MAGNETIC MEMORY TECHNIQUES FOR HIGH ACCELERATIONS

J. C. McALEXANDER
Bell Telephone Laboratories
Allentown, Pa.

S. C. COOK
Sandia Corporation
Albuquerque, New Mexico

Summary  A system to obtain and record impact data at accelerations of 3000 g’s has been designed around a 1024 word, 12 bits per word, piggyback twistor memory. Memory construction and potting techniques were developed to minimize the effect of large acceleration forces. The memory and system tests prove that the memory can withstand shock signatures beyond its original design requirements.

Introduction  In March, 1964, Sandia Corporation, Albuquerque, New Mexico, in conjunction with Bell Telephone Laboratories (BTL), Allentown, Pennsylvania, undertook to design and build an onboard monitoring and recording system for application at high accelerations. This system was to be used to monitor the acceleration of vehicles when it was not possible to hardwire or transmit the data, such as the impact of certain rockets, bombs, or artillery projectiles. After impact, the system would be recovered and interrogated.

Sandia requested BTL to design a 1024 word, 12 bits per word, piggyback twistor (PBT) memory module. The basic operation of the PBT memory module would be incorporated into a store with its associated drive circuitry by Sandia. Dynatronics, Incorporated, Orlando, Florida, would design an analog to digital converter, to Sandia specifications, for this application. This system was to monitor and record average shock signatures of 250 g’s for a duration of 200 milliseconds, the peak shock to be 3000 g’s. The size of the overall system was to be a maximum of 5 inches in diameter and 20 inches long. Of this overall length, the memory module was to occupy no more than 7 inches, the analog to digital converter 5 inches, and the power and drive circuitry 8

---

1 This work was supported by the United States Atomic Energy Commission.

inches. At the beginning of the initial proposal, it was hoped that future systems could be reduced to a maximum of 12 to 14 inches in length. At the time of this writing, an additional system has been built to the latter dimensions, but no tests have been conducted on this smaller unit.

**Recording System**  The basic recording system consists of two piezo-resistive strain gage accelerometers, appropriate dc amplifiers, a dual channel analog to digital converter, a PBT store, and associated drive circuitry, as shown in Figure 1. The two accelerometers with the dc amplifiers drive the dual channel analog to digital converter which controls the store through appropriate drive circuitry. The drive circuitry is turned on at the time of impact by the use of a piezoelectric crystal to sense the acceleration.

The analog to digital converter is a parallel output device and both six-bit words are fed to the drive circuitry as a single word. Since the PBT memory is a parallel or word organized memory, there is no need for sync words to reference the data. The data stored in each memory group (word) is the amplitude of the acceleration since memory groups or words are sequentially addressed, the time data of the shock wave is obtained from the memory cell location. In this system, the time between sequential groups, which is adjustable, has been set at 200 microseconds.

**Memory Construction**  A laminated twistor cable, multiple laminated solenoids, and a number of ferrite cores form the basis for a PBT memory module, as shown in Figure 2. To form these parts into a shock resistant unit, the solenoids are bonded to the twistor cable, and the ferrite cores are positioned by a suitable support and bonded directly to the twistor solenoid cable subassembly. By folding this assembled cable into a modular subassembly, as shown in Figure 3, and vacuum molding this unit with a suitable encapsulant, the module becomes a semirigid, compact unit.

To protect the brittle ferrite cores from large hydrostatic pressures, it was originally thought that the cores should be isolated from and mounted independent of other mechanical parts of the module. This compression isolation was accomplished by molding the cores within oversized holes in a thin phenolic support, as shown in Figure 4. Subsequent shock tests indicated that the ferrite cores could be encapsulated directly in the potting material, as shown in Figure 5. The access drive windings were wound directly on the cores prior to the molding operation. The laminated twistor cable is also shown with the molded core stick.

The first step of assembling a twistor plane is shown in Figure 6. Here the laminated solenoid cable is bonded directly to the twistor cable using a suitable transfer adhesive. The next step, as shown in Figure 7, is to bond the other side of the solenoid cable to the twistor cable. Then the core stick is bonded to this twistor-solenoid subassembly and the shuttle cores are placed in the appropriate holes in the core stick, as shown in Figures 8
and 9. The last step of the twistor plane construction is the bonding of the permalloy shields to each side of the plane, as shown in Figure 10. The planes are then folded and the modular assembly vacuum molded to form a semirigid, compact unit similar to the one shown in Figure 3. Finally the additional access drive windings and the bias windings are incorporated into the module. The circuitry to incorporate this module into a store is placed around the module, as shown in Figure 11.

Shock Isolation To adequately shock mount (isolate) a memory or a recording system to withstand forces from large accelerations, considerations as to the encapsulating material were as follows:

1. The density of the potting material when cured and the resulting internal hydrostatic pressures.
2. The viscosity of the encapsulant during pouring and the “wetting” qualities of the poured liquid.
3. The reactions of a long, slender, resilient tube to large impact forces.

Since the components of an encapsulated system are usually more dense than the potting material, during accelerations the components tend to “fall through” the potting material. This problem could be minimized by using as dense an encapsulating material as possible. The hydrostatic pressures could be reduced by using a more rigid material, but most of these materials effect large hydrostatic pressures as a result of the curing process. Although these resulting isostatic forces cannot destroy solid objects, characteristics such as the B-H loop of a ferrite core can be drastically changed. This problem could be minimized by using a less dense encapsulant such as foam or microballoons, but this would increase the acceleration between the enclosed components and the potting material. The obvious solution is to use an extremely dense encapsulating material which exhibits minimum internal hydrostatic forces during the curing process.

