This Report covers status up to
15 ~~April~~ Feb. 1958

DEVELOPMENT OF A SIGNAL ACTUATED DEVICE AND A TIME EVENT MARKER FOR A MINIATURIZED RECORDING SYSTEM

TABLE OF CONTENTS

DEVELOPMENT OF A SIGNAL ACTUATED DEVICE AND A TIME EVENT MARKER FOR A MINIATURIZED RECORDING SYSTEM

1.0 Introduction

1.1 This report covers the status of work on Project No. 74 to February 15, 1958.

1.2 All of our effort has been concentrated on TEM System "B". This system was described in Paragraph 3.0 in the report for work ending October 31, 1957.

2.0 Summary of Prototype Components, TEM

2.1 Negator Spring Drive to provide power for a watch used as the time base. This mechanical power source will be hand wound and will be used to power the watch only. This spring drive is identical to that used on a previous project.

2.2 The watch will have a once/minute contact to operate the calendar portion of the system by providing pulses to the units-disc calendar drive-solenoid.

2.3 Separate solenoid and ratchet systems will be provided for each of the digits discs, three in number. The first disc stores units information, while the second and third discs store 10's and 100's information, and 1000's and 10,000's information, respectively. In this calendar portion, the printed circuit discs are face down toward a printed circuit plate, on which are mounted the contact fingers which ride against the disc lower sides.

2.4 A TEM sweep bridge which reads out the coded calendar information stored in the three discs is also operated by a solenoid and ratchet system. Here, the movable portion is a bridge carrying the contact fingers over a commutator arrangement, the contact segments themselves being stationary and arranged circularly around the bridge. These segments are connected by printed circuit to their corresponding tie-in points with the calendar contact fingers.

2.5 A transistor multivibrator system is used to provide 10 pulses per second to the TEM sweep drive solenoid, upon reception of an external sweep command. This multivibrator is encapsulated and mounted on the TEM unit.

2.6 The necessary resistors and capacitors needed (see Section 4.1 and 4.2) for proper calendar solenoid operation are mounted both on the printed circuit plate and on the bottom plate of the assembly. Internal connections are made by stand-off terminals with feed through connectors.

2.7 External connections are made through an amphenol connector of a similar type to that used in a previous project. This connector will have a clamp to secure a mating plug and cable, since a cable system of connections between units is desired.

2.8 The watch movement used as a time base will have a mechanical hack arrangement for starting the time base, very similar to the arrangement used in a previous project.

3.0 Difficulties encountered which have delayed progress are:

3.1 An internal differential gear system was originally contemplated, as shown in the block diagram, Figure 2, report of August, 1957.

A reasonable investigation did not show any source for such small assemblies as would be necessary here. Differentials of various types have been used in other fields, such as radar servo systems, but the power involved is of a radically different order of magnitude.

In such cases, also, the primary consideration is close fit with no back lash, with less emphasis on the power required to overcome the friction of the sliding faces involved. Our experience has been mainly confined to straight gear trains always under compression, in which backlash is not a problem. After considerable study of a completed assembly, we concluded that we do not, at present, have the total facility for producing a satisfactory differential gear assembly.

3.1.1 A parallel development had been carried along using a magnet drive for each of the separate calendar discs in TEM as a safeguard against such insurmountable difficulties with the differential system. This latter system also presented difficulties, of course, in the solution of the various mechanical and electrical problems encountered. All of these problems seemed solvable with a reasonable amount of engineering expenditure, and at the time of writing, most have been solved, as present satisfactory testing of a nearly completed prototype attests. The latter method of drive, therefore, has been adopted.

3.2 Shafts used with the solenoid drive system are longer than in usual watch work, and in general, the power which must be delivered through them by ratchets to overcome inertia and contact finger friction on the printed circuit discs is considerably greater than the power needed by a watch. Consequently somewhat heavier staking for assembly of the ratchet to the shaft was necessary, but bending of the shafts during the staking operation with resultant wobble of the printed circuit discs mounted on the shaft ends proved to be a problem; a solution was found by enlarging the transverse shaft cross section and tempering the shaft.

