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AMMUNITION GROUP

WARHEADS AND SPECIAL PROJECTS LABORATORY

DEVELOPMENT SECTION II A

TECHNICAL MEMORANDUM
NO. DW-433

DEVELOPMENT
OF A
MODULAR MECHANICAL PROGRAMMER

BY
MATTHEW J. DUJETS

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MATTHEW J. DUJETS.

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ABSTRACT

The problem of selecting an optimum design for a warhead fuze system is usually complicated by the fact that system requirements remain undefined until development of the propulsion system is near completion, thus foregoing any extensive development program on the fuze itself. This report presents a modular approach to the fuze design problem by providing a compatible "building block" programmer made up of individual units which perform specific tasks. Once interchangeable modules capable of performing definite functions have been developed, approximately 80% of the specifications for any missile system can be met by an appropriate choice of the "off the shelf" modules. Consequently, all of the effort can be concentrated to fulfill the remaining requirements. Also, development and improvement of individual modules can continue without interruption in order to incorporate desirable state-of-the-art advances.

INTRODUCTION

Picatinny Arsenal initiated the development of a Modular Programmer in July 1961, in response to the need for a fuze package that is readily adaptable to a wide range of missile and rocket warhead systems. The Modular concept, in which the various subassemblies are segregated according to function, i.e., initiation, power, counter, time base and output, was utilized to provide the most flexible, inexpensive and direct means of meeting the various system requirements. The intent of the design is to provide modules having varied characteristics in each functional area. This approach will allow a satisfactory fulfillment of a requirement for a new system merely by selecting the proper modules. The usual "crash" nature associated with present fuze development programs will thus be eliminated.

Time and money normally expended on developing a completely new package can be applied to dual development of advanced state-of-the-art modules. Thus, timely delivery of laboratory tested hardware to meet system flight test deadlines can be realistically assured through a conventional design, while a parallel program is pursued, aimed at optimizing fuze performance by the application of the latest techniques.

At the present time, each fuze is uniquely designed for one specific application; therefore every new fuze package requires an extensive reliability program. Under the modular approach, reliability of each module will be independently determined, thus eliminating the necessary of requalifying modules for each new system.

The Modular Programmer herein presented embodies a combination of concepts and features which heretofore were not applied in fuze packages. Among these features are:

1. Building block modular construction.
2. Hermetic sealing to permit storage and shipment without use of sealed container.
3. Direct digital setting and readout dials.
4. Visual indication of safe or armed condition.
5. A simple re-cycling arrangement to permit testing and resetting without disassembly, except for case removal.
6. Complete elimination of pull pins.

The requirements incorporated in the design of this programmer are as follows:

1. Usable time; minimum of 1 second to a maximum of 199 seconds.

2. Arm and lock in armed position at 20 g acceleration for a minimum of .8 seconds.

3. No arming with accelerations less than 10 g.

4. If the programmer is set to any value other than safe and then subjected to accelerating forces (vibration on launcher, transportation or accidential drop) which are not sufficient to arm the unit but high enough to move the g weight, start the timer and last for a maximum of .2 seconds, the unit must return the counter wheels and the power spring to their original setting.

5. If a g force acting on programmer is large enough to fully depress the arming mechanism but lasts less than .8 seconds and more than .2 seconds, then the unit will return to an unarmed position; however, the mechanism will be locked, and if subsequently fired, it would be a dud.

6. The device shall meet the objectives specified in the various MIL-STD Tests normally used for fuze acceptance.

Figure 1 shows a schematic diagram of the programmer with its various modules and their inputs, outputs and functions.

