NEWTON THIN FILM TAPE HEAD

By

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ABSTRACT

NEWTON THIN FILM TAPE HEAD

The Newton program has successfully demonstrated the application of a thin film head for IBM Boulder tape drives. The combined Laboratory and Manufacturing Engineering effort has produced several magnetic tape heads that met design specifications. The magnetic tape head developed for the Newton program contained magnetoresistive Read track elements deposited by vacuum techniques. The Write tracks are inductive elements produced by electroplating.

The deposition process and related techniques used to manufacture the Newton tape head include: sputtering, vacuum deposition, electroplating, and photolithography. The mechanical operations required for processing ferrite are described in detail including: ferrite lapping, glassing, and grinding. The Newton program has demonstrated the importance of process control, and the critical interrelation between process variables and tape head performance.

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INTRODUCTION

This report culminates the efforts of Boulder Manufacturing Engineering on the Newton project (It is not intended to detract from any of the efforts extended by the laboratory. The laboratory and Manufacturing Engineering worked jointly to complete this project. The overall responsibility for head development and design rested with the lab, while the process development and preparation for manufacturing was the responsibility of Manufacturing Engineering.) This report has been prepared by AME, Department 516, Boulder, to document the results of all efforts that went into the making of the Newton head. The only exceptions were design considerations and final test results, which will be handled by the laboratory under separate cover (the complexity of these efforts required the expertise of many disciplines which would be impossible to separately mention other than to indicate that the involvement did constitute effort throughout the corporation).

In the early part of 1971, upon completing a functional 16-track Comanche head (BOM-0003-00-516), a reassessment of program priorities was established in which the Birch program took priority over the Comanche program which later became known as the Oak program. This shift in emphasis caused a redesign of film head parameters because of the different tape speeds and operating frequencies involved.

Because of this, the efforts of both Manufacturing Engineering and the laboratory were directed toward a head using multiturn write elements and the newly developed mangetoresistive (MR) elements for the read operation. The MR element was selected for reading because of its more useful applications at low frequencies and tape speeds.

A great deal of engineering effort has been extended in exploiting this technology. Unfortunately, the schedules, costs, and timing of these efforts made them impractical to incorporate into the Birch program as was originally intended. However, the Newton head was successfully demonstrated on a Birch tape drive. This demonstration was evaluated from a performance standard and did meet the performance objectives.

It was in this regard that we documented these efforts in preparation for future applications. This technology is still being pursued and presently being applied to other applications. The technologies developed for the Newton program are very viable and of great worth for many future applications.

GENERAL DESCRIPTION OF NEWTON HEAD PROCESS

The Newton head is built by assembling a read, write, and center section with two outer housing halves which are held together by means of tie bolts. A photo of the head components is shown in Figure 1.

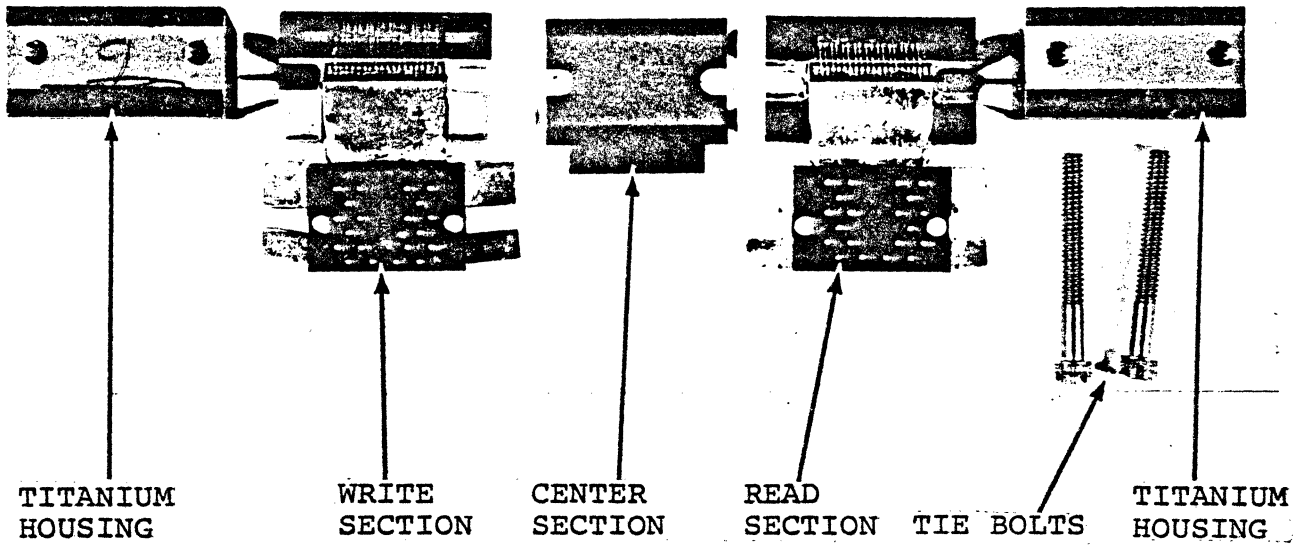


FIGURE 1

NEWTON HEAD COMPONENTS

The Newton head is designed to function as a nine-track read and write head, and maintain compatibility with existing circuit and media technology. The write tracks are inductive elements which are wire bonded to function as two turns. The read elements sense the magnetic transitions on the tape by an induced resistance change produced in the permalloy elements. The magneto-resistance signal obtained is independent of tape speed which gives this head a considerable advantage over existing head technology.

The read and write films are deposited on separate ferrite-titanium housing assemblies. A cross-sectional view of the read, write, and center section is shown in Figure 2.

The read section is built by first depositing 25 microinches of aluminum oxide on the ferrite surface of the read housing. The deposit serves as an insulator and a spacer to position the read element between the ferrite on the housing and the center section. Next, 1,350 angstroms of titanium and 300 angstroms of permalloy are vacuum deposited for use as the active biased magneto-resistive structure. The titanium serves as an adhesion layer and conductive deposit for biasing the permalloy layer. The permalloy is 83% nickel, 17% iron alloy deposited in a 40 oersted magnetic field.

The functional throat area of the permalloy titanium deposit is protected with a mechanical bar mask and 20 microinches of copper is vacuum deposited on the portion of the housing which will become the leg section. The deposits are then etched to the track configuration by photolithography techniques and magnetically tested. A final deposit of 25 microinches of aluminum oxide is sputter deposited (refer to Figure 2) on the element which aids in protecting and functions as a gap width spacer between the element and the ferrite center section. The aluminum oxide is etched from the copper legs on each track so wires can be terminated to the element.

The deposition layers on the write section consist of an initial sputter layer of 100 microinches of aluminum oxide which covers the ferrite surface of the housing. The aluminum oxide is etched to leave a bar of oxide at the upper edge of the housing for tape wear. The housing is next metallized with 500 angstroms of titanium and 1,000 angstroms of copper to provide an adherent conductive base for electroplating. A photoresist pattern is developed on the metallized layer to define the write track pattern. Copper is next electroplated on the surface to a thickness of 90 microinches. The electro-formed write tracks are complete except for removing the photoresist and etching the metallization layer between the electroplated lands. Write elements fabricated in this manner have excellent thickness uniformity and performance repeatability.

A complete process description is contained in the following sections detailing the specific parameters used in building the Newton head. Since this is an active development program, process improvements are being made and the respective authors should be contacted if additional details are required. Due to the confidential nature of this program, management approval and a need-to-know must be demonstrated before information is supplied.

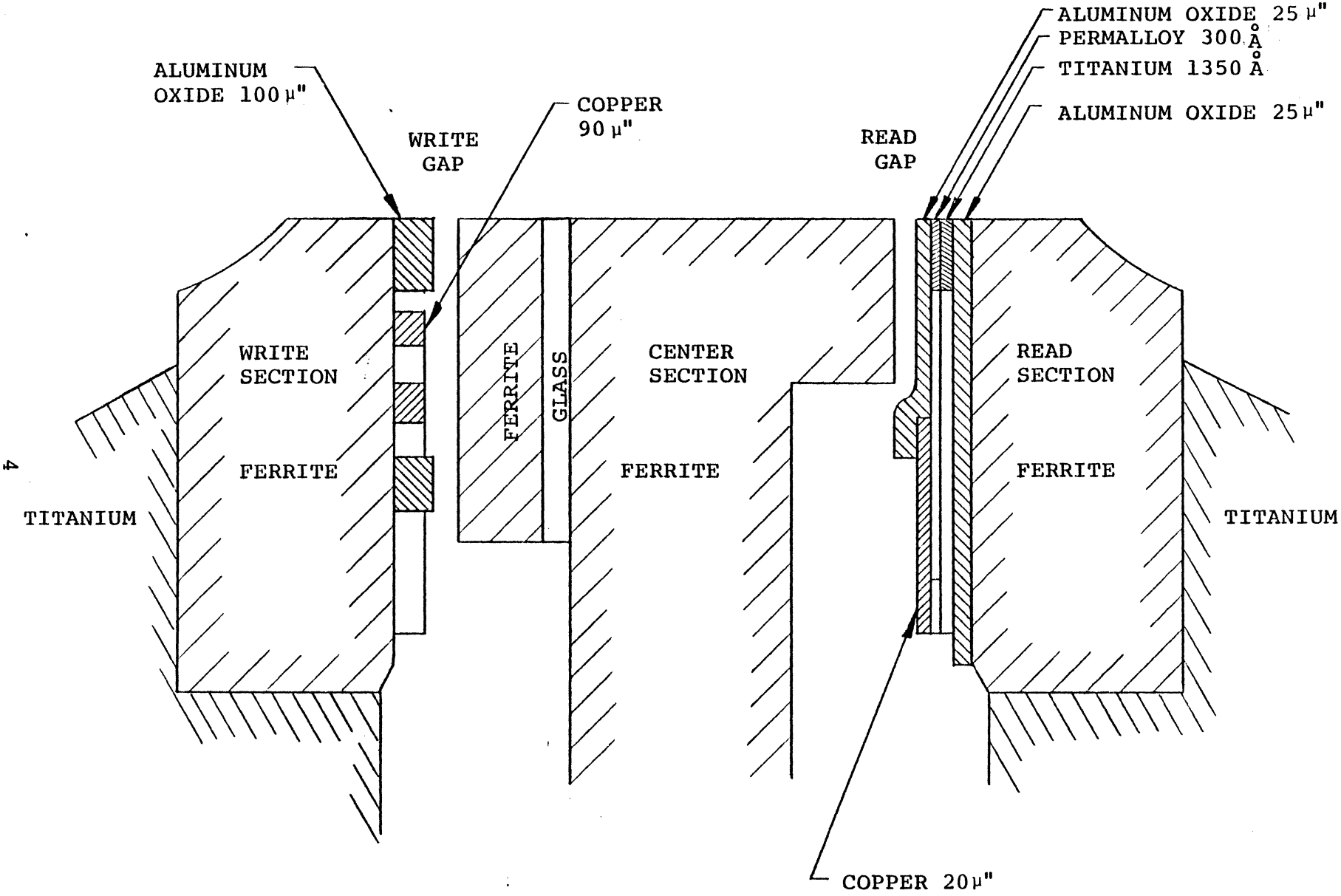


FIGURE 2

CROSS SECTION OF NEWTON HEAD

CENTER SECTION

The center section is a laminated ferrite-copper-ferrite (Fe-Cu-Fe) structure (See Figure 3). The ferrite read and write sections are brazed together with a .001 inch copper sheet in the center. Functional objectives require the write side of the center section to be divided into nine equal size lands. These lands must be accurately spaced, dimensionally stable, and isolated from each other. Land separation is accomplished with glass filled slots (Refer to Figure 4 for dimensional requirements).