3.3 The printed circuit coding discs are "outboard" mounted, so that each must be mounted on a portion of its ratchet shaft small enough to go through a bearing used to support the shaft. It is difficult to obtain true transverse mounting here due to this small shaft-end cross-section. This added to the problem of shaft wobble causing wobble of the printed circuit disc. Wobble of the printed circuit disc is extremely undesirable because it changes the contact pressures of the printed circuit contact fingers and also the point of contact of these fingers on the disc. This wobble, then reduces the alignment margin needed to absorb other uncontrollable variables in positioning.

Some difficulty was experienced by our supplier of printed circuit discs, so that the original lot of discs was unsatisfactory and had to be replaced. Since discs were received approximately two months after we had scheduled them, considerable delay was experienced in the development of good contacts from these discs; the problem of obtaining eleven consistent contacts running on paths .030 inches wide with 100 steps per revolution is not a simple one.

3.4 Considerable analysis of the problem of assembly of these contacts into proper relative positions maintaining high electrical conductance to the disc, has been made. Originally we had contemplated the use of adjustable contacts to allow individual contact tangential alignment after the contact system was in position. However, some study showed that the lengths of individual contacts could be controlled accurately enough to eliminate the need for the more complex adjustable contacts. Furthermore, it was felt that the introduction of a tangential adjustment would render more difficult simultaneous adjustment in height (which determines contact pressure) and in radius, (which determines position of contact from center of printed circuit disc).

3.4.1 To aid in contact adjustment, a transparent disc has been fabricated which is equipped with scribed lines defining the circular paths and relative angular positions of the ends of the contacts. This disc is first placed on the shaft to check the contact alignments before the printed circuit disc is mounted. Then, when the printed circuit disc has been assembled to its hub, the contacts should meet the disc in the proper positions. To check proper assembly of printed circuit disc and hub, the assembly is rotated on an optical comparator to determine the radial eccentricity, if any, of the disc relative to the printed circuit.

3.4.2 The final adjustment of the printed circuit disc to obtain precise angular alignment to the contacts is made with an electrical check as follows: A small brass block with two scribed lines on it, insulated on its lower side, is placed on the printed circuit in such a way that the scribed lines are level with and adjacent to a radial line scribed on the back of the printed circuit disc. The two scribed lines on the block correspond to one complete motion of the disc, a hundredth part of the circle. One mark on the block is aligned with the disc mark when an outer-most contact is just "making". The other mark, then, corresponds to the same contact just "breaking". The solenoid is now pulsed from the test input until one disc revolution is made. If disc adjustment is correct, the disc mark will stop half way between the block marks, since this indicates the disc contacts are stopping, after each pulse, with the contact finger ends midway across the contacts. If not, the three screws holding the disc are loosened, the disc is rotated slightly in the proper direction against the ratchet, which is held, and after the screws are

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retightened, the solenoid is pulsed to put the disc through one revolution, and a check is made to see that the disc mark falls half way between block marks. This procedure is repeated until precise alignment is obtained.

3.4.3 Some slight variations have been found in the printed circuit discs which were not expected and which are evidently due to machine-dividing errors in the original master disc made by the supplier, although the errors discovered could also have been due to poor photographic technique in producing the master.

3.5 The operation of the printed circuit with the solenoid type of operation introduced dynamic problems (see Section 3.1.1). These problems were (a) a means of returning the solenoid plunger to its rest position. (b) a means to prevent the plunger from rotating in the solenoid housing when the coil was energized. (c) a means to prevent the force of the solenoid from rotating the calendar disc and TEM sweep bridge more than 3.6 degrees and 24 degrees respectively; that is, a means to prevent overtravel of the driven system.

3.5.1 The solenoid was designed with a spring coiled loosely about the driving arm, which is actually an extension of the plunger. One end of the spring rested against the plunger, while the other end pressed against a slotted pin fastened upright to the solenoid mounting bracket and in line with the driving arm. The purpose of this spring was to return the plunger to its rest position.

The coil spring was designed to have a force of about 2 grams in its normal rest position and about 3 grams in its normal compressed position. This was calculated to be sufficient to return the plunger to rest regardless of orientation of the unit, since the plunger itself weighs about 0.8 grams.

The coil spring had a tendency to buckle in its middle when the solenoid was energized. As the spring buckled, it would seize the driving arm and cause a malfunction of the solenoid. Sometimes this malfunction showed up as a failure of the plunger to close fully and sometimes as a failure of the plunger to return to rest.

