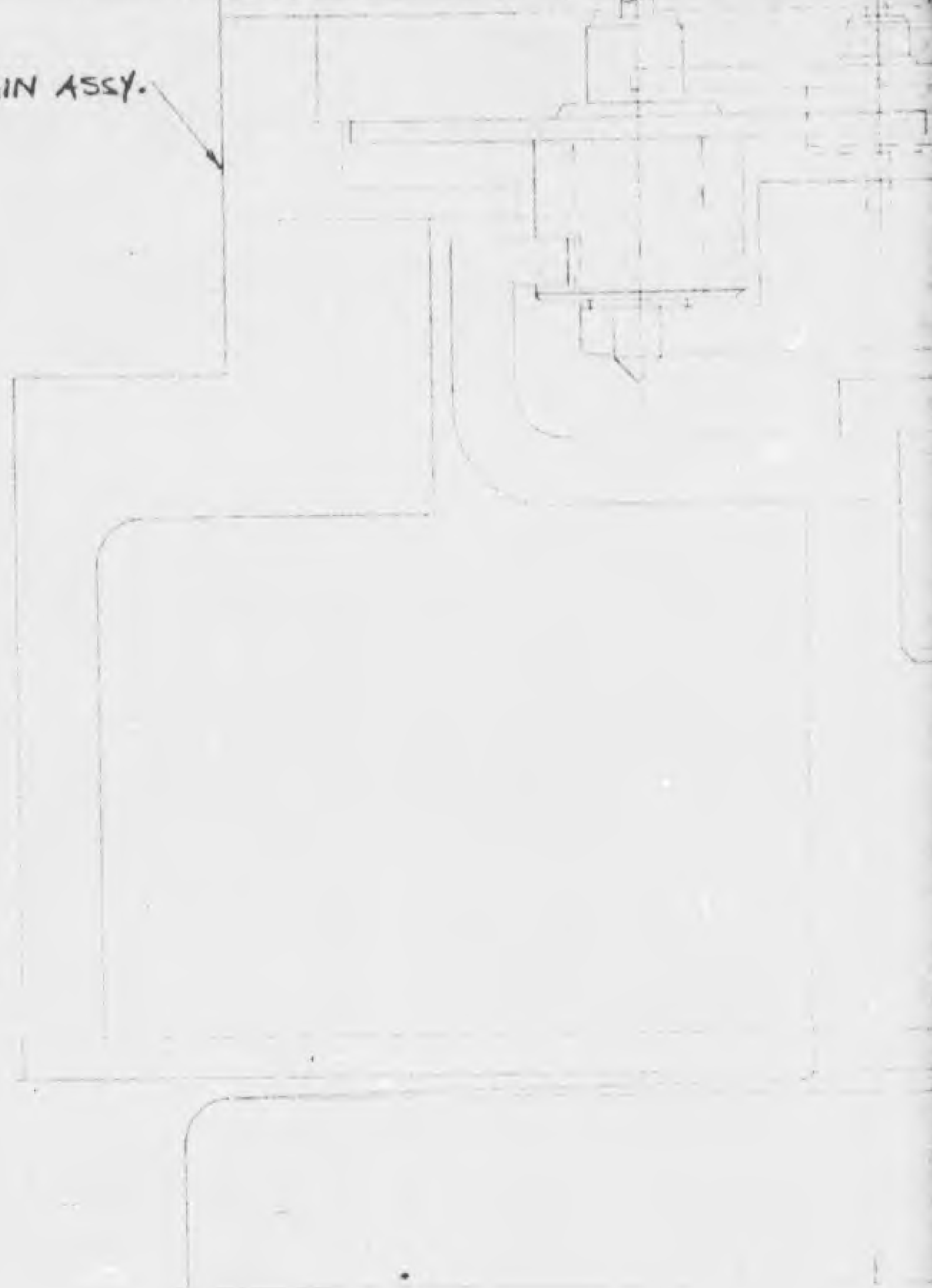
E. C. O.	REV.	DATE	DWN.	CHK.	APP.		CHANGE