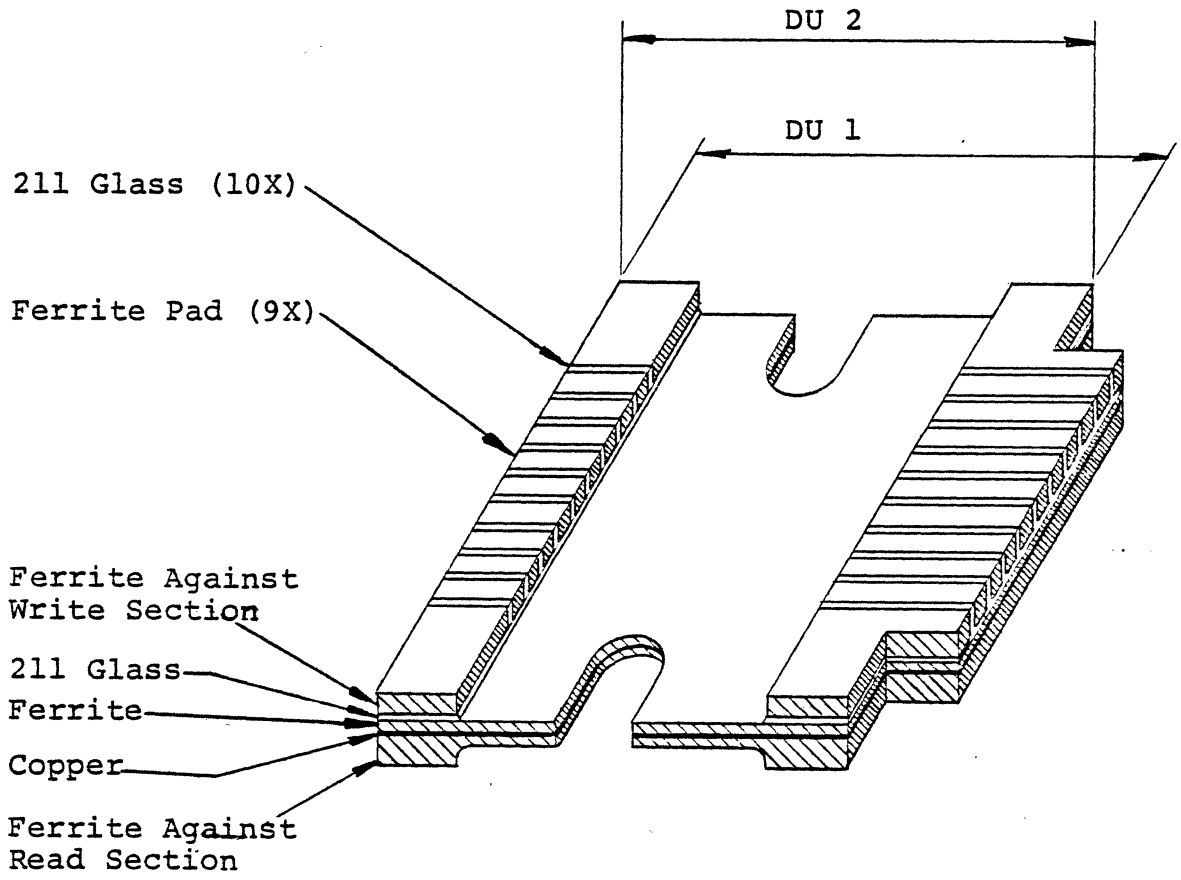


FIGURE 3

COMPLETED CENTER SECTION

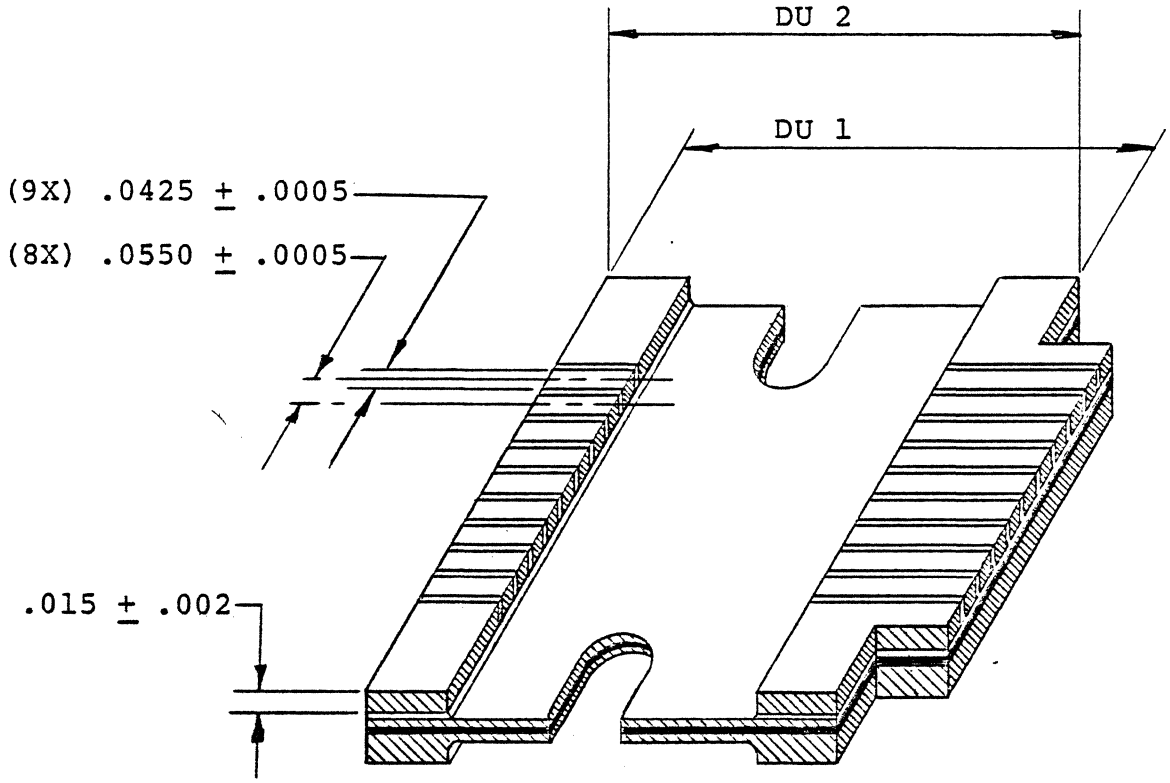


FIGURE 4

DIMENSIONAL SKETCH OF CENTER SECTION

The following processes are employed to accomplish center section fabrication:

DESIGN SPECIFICATIONS

Fe-Cu-Fe Bond

The brazed Fe-Cu-Fe structure must hold its shape throughout machining and glassing up processes involved in finishing the center section. The 5-mil metallic interface (1 mil, Cu and brazing alloy) should be uniform within .001 inch.

Glass Fill Requirements

The primary functions of the glass in the center section assembly are to provide write track separation and assure track dimensional stability. The glass cannot have voids, cracks, or bubbles larger than .001 inch, or recesses deeper than 10 micro inch below the plane established by the ferrite surface.

Center Section Dimension

The center section dimensions are derived from the following requirements:

Read and write section surface flatness must be within one light band, the surface finish must be scratch-free and have reflectivity better than one micro inch RMS.

The center section parallelism must be within 200 micro inches and DU 1 to DU 2 squareness must be within 200 micro inches.

PROCESS

Ferrite Section Machining

The ferrite sections are sliced from nickel-zinc ferrite bricks supplied by San Jose. Diamond slicing wheels are used in slicing the ferrite bricks to size. Machine RPM is 4800; feed rate is 3 IPM.

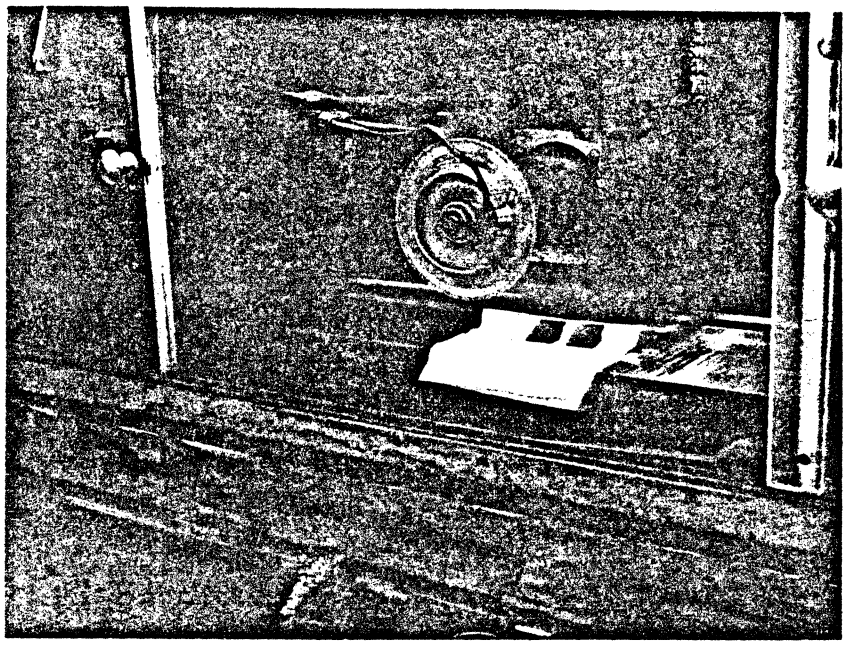


FIGURE 5

SLICING MACHINE WITH DIAMOND WHEEL

[redacted]

FIGURE 6

SECTION MATERIALS

Machine Center Section Geometry

The brazed Fe-Cu-Fe structure is ground to required outside geometry with a diamond wheel. Ten slots (.0125 ± .0025 inch wide), equally spaced and .030 inch deep are cut with a .012 inch diamond slicing wheel. A machine with a linear measurement system consisting of digital read-out counter, a dynamic line corrector, a linear encoder and scale (with 50 micro inch capability) was used to obtain precise slot location.

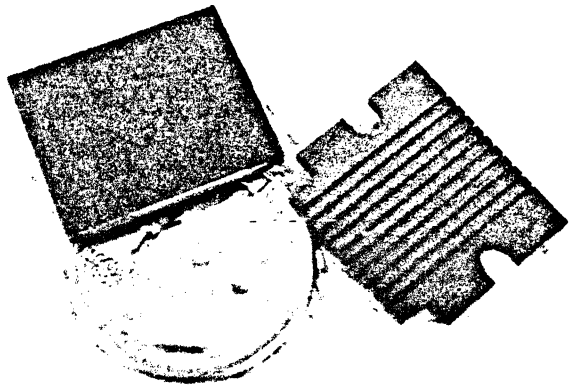


FIGURE 7

BEFORE AND AFTER SLICING

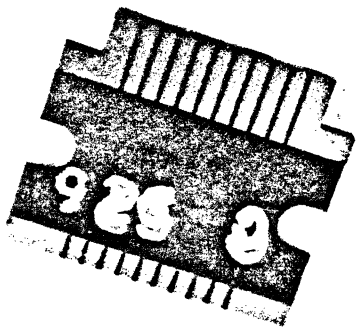


FIGURE 8

COMPLETED SECTION

The glass-filled ferrite sections are positioned at a 10° angle on an $Al_2 O_3$ block to:

assure optimum glass fill and glass buildup at the top of the center section, and to

aid in preventing glass bubble formation in the top slots.

A standard Hevi-Duty box furnace controlled by a Trend-Trak curve follower is used to heat the glass to the working point and the slots are filled by capillary action.

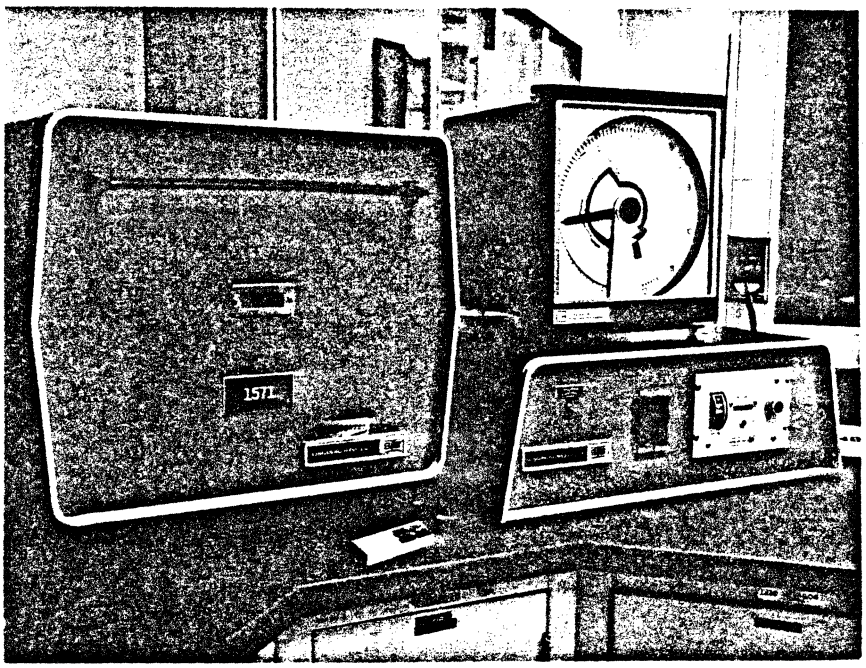


FIGURE 10

GLASS MELTING FURNACE

Glass Filling of Slots

Glass is used to achieve ferrite land isolation and to resist wear from oxide tape during the functioning of the tape head. The glass selected had to have a coefficient of thermal expansion from set point to room temperature that matched the Ni-Zn ferrite ($90 \times 10^{-7}/°C$).

The initial center section design required development of a two-glass system which employed IBM 391 and 211 glass. High build cost of this structure prompted a center section design change employing a one-glass system.

The brazing alloy used to laminate Fe-Cu-Fe has a softening point of 800° to 825° C which prohibits the use of 391 and 517 glass because of their high working point (950° C and 775° C respectively). IBM 211 glass with a working point temperature of 600° C and a coefficient of thermal expansion matching Ni-Zn (room to set point $86 \times 10^{-7}/°C$), appears to be satisfactory.

The IBM 211 glass cane (.09 diameter) is mounted on top of the slots in the ferrite and is held in position with Duco cement.

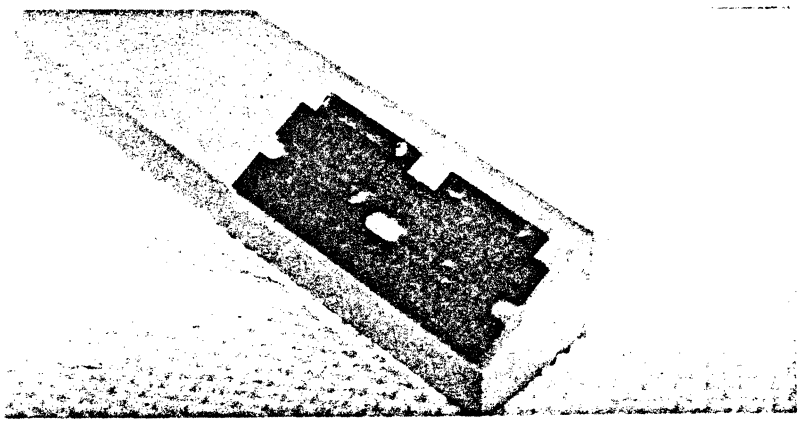


FIGURE 9

GLASS CANE MOUNTING PRIOR TO MELTING

To accomplish complete ferrite land isolation, a slot .012 inch wide and .100 inch deep is ground at the top of the center section with a diamond wheel.

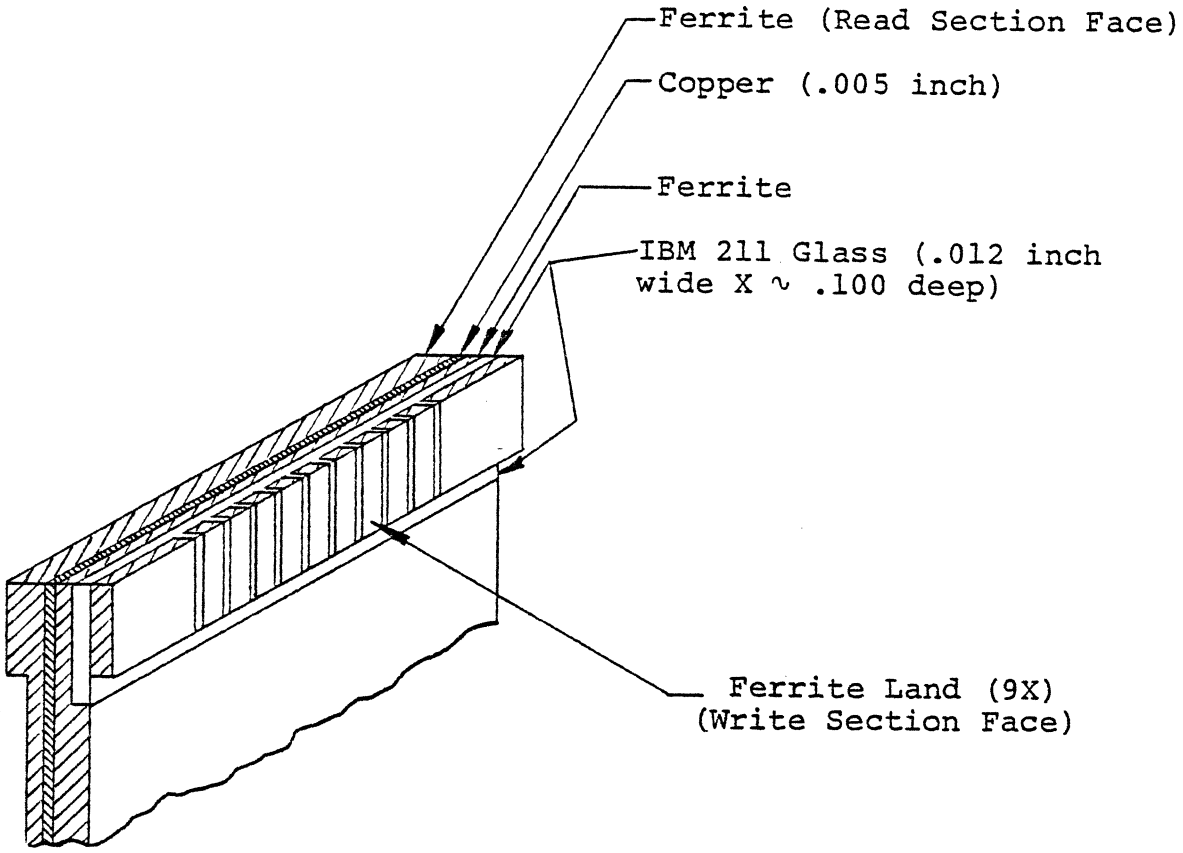


FIGURE 11

CENTER SECTION (AFTER GRINDING)

After the grinding the top slot, the parts are heated and glass flow is accomplished using the previously described procedure with an optimum firing cycle:

1. 15° C/min to 665°, dwell at 665° C/3 hours
2. Cool to annealing point of 400° to 410° C (10° C/min) and hold for 2 hours.
3. Shut off furnace and cool parts in furnace.

