Journal of Hazardous Materials, 4 (1980) 89—94

A DIGITAL ELECTRONIC THERMAL INTEGRATOR FOR MONITORING CHARGE AGEING

D. Kilpin and M.J. Mildren*

Department of Defence, Weapons Systems Research Laboratory, Defence Research Centre Salisbury, South Australia (* Advanced Engineering Laboratory, DRCS)

ABSTRACT

An instrument for monitoring rocket motor ageing is described. The unit measures temperatures in a magazine and produces an electrical output proportional to the rate of deterioration of the charge. This signal is integrated and the accumulated data stored in a memory which can be interrogated by an external readout unit to yield an "effective age" of the charge. The low cost long life instrument is accurate and versatile and offers substantial labour savings over present methods.

INTRODUCTION

During the storage of a rocket propellant charge for long periods of time chemical reactions and physical changes occur which result in the deterioration of the charge until ultimately safety or performance requirements are no longer met. Deterioration occurs more rapidly at higher than at lower temperatures so a temperature penalty system is often applied to a store which is subjected to a varying thermal environment. The penalty factor employed is derived from service life assessment studies and in effect expresses the activation energy of the most crucial degradation process. The factor is used in conjunction with a temperature history of the store to calculate equivalent life at 20°C which is compared with the nominated expiry life at 20°C to determine the status of the store. Since continuous records of actual propellant temperatures are rarely available for this purpose, approximate calculations are performed, usually based on daily maxima. A more accurate record would be obtained by using a small, self contained "thermal integrator". The thermal integrator should have a maintenance free lifetime comparable to that of the store, and a temperature accuracy of about 0.2°C to yield age accuracies of better than 2%.

DESIGN AND OPERATION OF THE UNIT

This thermal integrator would need to monitor the temperature continuously to assess the rate of deterioration to acçumulate the rate-time integral and, thereby, to indicate the accrued extent of deterioration. Such a device could utilize chemical reactions but electronic and/or optical instrumentation would be required to measure accurately the extent of reaction or "effective age". Purely electronic systems were investigated as a preferred alternative since they also offered flexibility in selecting and altering the activation energies of the deterioration processes. For design purposes it has been assumed that the rate controlling step in the deterioration is a first order process with an activation energy of 16 kilocalories per mole and the application is a store with a nominated expiry life of 5 years at 20^{o}C. Other activation energies and/or reaction rates could be used, but higher order, concentration dependent reactions are not considered in this paper.

Essentially the unit consists of four sections which are the temperature sensor, function generator, age integrator, and a power-control and timing centre. Power is conserved by switching on the first two sections at each measurement for only the minimum time necessary for accurate readings. Battery drain, although continuous for the crystal oscillator, programmable timer and volatile accumulator, is only about 50 μA so that battery lifetimes of 5 years should be achieved with modest sized batteries. A block diagram of the system is shown in Figure 1, which also shows an external readout unit for displaying the accumulator contents and the battery voltages. A reading of the "effective age" stored in the accumulator of each thermal integrator unit can be taken with a single readout/display unit at convenient intervals, e.g. weekly or monthly. The total age of a store can be determined by using a thermal integrator attached to it, or more economically by totalling the thermal integrator "ages" relevant to the calendar periods spent in each magazine.