3.5.1.1 A new spring was designed to overcome this difficulty. This new spring, made of pre-tempered Elgiloy special alloy strip, is a single leaf spring and is fastened to the top of the solenoid mounting bracket by a single screw. An elongated hole is provided in the spring for pre-tension adjustment. From the mounting screw, the spring comes forward, is looped back and bent down to rest against the plunger nose. The spring is slotted in order to straddle the driving arm.

This spring was adjusted to give a force of 1.8 to 2.8 grams when the solenoid is in the de-energized position and with the plunger adjusted to a gap of .020". When the plunger is fully closed, the spring has a force of 6 to 8 grams. This force is not disturbing since the plunger can counteract a restoring force of 65 grams when closed fully by the energized coil.

This design proved very successful. There were no malfunctions in any tests that could be attributed to this design.

3.5.2 The action of the solenoid when energized occasionally imparted a slight twist or rotary motion to the plunger. The slotted pin mentioned in 3.5.1 also served as a guide to prevent this, but the rotary motion of the plunger caused the driving arm to rub on one side of the pin, in turn causing excessive friction which contributed to the malfunction outlined in 3.5.1.

3.5.2.1 This fault was corrected simply by putting a .018" diameter hole in the outer portion of the plunger working face and pressing .015" diameter brass pin into the back end of the solenoid housing so that it extended through the hole in the plunger face.

Results showed no malfunctions in any tests that could be attributed to this design.

3.5.3 Upon assembling the solenoid in the unit with the ratchet wheel, shaft, and calendar disc, it was found that the force of the solenoid would cause the calendar disc to travel inertially further than the required 3.6 degrees.

3.5.3.1 The problem here was to prevent this overtravel without increasing the closing-load on the solenoid as would be the case if, for example, a stronger detent spring were added.

The problem was solved by adding a stop pin as close to the ratchet wheel as possible and in such a position that the driving arm would be pressed between the pin and one tooth of the ratchet wheel, preventing any overtravel motion.

The result was a positive single step operation without overtravel of the calendar discs. Work is still being done, however, to minimize the inertial effects of the TEM sweep bridge and associated gear train.

4.0 Operation of calendar driving solenoids

4.1 These solenoids are pulsed through series capacitors when their respective circuits are closed. The capacitors are charged rapidly, thus limiting average operating currents to small values even though the circuits may remain closed for substantial times. Then, when the circuit is opened, the capacitor discharges through a high resistance connected across it, at a rate which insures a discharge of 5 time-constants by the time the circuit is reclosed for another solenoid pulse.

4.2 The units disc solenoid is operated through once/minute watch contracts, while the next two solenoids are operated through the printed circuit discs and corresponding contact fingers. In any case, the contact fingers do not carry current during "make" (due to inductive delay in build up), and carry only micro-ampere levels during "break" (due to capacitive charging), and so contact life is not shortened by any arcing affects.

4.3 Detailed analysis has been made of this current pulse operation, which is basically a series R-L-C circuit energized by DC voltage at t = o. The L and R are determined by the solenoid itself, and the value of C stems from"energy needed" requirements. Too large a capacitor, supplying excess energy, causes unnecessary battery drain and too small a capacitor will not yield enough energy under the current pulse to operate the solenoid. Also, if the nominal C is near or below the critical value, the change of energy input with a small change in capacitance becomes appreciable, and circuit oscillation may occur. The actual capacitance and resistance vary with temperature; in order to insure operation under all temperature conditions a value of C equal to 180% that of critical was selected, using capacitors with manufacturing tolerances of plus or minus 15%.

4.4 Necessity for change to solenoid drive from the original escapement type watch was brought about by the following considerations:

4.4.1 Assume that a contact disc is mounted on the escapement shaft of a watch. The normal mainspring must then be strengthened so that it must drive not only the watch, but also the printed circuit discs. This introduces both static and dynamic mechanics problems.