Critical problems encountered were:

Formation of bubbles in the glass during the glassing process.

Formation of cracks in the glass.

The formation of bubbles was traced to improper positioning of the glass-cane on the ferrite when glassing, and to improper cleaning of the ferrite after the slot grinding operation. The previously described method of locating the glass-cane and thermal cleaning the ferrite (725° C for 6 hours) prior to the glassing process provided desired results.

Micro-cracks in the glass, noticed after the lapping operation, were due to an insufficient glass annealing time during the glassing process. Soaking the glass at 410° C for 2 hours eliminated the cracks.

Finish Machine Center Section

After the glassing process, the excess glass is removed by grinding to the required thickness with a 300-grit diamond wheel. Ferrite land isolation is accomplished by diamond wheel grinding the center section to the required geometry.

Six center sections are bonded to a part holder and lapped to obtain the proper surface finish, flatness, and parallelism.

The part holding technique and lapping process employed for the fabrication of the center section are described in the section on substrate assembly.

SUBSTRATE ASSEMBLY

The substrate assembly (see Figure 12) is a bonded Titanium-Ferrite (Ti-Fe) structure. The commercially pure Titanium part is the base of the assembly and the Ni-Zn Ferrite is the actual substrate material.

The Titanium was selected as housing material because its relatively close thermal expansion characteristics are near that of Ni-Zn Ferrite.

The Ni-Zn Ferrite is brazed to the Titanium with a silver-copper-nickel filler material.

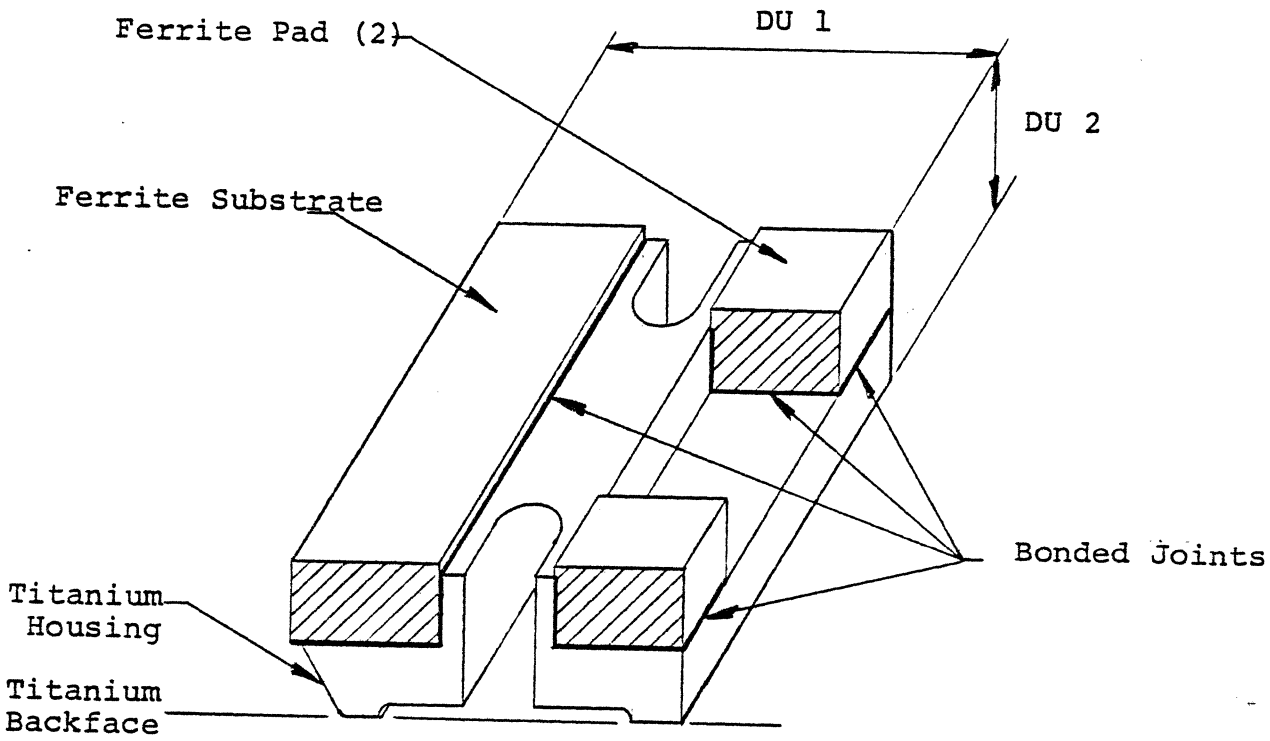


FIGURE 12

READ AND WRITE HOUSINGS

The substrate assembly must meet the following three major requirements:

1. Bonded Joint Requirement:

   The primary function of the Ti-Fe bond is to resist separation resulting from the mechanical load that occurs during machining. The minimum compressive shear strength used was 2,000 psi.

2. Substrate Surface Finish & Flatness:

   The substrate surface specification has been established based on functional requirements:

   Substrate surface flatness to be within 20 microinches.

   Substrate finish:

   a. Scratch-free reflective surface finish better than 1 microinch (RMS).

   b. Voids, a defect in the ferrite, not to exceed 200 microinches in diameter.

   c. No voids or pull-out's in functional area.

3. Substrate Assembly Dimension:

   Dimensional specifications were established to assure a minimum of alignment mismatch.

   The main criteria:

   a. Squareness of DU 1 to DU 2 within 200 micro-inches.

   b. Ferrite substrate and pads to Titanium backface within 200 microinches.

EQUIPMENT

Titanium Machining

Conventional machining processes are used to obtain the required housing geometry. A minimum of difficulty is experienced in milling and grinding of Titanium (carbide cutters for milling silicon and carbide grinding wheels for grinding give best results for these applications).

Ferrite Substrate Machining

Ferrite substrates and pads are fabricated from nickel-zinc ferrite bricks supplied by San Jose. Diamond grinding wheels (200 grit) are used in slicing the Ferrite bricks to required size (see Figure 13).

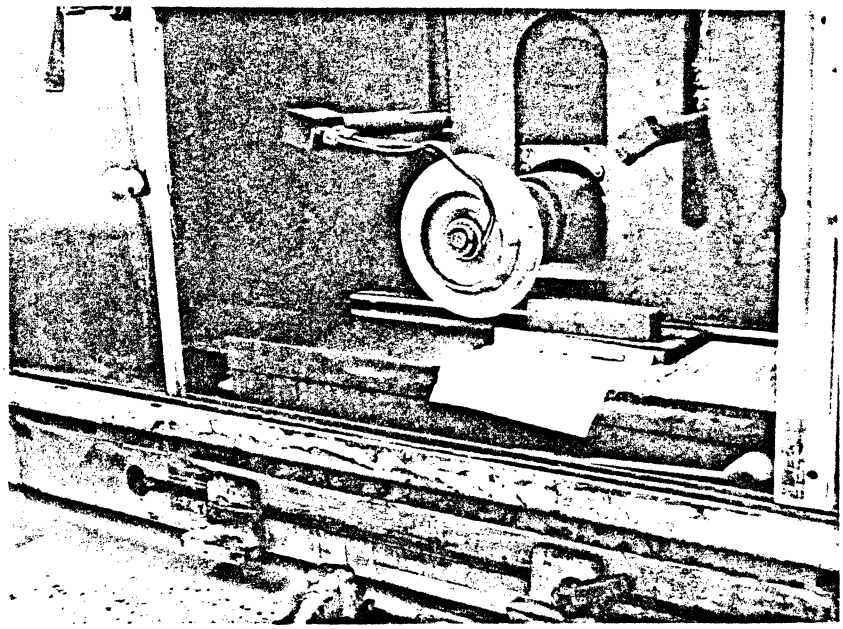


FIGURE 13

SLICING MACHINE WITH DIAMOND WHEEL

TITANIUM FERRITE ASSEMBLY

Bonding Process Development

The primary function of the Ti-Fe bond is to resist separation caused by machining forces involved in machining the assembly (refer to Figures 14 and 15).

The best process developed to date is to braze the Titanium and Ferrite using a 71% Ag, 28% Cu, 1.0% Nickel filler material. In order to braze the Ti-Fe, the Ferrite is metallized prior to brazing by vacuum sputtering a metal layer of 50 microinches 304 St steel onto the Ferrite surface.

The following process steps and parameters are currently in use:

1. Chemically clean Titanium and Ferrite.

2. Thermally clean Ti and Fe for one hour at 850° C in a 10^{-5} Torr vacuum environment.

3. Package Ti and Fe, placing the brazing alloy (1 mil sheet) at the joint site.

4. Pre-heat package in vacuum furnace (10^{-5} Torr) at 650° C for .5 hour, increase temperature to 825° C and dovell at 825° C for 3 to 5 minutes. Shut off furnace and cool parts in furnace.

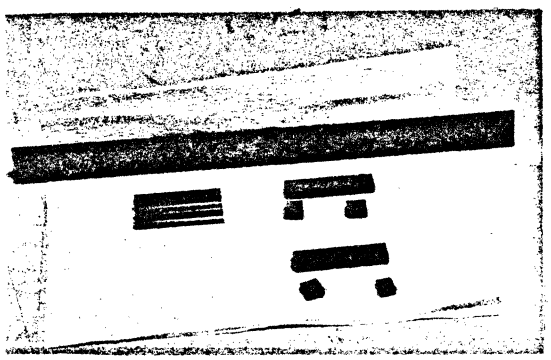


FIGURE 14

SUBSTRATE COMPONENTS

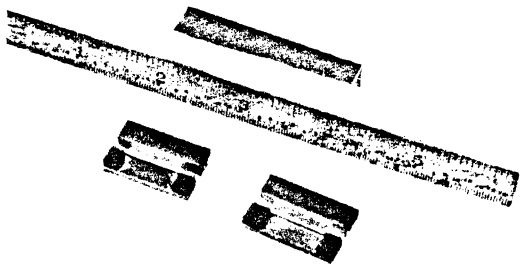


FIGURE 15

COMPLETED ASSEMBLY

Substrate Assembly Machining

The Ti-Fe structure is finish machined to the required dimension using a 300-grit peripheral diamond wheel. To prevent Titanium buildup on the diamond wheel, the parts are rough machined to within .0005 inch of the final dimension with a 320L silicon carbide wheel.

To obtain the required dimensional relationship of DU 1 to DU 2, four parts are loaded in Fixture 1 and the top and bottom sides are ground (see Figure 16). Using the ferrite pads as fixture reference, four parts are loaded in Fixture 2, and the sides of the assembly are ground to the required specification (see Figure 17).

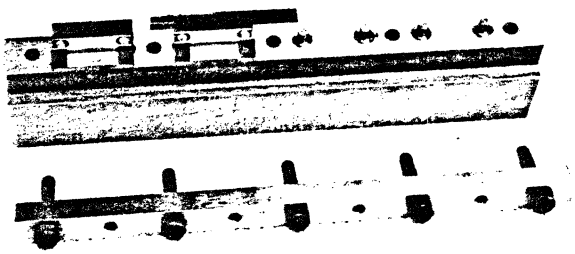


FIGURE 16

MACHINING FIXTURE 1

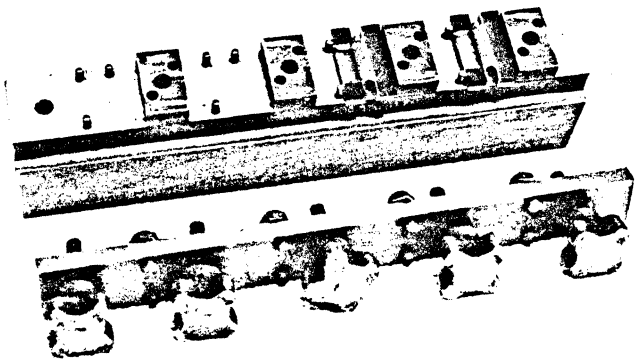


FIGURE 17

MACHINING FIXTURE 2

The proper lapping equipment, lapping abrasive, and part holding technique is critical for obtaining a scratch-free reflective surface (less than 1 microinch RMS, flat within one light band, and parallel within 100 microinches).

Lapping Equipment

The lapping machine being used for pilot production is a random motion machine (see Figure 18). The variable, two-way mechanical action of the machine results in constantly changing the point of contact between lapping plate and part. This motion results in increased surface life of lapping plates. All of the operational functions (other than loading and unloading) can be automatically controlled.

The abrasive flow is precisely monitored (auto-spray unit) to disperse 8 seconds of flow every 2 minutes.

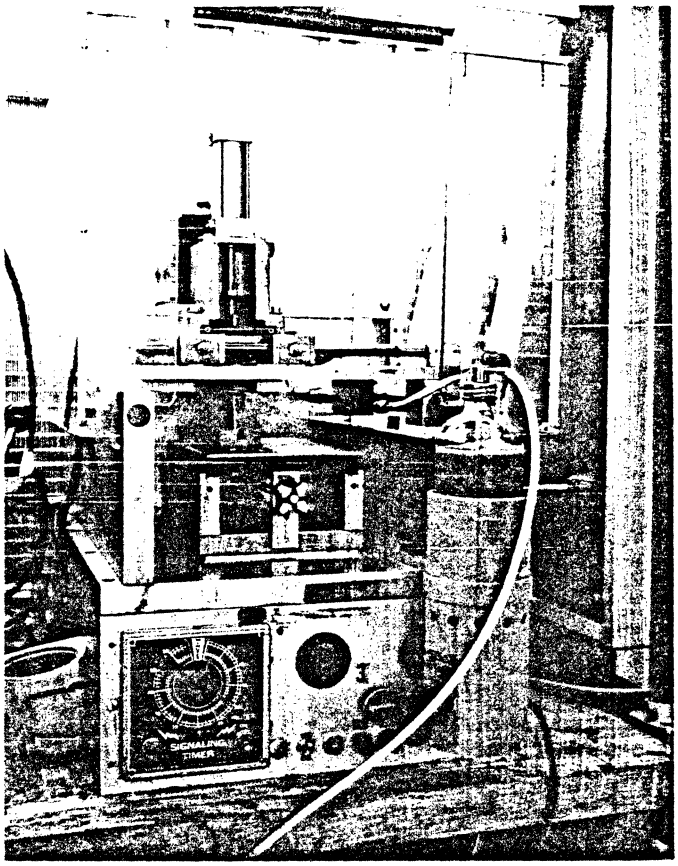


FIGURE 18

LAPPING EQUIPMENT

Lapping Parts

Lap plate flatness and material are the critical parameters in precision lapping Newton ferrite substrates.