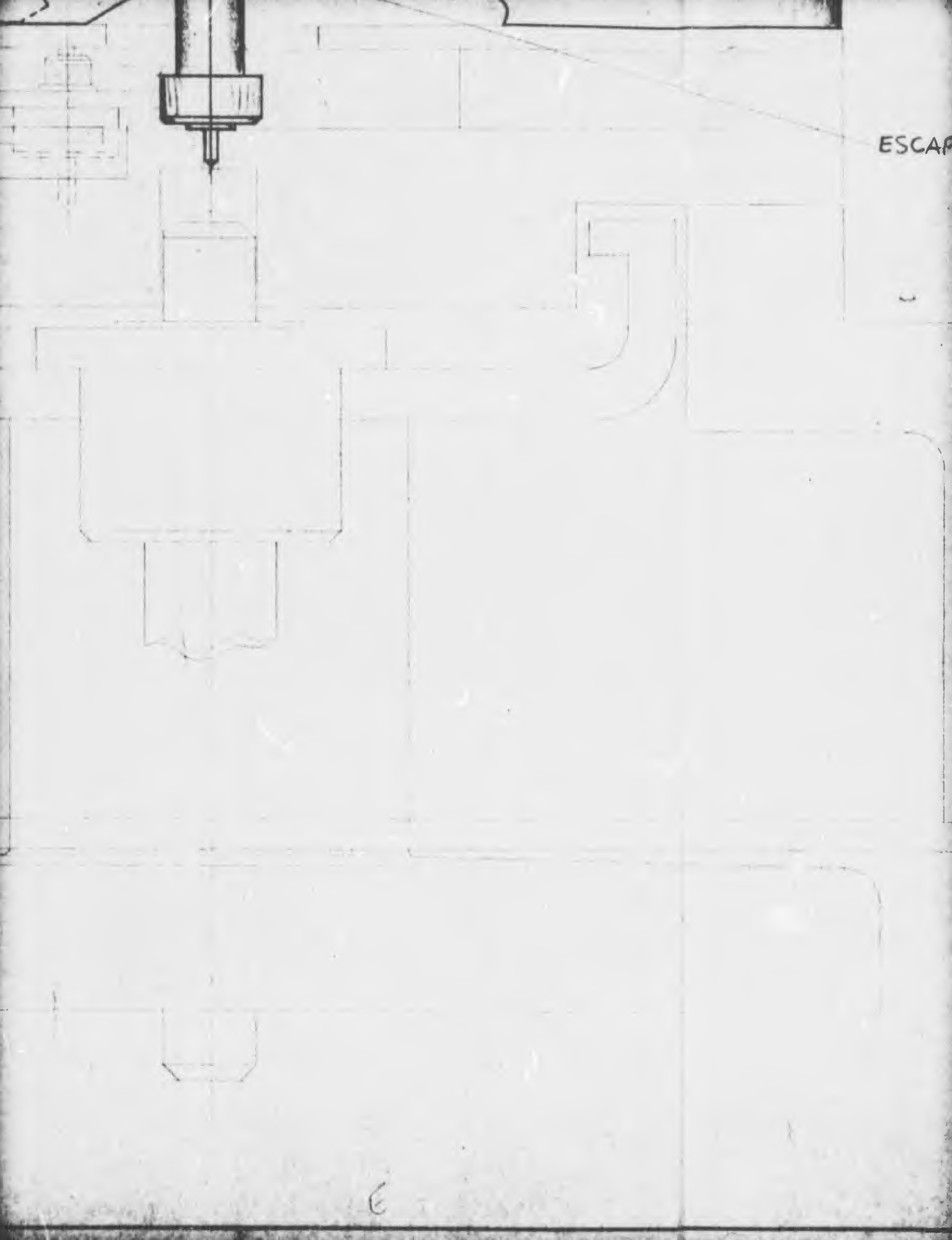
AP

PLATE 1

D

M577 POWER TRAIN ASSY.




ESCAP
6

ESCAPE WHEEL & PINION ASSY.

FIG. 3

JOB NO.	NEXT ASS'Y.
DO NOT SCALE DRAWING	

UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS ✓
FILLETS R. MAX.
BREAK ALL SHARP EDGES CHAM. MAX.
ALL DIMENSIONS HELD AFTER SURFACE TREATMENT
DECIMALS ±
FRACTIONS ±
ANGLES ±

MATERIAL	DWN.	CHK.	ENG.	APP.	TITLE
	C.B.				ES
FINISH					

BULOVA
RESEARCH AND DEVELOPMENT
LABORATORIES, INC.
WOODSIDE 77, N.Y.

SCAL
DWG.

SY.

FIG. 3

NO.	NEXT ASS'Y.

NOT SCALE DRAWING

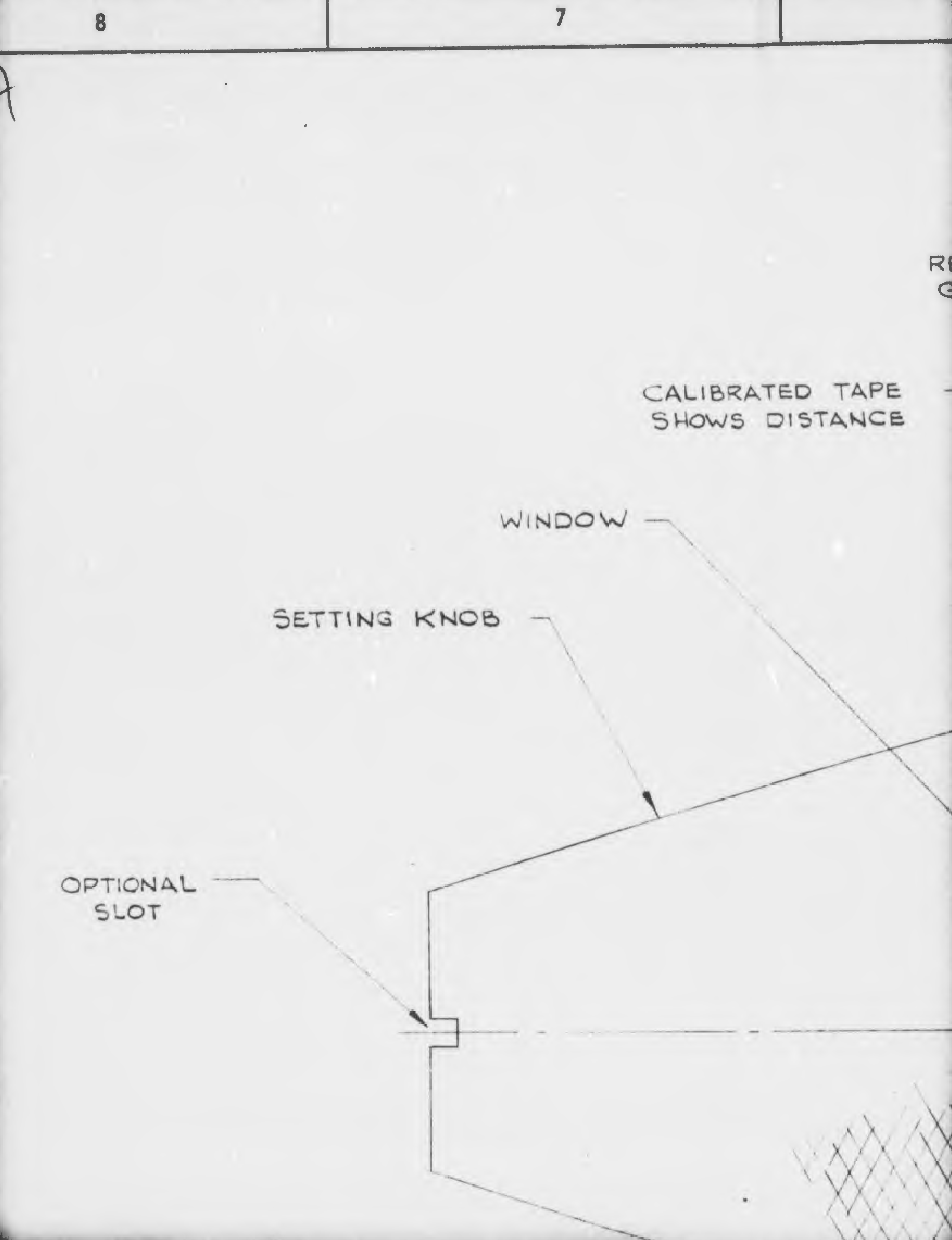
S OTHERWISE SPECIFIED
CE ROUGHNESS ✓
R. MAX.
ALL SHARP
CHAM. MAX.
IENSIONS HELD
SURFACE TREATMENT
LS ±
ONS ±

MATERIAL	DWN.	CHK.	ENG.	APP.	TITLE
	C.B.				ESCAPEMENT ASSY.
FINISH					

BULOVA
RESEARCH AND DEVELOPMENT
LABORATORIES, INC.
WOODSIDE 77, N.Y.