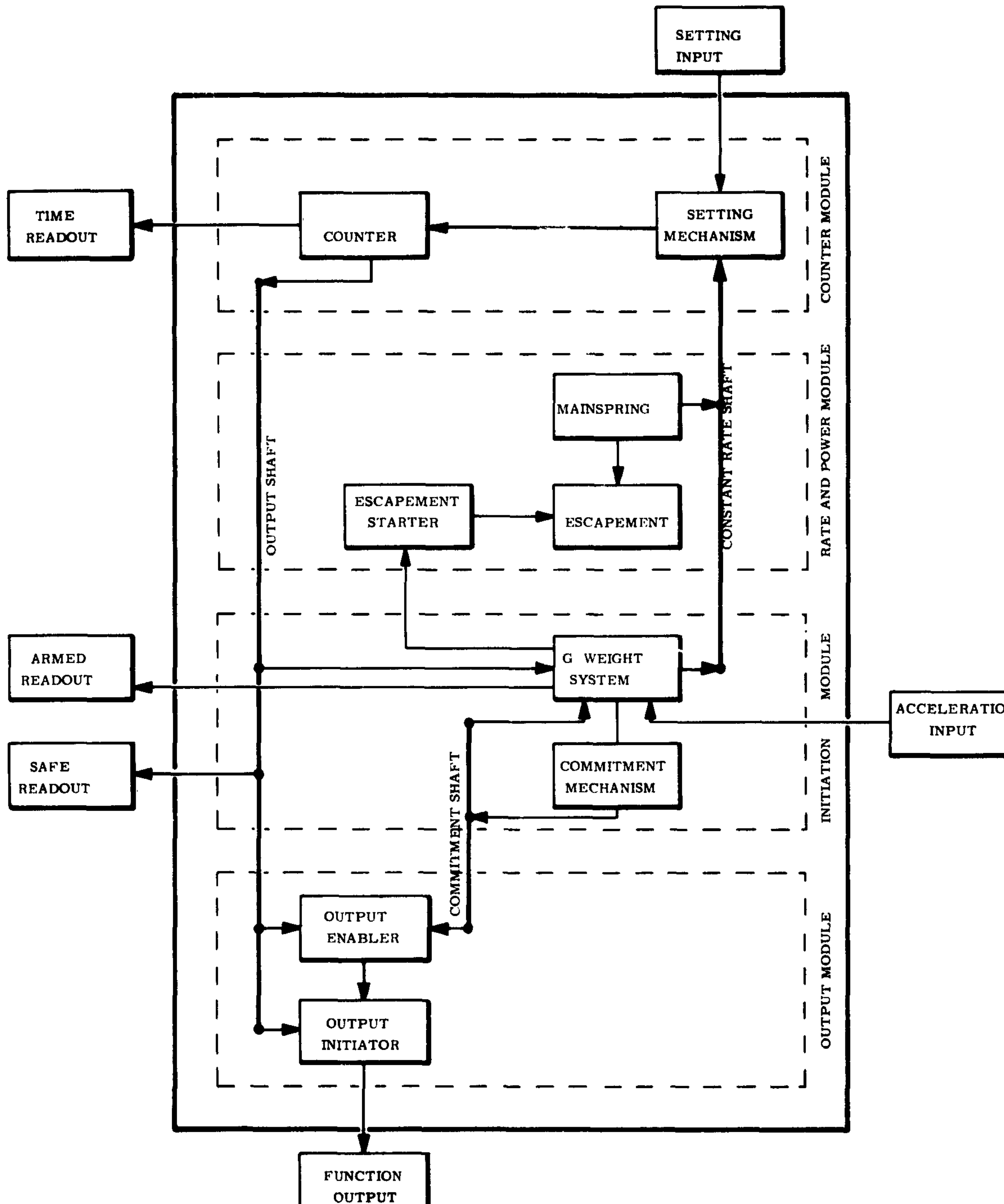

Figure 1. Schematic Diagram

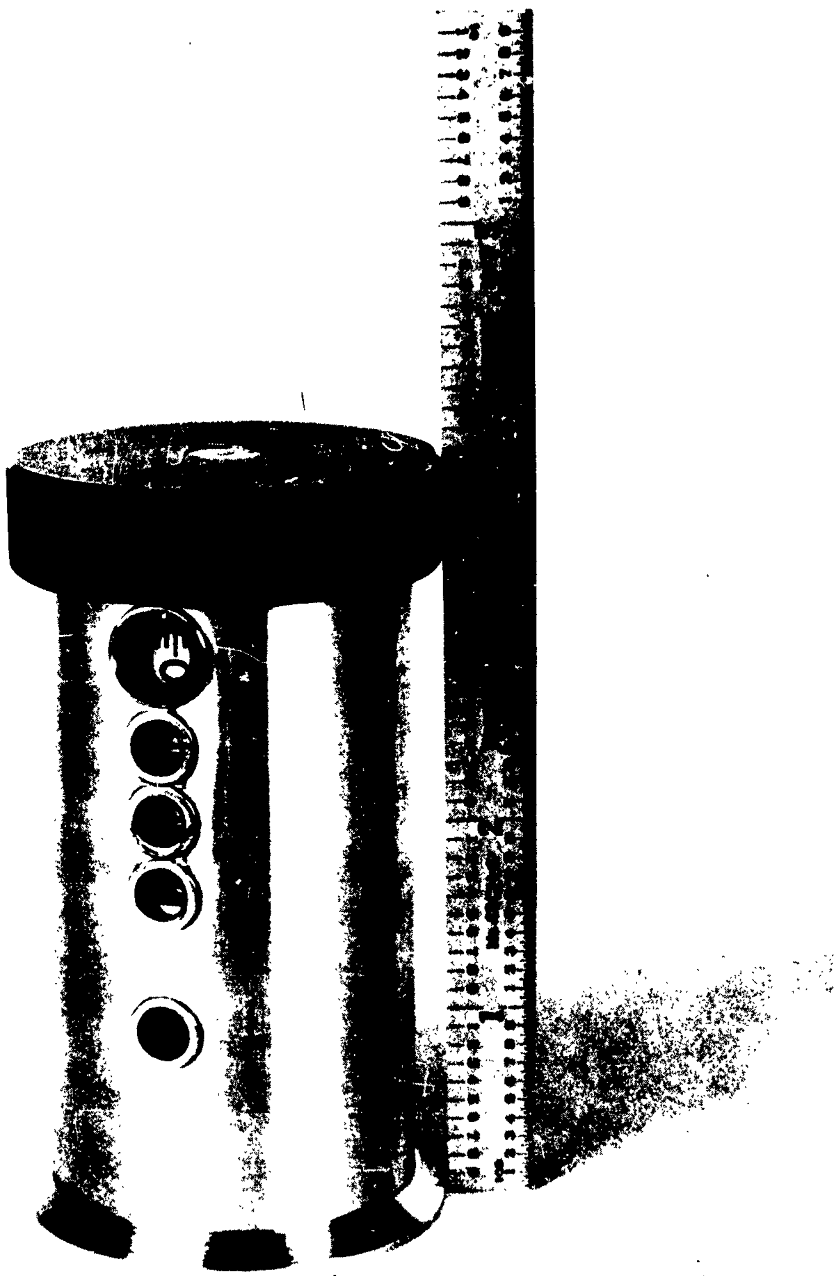

Figure 2. Modular Programmer

GENERAL DESCRIPTION

1. Case and Setting Mechanism

The components or modules which make up this programmer are contained within a cylindrical tube or case as shown in Figure 2. The overall dimensions of the case are 2 1/8" diameter by 3 7/8" long. The modules are hermetically sealed in the case thus eliminating the need for a separate shipping container. The base of the case is provided with a lip to be used in mounting the programmer in the missile. The body of the case contains five windows, the lowest of which indicates a safe or armed condition of the mechanism. When the g weight is locked so that initiation is impossible, the lowest window will indicate an "S". The g weight is locked in place for readings of 0 to 1.0 seconds. When times over 1.0 seconds are set into the device, the lowest window will then display a green flag. This indicates that the unit has not been started and that initiation can occur if the programmer is subjected to the proper acceleration. If, after a setting of over 1.0 seconds the unit is subjected to a forward acceleration of 20 g's or more, initiation will occur and a red flag will show in the lowest (arm-safe) window. If this window shows a half green-half red flag, it indicates that the unit has been started and, because of the lack of continued set back forces, has jammed. The upper four windows are for the digital counters. The time set into the fuze can be read directly to a hundredth of a second. During tests, the time remaining before initiation can also be observed. Figure 3, shows an exploded view of the programmer case and setting mechanism.