The final lap plate material was selected based on experiments performed with various metals (lead, tin-lead, copper and cast iron). Tin (.25 inch thick) bonded to mehanite backing plates gives the desired results and is presently in use.

Rough lapping is performed by using an accurately machined serrated mehanite plate (see Figure 19). To obtain consistent substrate finish quality, the lapping plates must be better than one light band over a 3.00 inch diameter area.

Out of flatness lapping plates are conditioned as often as necessary to maintain the desired performance.

Conditioning is accomplished by lapping the plates in the random motion lapping machine. Accurately machined ferrite blocks mounted on a 416 St-steel holder are used as the lapping tool.

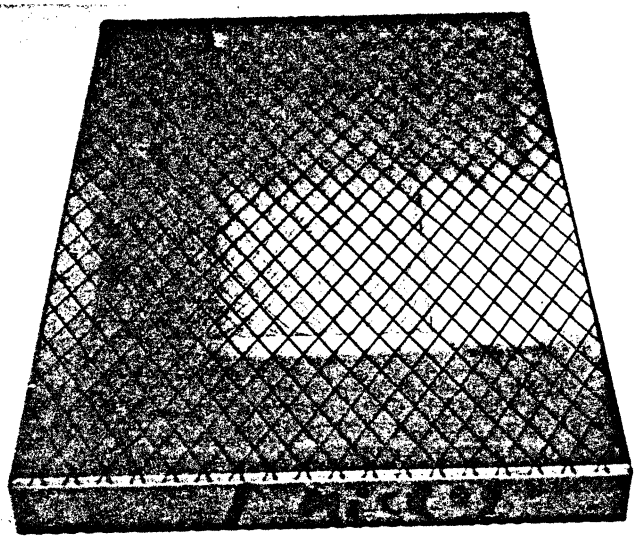


FIGURE 19

LAP PLATE

Lapping Abrasive

Various lapping abrasive solutions were used during the development of the lapping process for Newton hardware.

The micron diamond solution was selected based on excellent performance at San Jose's magnetic head manufacturing area.

Experiments, conducted in Boulder, with synthetic and diamond powder slurry showed that only synthetic diamond powder slurry is capable of producing Newton substrate surface finish (apparently because of it has more uniform synthetic diamond particles than the natural diamond particles).

The vehicle used for supporting the diamond particles (.5 gram to 16 ounces of lubricant) is a mixture of 30% ethelyne glycol to 70% DI water by volume. Uniform suspension of the diamond particles, which is essential to obtain the required surface finish, is accomplished by constantly stirring the solution with a magnetic stirrer.

Diamond slurries (#3, #1, and #1/2) are used for the rough and finish lapping operation. The slurry is sprayed for a duration of 8 seconds every 2 minutes onto the lap plate.

To assure quality lapping finishes, individual lap plates are used for different size diamond slurry.

Part Holding Technique for Lapping Process

An important factor in meeting the Newton substrate dimensional objectives is the proper mounting and holding of the substrate assembly for the lapping process.

The parts are loaded on a 416 St-steel part holder (see Figure 20) and held in position with an adhesive (IBM 076-1).

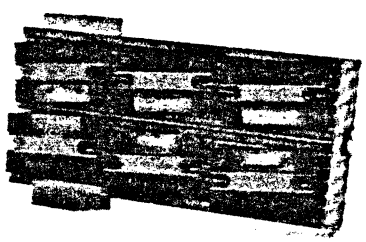


FIGURE 20

PART HOLDER FOR LAPPING

The part holder's primary design requirements are:

1. Thermal expansion match with Titanium and Ferrite.
2. Rugged construction to withstand mechanical load.
3. Chemical resistance to epoxy and solvents used during the bonding of parts.
4. Serrated surface to allow escape of solvents contained in the bonding material.

To hold the parts in position on the part holder during the lapping process, a temporary bonding material is required which meets the following objectives:

1. Control of bondline thickness within 40 microinches.
2. Control of flatness and parallelism within 1 light band.
3. Room temperature assembly of parts on lapping fixture.
4. Relatively short thermal cycle time for heating and drying - 1 hour.
5. Minimum shear strength - 300 psi.
6. Minimum attack of the adhesive by lapping solution.
7. Simple part removal - soaking in solvent.

All available customer and IBM adhesives proved to be inadequate because of inconsistent bondline thickness, which produced an out of flatness and out of parallelism condition.

Adhesive 076-1 developed in the San Jose Materials Lab, appears to meet requirements.

The adhesive is applied with a camel's hair brush and the part is immediately placed on the fixture. Finger pressure is applied and the part is moved slightly to squeeze out the excess adhesive. Care is exercised to keep the serration free of adhesive. Plugged serration will prohibit the solvents from escaping and the adhesive will remain soft.

The fixture, with the parts, is heated in a circulating oven at 250° F for a period of 36 minutes.

The most important aspect of the bonding operation is the cooling cycle. The fixture, with the parts, must be cooled uniformly to achieve stress-free bonding of parts. The following methods have been successful:

1. Allow fixture and parts to cool in oven with circulating air fan on.

2. Remove fixture and parts from oven and place on wood-lab bench top.

Method 2 is currently used for pilot production of Newton hardware.

Stripping of parts from the fixture is accomplished by submerging fixture and parts for 10 to 15 minutes in a tank containing a mixture of 70% methelyne chloride and 30% acetone by volume.

SPUTTERING

Sputtered Layers, and Requirements for the Newton Design

Material Choice:

A film material was needed to separate the MR element from the ferrite substrate on the read side housing, and to separate the ferrite center section from the read elements after assembly. Also, a filler was needed on the write side gap directly above the write elements. In each case, the material selected would be subjected to wear from contact with magnetic tape during operation, so a primary consideration was wear resistance material which would minimize gap erosion.

Another requirement was the ability to hold up during head contour grind and lap. These operations tend to tear materials out of the gap if poorly bonded, or erode them excessively if the material is too soft.

A third requirement was the ability to control thickness of the films within $\pm$ 5% in the range from 10 to 100 microinches. Fourth, the surface had to be relatively smooth and free of protrusions that would prevent proper closure of the read, center, and write sections.

Lastly, the material had to be etchable. The write side gap of 100 microinch must be etched down to the ferrite with not more than 200 microinch of undercut. Also, it was possible that the read elements would have a thin overcoat layer, and this would then have "windows" etched through it down to the copper legs. The etchant would have to open these "windows" without attacking the copper.

The materials selected for trial runs were quartz (SiO_2), aluminum oxide (Al_2O_3), silicon carbide (SiC) and Rhodium. Both SiO_2 and SiC were unacceptable due to excessive wear or gap erosion during grind, lap, or tape testing. Rhodium showed good wear characteristics, but it was nearly impossible to etch. Al_2O_3 looked excellent from all standpoints. Etchability problems occur if the Al_2O_3 becomes crystalline (but that can be prevented with proper temperature control).

Why Sputtering Process Was Used

Al_2O_3 has been deposited by a variety of techniques: reactive evaporation, plasma anodization, pyrolytic decomposition of organo-aluminum compounds, DC reactive sputtering and RF sputtering. RF sputtering was chosen for the following reasons:

1. Early samples used to make the choice of Al_2O_3 material were RF sputtered by T. R. Cole and J. R. Wiitala of the Boulder SDD group. They found that the rate of deposition was slow (approximately 1/3 that of SiO_2), but film quantities and thickness control were good.

2. T. N. Kennedy, IBM San Jose, was set up to perform that operation, and had written a report entitled, "Characterization of RF Sputtered Aluminum Oxide," dated March 4, 1971. Tom had agreed to deposit initial samples for our program as needed.

3. The AME RF sputtering unit could be quickly converted from SiO_2 to Al_2O_3, whereas any other deposition technique would have required more time plus equipment acquisition.

Thickness Requirements of Various Newton Layers

Each head requires four separate Al_2O_3 layers, with desired tolerances being $\pm$ 5% of nominal thickness. The different layers are:

read housing, initial layer - 6000 Angstroms
read housing, track overcoate - 2500 Angstroms
center section, read side layer - 2500 Angstroms
write housing, initial layer - 25,000 Angstroms

DESCRIPTION OF EQUIPMENT

Cleaning Equipment

Three pieces of equipment are used for the cleaning operations which precede sputtering:

1. Two-tank stainless steel cleaning unit, with one side for ultrasonic agitation and the other for Freon TMC vapor degreasing (see Figure 21).

2. Vacuum oven (oil diffusion pumped with cold trap) capable of reaching 600° C at a vacuum in the 10^{-6} Torr range (see Figure 22).

3. Stainless steel ultrasonic/vapor degreasing unit for Freon TF. The unit also has a pressurized spray wand for rinsing substrates with Freon TF (see Figure 23).

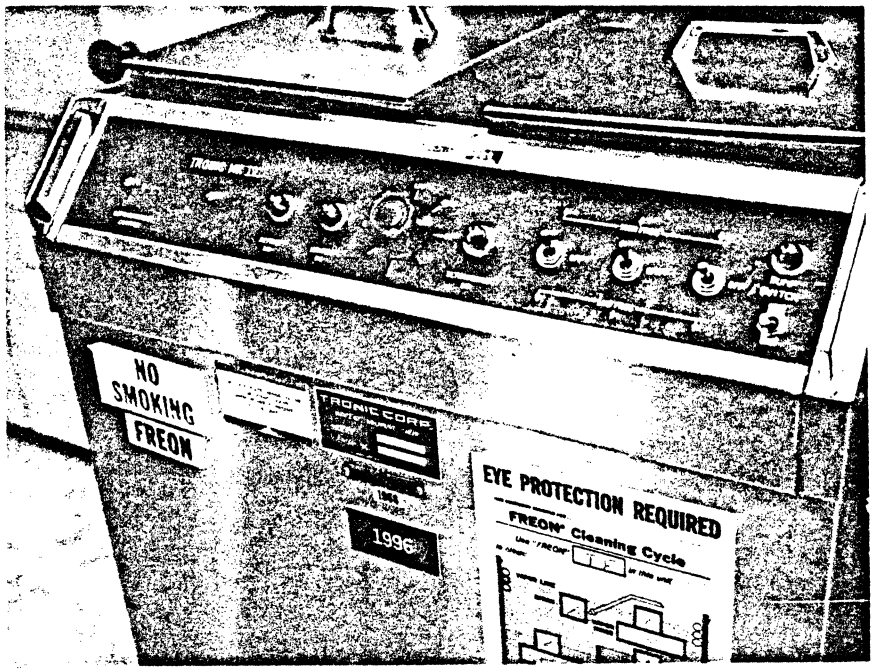


FIGURE 21

CLEANING UNIT

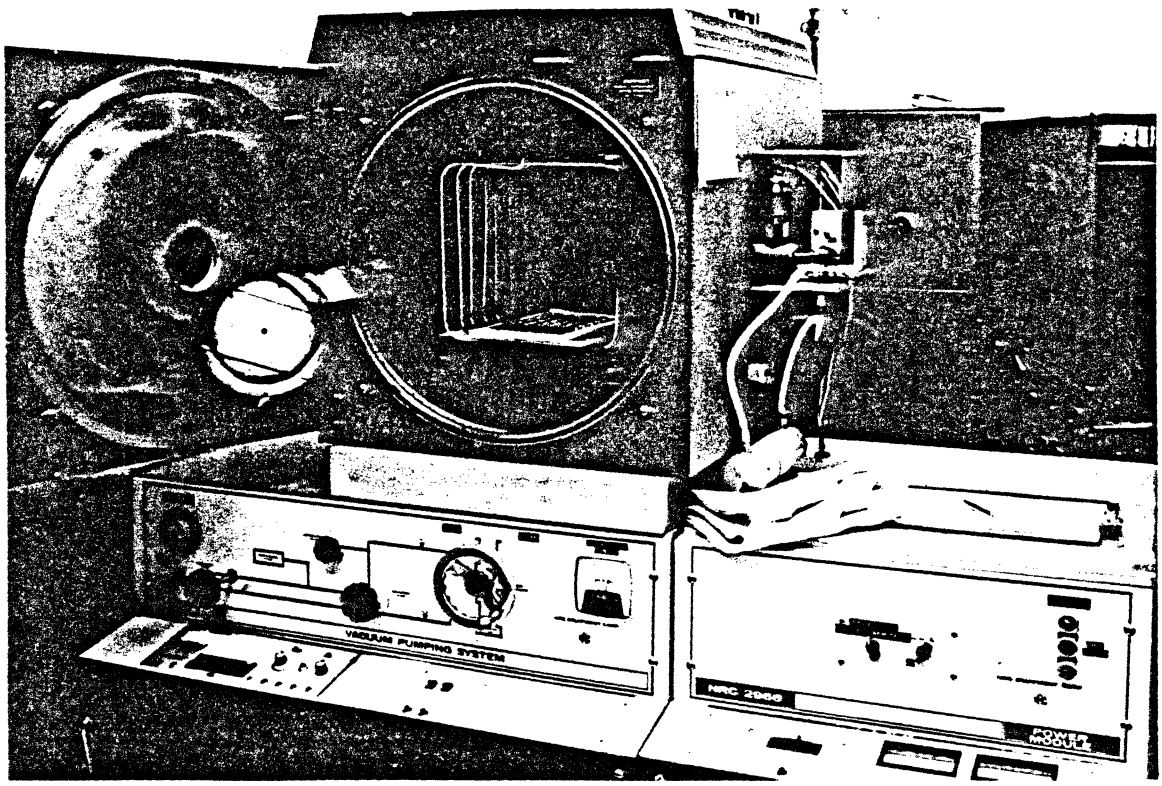


FIGURE 22

VACUUM OVEN

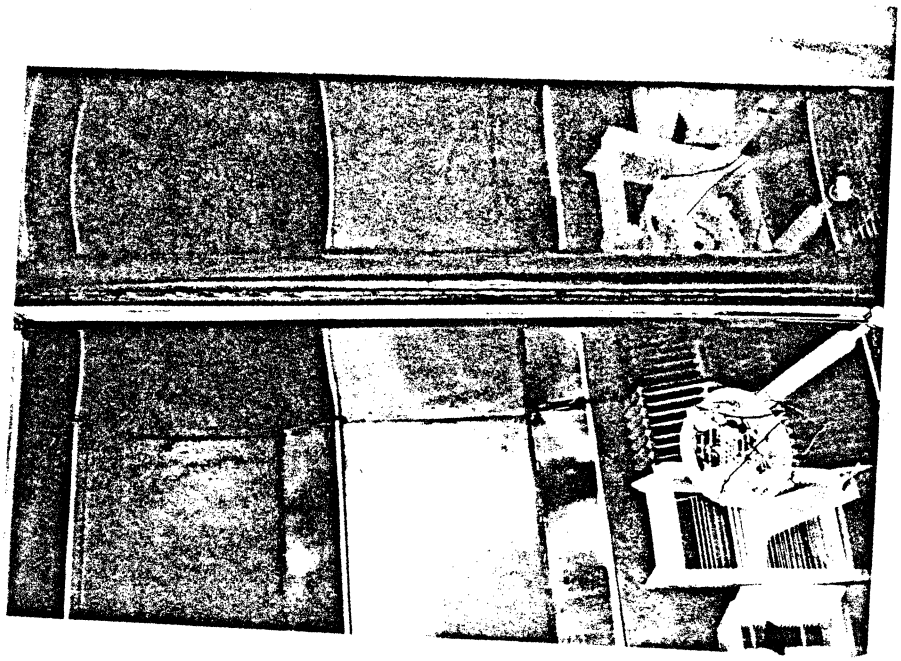


FIGURE 23

ULTRASONIC VAPOR DEGREASING UNIT

Sputter Etch Unit:

VTA Mini-Module is a completely self-contained RF sputter-etch and deposition unit. The sputter electrodes are arranged to etch samples on a lower plate, or deposit onto samples suspended from an upper plate. For the Newton program, we use this system only for sputter-etch.