SCALE

DWG. NO.	REV.
FIG. 3	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7
CALIBRATED TAPE
SHOWS DISTANCE
WINDOW
SETTING KNOB
OPTIONAL
SLOT


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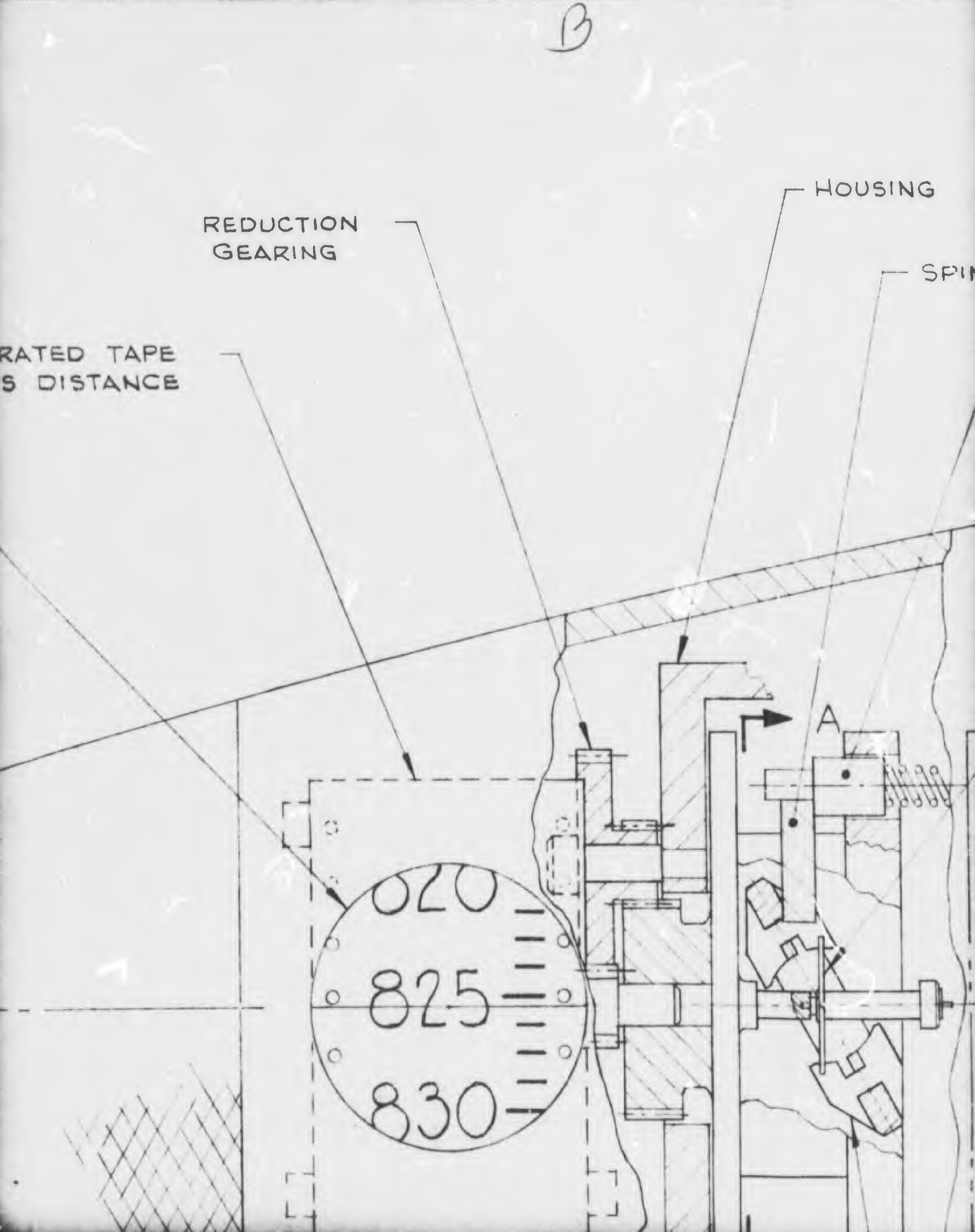
820
825
830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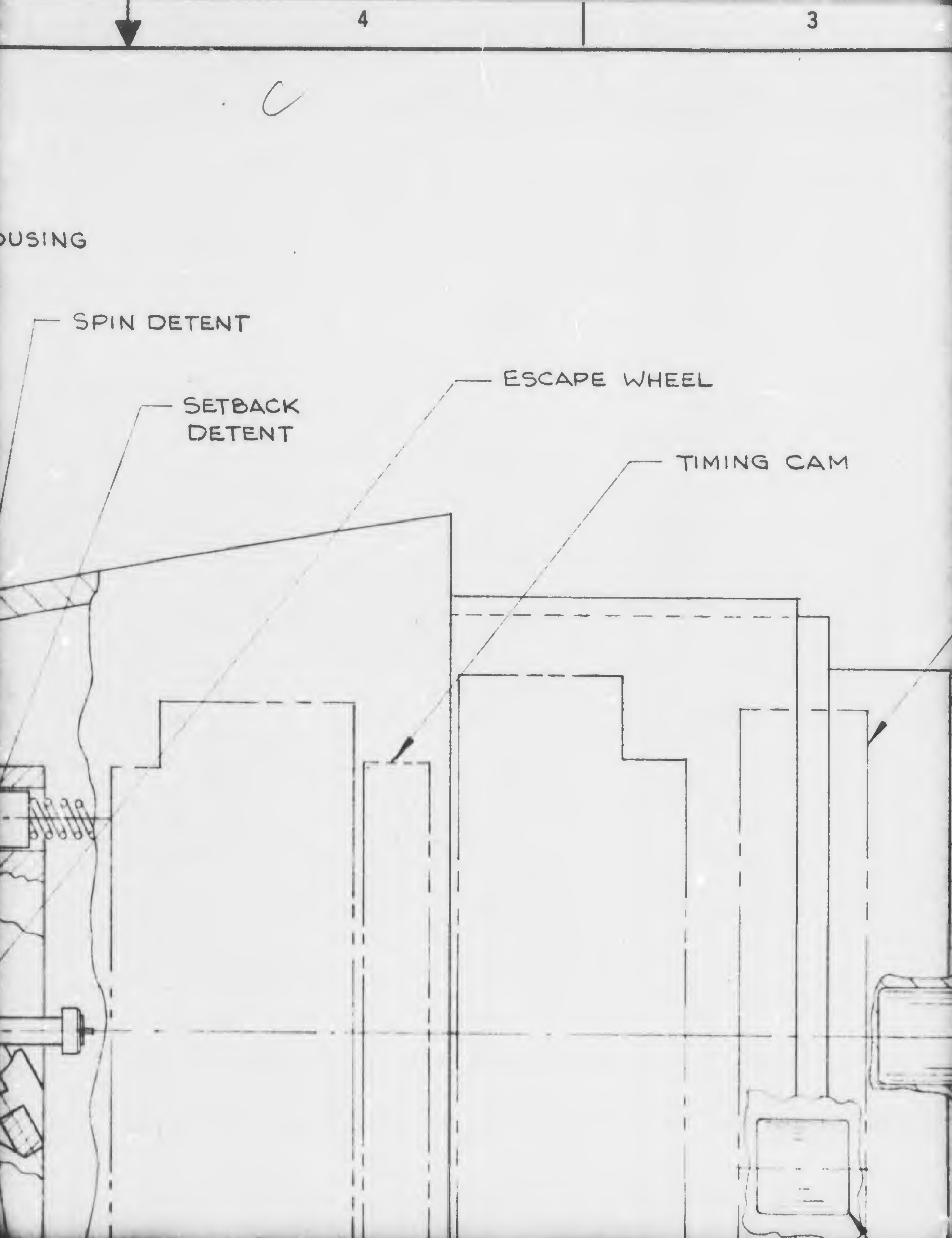

