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Computer-aided Testing and Fabrication of Magnetic Tape Heads

Abstract: A data collection and analysis system has been developed to control magnetic tape head testing and provide data analysis for manufacturing process control. Data collection is achieved by a system of test terminals controlled by an IBM 1130 computer, which is a satellite of an IBM System/360 Model 50 computer. The data base made possible by this system provides a means of tracing recurring failures and leads to a better understanding of the effects of process variables on the completed product.

Introduction

The manufacture of magnetic tape read-write heads is a process that offers interesting possibilities for closed-loop computer control. At the present time, however, no process model exists that accurately relates the functional properties of a finished head to the physical, electrical and magnetic properties of the parts made during the stages of the fabrication and assembly sequence. This paper reports an approach being used to implement the first step toward complete computer control of the process—the use of computers to collect and correllate a variety of test data obtained during the production of magnetic tape heads.

The data collection and analysis system is one application of the satellite computer installation[1] at IBM's Boulder, Colorado plant. At this installation the central computer is an IBM System/360, Model 50 (it was originally a Model 40), which currently supports ten satellites via a specially designed transmission control unit (TCU)[2] and the extension of OS/360 called PCOS (Process Control Operating System).[3]

One of the ten satellites is devoted to the testline for tape heads. It is an IBM 1130 with an 8K memory and the memory access-time option of 3.6 μsec per word (16 bits per word). The 1130, in turn, controls six test terminals through a second specially designed multiplexor called the Process Control Unit (PCU).

The following sections of the paper describe the major steps of the tape head manufacturing process, the nature and purpose of the tests and the design of the test terminals.

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Magnetic tape head fabrication and testing process

The parts and assemblies that exist at various stages of the process are shown in Fig. 1. The first major step in the process is the annealing of bulk lots of HyMu 80* core metal. Each segment of an annealed lot is called a *drape.* A sample is taken from each drape and tested for its hysteresis characteristics at several frequencies. Material that does not exhibit the specified hysteresis loop is reannealed. Acceptable material is used to make individual parts called *cores.* Two shapes of cores are made: C cores and L cores, which are used for the read and write sections and for the center section of the head, respectively.

Wires are wound around the C cores in a coil, pins are attached to the coil leads, and the whole assembly is encapsulated to form a read or write *module.* Modules are checked for dc resistance, direction of flux flow, and electrical shorts. The parts which fail one of these tests are culled and scrapped; those that pass are then tested for complex impedance. Acceptable modules are bonded together in groups of nine (one module per track recorded on tape) and placed in brass housings. These assemblies, called *sections*, are machined to shape and tested for complex impedance, flux direction and short circuits. Any section that does not pass all these tests is diverted to a rework operation.

The L cores are also tested for complex impedance. Each acceptable L core is sorted into one of four categories determined by its impedance value. Eighteen cores of the same impedance category are assembled into a center section and machined to shape.

* Reg. Trademark ,Carpenter Steel Co.

