Technical Memorandum

MASTER

THIS IS A *SANDIA CORPORATION* WORKING PAPER AND IS INTENDED PRIMARILY FOR INTERNAL DISTRIBUTION; THE IDEAS EXPRESSED HEREIN DO NOT NECESSARILY REFLECT THE OPINION OF THE CORPORATION.

~~THIS MEMORANDUM IS NOT TO BE REPRODUCED WITH-
OUT THE EXPRESS WRITTEN PERMISSION OF SANDIA
CORPORATION~~

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Technical Memorandum

~~THIS MEMORANDUM IS NOT TO BE RE-
PRODUCED WITHOUT THE EXPRESS
WRITTEN PERMISSION OF SANDIA COR-
PORATION.~~

(SCTM330-58(14))

NUCLEAR BATTERY POWERED TIMERS

MASTER

R. L. DesJardin - 1473-2

ABSTRACT

During the period from May 1957 to July 1958, four nuclear battery powered timers were fabricated and tested from two basic designs in the time ranges of one-second, three-second, and half-hour intervals. The timers were temperature-tested over a range of -65° to $+165^{\circ}$ F with accuracies over this temperature range from ± 10 percent to ± 15 percent. Each unit has a volume of 10 cubic inches, and the timer can be initiated either by an explosive squib or a pull-out wire. At the end of the timing interval, the timer has an output of 30,000 ergs. The cost of the program was \$24,000. From the results of this development program, it appears quite feasible to build operable nuclear battery powered timers on a production basis.

Work performed under AEC Contract AT-(29-1)-789

Case No. 780.11

September 19, 1958

473 001

DISTRIBUTION:

C. R. Carlson, 1261
A. A. Lieber, Jr., 1262
G. H. Mauldin, 1263
A. W. Fite, 1264
R. C. Reineke, 1451
H. E. Vaiden, 1452
E. I. Bruce, 1461
E. H. Copeland, 1471
A. J. Clark, Jr., 1472
R. P. Stromberg, 1473 (2)
K. L. Gillespie, 1474
L. Gutierrez, 8124
E. A. Aas, 8133
J. McMinn, 8221
M. G. Randle, 7221-2
R. K. Smeltzer, Central Record File, 7221-3
W. F. Cartens, 7223 (6)

RECEIVED
JAN 10 1964

TABLE OF CONTENTS

	Page
FOREWORD	4
Introduction	4
Circuits Investigation	4
Storage Circuit Operation	6
Timer Operations	6
Testing at Patterson-Moos	10
Conclusions	10
Further Development	11
List of References	12

LIST OF ILLUSTRATIONS

Fig. 1 -- Energy-storage unit	13
Fig. 2 -- CRC timers	14
Fig. 3 -- Triode timer	15
Fig. 4 -- Pulse-triggered timer	15
Fig. 5 -- Pulse-triggered timer with matched load	16
Fig. 6 -- Simplified pulse-triggered timer	17
Fig. 7 -- One-second timer circuit	18
Fig. 8 -- Half-hour timer circuit	19

NUCLEAR BATTERY POWERED TIMERS

FOREWORD

The following report covers R&D work done at Patterson-Moos Division of the Universal Winding Company during the period from May 1957 to July 1958. This R&D work was to prove the feasibility of nuclear battery powered timers applicable to Sandia Corporation needs.

Introduction

The nuclear battery, which is the power source for these timers, is a low-current, high-voltage, one-cell device with a shelf life of more than 10 years. The battery makes use of a radioactive, beta-emitting isotope to supply currents of the order of 10^{-10} amperes and voltages of the order of thousands of volts. The nuclear battery is essentially a constant current device and will maintain approximately the same current either shorted or at thousands of volts.

Circuits Investigation

Several timing circuits were investigated to determine if their characteristics would meet the requirements of 30,000 ergs output and ± 10 -percent accuracy. The circuits must have a power-supply section which is the energy maintained in a capacitor by a nuclear battery, the timing circuit, and some method of getting the energy out of the power supply and into the load after the timing cycle.

Figure 1 shows the power-supply section with the nuclear battery B, the regulating diode D_1 , regulating resistor R_1 , and the energy-storage capacitor C_1 . Because of the minute currents available from the nuclear battery, the storage capacitor must have an insulation resistance of the order of 10^{13} ohms over the temperature range of -65° to $+165^\circ\text{F}$. For example, if the battery had an output of 10^{-10} amperes and a regulating voltage of a thousand volts, then the capacitor would have to have a leakage resistance of at least 10^{13} ohms, ie, $\frac{1000 \text{ volts}}{10^{-10} \text{ amperes}} = 10^{13}$ ohms. This assumes no losses in the circuit. However, since we have losses in the diodes, potting compounds, and in the battery itself, the leakage resistance of the capacitor at 1000 volts must be higher than 10^{13} ohms. There is a possibility of operating the timer below 1000 volts.