The vacuum system consists of a mechanical pump and an air cooled and baffled diffusion pump to reduce backstreaming to a negligible value. Gauging consists of a high-pressure ionization gauge controller which reads out in a range from 1000 Torr to 4 X 10^{-6} Torr.

The etch chamber is 6 inches in diameter by 6 inches long, and the RF electrodes are 4 inches in diameter. The RF has a pre-tuned driver and an output of up to 200 watts directly coupled to the cathode feedthrough (see Figure 24).

Sputter Deposition Unit:

The system was previously used in Burlington on their SLT manufacturing line. As received, the unit was an NRC bottom pumped system (oil diffusion with mechanical backing pump) 16-inch diameter sputtering electrodes with a fused quartz target and 5 KW RF power supply applied to the upper electrode through an impedance matching network mounted above the stainless steel sputtering chamber.

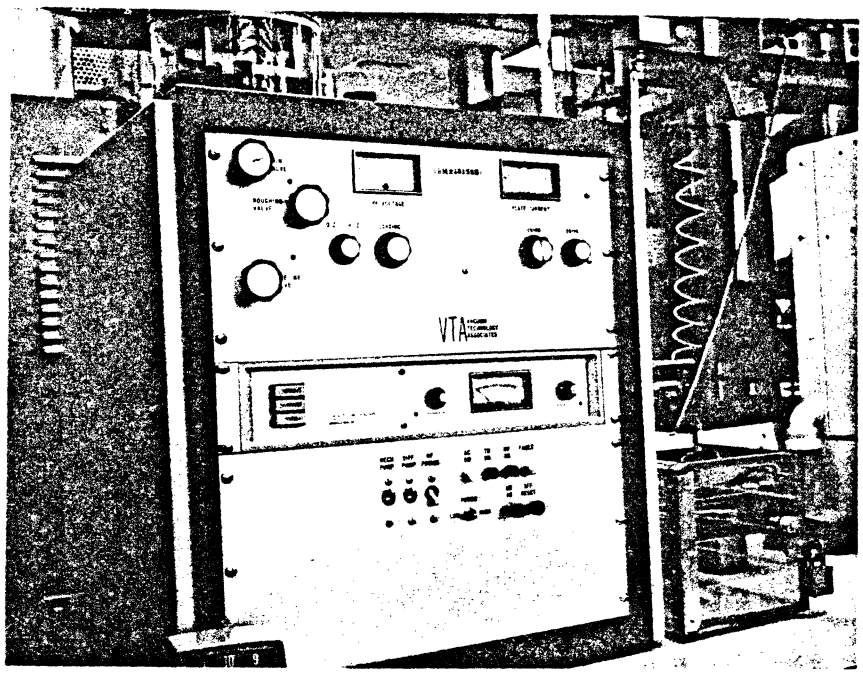


FIGURE 24

SPUTTER ETCH UNIT

A prior requirement was to overcoat a 600 Å metal step with 1000 Å of pinhole-free SiO_2. Consultation with Dr. Joe Logan and his group at East Fishkill resulted in the decision to modify our system to "Driven Substrate", which was the most recent technique for RF sputtering. Advantages to be gained include:

1. Less pinholes in deposited films.
2. Greatly improved edge coverage for overcoats.
3. Higher deposition rates.
4. Less substrate heating as a result of lower electron density.
5. Control over amount of resputtering by varying the amount of power to the anode.

Technical advice for the change was received from Joe Logan, John Keller, and George Donald from East Fishkill; Sol Krongelb from Yorktown (who had just completed a Driven Substrate Conversion of his lab unit); and Carter Kaanta and Mike Teuscher of Burlington (who had converted a 20-inch Tuned Anode to Driven). The main difficulty was in designing the anode feedthrough's and lower matchbox to one side of the diffusion pump package, which is directly under the chamber. The changeover was completed on schedule in July 1971, with the able assistance of Skip Barr from Department 516 (see Figures 25, 26, and 27).

Sputtering Process Parameters for Newton

Substrate Cleaning Process:

Cleaning techniques which had been used for pre-deposition cleaning of substrates on the Thin Film Head program were inadequate when tried on the lapped ferrite substrates for Newton. An SDD group (John DePew, Harold Dunn, Bob Herrmann, Bill Kehr, and Charles Parker) made an examination of the adhesives and lubricants used in slicing, grinding, and lapping of the Newton substrates. A cleaning procedure which combines chemical cleaning and thermal outgassing was then developed by the same group to remove all of these contaminants (see Attachment #1 for procedure).

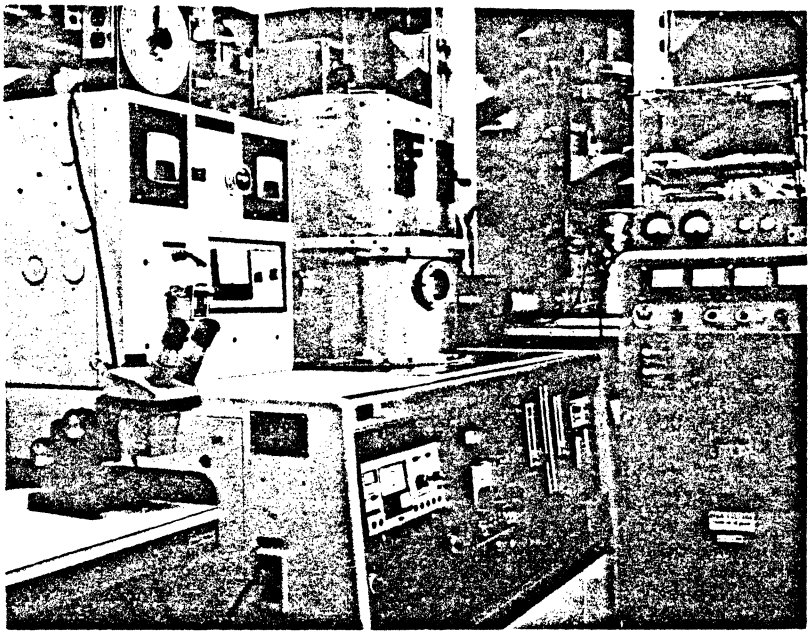


FIGURE 25 - SPUTTERING UNIT

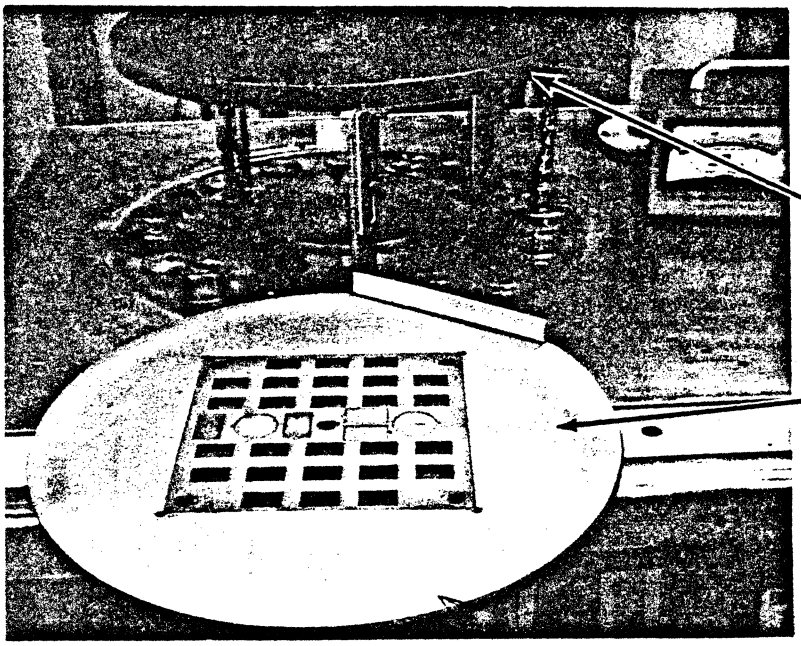


FIGURE 26 - ANODE PLATE TOOLING

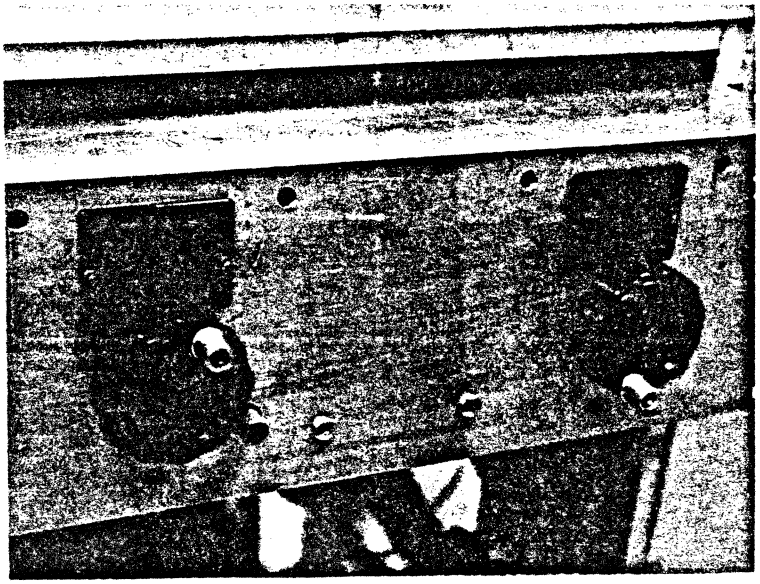


FIGURE 27 - ANODE MATCHBOX CONVERSION

ATTACHMENT #1

NEWTON OPERATING PROCEDURES

CLEANING PRIOR TO Al_2O_3 DEPOSITION

SCOPE

This document specifies the requirements for cleaning housings and center sections prior to sputtered Al_2O_3 deposition.

SAFETY

Follow departmental safety rules. Protective clothing and gloves must be worn.

MATERIALS

1. Freon TMC (M/C 310-801-014)
2. Reagent grade cellosolve solvent (2-Ethoxy Ethanol)
3. Lab filter paper

EQUIPMENT

Combination ultrasonic cleaner (vapor degreaser)

3,000 ml beakers

Teflon cleaning tray

Plastic tweezers

Clean hood

Vacuum oven, NRC (located in Bldg. 021, SDD)

PROCESS REQUIREMENTS

Set Up:

1. Position housing box in hood beside U.S. cleaner/degreaser.
2. Check U.S. cleaner for solvent level, boiling Freon TMC, and that refrigerator coils are "on". Ensure that no water is floating on the solvent surface.

NOTE

Both solvent tanks must be covered at all times to minimize contamination and evaporation of the Freon TMC.

3. Two covered beakers containing Cellosolve should be located in the clean hood.

NOTE

After every third lot, discard Cellosolve into waste solvent can and obtain fresh solvent (for both containers).

Chemical Cleaning Procedure

1. Use plastic tweezers to transfer parts from a housing box to the cleaning tray.

2. Put a clean insert into housing box, blow off with filtered N_2 gas, and place it in the clean hood.

3. Place Cellosolve beaker 1 into ultrasonic tank and uncover it.

4. Immerse cleaning tray and parts into Cellosolve solvent, replace cover, and turn on the ultrasonics for 3 to 5 minutes.

5. Repeat Steps (3) and (4) with Cellosolve beaker 2. Replace covers and relocate beakers in exhausted hood after use.

6. Dip cleaning tray and parts into boiling Freon TMC for 3 to 5 minutes.

7. Vapor rinse parts in Freon TMC for 5 minutes.

8. Quickly move tray from solvent vapor to clean hood. Use tweezers to place parts into clean housing box, ferrite surface up for transportation to the SDD vacuum oven.

Thermal Outgas Procedure

1. Use tweezers to transfer parts to the vacuum oven.

2. Evacuate chamber to 5×10^{-6} Torr.

3. Raise temperature to 600° C and maintain for 3 hours.

4. Cool to 200° C, then backfill chamber with Argon gas to atmospheric pressure.

5. Use tweezers to transfer parts from the vacuum oven to clean housing box, then transport to the AME Lab for further processing.

Sputter Etch Process

Read housings receive a layer of vacuum evaporated metal (Ti-Ni-Fe) at 250° C immediately following the Al_2O_3 deposition. Early in the program we found that the Al_2O_3 layer fractured during this metalization. The solution was to minutely roughen the ferrite surface with a sputter etch step prior to Al_2O_3 deposition (see Attachment #2 for the procedure).

ATTACHMENT #2

NEWTON OPERATING PROCEDURES

SUBSTRATE SPUTTER-ETCH CLEANING

SCOPE

This document specifies the operating procedures for sputter-etch cleaning of substrates prior to the Al_2O_3 deposition.

SAFETY

Follow departmental safety rules.