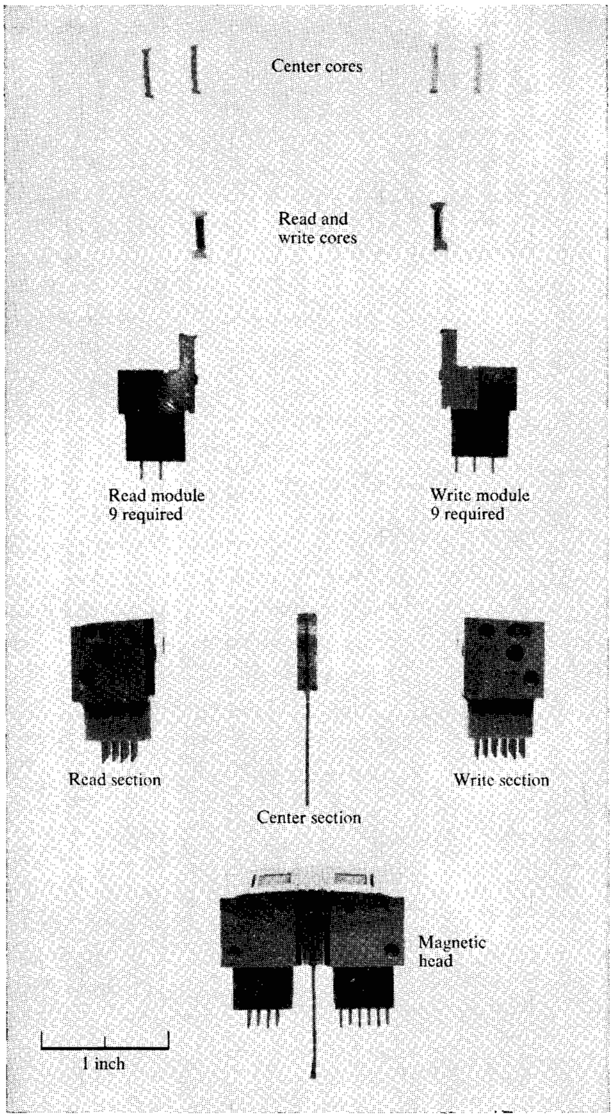


Figure 1 The tape head fabrication process.

Acceptable read, write and center sections are then assembled to form the basic structure of the finished head. After machining, the head is tested for complex impedance. If it passes the test, the head is again machined, tested again for complex impedance, plated with a nonferrous material, and given a finish machining. After the final machining, each head is tested one last time for complex impedance. Acceptable heads are then ready for tests of their ability to record and read data on magnetic tape.

The process flow as described here is illustrated in Fig. 2.

The foregoing discussion has mentioned the types of tests performed during the tape head manufacturing process. The particular parameters chosen for measurement have been selected on the assumption that they are important in determining the functional characteristics of the head. Table 1 summarizes the parameters measured, the conditions detected during the tests, the amount of data collected, and the accuracy and repeatability of the measurements. The total amount of data collected is currently about 330 16-bit words per head.

Effective use of test results requires precise part identification and traceability. If every part can be located at any time throughout the process, test data can be used to selectively assemble elements having complementary properties, thus achieving more uniform quality and increasing yield. Traceability also allows the determination of exactly how certain processes affect the performance of finished heads, so that correlations can be made and the causes of failures determined.

To achieve traceability, each component or subassembly must be labeled until it becomes part of a larger assembly. Sections and full heads are easy to mark with serial numbers and so present no special difficulty. Modules and cores, however, have no serial numbers and therefore do present an identification problem. Writing an identifying number on a core or module itself or on a tag attached to the component is not feasible; the time required would be too long and the marking itself could damage the component or interfere with its handling. A special tray, similar to a 35-mm slide tray, is therefore used to give each component an individual location. Each tray is assigned a number and as each component is tested it is deposited in a numbered slot within a tray. Each larger assembly—section or head—is marked with its own serial number, and the slot and tray numbers of its parts are assigned to that serial number for data retrieval purposes. With this labeling system only the identification data need travel with a part; test data can be stored on disk or magnetic tape for use only when needed.

Tracing is possible both from the raw material stage to the finished head and backward through the line to the raw material. If a new process is introduced into the manufacturing line it is important to know its effects on subsequent manufacturing operations and ultimately on the operating parameters of the product. If a head should fail the final test, it is possible with serial numbers and tray numbers to look back at what went into the head to determine whether there is a process defect.

Test system

All of the information and control paths of the present system are shown in Fig. 3. The process of testing begins when the IBM 1130 requests the transmission of a test control program that is stored in the central system. Once the program has been loaded into the core storage of the 1130, it alone controls testing. The 1130 contacts the central computer only when a batch of test results is