The nuclear battery which was used is a Patterson-Moos product with a strontium 90 isotope as the beta emitter. The battery has an output of approximately 100 micromicroamperes per 30 millicuries of strontium 90. The highest-current nuclear battery made by Patterson-Moos is a 200-micromicroampere battery and uses 60 millicuries of strontium 90. The regulator diode, D_1 , is an ordnance-type gas tube similar in size and shape to the familiar NE series glow lamps. The diode was developed by the General Electric Company, contains an external radioactive strip for stabilization, and belongs to the XD series. The special feature of this tube is the ability to transfer its equivalent resistance from a very high value, above 10^{13} ohms, to a very low value, under 100 ohms, by increasing the applied potential only a few volts. An electrostatic shield is connected to the negative side of the circuit to improve the stability of the tube.

The storage capacitor uses either teflon or polystyrene as a dielectric. The volume resistivity of polystyrene and teflon remains above 10^{15} ohm-centimeters even at $+165^\circ\text{F}$. The regulating resistor, generally 10^8 ohms, is used to keep the diode from dumping all the energy in the storage capacitor when the regulating voltage has been reached. The resistance value of this resistor is not critical.

Storage Circuit Operation

The nuclear battery B_1 will charge the storage capacitor C_1 at the rate of approximately 5 volts per hour, depending on the size of the storage capacitor. If the regulating diode D_1 were not in the circuit, the battery would charge the capacitor to some damaging equilibrium voltage at, say, 5000 or 10,000 volts or perhaps cause it to break down completely. However, when the regulating voltage of the diode is reached, the diode breaks down and allows excess charge to be bled off.

Timer Operations

Two of the more basic circuits are shown in Fig. 2. These are simple but, unfortunately, are quite inefficient. In Circuit A of Fig. 2, with switch S_1 in the normal position, the nuclear battery maintains a charge on capacitors C_1 and C_2 . Upon closure of switch S_1 or at time T equals zero, capacitor C_2 decays through R_2 , thus increasing the voltage across the diode. When the voltage difference reaches the breakdown voltage of the diode, the diode breaks down and dumps some of the energy in C_1 to the load R_L , leaving a large amount of energy in C_2 . In Circuit B of Fig. 2, the nuclear battery maintains a charge from the energy-storage capacitor C_1 . At the closure of switch S_1 , C_1 decays through R_2 and builds a voltage on capacitor of C_2 . When this voltage reaches the breakdown voltage of diode D_2 , the diode dumps most of the energy in C_2 through the load R_L , leaving considerable charge in C_1 .

Reliable and accurate timing devices have been designed from the circuits of Fig. 2. They find most applications wherever efficiency is no criterion, and this occurs only at the low-energy-output levels below 5000 ergs. The desire to increase energy output of the nuclear timer has led to investigation of other circuits. The first of these was designed around a miniature cold-cathode gas triode (see Fig. 3). This tube and others like it were ultimately rejected for their objectionable properties, such as high grid leakage current, the grid voltage dropping to zero after firing, and poor repeatability. The triode circuit, however, did contain the essential features to yield a greater energy efficiency than obtainable from the CRC variety mentioned in Fig. 2. The ratio of C_1 to C_2 may be about 10, and this restricts the energy expended

from the timing action to less than 15 percent. Furthermore, the source of stored energy is connected directly to the load through the triode, to facilitate the proper expenditure of all the available energy. The circuit losses were confined to the tube, resulting in a system efficiency of about 50 percent. The triodes were abandoned, but the desired features of the circuit were retained.

The circuit of Fig. 4 evolved from another approach. It operates on a different but reliable principle. The relationship and the function of C_2 , R_2 , and D_2 are the same as for the triode circuit in Fig. 3, which limits the energy expended for timing to less than 15 percent. The diode D_3 has a breakdown potential about 50 volts greater than the regulating diode D_1 . D_4 is a miniature power silicone diode with a very low forward resistance and a very high inverse resistance. When switch S_1 is closed, C_1 discharges through R_2 and charges C_2 to breakdown voltage of D_2 . Diode D_2 then breaks down and dumps the energy in C_2 into transformer T_1 . The transformer inverts the polarity of the trigger signal supplied by C_2 and this appears across the high inverse resistance of D_4 . Polarity of this signal across D_4 is such that it will add to the voltage remaining on C_1 which is slightly less than at $T = 0$. The diode D_3 is exposed to the sum of the two voltages, which is much higher than the breakdown potential, and the tube fires. D_4 conducts the discharge current and delivers the energy to the load.