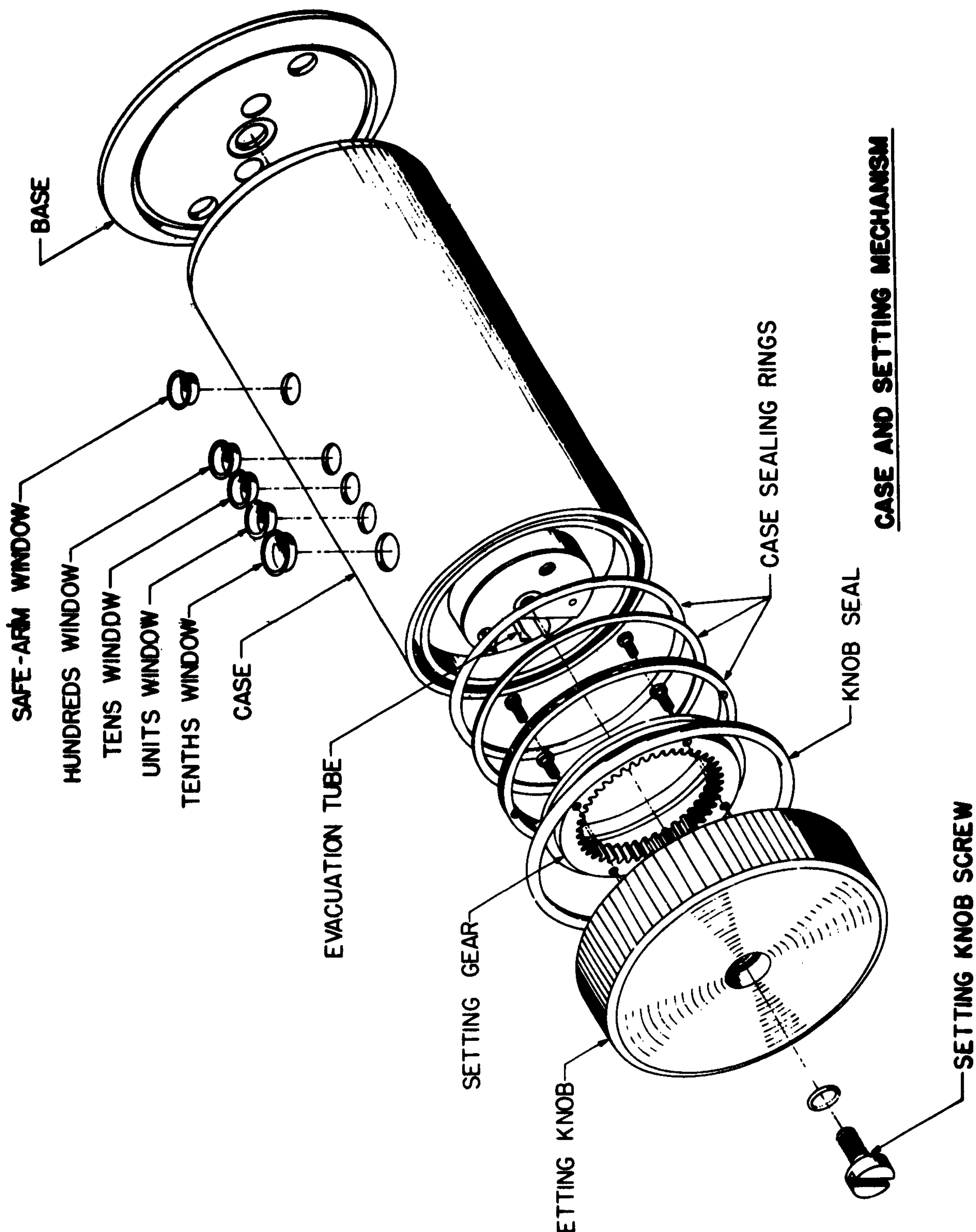

Figure 3. Case and Setting Mechanism

The upper end of the case has a knurled setting knob which is geared thru the setting gear and setting pinion to the sealed drive. This feature allows the rotating motion of the setting knob to be transmitted thru a hermetic seal to the setting differential and then to the counter (indicator) wheels. The location of the counter wheels can be seen in Figure 4. This view shows the programmer with the outer case and setting knob removed.

During preliminary tests the unit will be sealed with "O" rings, but after the final tests are completed, the unit will be soldered.

2. Indicator Module

The primary function of this module, sometimes referred to as the counter module, is to indicate the time values set into the programmer. Figure 5 shows the assembled indicator module and Figure 6 shows an exploded view of this unit. The time setting is provided by indicator wheels which are easily read and which do not present the difficulties inherent in the vernier timing disc arrangement. In previous fuzes, the time setting was determined by the angle through which a timing disc slot was turned away from a time finger bearing on the disc. In order to achieve a resolution of .01 seconds on a 200 second timer, a timing disc would have to be positioned with an accuracy of .018 degrees. If the disc has a radius of one inch, then the positional tolerance between the finger riding the disc and the location of the slot in the disc must be less than .0004 inches. The nature of the parts involved is such that tolerances of .005 inches are difficult to hold in mass production.