MATERIALS

Lint free cloth

White nylon gloves

Argon gas, 99.996% pure, dry

Freon TF

EQUIPMENT

VTA miniature sputter-etch system

SiO_2 cathode cover plate

Clean box for transporting parts

Plastic tweezers

Stainless steel tweezers

Clock timer

Freon dryer

Teflon cleaning tray

PROCESS REQUIREMENTS

Set Up:

1. Always wear white nylon gloves when touching surfaces or tooling inside the vacuum chamber.

2. Check VTA panel board to assure that pumps are operational.

3. Check Freon dryer to proper level of Freon TF, tank heaters on, and boiling fluid in the degreasing tank.

PROCEDURE

1. Using plastic tweezers, place substrates into the Teflon cleaning tray.
2. Spray rinse substrates with Freon TF.
3. Suspend cleaning tray with parts in the Freon TF vapor zone for 10 minutes.
4. Transport to the sputter etch unit.
5. Vent sputter etch vacuum chamber and remove jar.
6. Use plastic tweezers to transfer substrates from the clean box to the vacuum chamber. Lay parts on the SiO_2 cathode cover plate, then replace chamber and evacuate. When pressure reaches 5 X 10^{-5} Torr, sputter etching can begin.
7. Backfill chamber with Argon gas to a steady pressure of 10.0 microns (1 X 10^{-2} Torr).
8. Knob settings: Low power setting
   Drive at minimum
9. Turn on RF generator, raise Argon pressure to ignite glow (40 to 100 microns), then lower Argon pressure back to 10.0 to 11.0 microns.
10. Power setting to "High", drive up to Max, and start timer (set for 5 minutes).
11. Tune as follows:

    Load for a peak in RF volts, and tune for a dip in plate current. Go back and forth until:

Current	=	135 to	140 Ma
Voltage	=	1300 to	1400 volts

12. When time is completed, extinguish glow and let parts cool for 10 minutes with Argon flowing.
13. Close Argon valve and Hi Vac valve. Vent chamber and remove bell jar.
14. Use plastic tweezers to transfer parts from sputter-etch chamber to the clean box where they will remain until sputter deposition.
15. Replace jar and evacuate.

NOTE

Hi Vac valve must always be closed with chamber evacuated during non-working hours.

Sputter Deposition

The reasons for choosing Al_2O_3 and sputter deposition were discussed earlier. It took nearly six weeks to obtain a 16-inch diameter Al_2O_3 target bonded to one of the copper cathodes, and during that period, we had sample substrates done at both SDD Boulder (Cole and Wiitala) and SDD San Jose (Tom Kennedy). The Newton schedule dictated a lack of time for characterization of our unit prior to "B" test. As it was, we barely had time for target break-in and a determination of deposition rate before "B" test head sections were in progress. The basis for our "B" test operating conditions were a result of prior work reported by T. N. Kennedy, "Characterization of RF Sputtered Aluminum Oxide," and some limitations of our equipment.

Dr. Kennedy investigated dependences of deposition rate, etch rate, Argon content, refractive index, and structure on the following sputtering conditions:

Power input 5 to 26 watts per square inch

Amount of bias +9 to - 400 volts

Substrate temperature 150 to 450° C

Argon pressure 2 to 4° microns

Limitations of our sputtering unit are as follows:

Power Input - The aluminum oxide target fractures above 15 watts/square inch. This is caused by the large mismatch in coefficient of linear thermal expansion between the OFC copper cathode and the Al_2O_3 target.

Substrate Temperature - The anode plate is water cooled only. Also, the .200 inch thick substrates of BTC and Ferrite do not conduct heat well enough to provide any measure of cooling from anode surface to substrate surface.

Argon Pressure - We have no variable throttle valve between the chamber and pump, but rely on a fixed orifice plate. Increasing the Argon pressure above 10 to 15 microns overloads the pumping system, while decreasing the orifice creates excessive pumpdown time. In addition, the electrode shield designs are such that arcing occurs at an Argon pressure above 10 to 12 microns.

Sputtering Parameters

The only difference between read sections and write sections is the power density and amount of bias. The initial read layer can be crystalline, or nearly so, while the write sections must have aluminum oxide which etches easily and uniformly. In accordance, read sections are processed with higher power density and less bias (as % of input power).

Parameter	Read (Initial Layer)	Write
Power Density (Watts/In^2)	12.5	10
Anode Watts	125	125
Anode Voltage (AC peak to peak)	150	150
Argon Pressure (Microns)	10	10
Measured Substrate Temperature (°C)	250	235

(See Attachment #3 for operating procedure)

ATTACHMENT #3

NEWTON OPERATING PROCEDURES

SPUTTERED Al_2O_3 DEPOSITION - 16" TARGET
NRC SYSTEM (AME LAB)

SCOPE

This document specifies the operating procedures for sputtering a layer of Al_2O_3 onto a housing or center section.

SAFETY

Follow departmental safety rules.

MATERIALS

Lint free cloth

White nylon gloves

LN^2

Argon gas, 99.996% pure, dry

Nitrogen gas, dry, filtered

EQUIPMENT

Glass anode plates

Sputter system, 16: bottom-pumped NRC and controls

Sputter flaking shield

Clean box for transporting parts

Plastic tweezers

Stainless steel tweezers

Filtered, dry N_2 gas supply (hose and nozzle)

Clock timer

Al_2O_3 target, 99.98% pure

PROCESS REQUIREMENTS

Set Up:

1. Move clean box containing sputter-etched parts as close to vacuum chamber as possible.

2. Check to see that LN^2 supply is adequate for run.

3. Check D.I. recirculator for level and operation.

4. Check automatic pumping panel board to assure that unit is in proper operating mode and that pumps are functioning.

5. Always wear white nylon gloves when touching surfaces or tooling inside the vacuum chamber.

6. Each time chamber is opened, inspect S.S. shield and anode cover plate for flaking. Replace if flaking is evident.

PROCEDURE

1. Turn on LN^2 supply to cold trap for 30 minutes prior to operation.

2. Turn on D.I. water recirculator. Flow to be 30+ cc/min. to each electrode.

3. Vent vacuum chamber and raise bell jar.

4. Remove anode cover plate and housing fixture.

5. Using plastic tweezers, load parts from the clean box onto recessed areas in the housing fixture. Also load 5 monitor discs.

6. Replace anode cover plate and housing fixture on top of anode.

7. Use filtered N_2 to blow off surface of housings and plate.

8. Lower bell jar and evacuate chamber. When pressure reaches $2\text{-}3 \times 10^{-6}$ Torr, sputtering can begin.

9. Set timer as follows:

   Read head, initial layer - 100 minutes
   Read head, overcoat layer - 64 minutes
   Write head - 425 minutes
   Center sections - 64 minutes

10. Backfill chamber with Argon gas to a steady pressure of 10.0 microns (1 X 10^{-2} Torr). Approximate flow rate will be 130 to 140 cc/minute.

11. Turn on RF generator, raise Argon pressure to ignite glow (40 to 100 microns), then lower Argon pressure back to 10.0 microns and start timer.

12. Adjust total power at 2.0 KW with .12 KW going to the anode. Tune both matchboxes for 0 reflected power. Periodically, adjust tuning and Argon flow rate to maintain proper level.

NOTE

Read head initial layer, power is 2.5 KW, .12 KW to anode.

13. When sputtering time is completed, extinguish glow and let parts cool for 30 to 60 minutes with Argon flowing.

14. Close Argon valve, vent chamber, raise bell jar, remove anode cover plate and housing fixture.

15. Using plastic tweezers, take parts from fixture and place in clean box for transportation to vacuum metallization. Remove monitor discs and measure thickness.

16. Lower jar and evacuate.

NOTE

Hi Vac valve must always be closed if LN^2 is turned off.

RESULTS OBTAINED

Thickness control, within a batch, and from run to run.

Sputter tooling consists of an 8-inch square plate with nests for head housings and thickness monitor disks. The nests are recessed so all substrate surfaces which receive Al_2O_3 are at the same level (1.25 inches from the target). Five monitor disks are used with each lot to be deposited. Four disks are located at the extreme corners of the holding fixture and one disk is in the center (see Figure 26).

Measurement of the aluminum oxide thickness is made with an interferometer. Some samples are checked with a brush or Dektak surface analyzer.

Deposition rates have been plotted against time on Graph 1 (Figures 28 and 29). The resultant curves for 2.0 KW and 2.5 KW power input both show a drop in rate for the first 1 to 1.5 hours of sputtering, followed by a steady rise in rate from that time on. Apparently, the amount of resputtering increases initially, and then drops off (resputtering is material deposited upon the substrates, then removed by Argon ion bombardment from anode biasing).

A statistical analysis of all runs performed to date on Newton head substrates shows that 2.0 KW power input gives a more uniform thickness than deposits at 2.5 KW power input:

Thickness Control (95% Fall Within)

Power Input	Run to Run Variation From Mean	Variation of 5 Samples Within a Batch From Mean
2.0 KW	± 10%	± 5%
2.5 KW	± 17%	± 12%

Importance of Sputter-Etch and Problems Encountered

Early SDD Al_2O_3 sputtering experiments by T. Cole and J. Wiitala indicated the necessity of sputter etch cleaning the ferrite surface before Al_2O_3 deposition. They found very poor adhesion between the ferrite and alumina unless the ferrite surface received a few minutes of sputter etching.

Initially, several batches of read and write housings were processed in the AME Lab without any sputter etch treatment. No problems were observed with the write housings during deposition of the 100 microinch alumina, or during chemical etching to remove all but the bar stripe. Read housings gave no indication of problems during alumina deposition, but we found that the Al_2O_3 film (25 microinches) crazed and cracked during the subsequent operation where metals are evaporated at 250° C. This problem has shown up in every instance where sputter etching was omitted, but never when sputter etching was included in the process.