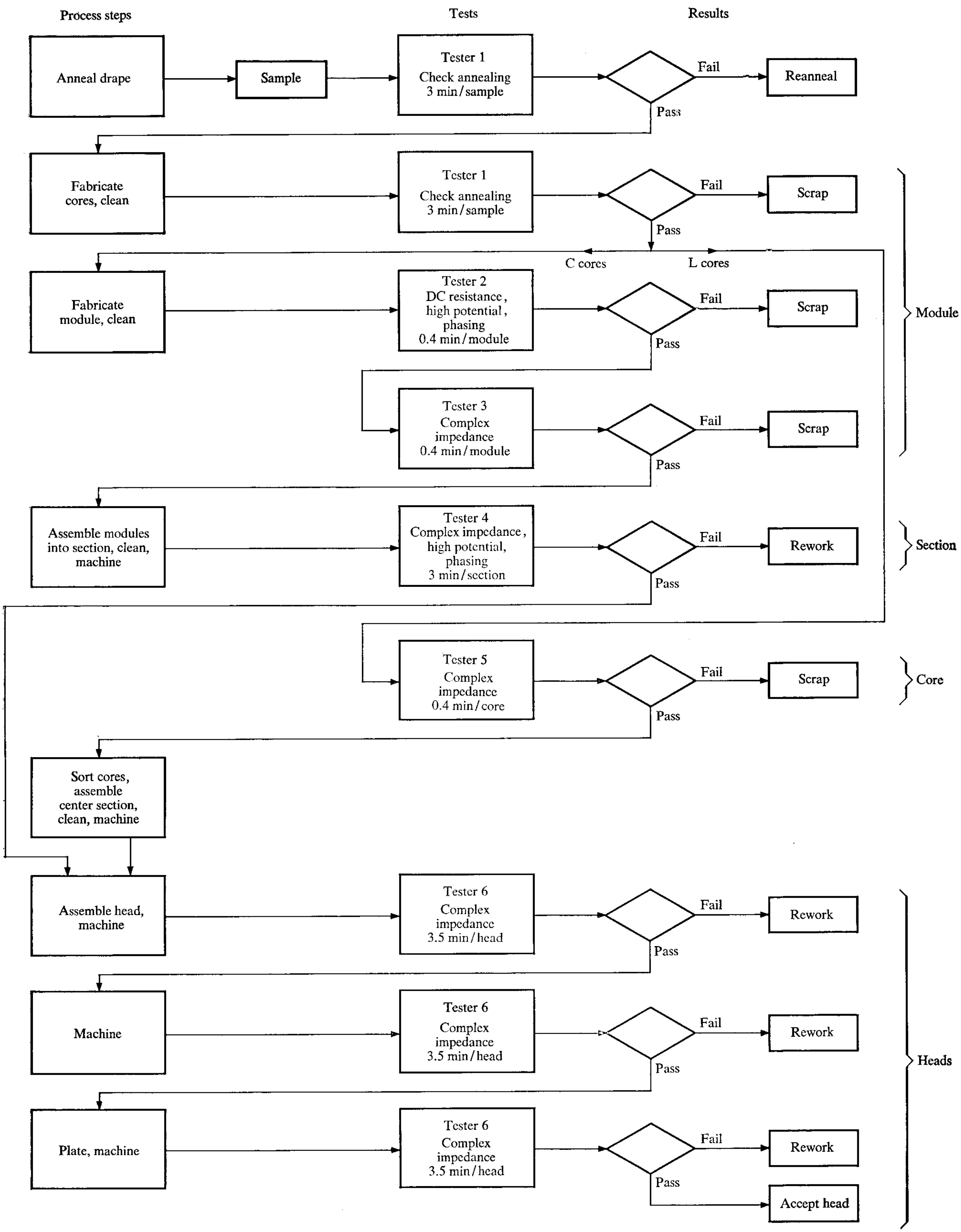


Figure 2 Block diagram of process flow.

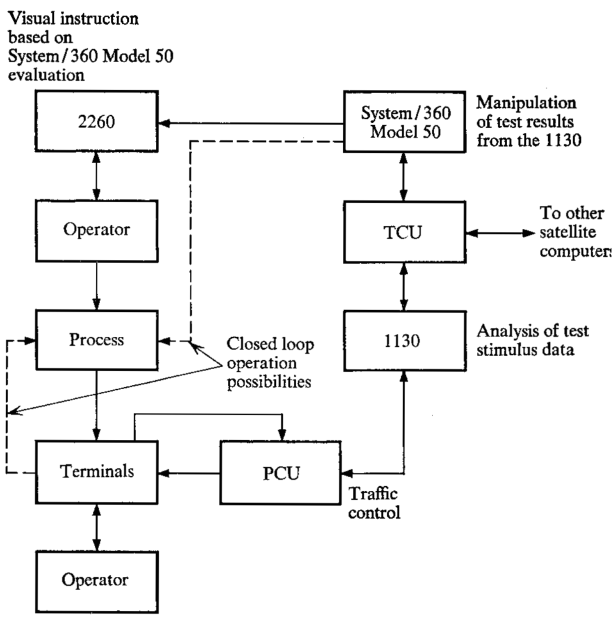
Table 1 Summary of tests.