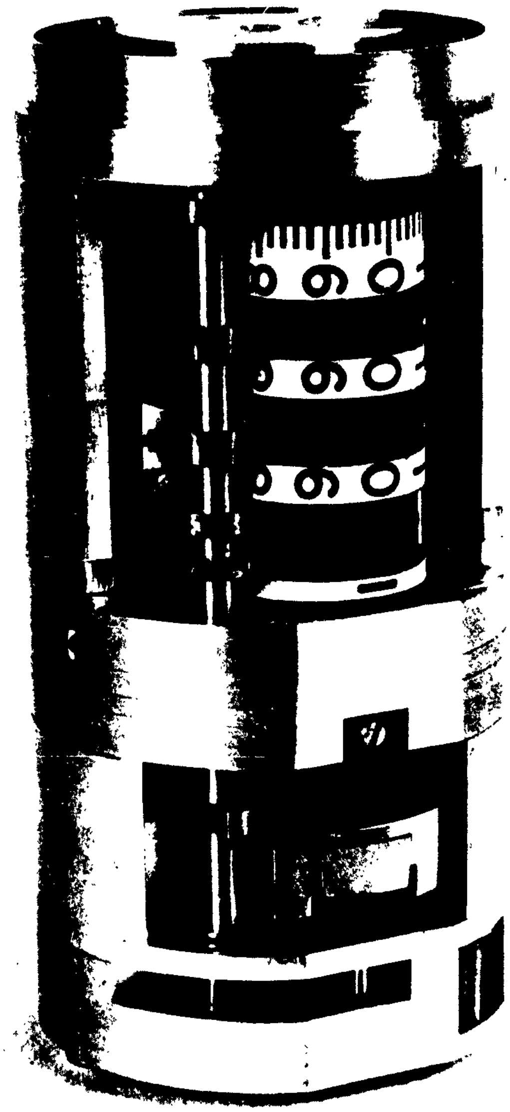

Figure 4. Modular Programmer with Case Removed

Figure 5. Indicator Module

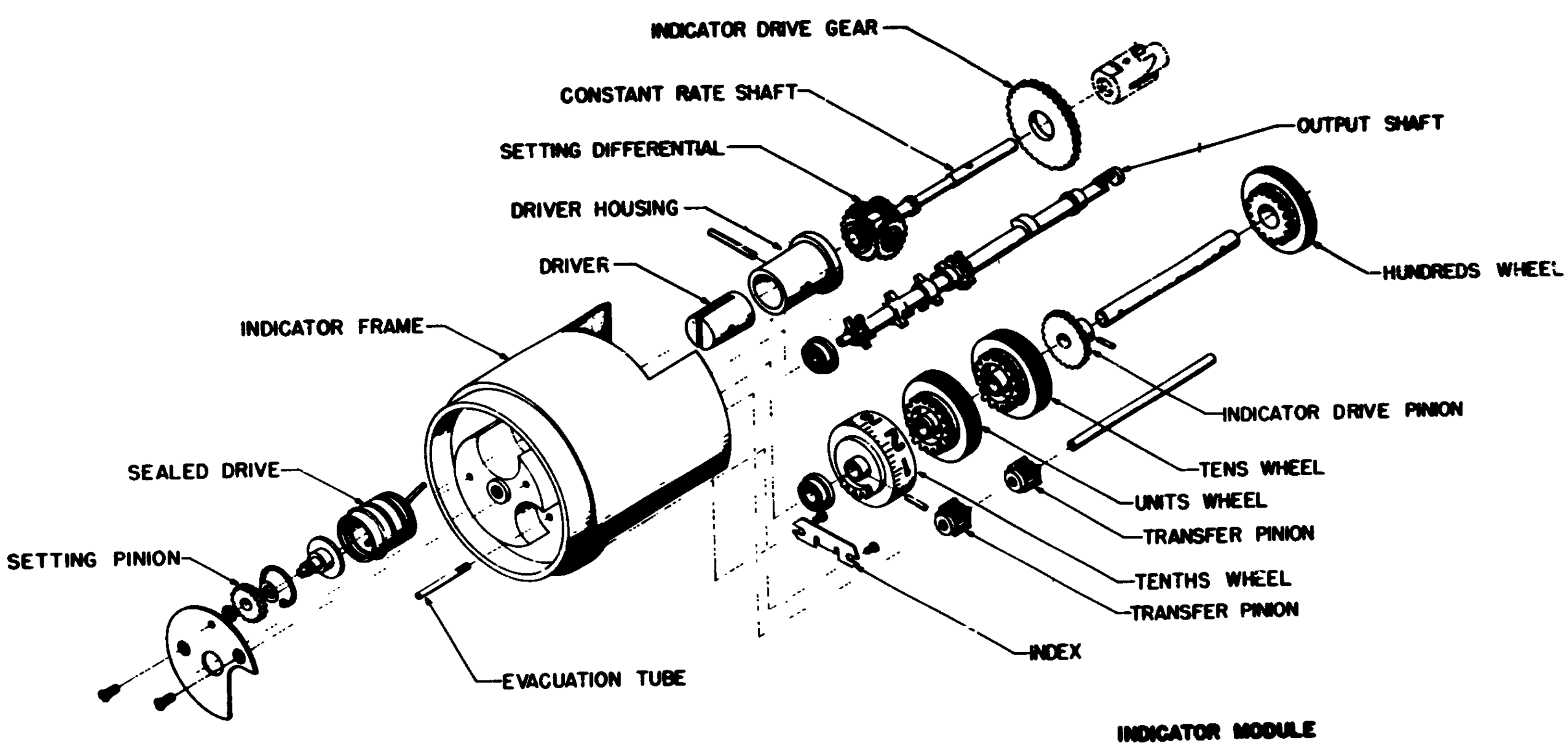

Figure 6. Exploded view of the Indicator Module

In the present systems, not only must the configuration of a disc and finger be closely controlled, but the set position of the disc must be indicated to the man setting the timer. Precision ruling of the setting circle and a vernier scale are not fully satisfactory because of the difficulty in training personnel to use a vernier scale accurately.

The in-line digital counters used in this module provide an easily read, high resolution display of the set time. The desired time setting is made by rotating the setting knob. This motion is transmitted through the sealed drive to the setting differential. Since the constant rate shaft is locked in the initiation module, the motion from the knob is transmitted by the differential thru the indicatior drive gear to the counter wheels. When the timing cycle is initiated, the counter is driven by the constant rate shaft through the differential so as to count down toward zero. The design of the counter output shaft mechanism is such that the motion of the counter wheels is transmitted to the output shaft in the form of an intermittent drive. As the counter counts down from a reading of 1.0 seconds to .9 seconds, the output shaft will be rotated 72° for final arming, and as the counter passes from a reading of 0.1 to 0.0, the output shaft will be rotated an additional 72° at which time the final event occurs. It is this large angular motion of the output shaft, driven at a constant velocity, which permits the extreme accuracy of function time. The fact that the very device which indicates fuze time also actuates the fuze function, means that virtually no difference can exist between zero setting of the counter and the functioning of the final event. The small mass of the moving parts, as well as the positive detent action, forecast extreme durability under severe shock and vibration environment.

The indicator frame not only serves as the body for the indicator module mechanism, but also is the upper cover for the case. The sealed drive, which carries the finger for transmitting rotary motion thru a sealed bellows, is soldered to the indicator frame base. In addition, a tube is also provided in this base to allow evacuation of air from the case, and if desired to fill it with an inert gas.

In order to prevent excessive torque from damaging the sealed drive, the setting knob input is transmitted through a clutch made by using a "tru-arc" ring pressing against the setting pinion.

3. Power and Rate Module

To insure a more compact design, the power and rate modules were combined into one unit as shown in Figure 7. This module, by means of a 20 turn Negator Spring, delivers the power necessary to drive the programmer, and also by means of the escapement, regulates the rotation of the counter wheels.

A Negator Spring was chosen for this unit because it allows a relatively large number of turns of the output drum which thus reduces the number of gear stages in the escapement train. The smaller gear ratios permit improvements in the smoothness of torque transmission to the escapement. Large gear ratios at individual gear meshes are avoided. The Negator Spring also provides a more constant torque than a conventional power spring during the operating cycle.

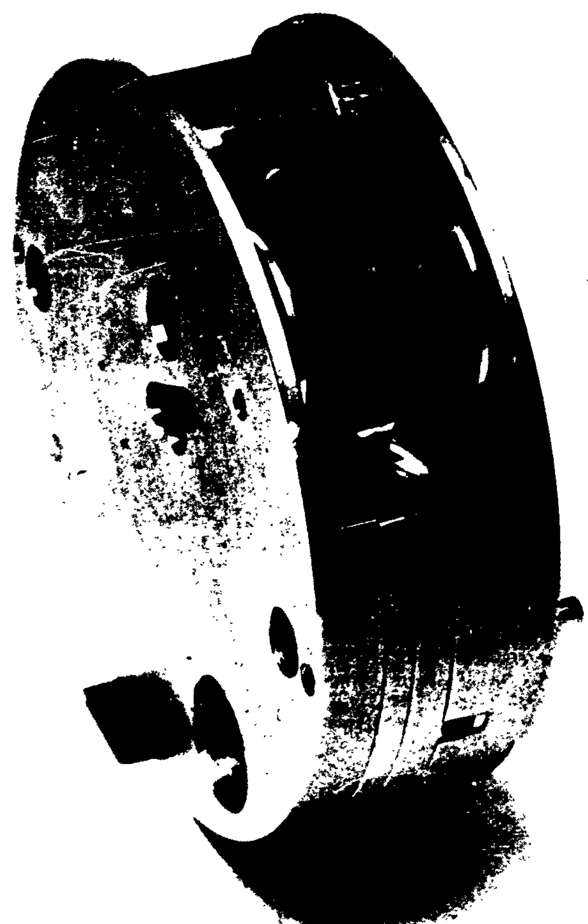

Figure 7. Power and Rate Module

Due to the higher turning rate of the Negator Spring drum over the conventional spring, fluctuations in available torque occur at correspondingly higher frequencies and thus average out to a mean torque over a shorter time interval. For this reason, local changes in the spring material, which affect the torque only while that particular section of the spring is active, will contribute less to changes in the escapement beat rate and thus lend greater accuracy to the time base.

Because the rate portion of this module must remain accurate under variations of torque, an evaluation program was set up to compare eight available escapements. This program is described in Appendix 1. The variation in torque is caused by the engagement of the various counter wheels during the countdown from set time to zero.

The spring drum shown in the exploded view of Figure 8 is geared thru the power gear to the constant rate shaft which protrudes into the initiation module. In order to prevent the running of the escapement while the spring is being rewound, a one-way ratchet is built into the spring power drum. The ratchet has a 49 tooth wheel with 12 pawls. This provides a positive high engagement between the power drum and the escapement during operation but does not create excessive drag during reset.

To insure starting of the timer, an escapement starter is made to flick the escapement lever when the "g" weight moves due to set back forces. This action, coupled with the application of power from the Negator Spring, assures starting of the escapement. The escapement then regulates the rate of rotation of the spring drum which is geared to the constant rate shaft.