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SPIN DETENT
SETBACK
DETENT
ESCAPE WHEEL
TIMING CAM

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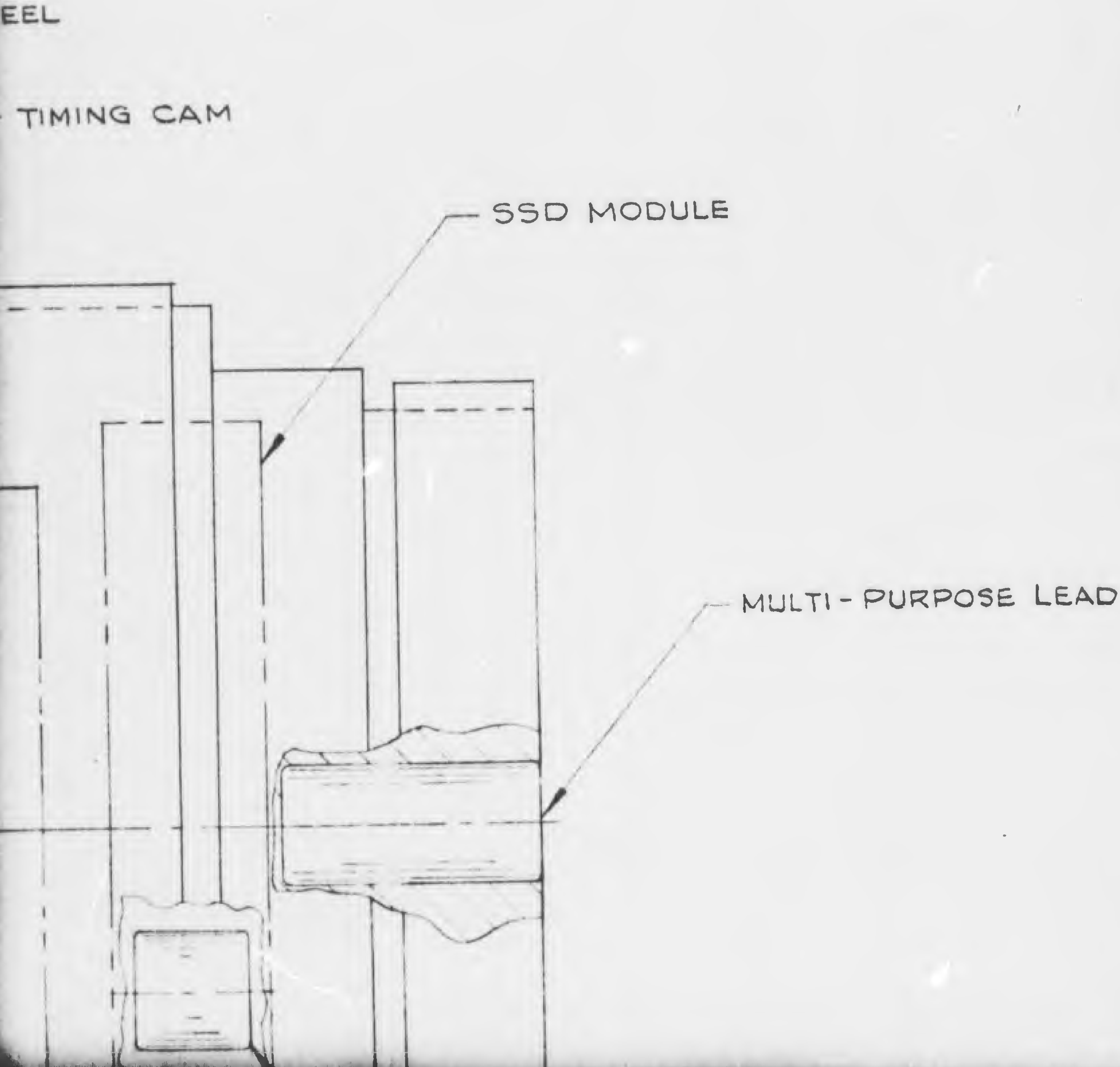
REVISIONS

ZONE	LTR	DESCRIPTION



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REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