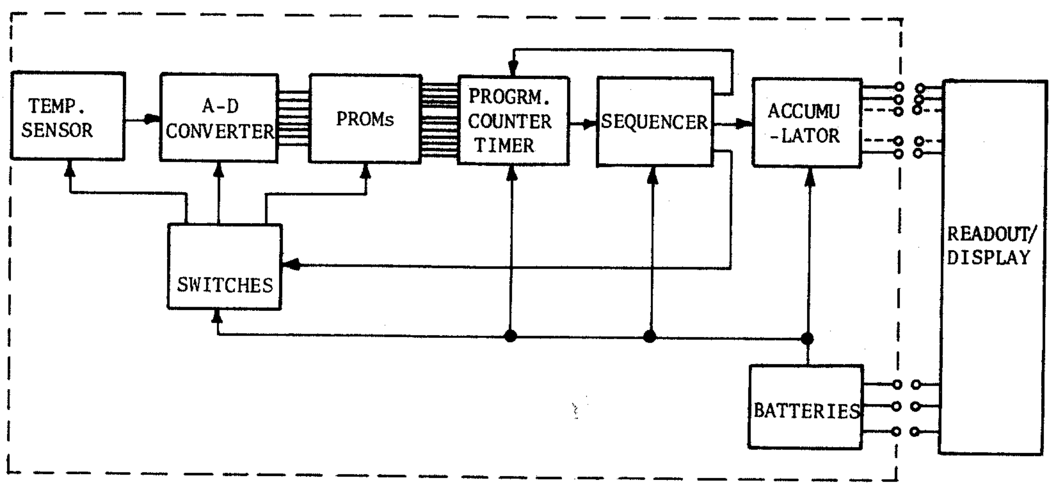

Fig. 1. Block diagram, thermal integrator

Isothermal temperature testing of a prototype unit is now being carried out. Temperature cycling and vibration tests will soon be undertaken and will then be followed by distribution of several prototypes for long life testing under magazine conditions.

Future development will concentrate on the "age" accumulator and improvement of component lifetimes, especially of batteries, although current drain reductions would also be desirable to decrease the number of batteries required and thereby the total bulk of the unit. The first prototype unit uses a volatile 16 stage accumulator from which all stored data is lost when power is unavailable. Subsequent models will probably incorporate non-volatile memories and perhaps only 10 or 8 binary bits of resolution.

SERVICE USE

As a unit for service use the thermal integrator will measure about 15 x 15 x 10 cm and weigh about 4 kg including batteries and case. The compact size and low thermal mass of the unit will permit it to be secured at an appropriate position in a magazine to measure temperatures typical of those experienced by the stores. The lightweight unit may be removed easily from the magazine to an electronic readout or printout device for the calendar time/effective age log of that magazine.

The cost of this instrument is expected to be about the same as the recording thermograph which it will replace. It offers savings in chart costs and maintenance and a considerable reduction in time expended on determining service life. With a thermograph, the chart must be removed (usually at weekly intervals) and the daily maximum and minimum temperatures transcribed from it to log books for later calculation of temperature penalties. Laborious manual processing of these records, and the errors arising therefrom, will be replaced by a direct accurate reading from a thermal integrator. All that is required with a thermal integrator is interrogation with a readout unit to display the accumulated life of stores accompanying the unit. Such interrogation would occur at regular intervals and whenever stores are transferred.

Although one activation energy for the deterioration process has been considered here, different stores may have appreciably different factors of temperature dependence. These factors are readily incorporated in an instrument by programming a different temperature function in the PROMs for stores of one kind. However, when stores of several types (of activation energies of ageing) are held in one magazine, only two thermal integrators of different activation energies will be required. "Effective ages" for other activation energies can be readily determined by interpolation or extrapolation from that pair of results.

CONCLUSION

The thermal integrator described here will provide a convenient method of measuring the "effective age" of a store. It is readily suited to a wide variety of stores where the temperature dependences of the ageing processes are known. New knowledge of deterioration rates of the stores will require a change of the temperature-rate function stored in the memory. It may also be necessary to introduce a second variable, such as the concentration of a diffusing or deteriorating reactant which varies with time, temperature or extent of reaction. Such sophistication can be readily incorporated when the parameters controlling the ageing process are better understood. The present device, under typical temperature conditions of storage, should enable the "age" of a particular store to be determined to an accuracy of about 2% and thus provide the maximum utilization of expensive stores.

APPENDIX

DETAILS OF THE THERMAL INTEGRATOR

The electronic system uses components that were chosen to work from power rails as low as 5 V, so that sufficient voltage is provided by only four mercury cells (5.4 V). In the variable time system of integration used a constant number (a "1", equivalent to about 40 minutes ageing at $20^{o}C$) is added to a store at different time intervals determined by the measured temperature and stored temperature function.

The temperature sensor is the LX 5600 (National Semiconductor) integrated circuit with a current drain of approximately 1 mA. Its output is linear at 10 $mV/^{o}K$ but it contains an operational amplifier which can provide gain and offset for scaling purposes. While A-D converters usually require $\pm$ 12 V power rails, the AD 7570 is a CMOS integrated circuit capable of using + 5 V only, and requiring a comparator amplifier (LM 311) which uses $\pm$ 5 V, with the combination drawing about 5 mA current.