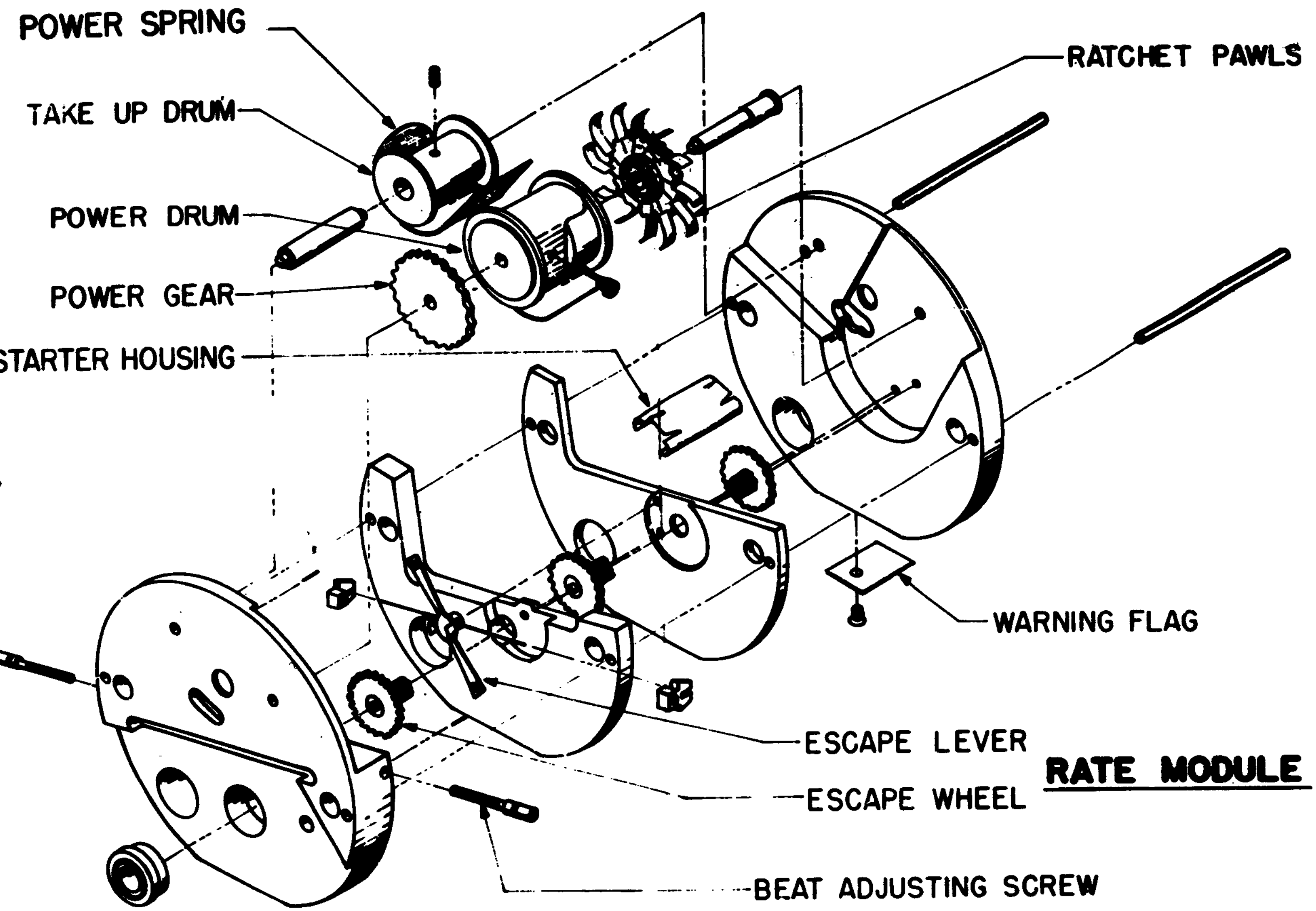

Figure 8. Exploded view of the Power and Rate Module

Figure 9. Initiation and Output Module

4. Initation Module

The Initiation Module of the Modular Programmer, Figure 9, is an acceleration sensing device which initiates programmer operation, cocks the firing pin springs of the output module, unlocks the constant rate shaft and operates the safe arm indicator. Prior to setting time into the programmer, the g weight is locked in the unoperative position by the output shaft. When the g weight is in this position, the firing pin springs are uncocked and the constant rate shaft is locked. The g weight has, in addition, the function of indicating whether the fuze is in the armed or safe condition. When the g weight is in its upper or unoperative position, the green flag, which it carries, appears in the safe-arm window for settings from 1.0 seconds to 199.9. Settings from 0 to 0.9 are indicated by the letter S in the safe-arm window. If the programmer is exposed to set back forces of 20 g for a minimum of .8 seconds, then the g weight will be locked down by the commitment shaft and the safe-arm window will show a red flag, thus indicating an armed condition.

An exploded view of the initiation and output module showing the relationship of the various parts is shown in Figure 10.

Setting the timer for values above 0.9 seconds causes the output shaft to rotate and unlock the g weight. Under this condition, the g weight is free to operate whenever it is subjected to acceleration forces of 20 g's or more along its sensitive axis. When the unit is subjected to an acceleration of this magnitude, the g weight will be displaced thereby unlocking the constant rate shaft, starting the escapement, compressing the firing pin springs and compressing the g weight springs.