Most nuclear timers have been designed for operation with electric pulse initiators; the one- to three-ohm values are popular, but operating the circuit of Fig. 4 into loads of these values produces a very undesirable condition. Because of low resistance at the instant of firing, the peak of the transient current is so high that the diode is driven into the arc-discharge region of the tube characteristics. The diode losses under this condition are the greatest and limit the circuit efficiency to about 50 percent. Reducing the current will restrict the operation to the glow discharge region, where the tube losses will be held to a minimum. The desired result is achieved by coupling the low-resistance load to the circuit with a suitable transformer. The impedance transformation supplies the additional impedance to limit the current to the glow discharge region. The result is an increase in the circuit efficiency to about 70 percent. Some losses occur in the transformer, but these can be tolerated.

The circuit of Fig. 4 is not complete in one other respect. All GE diodes of the XD series have an ionization time of about 200 milliseconds when fired in total darkness. The transformers employed in these timers for inverting the trigger signal are a commercial type not ideally suited for this application. The pulse width and amplitude of the trigger signal have minimum values, and any additional reduction of either will result in a misfire. This problem has not been solved directly. It is possible to obtain reliable firing by inserting a pulse stretcher, consisting of a silicone diode D_5 and a shunt capacitor C_3 , across the secondary of the transformer. The completed circuit takes the form of Fig. 5. The capacitor C_3 is charged through the low forward resistance of diode D_5 to the indicated polarity. The potential is maintained for sufficient time to permit D_3 to ionize and discharge C_1 . The high inverse resistance of D_4 and D_5 supplies the necessary time delay.

Although the circuit in Fig. 5 serves the purpose, it has one objectionable feature--complexity. From Fig. 5, the circuit of Fig. 6 was developed. The functional relationships of all components except the transformer are identical to those in the circuit of Fig. 5. The actions of the two transformers in the preceding circuit, Fig. 5, have been combined. Capacitor C_2 again supplies the trigger signal and discharges through the lower half of the primary. An induced voltage appears across the other half of the primary with the correct polarity to add to the voltage remaining on C_1 . The sum of the two voltages is again very much greater than the breakdown of D_3 . The current of C_1 passes through the upper half of the primary and delivers the energy to the load R_1 . Efficiency of this circuit, 65 percent, is less than that of Fig. 5 because of the transformer arrangement.

We have a new problem here which is again related to the pulse width and amplitude. The impedance of the transformer when loaded with 1 to 3 ohms is very low. This impedance plays a vital role in forming the trigger pulse. Because of this low value, the dumping diode does not always ionize, and so the circuit operation is not reliable without reapplying the pulse stretcher. The solution may be found only by evaluating the proper constants for the transformer. Several commercial transformers were tried, to possibly eliminate the pulse stretchers in the circuit. All circuits, however, still employ the pulse stretcher, which assures reliable operation.

Since the program was to determine if the nuclear battery timer was feasible for commercial production (and because we did not want to spend more

money at the time with PM to develop a new transformer), the commercial transformers and pulse-stretching circuit had to be retained.

The complete circuit of Fig. 6 appears in Fig. 7 and is preferred for short time intervals from fractions of a second to 2.5 minutes. Figure 7 includes the nuclear battery B, regulating branch D_1 , R_1 , and the pulse-stretcher network C_3 , D_4 . The necessary switching functions have also been included. The switch S_1 is shown in the normal or unarmed position. The load will be connected to terminals A and B of the connector J_1 , which are short-circuited to ground and disconnected from the transformer for the unarmed condition by contacts 4 and 6 of switch S_1 . Capacitor C_2 , which supplies the trigger pulse during operation, is also short-circuited and grounded in the normal condition. Terminal C of J_1 is grounded when the switch is operated. This terminal may be used for starting other electrical timers or for checking the timer accuracy of this circuit. Connector J_2 is for rapidly charging the storage capacitor by external means during repeated testing. Since we have approximately the same problems with the long-time timer as the short-time timer, Fig. 8 is considered to be one of the most efficient circuits for the half-hour timer.