Output from the 8 bit A-D converter addresses the Programmable Read Only Memory (PROM) in which the temperature-rate function is stored. These 8 bits give 256 addresses, so 250 function values at $1/5^{o}C$ intervals are stored for the 0 to $50^{o}C$ range. PROM outputs are used to preset a counter which counts down to zero to produce the variable time interval which is derived from the ageing rate in the following way :

Time interval i.e. counter preset P = constant/k

where k = ageing rate = $6.4542 \times 10^{12}\ e^{-16000/1.987(T + 273)}$ T in ^{o}C

By setting the constant at 3995 gives $P = 6.1975 \times 10^{-10}\ e^{8052/(T + 273)}$

Then at $0^{o}C$ P = 3995 (Binary 1111, 1001, 1011)

and at $50^{o}C$ P = 42 (Binary 0000, 0010, 1010)

Values outside the working range are set arbitrarily as shown in Figure 2 at 4095 below 0^oC and at 31 above 50^oC. Note that at 50^oC the programmed value is 42 while at 49.4^oC it is 44 showing the 12 bit output gives resolution of 0.3^oC at the high temperature end. PROMs used are Intel 3621 which are 256 x 4 bit (3 required) and can operate on 5 V drawing 150 mA each.

The programmable counter uses a crystal oscillator as the main clock with a divider producing 0.22 Hz, so that at 50^oC an interval of 3.18 minutes results (0.22 Hz ÷ 42) while at 0^oC the interval is 5 hours (0.22 Hz ÷ 3995).

The sequencer is a CMOS circuit which detects the zero count of the counter and produces pulses to (1) switch on the temperature sensor and A-D converter, (2) after the temperature sensor has settled, start the converter, (3) after conversion is complete, switch on PROMs, (4) load the counter and switch off PROMs, and (5) switch off temperature sensor and A-D converter, and then add 1 to accumulator. The accumulator is a simple 16 stage counter which at 50^oC would total 2^{16} intervals of 3.18 minutes (totalling 0.389 years) or at 0^oC, 2^{16} intervals of 5 hours (totalling 37.4 years).

Battery drain is continuous for the programmable counter and the accumulator which draw approximately 50 μA. PROMs which draw most of the current, only do so during measurement (which can be less than one millisecond). The temperature

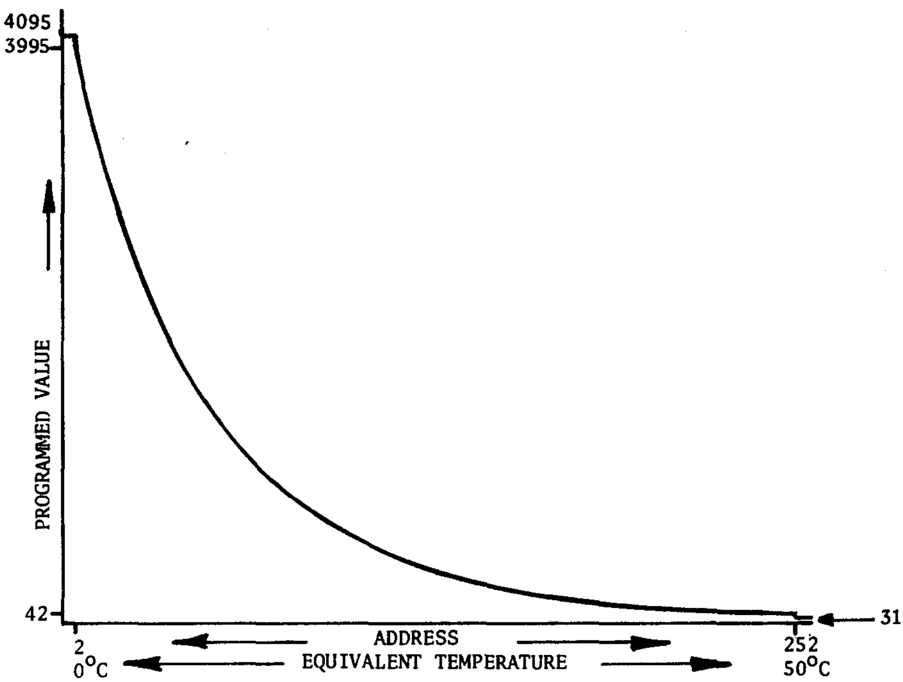

Fig. 2. Temperature function stored in PROMs

sensor has the longest settling time of the components after switch on, but even that is only 250 μsec. For normal conditions the total current drain is about 0.5 A for 0.5 msec every 20 minutes to give an average current of 0.25 μA which is negligible compared with the counter, accumulator and leakage currents. A generous safety margin of current capacity would therefore be provided by two parallel sets of RM42R batteries.