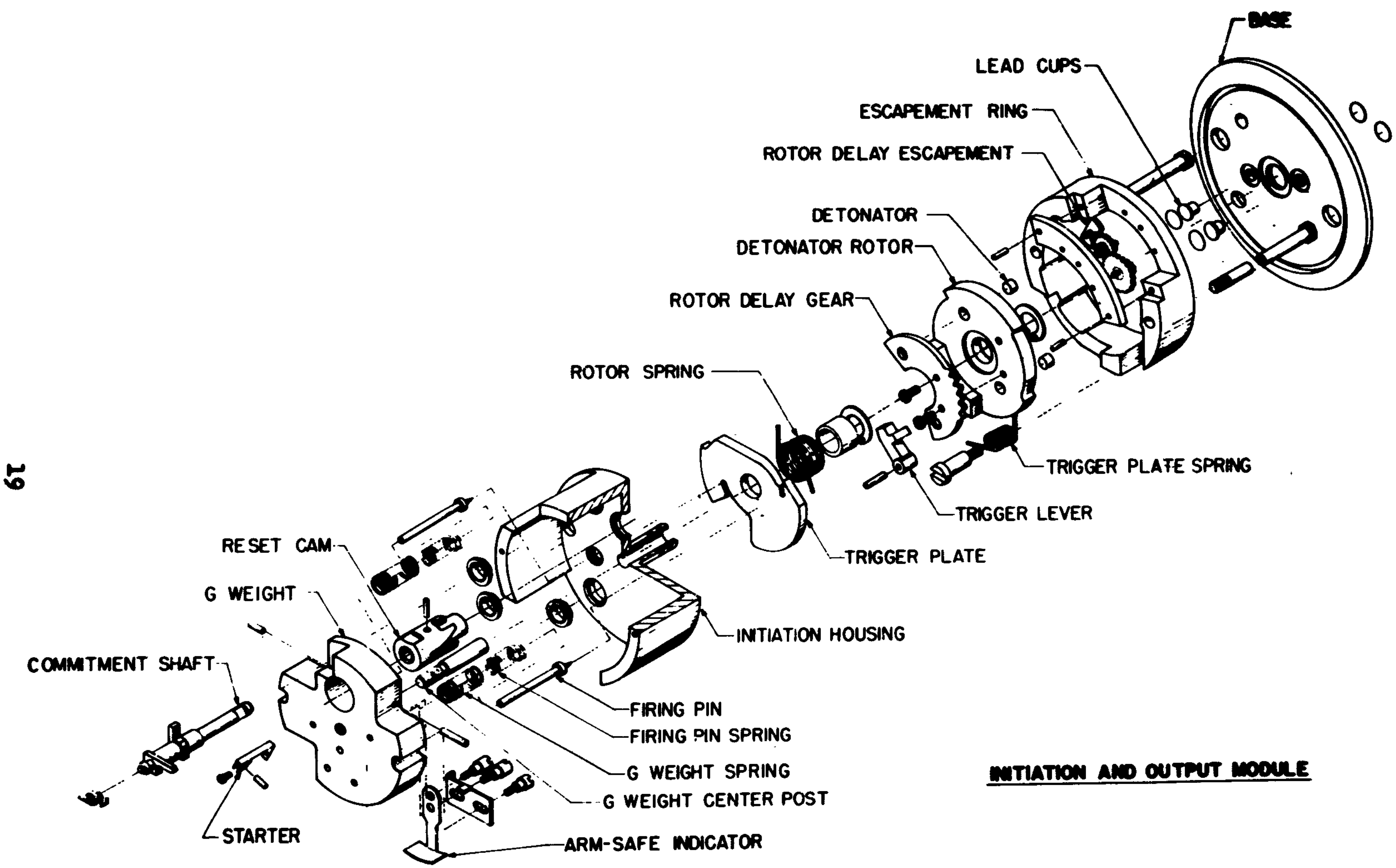

Figure 10. Exploded view of Initiation and Output Module

If the acceleration is maintained for less than .2 seconds, the g weight will return to its original position thereby resetting the counter to its initial setting and rewinding the power spring. If the acceleration is maintained for more than 0.2 seconds but less than 0.8 seconds, the g weight will partially return to its initial position. Complete return is prevented by a cam surface on the constant rate shaft which engages the g weight if it attempts to return during this period. Timer operation continues until the cam and the g weight locks up (approximately 0.2 sec). When the g weight is in this position, it also provides a blocking surface which prevents complete operation of the output shaft. This condition is indicated in the safe-arm window by displaying a half-red half-green flag. Resetting of the fuze from this position requires a partial disassembly.

The programmer is allowed to complete its cycle only if set for values of 1.0 seconds or more and if subjected to an acceleration of at least 20 g for a period of time in excess of 0.8 seconds.

5. Output Module

At the end of the programmer cycle, an output is provided by the output module shown in Figure 11. This module contains an out of line detonator mechanism with two detonators, dual firing pin and spring assemblies, and a firing pin trigger mechanism. In order to provide a slight delay in the detonator rotor assembly and thus assure proper programmer operation, a verge type escapement is included in the detonator rotor assembly.

The interrelation of the output module with the counter and the initiation modules is such that the output module cannot be operated until after proper initiation has occured.

Figure 11. Output Module

During the time that an acceleration of 20 or more g's holds the g weight at the bottom of its travel, the constant rate shaft rotates. If this time is in excess of 0.8 seconds, then the reset cam will have turned far enough to operate the commitment shaft thus locking the g weight in place. This then keeps the detonator firing pin springs in a cocked position. Release of the commitment shaft also unlocks the detonator rotor, allowing it to rotate until it comes in contact with the blocking surface of the output shaft. As the counter module counts down from 1.0 to 0.9 seconds, the output shaft is rotated 72°, releasing the spring loaded detonator rotor. The detonator rotor is retarded in its travel to the final position by a verge type escapement geared to the rotor. This retardation, which amounts to approximately 0.8 seconds, prevents premature detonator initiation in the unlikely event that the main programmer timing train should fail. Release of the detonator rotor unlocks the trigger plate lever so that the lever is now restrained from turning only by the output shaft. At a counter indication of approximately 0.1 seconds the detonator rotor reaches its final position, thus aligning the detonators with the firing pins and the lead cups. As the counter moves from 0.1 through 0.0, the output shaft rotates and releases the firing plate trigger. The trigger now allows the firing plate to rotate and thereby release the firing pins, which impinge on the detonators and initiate the explosive train.

FUTURE WORK

Effort is being continued to improve the existing programmer. Modified modules are now being tested, and after results are analyzed, further necessary changes will be incorporated to produce units for firing tests.

Rate modules have been obtained from several sources. They will be tested and evaluated as possible replacements of the present rate module.

Scopes of Work for the various modules are being released to obtain new ideas that will improve any of the modular areas.

A modification, which will reduce the power consumption of the indicator module, is to be incorporated in the future programmer. The present configuration which runs at a rate of 1 r.p.s, permits a setting resolution of .01 seconds. By changing the running rate to 0.1 r.p.s. the resolution during setting will be reduced to 0.1 seconds. This figure is more commensurate with the anticipated accuracy of the programmer.

APPENDIX I

MODULE REQUIREMENTS

To demonstrate the modular concept, alternate modules should be developed. These, then, would be substituted for the existing modules to show how the characteristics and requirements of the programmer could be changed.

The first step in this direction was performed in choosing the escapement to be used in the present rate module. Tests were conducted on available escapements to determine the maximum torque variation which would result in an escapement frequency change of 0.1% at room temperature.

Curves showing the results obtained in testing escapements from eight sources are shown in Figure 12. From this preliminary study, it was decided that the first rate modules would be fabricated with the XM-7 escapement because it maintained a relatively constant operating time (less than 0.1% change) over a range of 100 percent change in driving torque.

The beat frequency of the sample escapement mechanism was checked indirectly by measuring the time required for the input shaft to turn one complete revolution with various values of driving torque. A Hewlett Packard electronic counter was used to measure the time required for the drive shaft to turn the one revolution. The driving force was obtained by using gram weights on a string wound on a four inch diameter wheel.

Additional timers will be obtained from sources showing promise of meeting the specifications outlined in the following pages. These specifications will vary depending on the application of the programmer. It is