Test name	*Parameter measured*	*Conditions detected*	*Amount of data collected per measurement*	*Accuracy (percent)*	*Repeatability (percent)*
Annealing check	B vs. H	Shape of hysteresis loop	10000 words per batch	1	1
DC resistance	Coil resistance	1. Coil continuity 2. Bifilar matching of write-modules	2 words	1	1
High-potential insulation (Hi-pot)	Breakdown voltage of module insulation	1. Quality of insulation between coil and core and shields 2. Detects exposed pins and potting voids	1 word	1	1
Phase test	Polarity of flux when signal is applied	Out-of-phase modules	1 word	1	1
Complex impedance	Magnitude and phase of impedance at specified frequency	1. Incorrect number of coil turns 2. Shorted coil turns 3. Magnetic condition of core material before and after machining or plating 4. Improper assembly of sections	2 words	3	1

ready for permanent storage or when time-of-day information is desired.

The test programs permit the 1130 to check part identification and test results, and error messages can be printed if desired in addition to the normal output of test results to each terminal. Test programs assure that a calibration test will be performed periodically by each terminal, with the 1130 printing out calibration result messages. Calibration testing is currently being performed every four hours to assure accurate test data. Program changes can be made manually at the 1130 but are normally made through the central computer by means of punched cards.

Figure 3 Data collection system data flow.



The test terminals apply the test stimulus to the parts under test and, upon request, send the test results through the PCU to the 1130 for analysis. The PCU monitors all test terminals and connects any terminal in need of service to the 1130. This connection is made with the use of a priority interrupt scheme which permits the terminal requiring most immediate access to the 1130 to be connected first.

The PCU is a unit especially built for use by IBM Manufacturing. It was designed at the IBM Rochester plant to connect test terminals with an IBM 1130. It was modified for use in the Boulder tape-head line by the incorporation of priority interrupt logic and commutation functions which minimize interference between interrupt signals. Its line driver and receiver circuits were also modified to permit transmission of data between the PCU and a test terminal over a coaxial cable up to 600 ft long. Software control is maintained by the application programming in the 1130, which controls data flow over the 1130 storage access channel (SAC) link to the PCU. Each test terminal is connected to the common logic of the PCU through two boards of SLT logic (referred to as *Module/Adapter pairs*). Each Module/Adapter pair can accommodate eight test terminals, while six are being used at present. The adapter circuits can be varied within the PCU to accommodate different terminals, but since the terminal logic is common, the circuitry is