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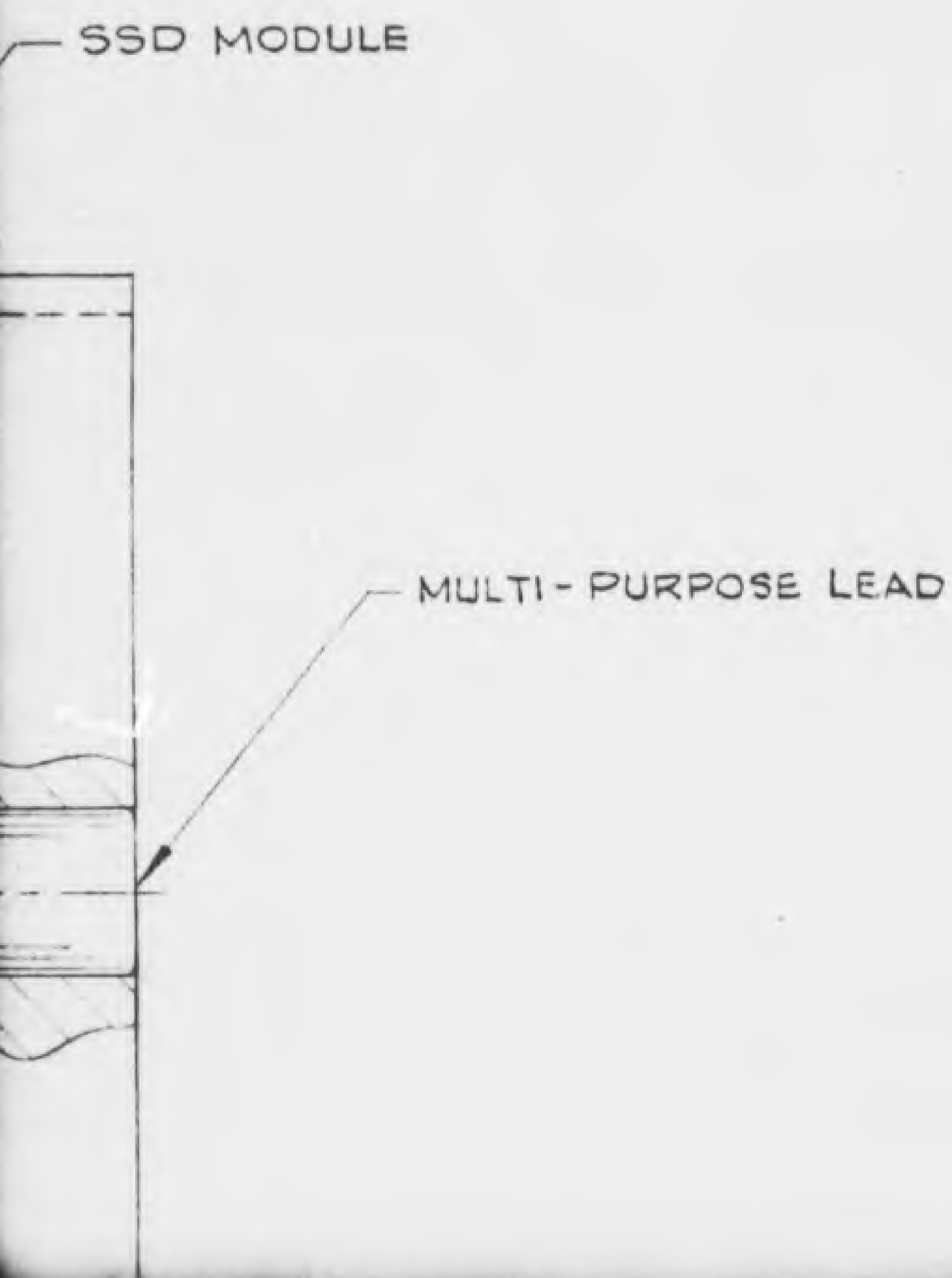

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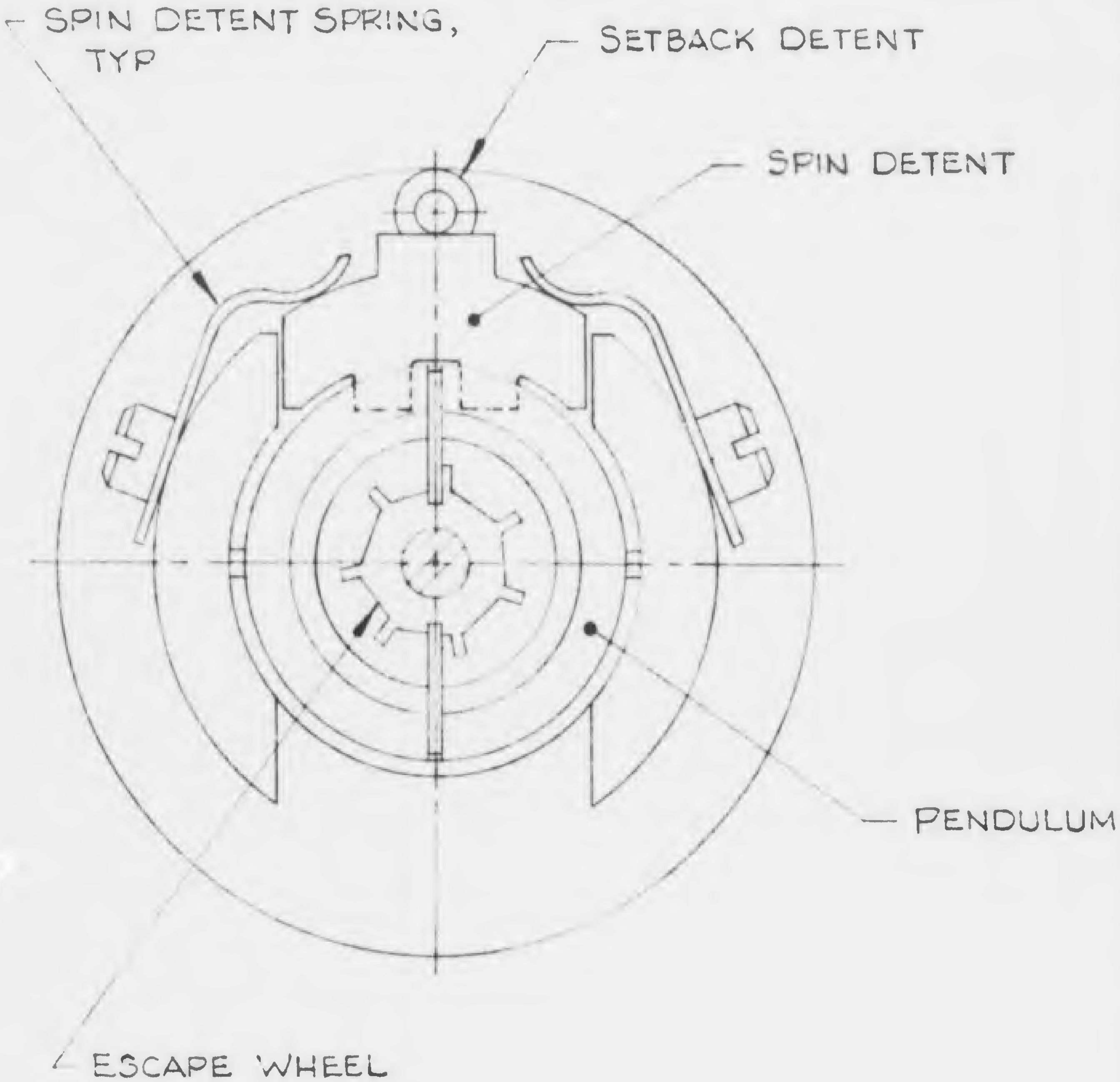