With reference to item two above, encapsulants should be of such a consistency so as to readily flow throughout the entire mold during pouring and therefore eliminate voids in the molded structure. Also, this liquid should have good “wetting” qualities and readily adhere to all of the components within the molded structure.

After testing several different types of epoxies, epoxy with polysulfide rubber modifiers and other materials, Adiprene L-100 polyurethane most nearly met the above requirements. During pouring, Adiprene L-100 is a low-viscosity liquid with good wetting qualities and cures to a dense resilient material with low internal stresses.

When a resilient cylindrical object is compressed along its axis, the object will tend to fracture around the circumference of the cylinder from internally induced stresses.
Therefore to alleviate this problem and to complete the recording system, the memory with its associated circuitry was wired and placed in a 5" diameter metal tube. The tube was then filled with Adiprene L-100 polyurethane, and cured under vacuum conditions.

**Memory Evaluation** In order to “prove in” the proposed modular design, a two-plane memory was constructed by BTL, electrically programmed, and given to Sandia for their evaluation. This memory was subjected to impact accelerations in the range of 3000 g1s, retrieved, and returned to BTL. Inspection showed the module to be in excellent mechanical condition and electrical tests indicated that the module would retain stored data under high shock conditions. Having tentatively shown that the proposed module would withstand large impact forces, the next step was to test the associated equipment in conjunction with the memory. Therefore, a two-plane memory with drive windings and access diodes was constructed and sent to Sandia for further tests. This memory was air gun tested with short duration shock pulses of 20,000 g1s with information recorded before and read after shock tests. Indications were that the memory would survive environments in excess of 20,000 g’s. The first complete memory (1024 words) was tested as part of an operating system to impact levels in excess of 3000 g’s. During these impact tests, environmental data was sensed and stored in the memory. The information obtained correlated with values predicted by extrapolation from other means of monitoring large accelerations.

**Conclusions** The design of a PBT memory to record high impact signatures has been discussed. The desired shock dampening was obtained by suspending piece parts and subassemblies in a dense polyurethane. Then, by externally containing this resilient mass, it became relatively incompressible. The two-plane memory tests at 20,000 g’s and other supporting tests indicate that a PBT memory could be used for more stringent applications than previously considered.
FIGURE 1. SYSTEM BLOCK DIAGRAM

FIGURE 2. PIGGYBACK TWISTOR MEMORY SUBASSEMBLY
FIGURE 3. PIGGYBACK TWISTOR MEMORY ASSEMBLY

FIGURE 4. ENCAPCAPPED CORES
FIGURE 5. CORE STICK MOLDED OF ADIPRENE L-100 AND THE LAMINATED TWISTOR CABLE

FIGURE 6. THE MULTIPLE LAMINATED SOLENOID BONDED TO THE LAMINATED TWISTOR CABLE ON ONE SIDE
FIGURE 7. THE MULTIPLE LAMINATED SOLENOID BONDED TO THE LAMINATED TWISTOR CABLE ON BOTH SIDES

FIGURE 8. THE CORE STICK BONDED IN PLACE AND THE SHUTTLE CORES INSTALLED IN THE PROPER HOLES
FIGURE 9. PLANE CONSTRUCTION COMPLETED BY WELDING THE SOLENOIDS TO A GROUND STRIP

FIGURE 10. THE COMPLETED PLANE WITH THE PERMALLOY SHIELDS INSTALLED
Figure 11. The Completed Memory Module with Store Circuitry
The basic element of the Piggyback Twistor (PBT) Memory is a copper wire wrapped with two magnetic materials. These two materials have dissimilar B-H loops. Their composite loop permits four stable flux levels, one at each intersection of the loop with the vertical \( (H = 0) \) axis.

When a short section of the hard magnetic tape is switched within a longer section of demagnetized tape, a demagnetizing field is created. The coercive force of the soft tape \( (H_c) \) soft is low enough to permit this demagnetizing field to switch it. The composite loop now becomes a two stable state loop.

The Memory Bit consists of the intersection of two PBT wires and a word solenoid driven by a biased core switch. The components of the wire and solenoid fields produce a resultant helical field that tends to switch the tapes.
In order to write a "ONE" at a particular bit location, a wire current is circulated in the wire pair and the access core is switched. The resultant field drives the wires to opposite sides of their B-H loops, as long as:

\[ H_{\text{sol}} + H_{\text{wire}} \geq H_c + H_{\text{demag}} \]

and

\[ H_{\text{sol}} - H_{\text{wire}} \leq H_c - H_{\text{demag}} \]

To prevent disturbing other locations in the same wire pair, it is required that:

\[ H_{\text{wire}} \leq H_c - H_{\text{demag}} \]

To read the written information, the access core is again pulsed but no wire current is used. The solenoid read field must be such that:

\[(H_c)_{\text{soft}} + H_{\text{demag}} \leq H_{\text{read}} \leq H_c - H_{\text{demag}}\]

A voltage is induced in each wire. The total output voltage \((V_t)\) at the terminals of the wire pair is the difference between the individual wire voltages.

In writing a "ZERO", the wire current is reversed, reversing the voltage outputs.