4.4.2 Consider for the moment only the comparatively static problem arising when the escapement stops against its banking pin in one position or the other. Here, in the normal operation of a watch, the pallet stone angle is such that its escapement is locked by the force of the gear train. When the balance wheel returns from its furtherest excursion and before it unlocks the escapement wheel, it first backs this wheel and the gear train up a small amount. Normally this action is readily accomplished, but if the mainspring pressure has been greatly increased (to overcome the added resistance of the contact disc springs), the force required to unlock it is also increased. However, when the pallet fork is over and locked against the escapement wheel tooth, there is no longer any friction drag from the printed circuit

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disc. Consequently the mainspring's total force (which might be several times that required to operate the escapement alone) is now locking up the pallet fork so that the work to be done by the balance wheel when it returns is much larger than would normally be the case. If it does unlock the pallet fork, however, so that the escapement wheel drives the balance wheel, the escapement wheel must immediately take up the friction load of the contacts on the printed circuit disc while it is delivering power to the balance wheel in such a manner that the balance wheel is not overbanked.

4.4.3 Because of the foregoing, the seriousness of which being previously overlooked, attention has been turned to a new drive system using solenoid and ratchet drive assemblies. This latter system has subsequently been incorporated in the prototype TEM unit.

4.5 Solenoid design considerations

4.5.1 Tests showed that the shaft of the first solenoid design was saturating at the ampere-turn levels necessary to provide sufficient mechanical output to overcome the inertia and static friction of the load. Furthermore, calculation indicated considerable energy was being lost at the top air gap of the solenoid, which is a non-working gap.

4.5.2 Solenoid plunger saturation at working ampere-turn levels became evident from (a) examination of plotted data, pull (in grams) vs. ampere turns applied, where the pull needed is obtained at the cost of greater and greater ampere-turn increments; and (b) measuring flux in the plunger by means of a pick up coil and comparing the corresponding calculated flux density with the B-H curves for the 4750 steel, which curves are supplied by the manufacturer.

It was desired to operate at incipient saturation, since above this point energy is being supplied at diminishing utilization (as outlined above) and below this point plunger shaft cross section becomes unnecessarily large, which, in turn, results in (a) unnecessary increase in solenoid volume, and (b) decrease in the coil constant, Gc, for the solenoid coil. A decrease in this coil figure of merit results in decreased overall efficiency.

In view of the above, a new solenoid was constructed of relay steel #5, having the same dimensions as the original solenoid of 4750 steel. Now at a flux density of fifteen kilogauss (the value needed to produce forces large enough to overcome the load), 4750 steel has a high magneto motive force per unit length (being highly saturated), whereas relay steel #5, for this same flux density, has a relatively low mmf gradient corresponding to incipient saturation. Tests of the new solenoid confirmed the above; operation was shifted to plunger incipient saturation. Therefore, relay steel #5 was adopted in lieu of 4750 steel, and the solenoid dimensions remained unaltered.

4.5.3 Regarding the top air gap; calculation indicated this gap to be 15% of the maximum solenoid gap. However, a reduction of the reluctance of this gap was complicated by several factors; reductions to the second power of any increase in plunger shaft cross section would be desirable from this viewpoint, but undesirable from other considerations, (see above). Therefore, a reduction to the first power of a dimension change was used. This could be effected either by increasing the axial dimension of gap face (thickening the housing and lengthening the shaft accordingly) or by decreasing the length of the gap itself. This latter was down to .0007" nominal already and any further decrease not only would entail machining complications, but would also enhance any tendency toward radial pull (seizure) present due to eccentricity of fit, since for a given eccentricity, the radial pull increases as the length of the gap decreases. In view of these considerations, the former method of decreasing top gap reluctance was tried. The solenoid housing thickness was increased 130%, with a corresponding decrease in top gap reluctance. This was verified during test of the new configuration by noting the pull-in force to be 15% higher than previously, for a given coil current.

4.5.4 This work is still in progress. Other solenoid design problems still under investigation are:

(a) Magnitude of electrical losses due to circulating current in brass coil bobbin.

(b) Reduction of radial pull at top air gap due to minute eccentricities in fit of plunger, bobbin and housing.

(c) Coil configuration and wire size agreement to produce ampere turns per volt ratio yielding operation at incipient saturation.

(d) Use of modified circuitry to prevent the heavy solenoid current pulses from passing through the power source.

(e) Development of higher-power solenoid as an alternate method of winding the time base, to allow elimination of the negator spring.