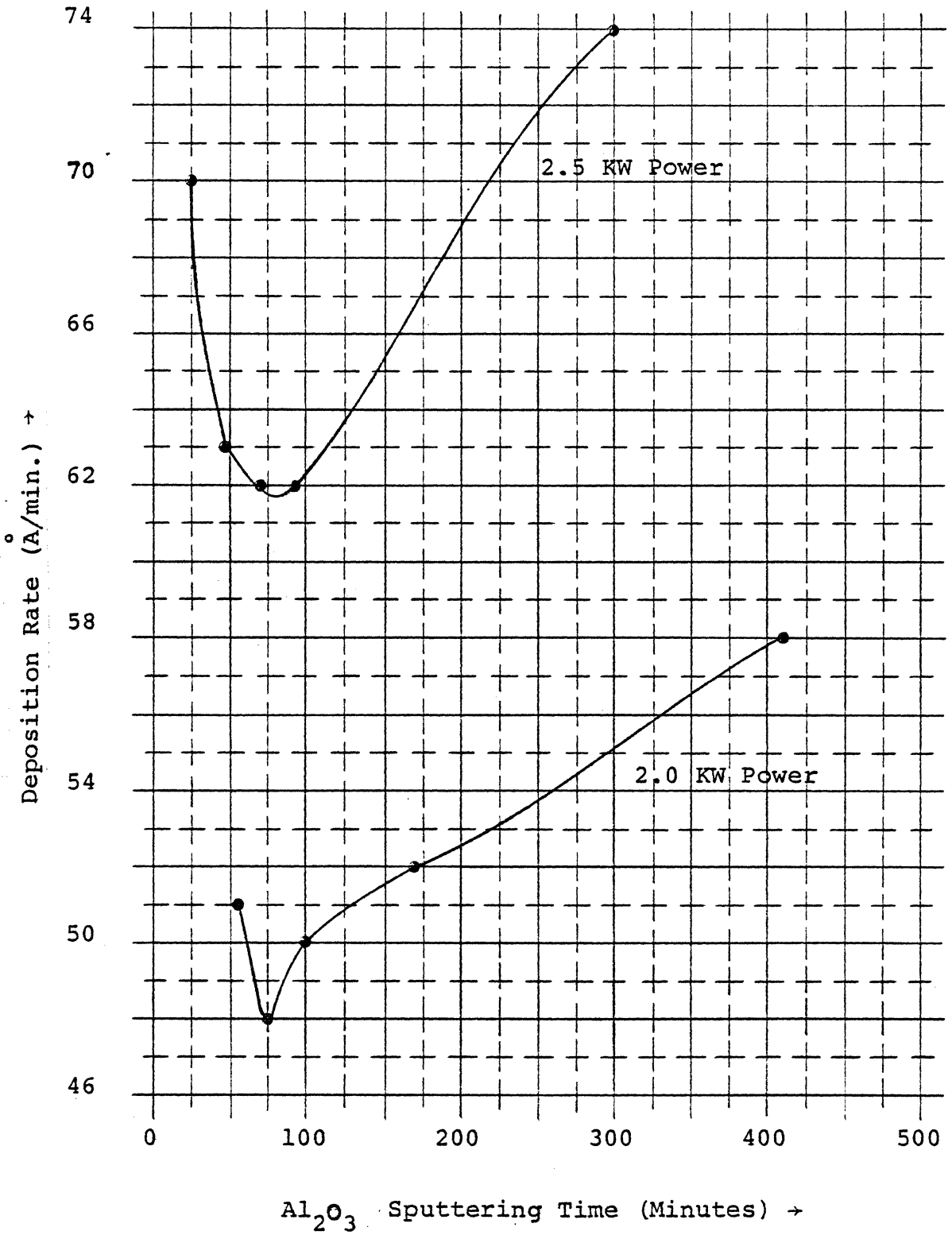


FIGURE 28

DEPOSITION RATE VS SPUTTERING TIME

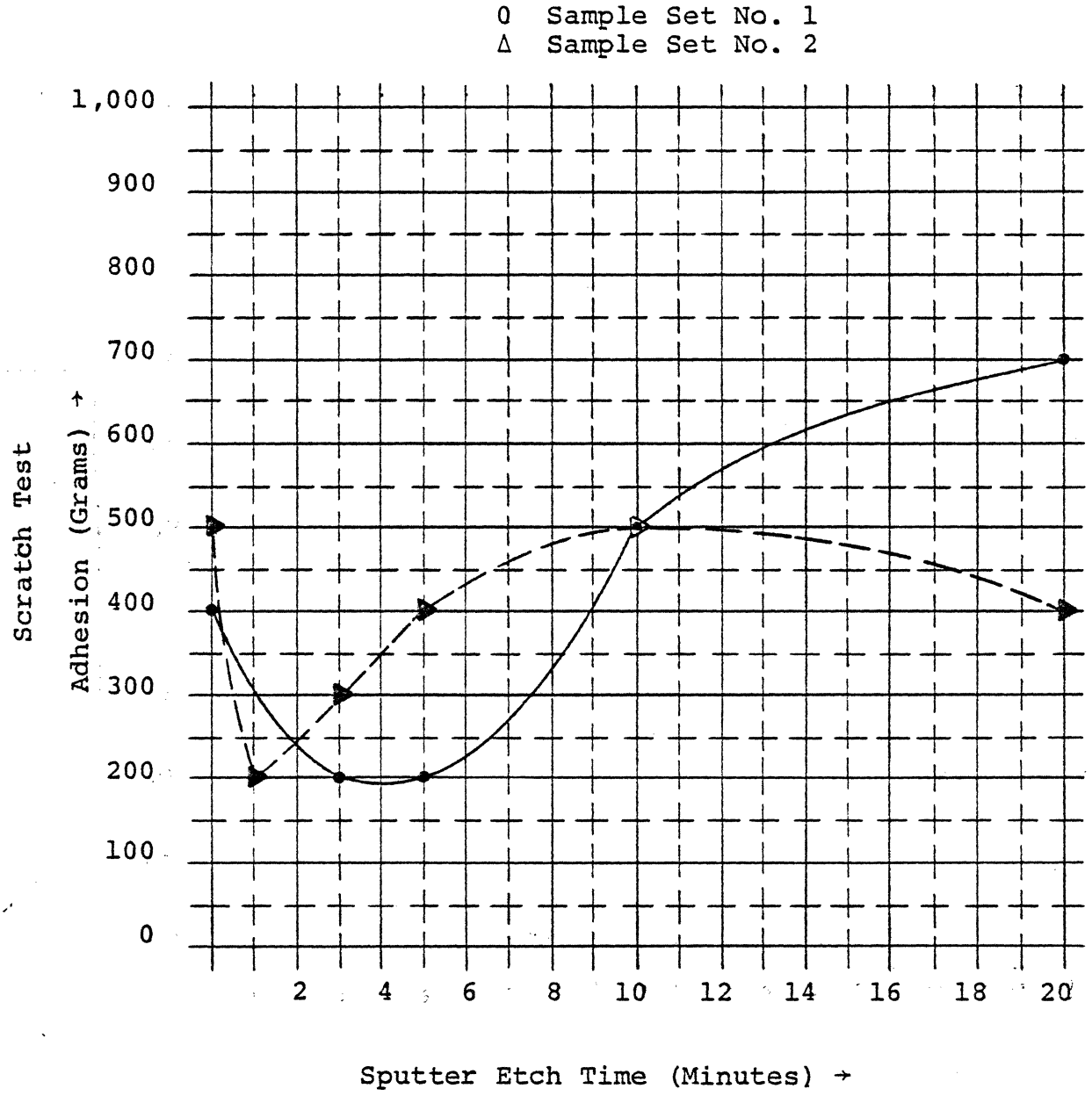


FIGURE 29

ADHESION VS SPUTTER ETCH TIME

SEM (Scanning Electron Microscope) and optical microscopy were used to study the sputter-etched ferrite surface. These studies indicated that 5 minutes of sputter etching just begins exposing grain boundaries, while 20 minutes causes considerable erosion to grain boundaries. Surface analysis with a Brush Proflicorder showed barely detectable roughening on 5-minute etch samples, while 20-minute samples showed significant roughness.

Adhesion of the Al_2O_3 film to the ferrite was measured with an SDD gram loaded scratch tester. Plotting adhesion versus sputter etch time showed an initial drop followed by a slight increase (see Graph 2 on Figure 30), but the results may be influenced more by film thickness and stresses than on sputter etch time. Graph 3 on Figure 31 plots film thickness versus adhesion, and a general decrease in adhesion is noted with increased thickness.

Etchability of Write Sections and Overcoat Layers:

A discussion of the sputtering parameters which affect the etch rate of Al_2O_3 films will follow the next section. Etching the Al_2O_3 films on Newton head housings was erratic and unpredictable for the first 4 months of the program. Both the rate and amount of undercut varied widely from part to part. It was known that Al_2O_3 films deposited above 350° C become crystalline (T. N. Kennedy report of 03/04/71), and are unetchable with phosphoric acid. However, Yorktown analysis of the films indicated that they were amorphous and our spot checks of surface temperature showed 250° C during deposition.

A later analysis of our Al_2O_3 films by Mr. J. N. Ramsey of East Fishkill, showed there were distinct crystalline phases present within the top 200 Å of the surface, while the bulk of the film was indeed amorphous. During this same period, a problem with the sputtering unit was discovered. RF power supplied to the cathode along copper water lines was shorting across a narrow gap between the cathode bolt washer and the aluminum holder plate, and then diverted to heat the bolt and washer to the point that they melted into the teflon block. This localized heating apparently caused the crystalline phases and etching problems. Recent samples have been sent to J. N. Ramsey for confirmation. After the RF short was corrected, all parts were uniformly etched.

Al_2O_3 Experiment:

A test plan for sputtering of Al_2O_3 was set up by K. K. Simons (Attachment 5). The plan was designed to determine the effect of power ratio (cathode/anode), mode (floating and non-floating), and sputtering time on the following measurements:

Etch rate, adhesion, thickness, hardness, and Argon content.

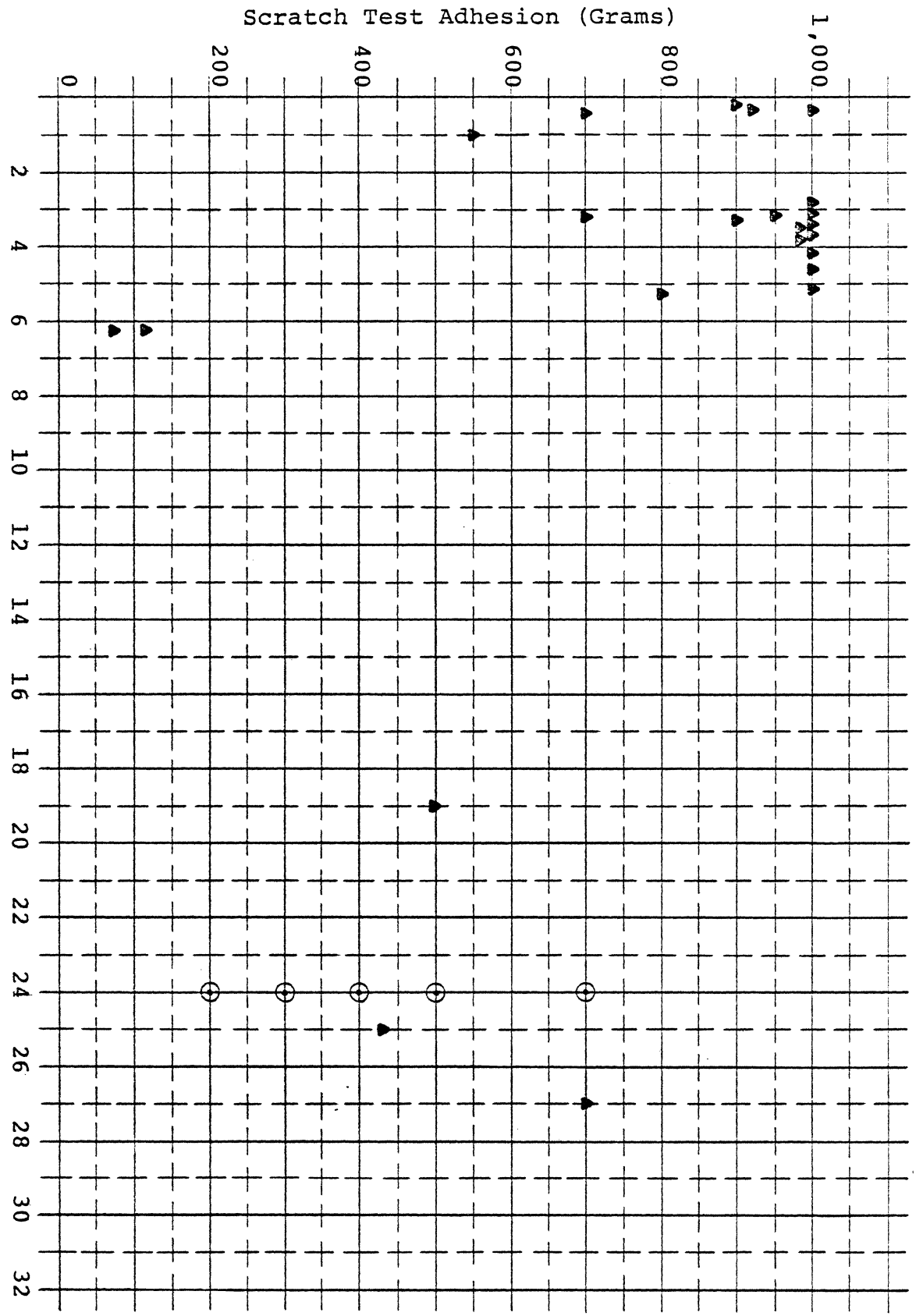
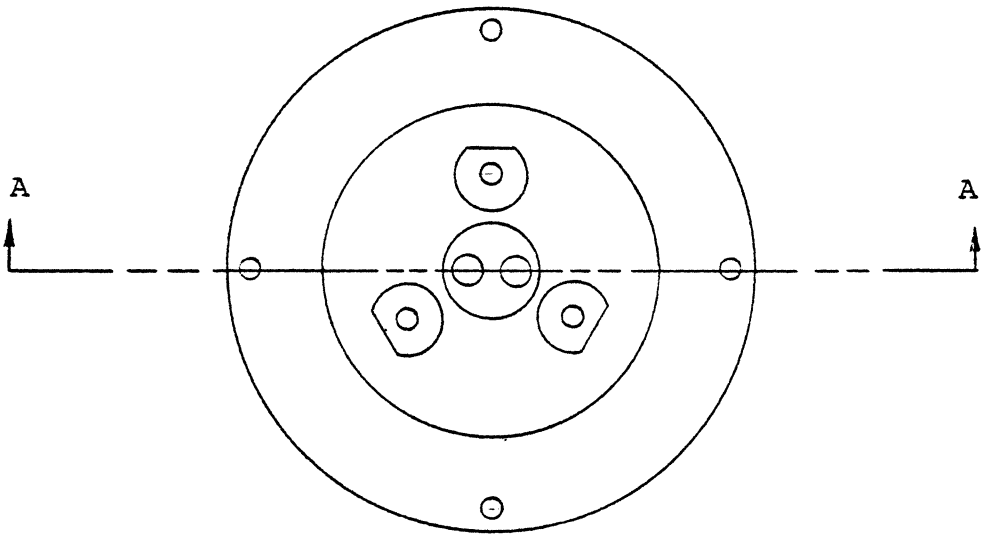


FIGURE 30

ADHESION VERSUS Al_2O_3 THICKNESS



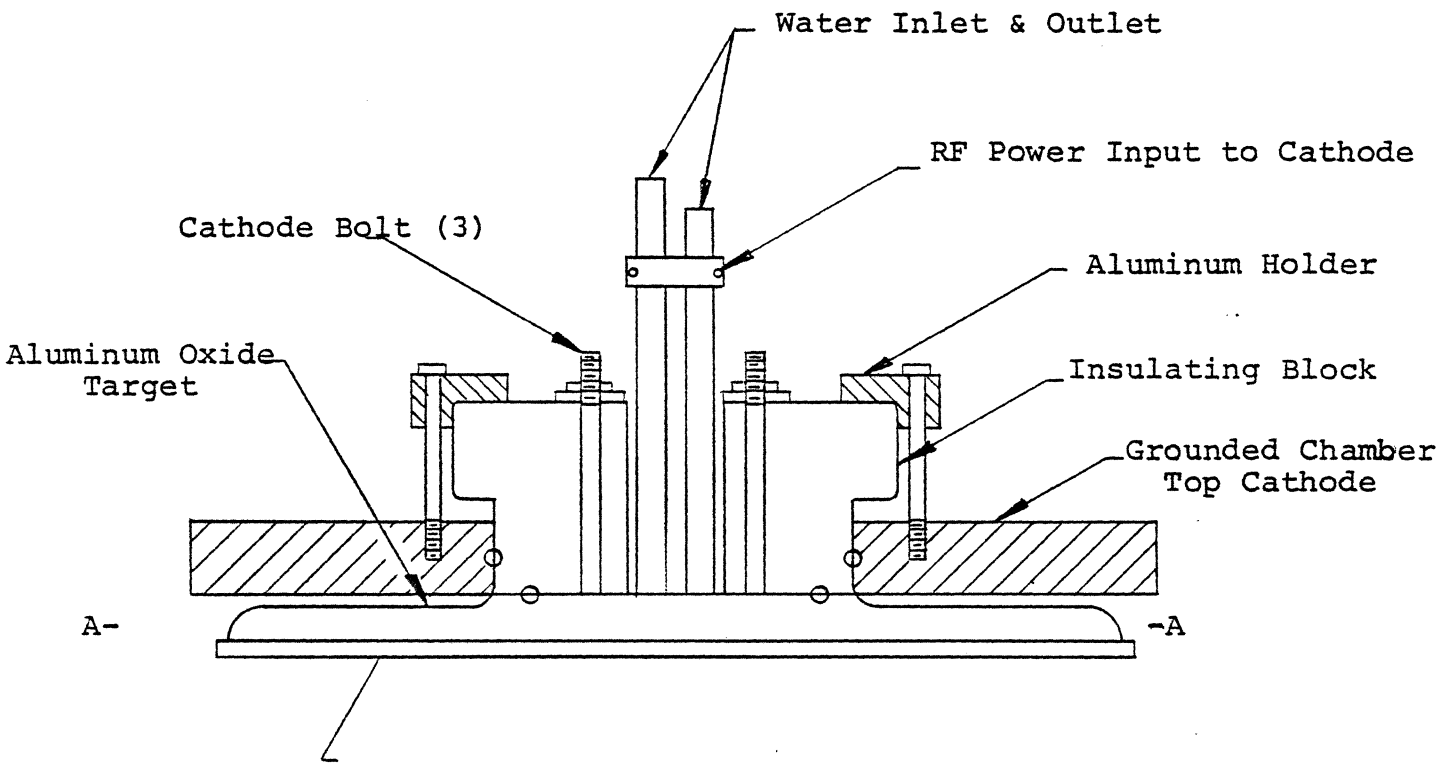


FIGURE 31

SKETCH OF CATHODE ASSEMBLY

The complete statistical analysis is listed in Attachment 6 (results are only valid for 10.0 watts/in ^{2} power, time between 60 to 460 minutes, 7/1 to 15/1 power ratio, and for floating or non-floating mode):

1. Film thickness, Argon content, and etch rate are all dependent upon sputtering time (mode and power ratio constant).

2. Thickness tolerance within a run, and between runs appears to fall within $\pm$ 10%. Mode and power ratio do not affect thickness.

3. Etch Rate: RF mode (non-floating) gives slower etch rates than floating. At constant RF mode, etch rate is a function of time (positive, and curving upward) and power ratio (more anode bias, faster etch rate). Most of the relationship is due to time.

4. Argon Content: Function of time (positive, and less than linear) and power ratio (more anode bias, higher Argon content). Time is the most influential.