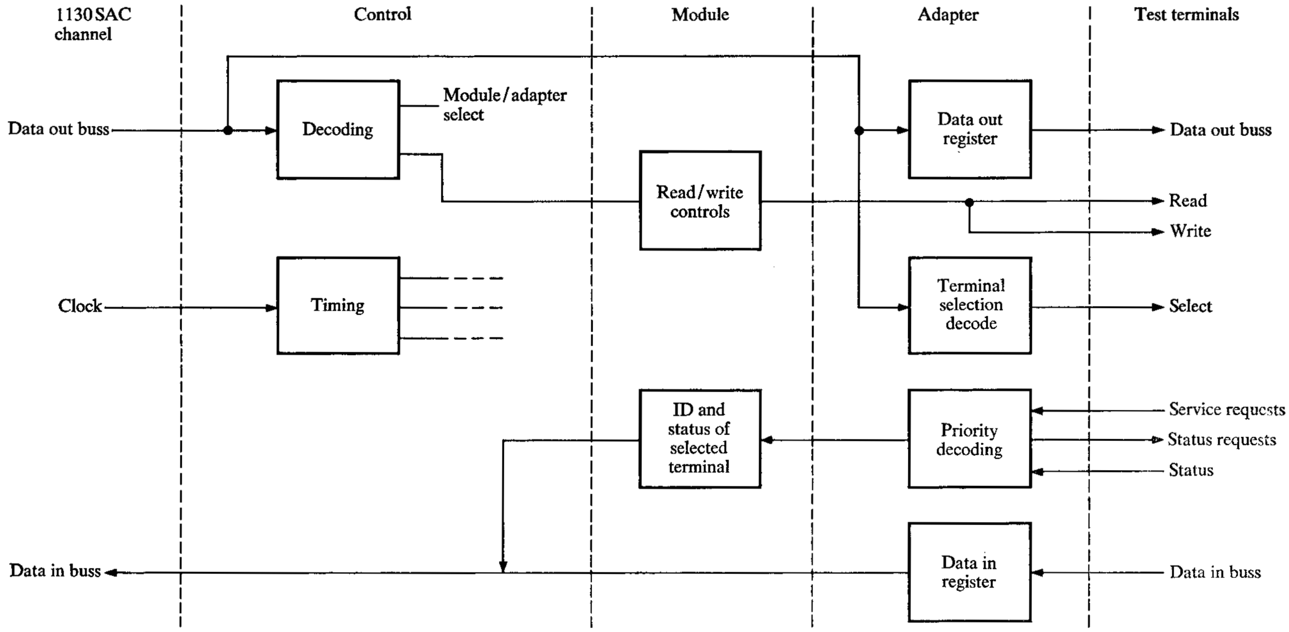


Figure 4 The Process Control Unit.

identical in this case. Figure 4 shows a block diagram of the PCU.

After a day of testing has been completed, the central computer analyzes the test data and stores both the correlated test results and the information required for selective assembly and process control. The daily updated files are available to production personnel through IBM 2260 graphic display terminals for on-line selective assembly; in addition, updated files provide the data base for manual alteration of basic process parameters, calibration and maintenance of test terminals, and updating of the 1130 testing programs.

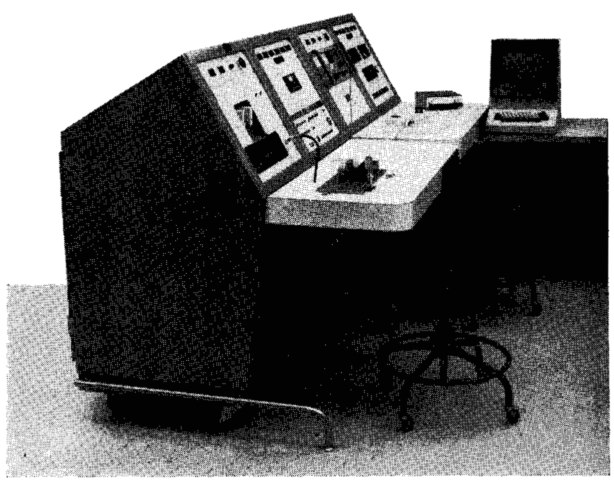
The System/360 programs for data analysis are written in PL/1 language. The first program is run each day as soon as all test data for the day have been received. This program classifies parts for selective assembly on the basis of test results and updates the identification/location status of units and assemblies in the line. Other programs are used to produce histograms and other information on trends, yields, rejects and the causes of rejects. The hard-copy output of these data analysis programs is used off-line to assist in controlling and updating the operations of the process line.

Finally, there is a trend program that tracks the calibration of each test terminal. With this program one can monitor the performance of each terminal and determine when maintenance will be required.

Test terminals

Six different test terminals were needed in all, and although each had its own unique functions it was possible to design 75% of the basic unit to be common to all six. The power supply, the bulk of the internal logic circuitry, the data buffer and the interface to the control unit and the 1130 could be identical in each terminal, permitting considerable economy in over-all design, assembly and maintenance. The remaining 25% of each terminal comprises the fixtures required to handle the particular part to be tested and the controls and cables needed to accept test input and make the common logic operate as required by the application. A photograph (Fig. 5) of two of the terminals conveys an idea of their size.