SECTION A-A

B

A

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K+E ALBANENE® TRACING PAPER

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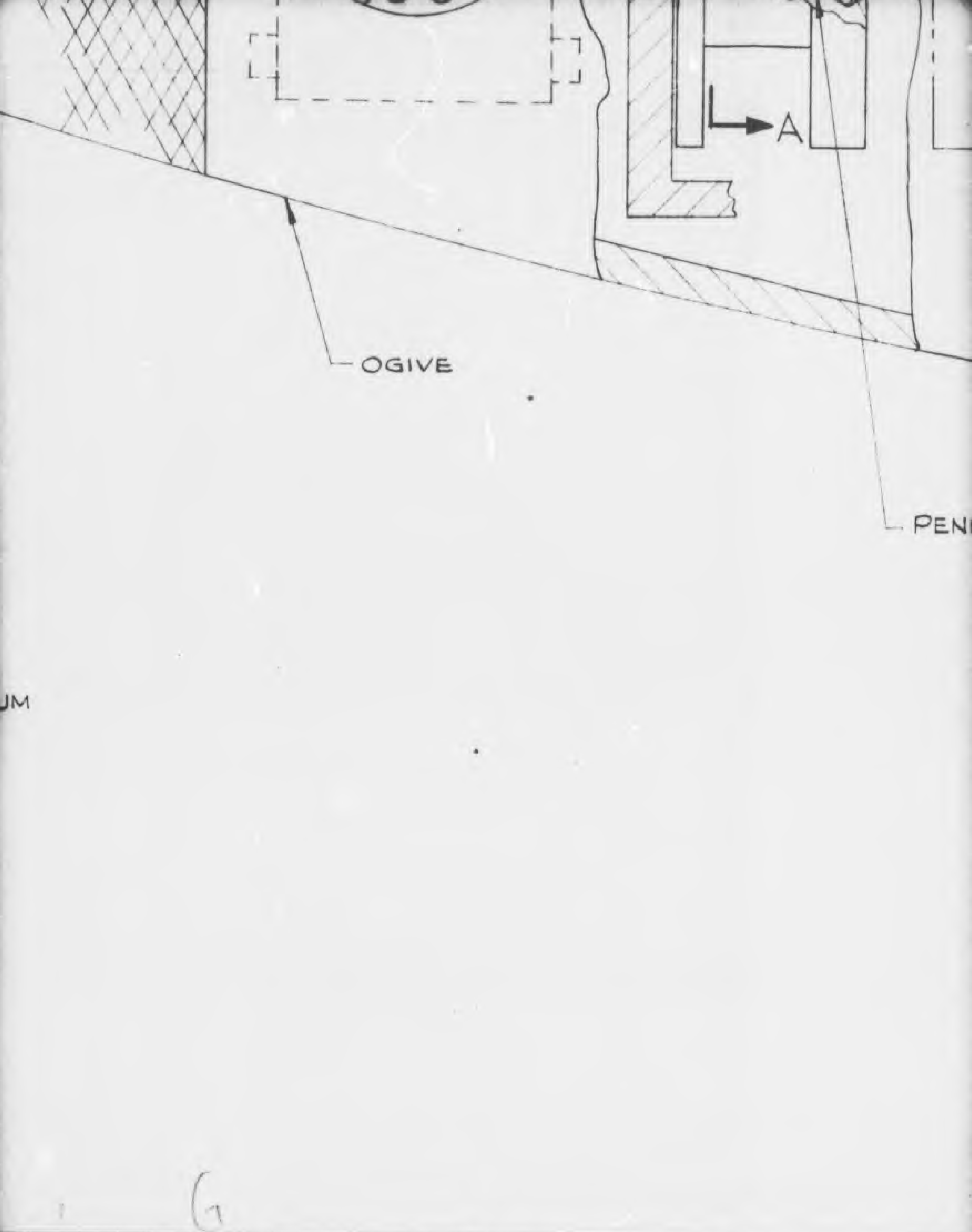
A
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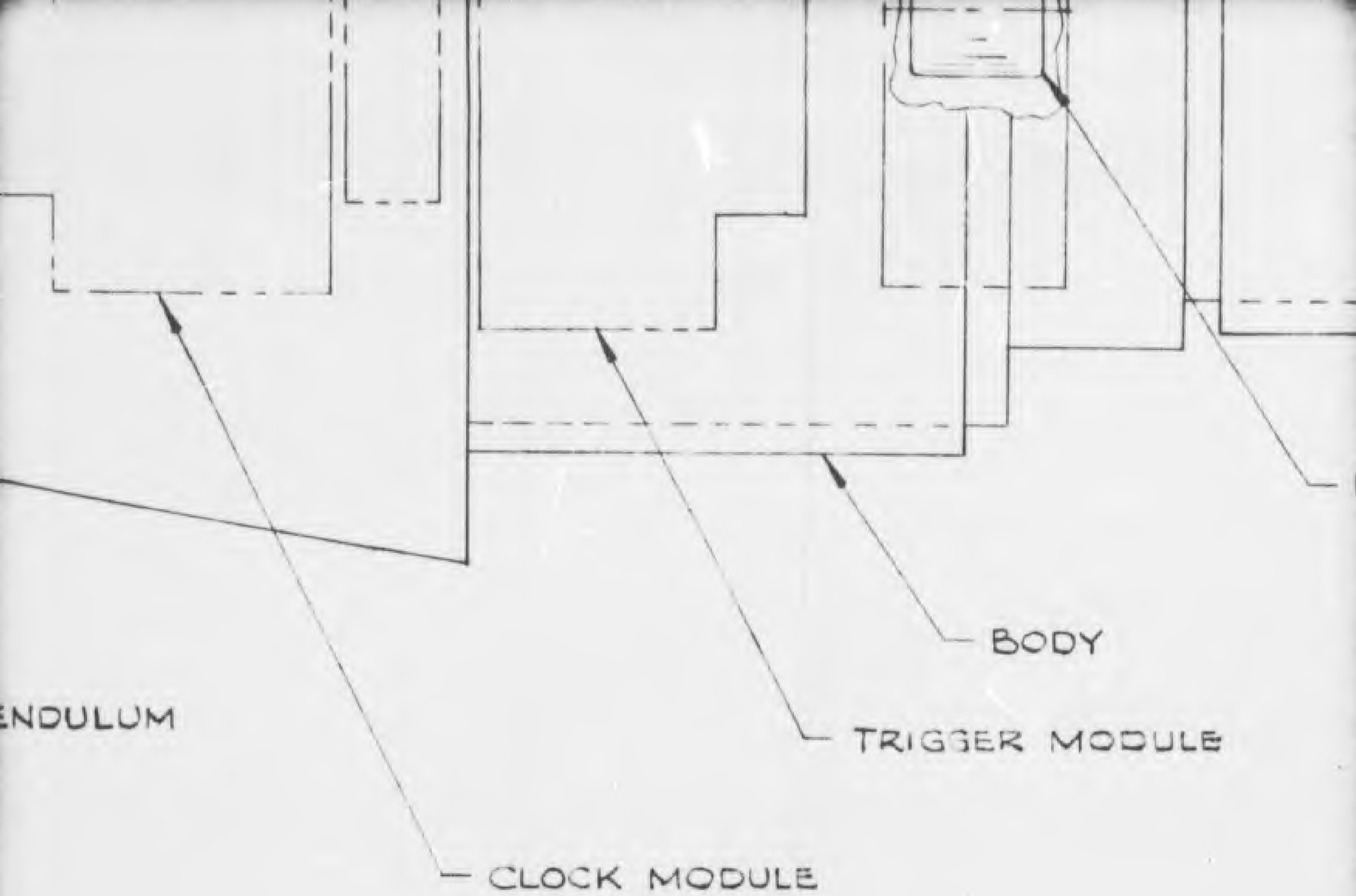
UM
G