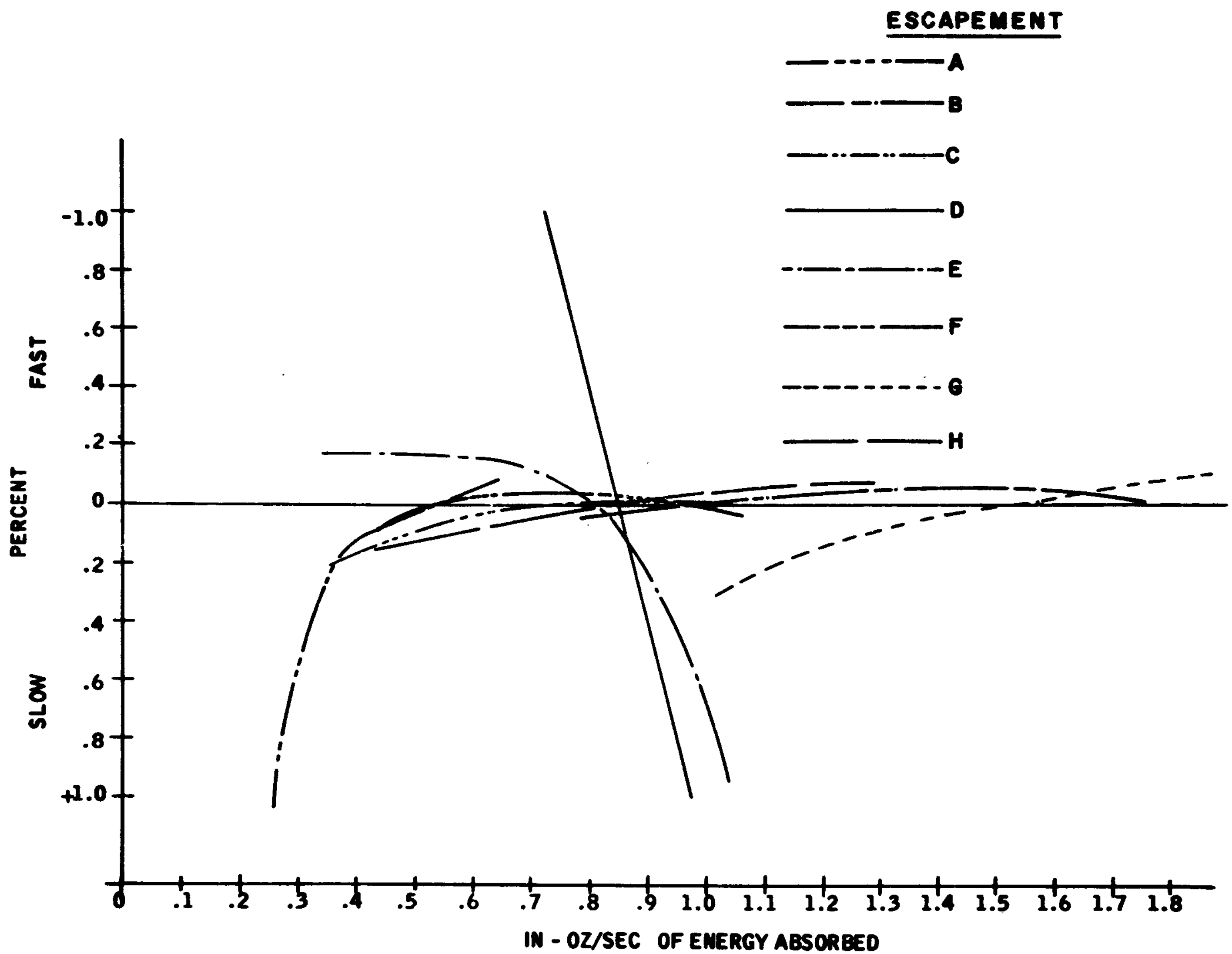

Figure 12. Escapement Tests

evident that, because of varied requirements depending on the system under consideration, several types of rate modules will be necessary. The same applies to the other modules. Eventually, a programmer may be chosen for a system by merely picking the suitable "off-the-shelf" modules to assemble the desired package.

RATE AND POWER MODULE SPECIFICATION

1. Description: The rate and power module shall consist of a mechanical escapement, a one-way clutch assembly (optional), a mechanical power supply and mounting provisions. The module must be driveable backwards, either because the escapement itself can start and run backwards, or because a one-way clutch is incorporated into the module such as to permit resetting of the power supply without necessarily backing up the escapement.

Design of the device shall be such that the unit is compatible with the other modular programmer components in both assembly and operation.

2. Configuration: The configuration of the device shall be cylindrical, 1.75" max. outside diameter and 5/8" long. The escapement drive shaft shall be 3/16" in diameter.

3. Design requirements:

3.1 Timing accuracy: The drive shaft rotation speed shall not vary more than 1.0% as the torque absorbed from the rate shaft by the mechanisms outside the rate and power module varies from 0.0 oz-in to 0.8 oz-in, and shall be repeatable within .05% desired, .1% required when a constant torque is absorbed.

3.2 Drive shaft rate: The drive shaft turning rate shall be 0.4 rps.

3.3 Drive torque: The rate and power module must be so overpowered that it can continuously deliver to the rate shaft (for absorption by the other programmer elements) 0.8 oz-in of torque without exceeding the inaccuracy allowances in 3.1 above.

3.4 Reset torque: The power supply must reset to its original condition, when the rate shaft is forcibly backed up to its original position, without absorbing more than 2.0 oz-in of torque from the rate shaft.

3.5 Clutch and Excapement Resolution: The total resolution loss during resetting due to backlash in the gear train, tooth spacing in the one-way clutch, and half-cycle period in the escapement, may not exceed .05 seconds of time.

3.6 The rate module will be used in a hermetically sealed device capable of meeting the operating requirements stated in paragraphs 3.1, 3.2, and 3.4 after a storage period of 10 years.

3.6 The rate module shall meet the requirements of paragraphs 3.1, 3.2 and 3.4(operational) while in an environment of 25 rps (optional) (spin axis at longitudinal center line of module) and 100 g axial acceleration acting along the module longitudinal center line.

4. <u>Environmental requirements</u>: The device shall be capable of meeting the requirements specified in the following tests when assembled in the modular programmer or fixture which simulates the programmer.

4.1 Operating temperatures: The module shall be capable of meeting the requirements of section 3 when tested at any stabilized temperature between the extremes of -65°F and +165°F.

4.2 **Jolt and Jumble Test:** The module shall be operable and comply with section 3 of Mil-Std-301 after being tested per Mil-Std-300 and Mil-Std-301.

4.3 **Five-foot Drop Test:** The module shall meet the requirements of Mil-Std-358.

4.4 **Transportation Vibration:** The module shall be capable of meeting the requirements of section 3 after being tested per Mil-Std-303.

4.5 **Operational Vibration:** The rate module shall be subjected to and operate during the following Vibration Test. Timing accuracy shall not vary more than ± 1%.

TIME (SECS.)	TYPE OF SIGNAL	RATIO OF TEST LEVEL TO CALIBRATION LEVEL	RMS G LEVEL
0-20	Noise Calibration A	1	Set Gain to give 2 RMS
20-30	None	0	0
30-31	Noise Calibration A	11	22
31-46	Noise Calibration A plus Sinusoidal Calibration B	4.25	8.5
	Noise Alone	3.75	7.5
	Sinusoidal Alone	2.00	4.0
46-61	Noise Calibration A plus Sinusoidal Calibration C	8.5	17.0
	Noise Alone	7.5	15.0
	Sinusoidal Alone	4.0	8.0
61-99	Noise Calibration A plus Sinusoidal Calibration D	4.25	8.5
	Noise Alone	3.75	7.5
	Sinusoidal Alone	2.00	4.0
99-100	Noise	11	22

(A) Band Limit (15 - 1500 cps) White Gaussian Noise

(B) Sine Wave swept from 800 - 1300 cps with a frequency change directly proportional to time. One full sweep shall be 15 seconds.

(C) Sine Wave swept from 1300 to 800 cps with a frequency change directly proportional to time. One full sweep shall be 15 seconds.