Figure 5 Two test terminals. Tester 2 is shown in the foreground and Tester 6 in the background.



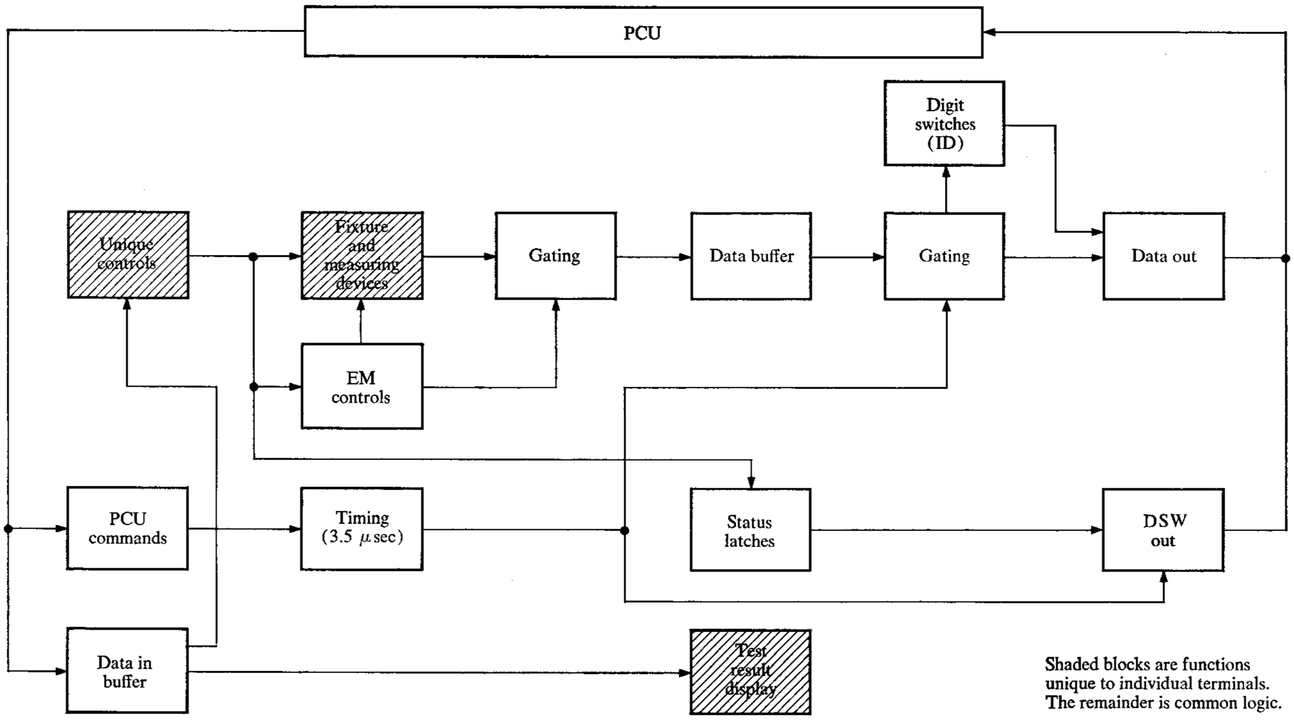


Figure 6 Typical test terminal logic flow.

A schematic diagram of the common portion of the test terminal is shown in Fig. 6. The logic accepts digital BCD (binary-coded decimal) signals from the application portion of the terminal and stores them in the terminal buffer; when the test data have been stored, it signals the 1130 for service through the PCU and transmits the data out of the terminal. It also accepts and transmits part identification data from the terminal operator, starts and stops the test operation in response to signals from the 1130, the terminal buffer or the operator, and transmits "decision" signals from the 1130 to the application for part disposition, data display, and possible error-interrupt action.

The buffer has a capacity of six BCD words, and is included because the data rate of a test operation is generally much slower than that of the 1130 link. With a buffer the terminal can run tests at its own pace, independently of the computer. The 1130 can thus occupy itself with other terminals (or other operations entirely), being interrupted only occasionally when the test being run is completed.