5.0 <u>Printed Circuit information</u>

5.1 The printed circuit used for TEM consists of an epoxy plate .030" thick with printed circuitry on both sides. Since this is mounted against a brass plate, the printed circuit must first be insulted by a spacer or shim. For this purpose, a .010" epoxy sheet has been cemented to the brass plate. The holes in this sheet for bringing through the upper ends of the ratchet shafts have been cut oversize to prevent any adhesive (which is used to bind the epoxy sheet to the brass plate) from being squeezed into the ratchet shaft bearings.

5.2 The posts for the contact fingers are fastened to the .030" thick epoxy printed circuit plate. The contact post consists of a headed cylinder with an internal thread in the smaller

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diameter. This post is a screw machine part in stock from a previous project, requiring a spacer to permit the screw (which is threaded into the bottom of this headed cylinder), to clamp the cylinder tightly to the printed circuit plate. The twin contact wires are staked into parallel slots in the head of this cylinder, which is on the top, or disc side, of the printed circuit. After adjustment of position (see Section 2.4), the wires are soldered to the machined part to insure high electrical conductivity and mechanical rigidity.

5.2.1 Most of the contact wires for the prototype are of special gold alloy designated [redacted] which, although yielding excellent contact conductance, has a slight tendency to wear against the disc. The units calendar disc, therefore, receiving ten times the wear of the next disc, has been fitted with .005" contact wires of hardened Paliney #7 alloy, (a harder substance than C-12), to reduce wear. This material also shows excellent contact conductance for like contact pressures, but because of its 20% higher co-efficient of elasticity, similar pressures (1 gram per wire) are obtained at smaller downward deflections of the printed circuit disc. This effect slightly increases the load on the drive solenoid for the same downward deflections of the printed circuit disc. However, tests show that sufficient solenoid force is available.

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5.3 First samples of this printed circuit plate show considerable bowing, convex upward, across the plate's width dimension. As this deviation is approximately .018", appropriate places have been found for additional screws on the layout to hold the printed circuit down solid against the lower plate. Because the printed circuitry on the bottom of the printed circuit plate projects about .002" out from the bottom face of the plate, all hold-down screws are equipped with .002" washers placed on the screws between the printed circuit plate and the epoxy spacing plate.

5.3.1 In future units, this will be accomplished by incorporating support pads directly to the bottom side of the printed circuit plate.

5.4 In the previously contemplated configuration, provision had been made for a viewing hole in the printed circuit plate so that the Balance Wheel of the watch could be observed. This introduced complications in construction of the printed circuit. In the present TEM unit, wherein the negator spring drives nothing but the watch (see Section 4.3) the watch is mounted in a drawer which is pushed into the unit. This is similar to the drawer-mounting used in a previous project in which various components were drawer mounted. In the present TEM unit, therefore, the watch is not only observable (from the bottom of the unit), but is also accessible from both top and bottom when the drawer is pulled out. The once/minute watch contacts are thus also readily accessible.

6.0 Selection of Power Supply, TEM

6.1 Careful attention must be paid to the selection of power supply for operation of the TEM prototype. A battery capable of handling

50 ma pulses of current with no more than 10% fall in terminal voltage during delivery of current, must be used.

6.1.1 Also, for the prototype only, a battery potential of nine volts open circuit should be used during actual unit operation. This should be reduced to six volts, however, when a solenoid is pulsed directly through its test input position, as otherwise the solenoid will be overpowered and damage to the coil and/or driving members may result.

6.2 In all subsequent TEM units, a battery open circuit voltage of six volts will suffice during actual operation since the latest solenoid design has an ampere-turns per volt ratio which brings operation down to the six volt point.

6.2.1 Unless specifically stated in a future report, the power supply needed for future units must still pass the peak currents outlined in Section 6.1 above.