The circuit used for long time intervals, 2.5 minutes to several hours or days, is shown in Fig. 8. The time interval is determined by the time it takes the nuclear battery B to charge the capacitor C_2 to the breakdown voltage of diode D_2 . The remaining circuit operation is the same as in Fig. 7.

From the circuits of Figs. 7 and 8, one 1-second timer, one 3-second timer, and two half-hour timers were assembled, encapsulated, and tested at room ambient at $+165^\circ$ and -65°F . All of the units performed properly at Patterson-Moos and were shipped to Sandia Corporation.

Upon receipt at Sandia Corporation, the four timers were tested at room temperature, $+165^\circ$ and -65°F . The 1-second timer and one half-hour timer appeared satisfactory, being approximately ± 10 to ± 15 percent accurate over the temperature range. However, the 3-second timer would not work at all, and the other half-hour timer was very erratic after several operations at high temperature. These two timers were returned to Patterson-Moos for an autopsy. Upon analyzing the timers, Patterson-Moos found that the switch in the 3-second timer has been assembled without any glue on a backing nut and the nut had come unscrewed, allowing malfunction of the switch. The potting compound was then drilled away and the switch was repaired. It is presently in good

working condition. The half-hour timer was found to have a defective transformer; it is unrepairable because the transformer is inaccessible in the potting compound.

Testing at Patterson-Moos

On the 1-second timer, approximately 67 tests were taken after encapsulation of the timer; the tests revealed an over-all accuracy of +11 percent and -2 percent over the temperature range of -65° to $+165^{\circ}$ F. The output energy of the 1-second timer was approximately 47,500 ergs, and no failures were encountered. On the 3-second timer, 123 timing runs were made at Patterson-Moos with the following results: The time was 3 seconds +12 percent -0 percent. The output energy at room temperature was 40,000 ergs. No failures were encountered in the 123 timing tests. In 28 timing runs of the half-hour timer after encapsulation, the accuracy was +30 percent -0 percent. The output energy was approximately 47,000 ergs. No failures occurred during the 28 timing runs. On the second half-hour timer, 11 timing tests were run after encapsulation; the accuracy ranged from +11 percent to -3 percent. The testing at Sandia Corporation generally agreed with the testing at Patterson-Moos except for failure of the 3-second timer and the half-hour timer as previously noted. For more detailed information on these timers, see Reference 1.

Conclusions

The results of this nuclear battery timer contract were "satisfactory," and it appears that nuclear battery powered timers will be feasible components. Although the timer is presently very large (10 cubic inches), no problem is expected in miniaturizing it to about 5 cubic inches, in view of the present inefficient use of space in the timer. I recommend that further development work be done to decrease the size, increase the energy output, and increase the accuracy to ± 1 percent.

Further Development

The present 1-second and half-hour timer contract (PO 14-5804) has been extended to include development of a high-energy, 2.5-minute, fixed-interval timer with a 250,000-erg output, a smaller volume, and an increase of accuracy to about ± 3 percent. Patterson-Moos is also working on a variable timer with 20 intervals between 10 and 70 seconds. In addition to this work at Patterson-Moos, a slightly different type of nuclear battery timer is being developed by Division 1473. This timer may have either a low-energy or high-energy output as required, and it is hoped that the timer will have an accuracy of ± 1 percent to ± 2 percent over the temperature range. The present Division 1473 nuclear battery timer program and external development work at Patterson-Moos are scheduled to run until about March 1959 and will be reported on in another technical memorandum.

LIST OF REFERENCES

1. Final Summary Report on Contracts 14-5804 and 14-5196, Patterson-Moos, Division of Universal Winding Company, Inc., 90-28 Van Wyck Expressway, Jamaica 18, New York, May 28, 1958.
2. Monthly Progress Report No. 1, Phase II, on Contracts 14-5804 and 14-5196, Patterson-Moos, Division of Universal Winding Company, Inc., 90-28 Van Wyck Expressway, Jamaica 18, New York, April 15, 1957.
3. Phase I Summary, 14-5804, Patterson-Moos, Division of Universal Winding Company, Inc., 90-28 Van Wyck Expressway, Jamaica 18, New York, July 12, 1957.
4. P.O. 14-5804.
5. P.O. 14-5196.

Fig. 1 -- Energy-storage unit

(A)

(B)

Fig. 2 -- CRC timers

Fig. 3 -- Triode timer

Fig. 4 -- Pulse-triggered timer

Fig. 5 -- Pulse-triggered timer with matched load

Fig. 6 -- Simplified pulse-triggered timer

Fig. 7 -- One-second timer circuit

Fig. 8 -- Half-hour timer circuit