				ITEM NO.	
QTY REQD PER DASH NO.					

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES ON:
FRACTIONS ± DECIMALS ± ANGLES ±

MATERIAL

CON

PRE

CHE

APP

OTH

M94 DETONATOR

ITEM NO.	NOMENCLATURE OR DESCRIPTION	CODE IDENT	PART OR IDENTIFYING NO.	SPECIFICATION	MATERIAL OR NOTES	ZONE

LIST OF MATERIALS OR PARTS LIST

CONTRACT NO.

BULOVA WATCH COMPANY, INC / SYSTEMS AND INSTRUMENTS DIVISION VALLEY STREAM, N.Y. 11582

GENERAL ARRANGEMENT OF THE PENDULUM REVOLUTION COUNTING FUZE

PREPARED	F.L.	19 JUN 1973
CHECKED		
APPROVED		

OTHER

SIZE	CODE IDENT NO.		REV.
D		FIGURE 4	

SCALE 4/1	UNIT WEIGHT	SHEET

A

2 1

EXECUTION

PEND 09:11 06/19/73 TUESDAY 103

SHELL REV/MIN	SHELL REV/SEC	PERIOD MILLISEC	GEN.CIRCLE RAD/SEC	PENDULUM MAX RAD/SEC	IMPULSE PIN MAX IN/SEC	MAX ANGLE 15KRPM=15°
60000	1000	1	6283	1644	***	3
30000	500	2	3141	822	82	7
19999	333	3	2094	548	54	11
15000	250	4	1570	411	41	14
11999	199	5	1256	328	32	18
9999	166	6	1047	274	27	22
8571	142	7	897	234	23	26
7500	125	8	785	205	20	29
6666	111	9	698	182	18	33
5999	99	10	628	164	16	37
5454	90	11	571	149	14	41
4999	83	12	523	137	13	44
4615	76	13	483	126	12	48
4285	71	14	448	117	11	52
3999	66	15	418	109	10	56
3750	62	16	392	102	10	59
3529	58	17	369	96	9	63
3333	55	18	349	91	9	67
3157	52	19	330	86	8	71
2999	49	20	314	82	8	74