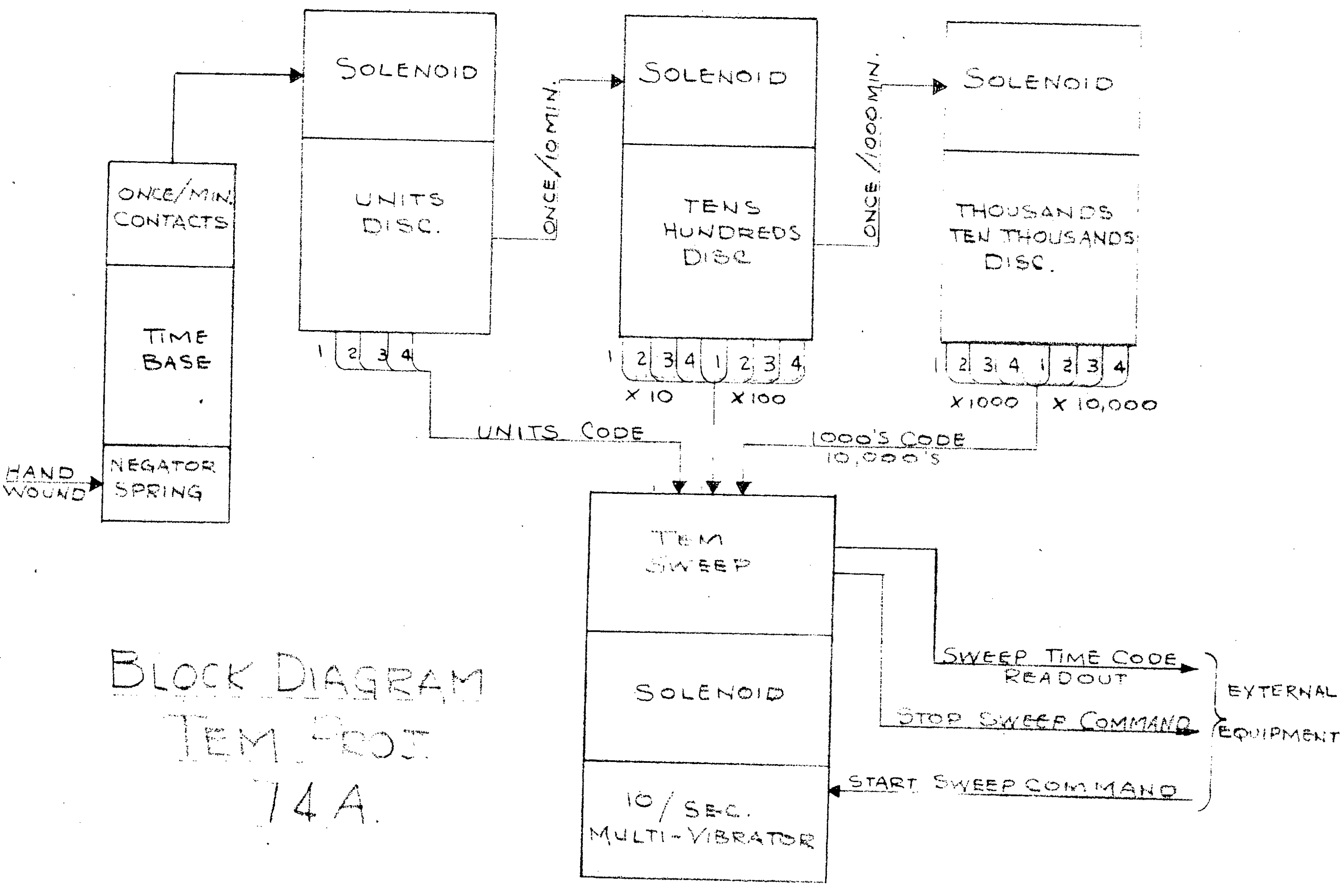
6.3 Detailed investigation of shelf life, ampere hours per unit volume, change of voltage with temperature, peak current capability, etc., of various types of miniature electromotive cells is presently in progress. This is being done with a view toward recommendation of the best type and size of cell compatable with the requirements of this project.

7.0 General status of S.A.D., Project 74B

7.1 The printed circuit plate has been ordered from a supplier and is being awaited.

7.2 All machined parts for this unit are completed.

7.3 The modified watch movement and hack mechanism for this unit are presently being fabricated.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UNITS DISC.
ONCE/10MIN.
SOLENOID
TENS HUNDREDS DISC
ONCE/1000MIN.
SOLENOID
THOUSANDS TEN THOUSANDS DISC.
ONCE/MIN. CONTACTS
TIME BASE
NEGATOR SPRING
HAND WOUND
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