(D) Sine Wave swept from 15 to 1500 cps and back to 15 cps with a frequency change directly proportional to time. One full sweep shall be 38 seconds.

4.6 The rate module shall be subjected to three shocks in each direction of the three mutually perpendicular axes. (18 shocks). The shocks shall have an amplitude of 100 g's with a 11 ± milliseconds duration. Following the test, the rate module shall meet the requirements of paragraphs 3.1, 3.2 and 3.3 .

SUPPLEMENTARY INFORMATION

I. GENERAL

This supplement more fully describes some of the rate and power module characteristics needed to ensure compatibility with the rest of the Modular Programmer.

II. FUNCTIONAL REQUIREMENTS

1. Escapement Starter

At the instant of setback acceleration, the G-weight (in the initiation module below the rate and power module) drops .30 + .05 inches. This motion may be used by the rate module to operate a starter for the escapement, provided the forces transmitted into the setback weight by the starter never exceed .05 lbs.

Any starter location not interfering with the functioning of the initiation module may be used.

2. Rate Shaft Release

At the instant of setback acceleration, an interlock mechanism in the initiation module frees the rate shaft to turn clockwise, as viewed from above. If the escapement is reliably self-starting, this release of the rate shaft may be used as the start signal to the escapement.

3. Setback Forces

At the time the escapement is to start counting time, the entire device will experience an acceleration of 10 G or more forward. This acceleration is the direct cause of the setback weight motion which operates the above mentioned escapement starter and rate shaft interlock.

This setback acceleration may be used directly as the escapement start signal, provided no other operating advantages of the programmer are compromised, particularly as regards reset capabilities.

4. Rate Shaft Reset

Under some conditions (setback acceleration dropping off before committment time) the rate shaft will be mechanically blocked from further rotation and/or reset forcibly back to its starting position. During such resetting, the power supply must return to its original condition; and the escapement may be driven backwards or may be temporarily disconnected with a reliable unidirectional clutch.

In any case, the torque absorbed by the rate and power module from the rate shaft during resetting may not exceed 2.0 oz-in.

5. Torque Output

During running of the escapement, the rate and power module must be able to deliver to the rate shaft 0.7 oz-in minimum torque at any time without exceeding the allowable timing inaccuracy.

6. Rate Output

The rate and power module must drive the rate shaft at a constant speed of 0.40 revolutions per second.

The above rate shall not vary with the above 0.8 oz-in torque output variation by more than ± 1.0% and shall be repeatable within ± 0.2% if output torque is held constant.

APPENDIX II

REMOTE SETTING

The recent demonstration of the Mechanical Modular Programmer has made apparent the desirability of a remote setting feature capable of setting the programmer from the control panel of the weapon launcher or vehicle. A programmer having a remote setting capability would substantially enhance the weapons mobility by reducing the period of installation, programming, check-out, and weapon deployment.

Remote setting for the programmer could be made by making the counter wheels decade switches. The sealed drive would be eliminated and a stepping motor would be inclosed within the hermetic case. The stepping motor would be controlled from a remote master setter which consists of a digital counter combined with decade switches and electrically connected to the switches of the programmer. Figure 13 is an artist's sketch showing the remote setting concept.

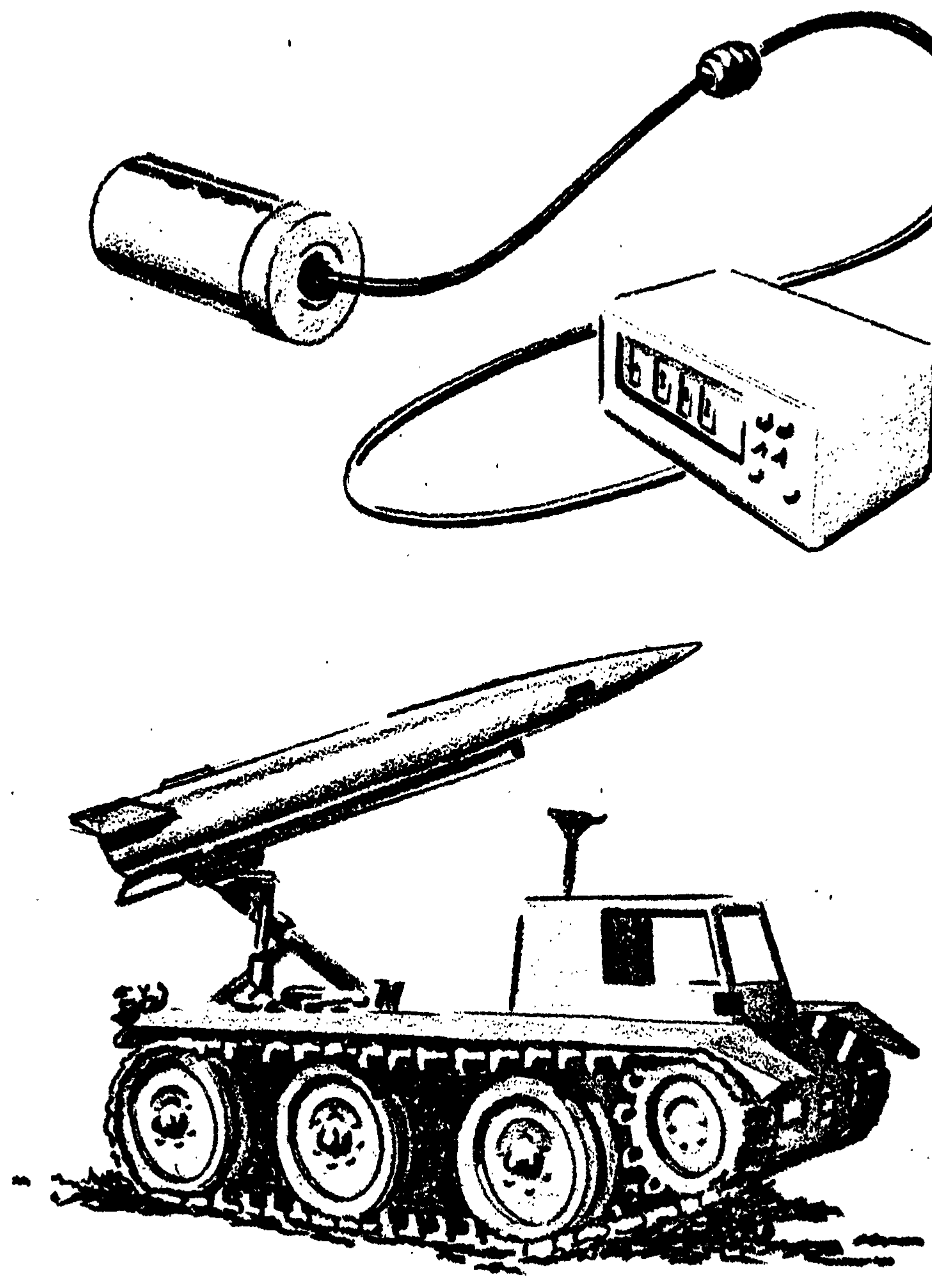

Figure 13

MODULAR PROGRAMMER REMOTE SETTING CONCEPT

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