FIG. 5

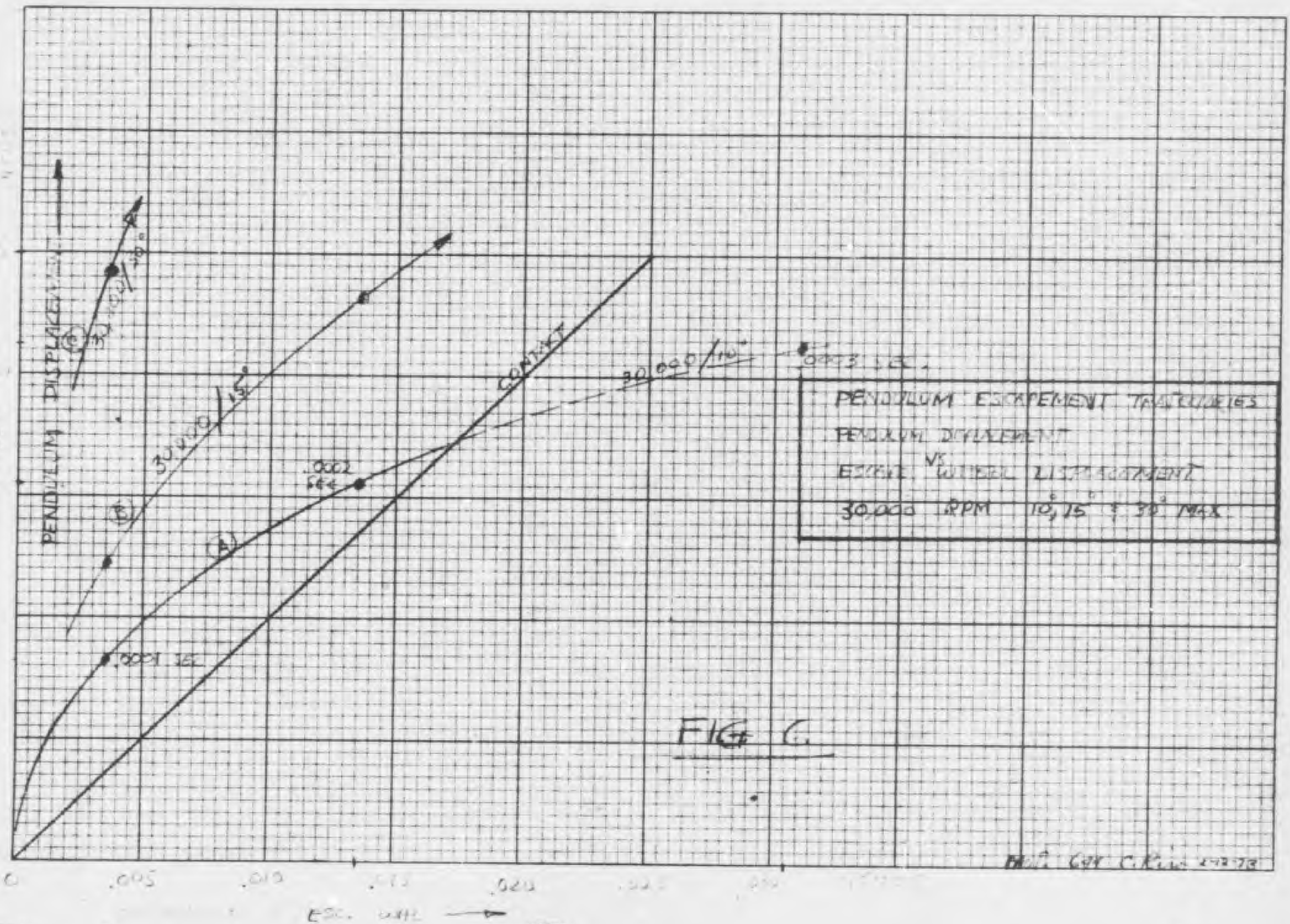

PENDULUM DISPLACEMENT
ESC. WHL
0
.005
.010
.015
.020
CONTACT
.0001 SEC
.0002 SEC
30,000/10°
30,000/15°
30,000/30°
A
B
C
PENDULUM ESCAPEMENT TRAJECTORIES
PENDULUM DISPLACEMENT
VS
ESCAPE WHEEL DISPLACEMENT
30,000 RPM 10°, 15° & 30° MAX

FIG. 6

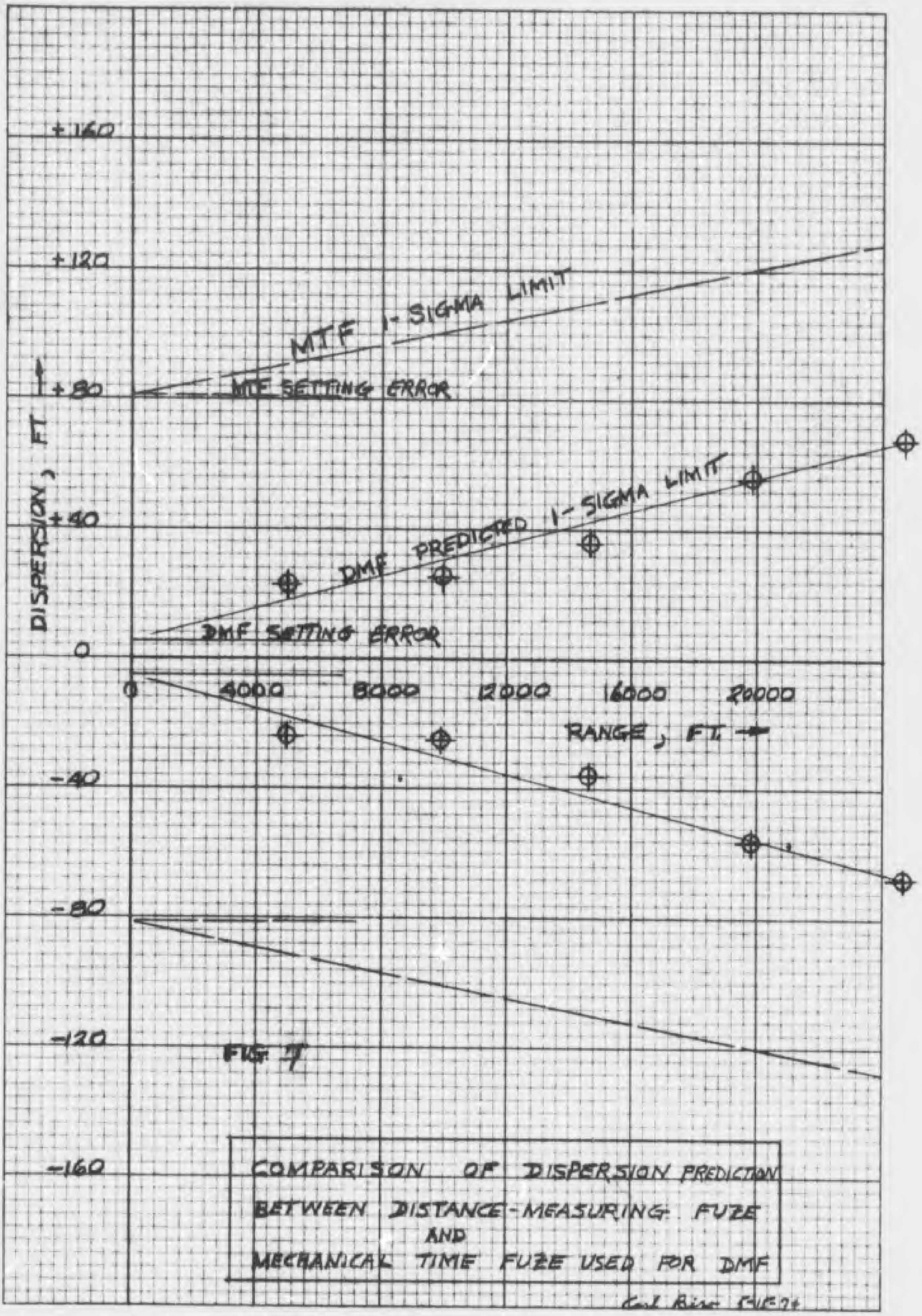


FIG II

COMPARISON OF DISPERSION PREDICTION BETWEEN DISTANCE-MEASURING FUZE AND MECHANICAL TIME FUZE USED FOR DMF