At the completion of a test the terminal logic signals the 1130, which compares the test data with programmed specifications, stores the data and the results of the comparison for later analysis, and returns a signal to the terminal. The terminal logic responds to the "decision" signal by accepting or rejecting the part and, depending on the test application, by either starting a new test cycle or signaling "ready" to the operator.

The unique portion of each terminal is modular and can be easily removed and replaced by another element; the various test functions are therefore interchangeable by means of a simple conversion.

Part identification and traceability can be implemented in the terminal by any of several means. The present design requires the terminal operator to enter identification data by means of digit switches, a simple and economical approach for small amounts of data. It has been found, however, that despite the computer storage capability more data must travel with each part than can be conveniently entered by hand. Accordingly there are plans now to supply each terminal with a small card reader, which would permit the use of punched cards for identification; one card would travel with each group of parts and identification for all parts in a group could be entered at the terminal in order of testing sequence.

To avoid production shut-downs in the event of computer failure, the first terminals were built to operate optionally as independent units, with an operator recording data and keying the disposition response. System reliability has shown the stand-alone feature to be unnecessary, however, and it is to be eliminated from future terminals. (Over the first eight months of operation the IBM System/360 Mod 50, 1130 and PCU portions of the system had an availability figure of 99.8%, while the test terminal availability was 96%.)

We will briefly describe the six applications, to show how the common design has been matched to the test requirements discussed in the preceding section.

Test Terminal 1 tests the hysteresis properties of ring samples of annealed core material. Hysteresis properties are conventionally measured by commercial *B-H* loop testers at 60 Hz, but the characteristics found in this way are often not valid when the same magnetic material is operated at higher frequencies, of the order of 500 kHz. Therefore, the *B-H* tester for this application was designed to measure magnetic properties at or near a specified operating frequency, and to use digital integrators instead of the conventional analog devices.

This terminal uses repeated measurements in a time-sampled mode, and integrates the sampled data to calculate the hysteresis profile. The inputs to the tester are amplitude samples from the induced voltage in, and samples of the drive signal to, a winding placed on the ring for test purposes.

The samples are strobed and held by a sample/hold amplifier until they can be converted to a digital signal, at which time they are stored in the test terminal buffer. Once the buffer is filled, the terminal interrupts the 1130 for service and then transfers the data. The 1130 then releases the terminal to continue sampling, and this cycle is repeated until the test is complete. At the completion of sampling the 1130 converts the data, compares the results to previously stored limit specifications, and transmits an accept or reject signal to the terminal.

The data conversion program in the 1130 computer multiplies the digitized data for the *H* parameters by a constant to obtain magnetic field strength in oersteds. The *B* parameters are multiplied by a constant, and a summation operation is performed to obtain magnetic flux density in gauss.

Test Terminal 2 is used to check the subassembly modules. Each module is tested for dc resistance, high-potential insulation breakdown and phase. The tester mechanically sorts the good and bad modules and the results of each test are stored in the computer system.

Each module is loaded by an operator and all test sequencing is done automatically. The results are sensed by a digital voltmeter (DVM). The BCD output of the DVM is temporarily stored in the tester buffers. At the completion of the last test, the terminal interrupts the system. When the 1130 recognizes the terminal, all data are read from the tester into the system. After the data have been compared to limits stored in the computer, one word of data is transmitted back to the tester. The tester decodes this word as a "Go/No-Go" decision. If all tests are "Go," the module is deposited into a carrier tray, which indexes with each module. If any one test is "No-Go," the module is placed in a reject tray.

Test Terminal 3 uses a vector impedance meter to measure the impedance and phase angle (Z and θ) of read and write modules. The analog output signals of the vector impedance meter are input to two digital voltmeters for display and conversion to BCD. The BCD outputs of the digital voltmeters are stored within the test terminal until the 1130 computer requests the data via the PCU. When the 1130 has completed analyzing the test data, it sends the test results to the test terminal. Upon receiving the test results, the terminal automatically places the module under test, if good, into a carrier tray or, if bad, into a reject bin. The possibility of good and bad parts being intermixed is nil since the test terminal operator does not handle tested parts.

Test Terminal 4 is used to check magnetic head sections after machining but before assembly into a full head. Each track of the section is tested for complex impedance, breakdown voltage, and phase. The results of each test are stored in the computer system for use in part selection for final assembly.

The section is mounted on a carousel jig by the operator and all tests are performed on one track before the next track is tested. The two DVM's in this terminal are shared by the vector impedance meter and the breakdown voltage and phase sensors. All results are sensed and converted by the DVM's and stored in the terminal buffer.

Upon completion of the last test for a given track, the terminal interrupts the 1130 system and transfers the test results. After the 1130 compares the data to the stored programs, one word of data is transmitted back. If all test results are within limits, the tester will step the carousel jig to the next track and repeat the test cycle. If, on the other hand, any one test is out of limits, a reject indicator will light up, showing the reason for the reject. The tester then stops until the operator manually advances the jig to the next track or inserts a new part.

Test Terminal 5, used to test center sections for complex impedance, is essentially the same as Test Terminal 3 with three exceptions:

1) Since center sections have no windings, the vector impedance meter is connected to a search coil rather than to the part being tested. The test part is inserted into the coil and the resultant change in Z-θ reading is sent to the 1130.

2) The readings are compared against several limits within the 1130 and categorized. In addition to making the accept/reject decision, the computer assigns each accepted part to one of four groups, the assignment depending on the test results.

3) The test terminal, upon receipt of the test and grouping results, places the tested part into one of four storage

trays or into the reject bin, and its logic must therefore select from five possible part assignments instead of only two.

Test Terminal 6 is essentially the same as Test Terminal 3, the exceptions in this case being that 1) the test is run on fully assembled heads and 2) the part fixture is a carousel jig similar to that of Terminal 4. Upon receiving acceptable test results, the terminal automatically indexes the carousel to the next track to be tested. If any track is rejected, the carousel will not index, but the operator can override the interrupt and advance the jig to continue testing the head. When all 18 head tracks have been tested, the computer signals the terminal to indicate an accept or reject disposition for the head.

Potential for further development

The computer-aided test system just described is not now a fully automated, closed-loop system. There is no direct feedback path by which the fabrication process can be altered on-line without operator intervention. With experience, however, it will be feasible to design a process that will respond directly to the monitoring function. On-line testing will then control the fabrication and yield of parts having desired characteristics, rather than merely measure and report them. For example, the existing terminal that monitors core permeability may be able to control annealing oven temperatures, thereby controlling the magnetic properties of the raw material. With the development of new test equipment, real-time control of head and section machining and plating operations may be possible.

Another possibility would be to use the IBM System/360 Model 50 for inventory control. Since that system receives and records all test data on all head components, it is reasonable to expect a straightforward extension to inventory control, eased somewhat by a reduction in processing burden as closed-loop control by the terminals is increased.

At present each test terminal requires an operator and performs a limited number of tests. A later generation of test terminals might have several "terminals" consolidated into one unit, with parts being handled only by automated handling devices.

Also, the Module/Adapter boards on the PCU can accommodate no more than eight test terminals, and the distance between the PCU and any terminal is limited to 600 feet. Expansion of the system and the development of improved transmission facilities would permit the use of additional terminals at greater distances from the PCU. Each additional Module/Adapter pair would provide for eight more terminals, with storage facilities at the System/360 expanded as needed. Since the PCU can accommodate four sets of Module/Adapter boards the system could be expanded to control 24 terminals.

Summary

The objective of this testing system is to provide a series of computer-controlled terminals that will perform on-line testing of magnetic head subassemblies and transmit the test data to a central computer. In combination with off-line data analysis, the system now in use makes two important contributions. The first is the immediate and considerable impact of more effective testing on process monitoring, quality control, selective assembly and parts control. The second, which will have its greatest effect over the longer term, is that it is a step that must be taken first in preparing for fully automated process control. With the data base and the data analysis programs one can analyze and correlate the effects of process variables on the properties of the product; this knowledge will permit the process as a whole to evolve toward closed-loop control without a long shut-down for conversion and testing.

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