5. Etch rate and Argon content show a near linear increase with increasing bias (mode and time constant).

6. Adhesion: RF mode gives higher adhesion than floating. Using RF mode only, adhesion is a function of time (positive exponential), power ratio, and power ratio squared. Time is the most influential.

7. Position of the ferrite sample in the chamber did not affect any of the dependent variables.

8. Cleaning methods did not appear to have any effect on the dependent variables.

NOTE: Graph 4 on Figure 32 shows the anode voltage (AC peak to peak) at various power ratios.

Head Grind and Wear Study:

A number of dummy heads were deposited with Al_2O_3 in the head gap. Several of these heads were also subjected to tape wear testing in a drive, where the depth of gap erosion was measured at periodic intervals.

This test was our first indication that Al_2O_3 deposited in the floating mode was unsatisfactory because of pull-out's and chipping for grinding and lapping, while Al_2O_3 deposited in RF mode (non-floating) performed very well (see Figures 33 and 34).

Re-running the test with the read and write deposition modes reversed confirmed that RF mode was essential for good grind and lap characteristics. Also, results of the Al_2O_3 experiment showed that RF mode provides a better adhesion between Al_2O_3 and ferrite, than does the floating mode.

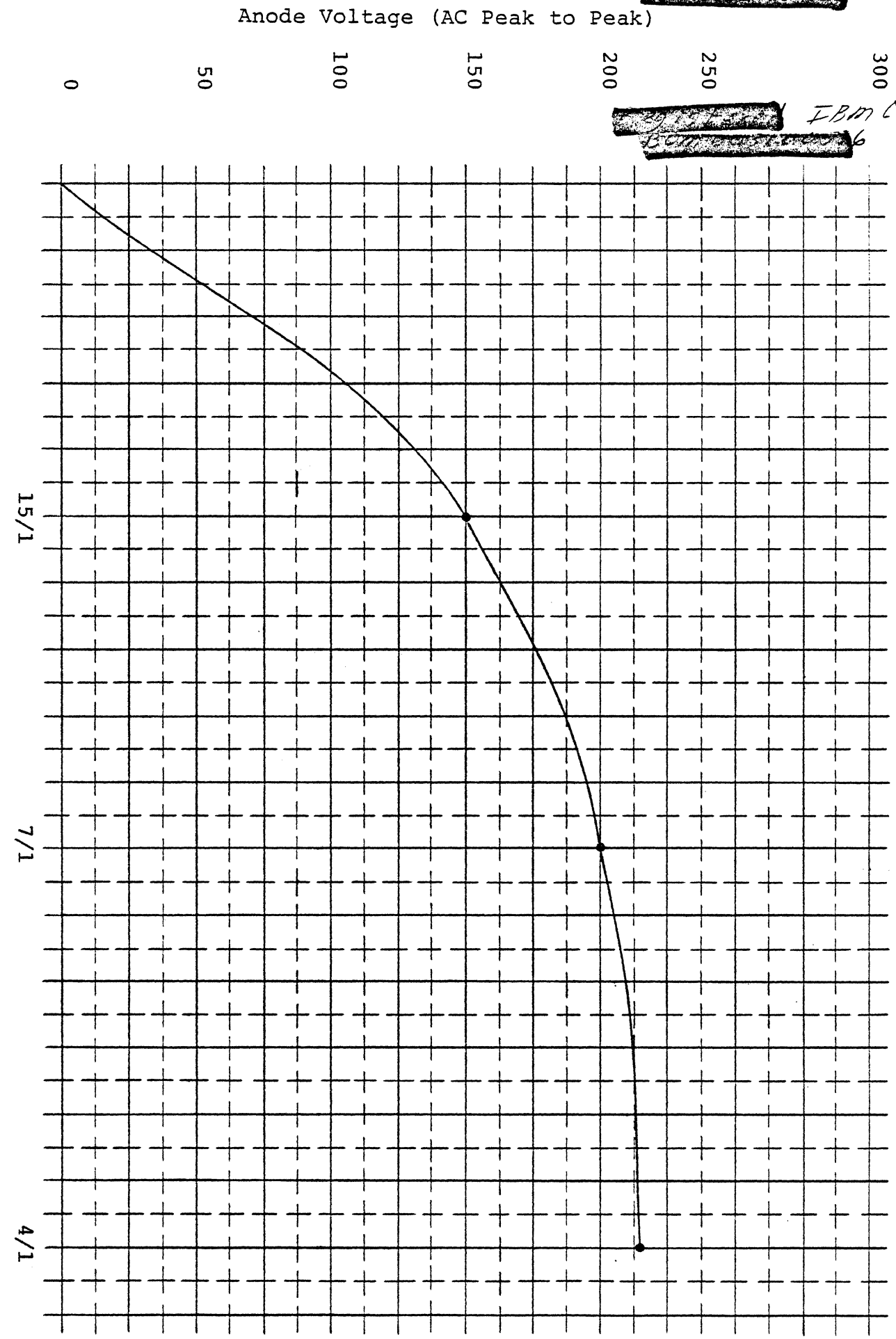


FIGURE 32
ANODE VOLTAGE VS POWER RATIO

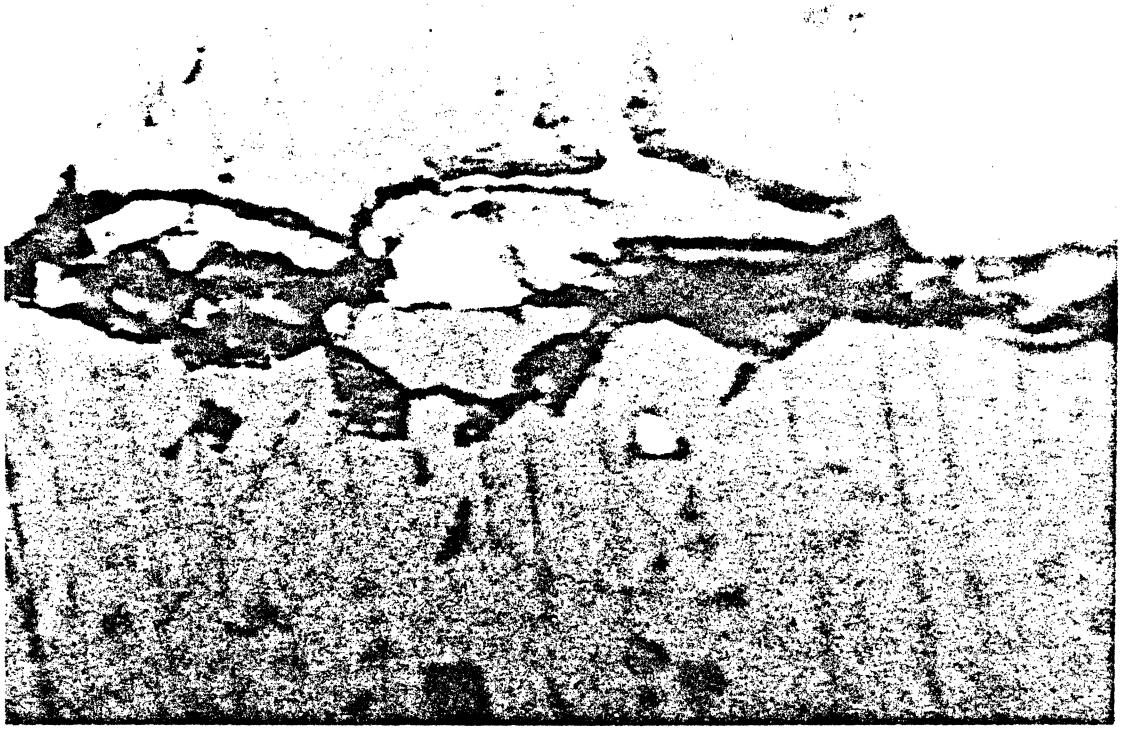


FIGURE 33

ALUMINUM OXIDE DEPOSITED IN FLOATING MODE (1000X)

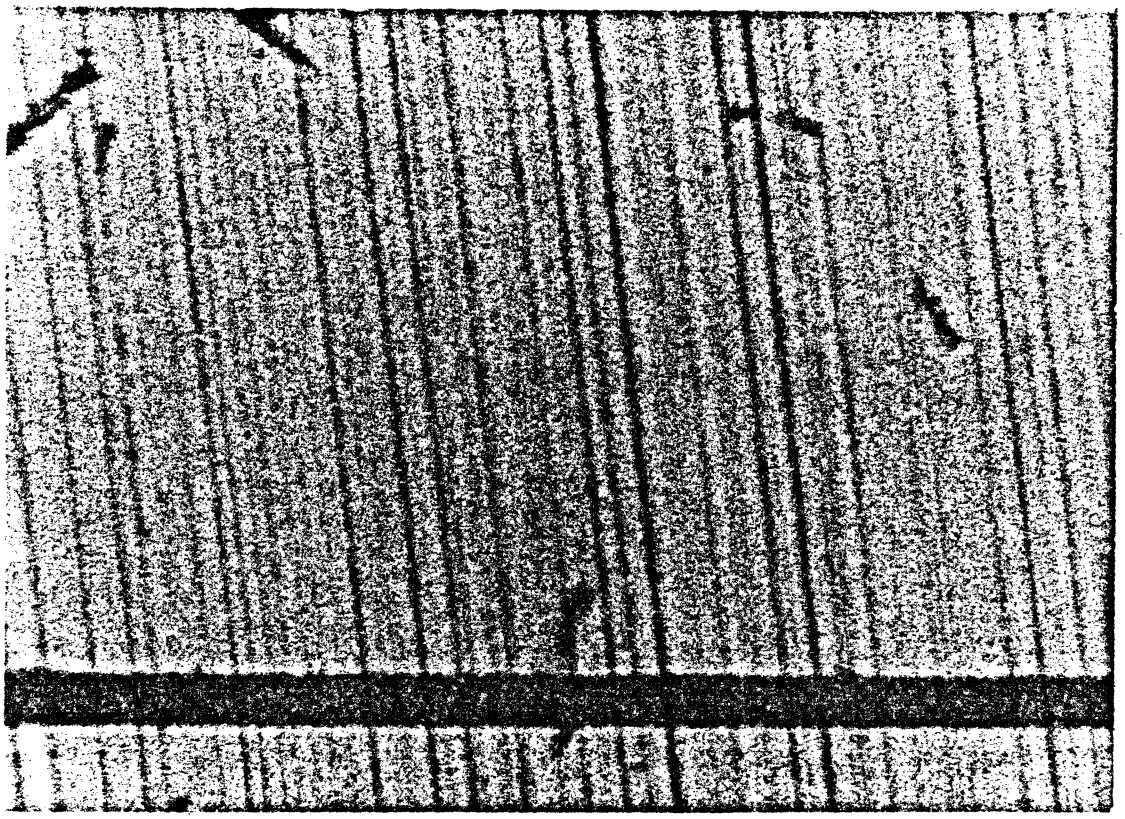


FIGURE 34
ALUMINUM OXIDE DEPOSITED IN RF MODE (1000X)

Tape wear tests have shown that our Al_2O_3 is not as abrasion resistant as the films deposited by Kennedy at San Jose, or by Cole and Wiitala at Boulder SDD. The AME erosion is approximately double that of SDD (1,000 hours), but still should present no difficulties over the life of a head. The SDD films are deposited at higher power density in San Jose, and at higher temperatures in SDD Boulder (non-etchable).

VACUUM DEPOSITION

Vacuum deposition was the best method found for depositing the thin film of NiFe onto the ferrite and Al_2O_3 substrates. Many experiments were conducted on different processes to achieve the desired results. Design of the head dictated the following deposition requirements:

Adhesion - The films deposited on ferrite and Al_2O_3 must sufficiently adhere to the substrate so all subsequent operations (plating and etching) will not lift the film.

Thickness and Uniformity - Thin films on the order of 300 $\pm$ 50 angstroms have been specified. However, measurement accuracy of films in this thickness range is difficult to obtain. However, efforts to obtain greatest accuracy are exerted. Uniformity across a one-inch surface should be no problem and is not specified.

Stoichiometry - A NiFe film of 83% $\pm$ 1% Ni has been specified.

Film Orientation - The magnetic orientation of the NiFe film to the "easy axis" and parallel to the tracks must be accomplished during film deposition.

Two of the vacuum systems are standard NRC systems with the VHS "pot bellied" diffusion pump. Both are equipped with automatic pumpdown. One system has a motor drive bell jar hoist; the other is manual. Both systems are backed up by a 17.5 CFM mech pump (see Figure 35).

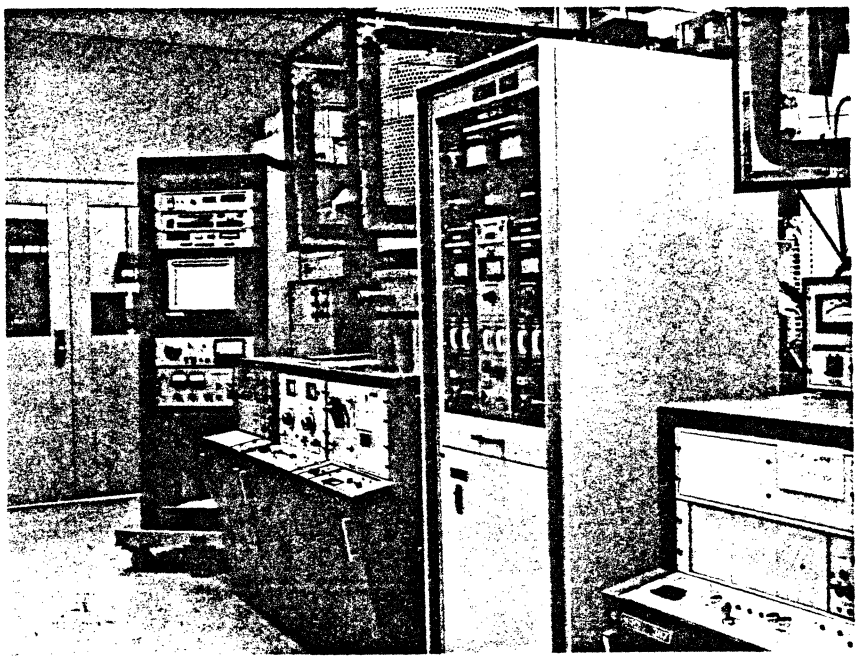


FIGURE 35

VACUUM SYSTEM WITH E.B. POWER AND HELMHOLTZ COILS

The third system is "home built" with an NRC VHS diffusion pump (backed up by a 50 CFM mechanical pump), a manual pumpdown, and a motorized bell jar hoist mechanism.

All systems employ Meisner traps and are capable of depositing a "non-gettering" material at 10^{-6} Torr.

Deposition Source - A 10 KW electron beam power supply is used for all three systems (refer to Figure 36).

A four-position electron beam gun is mounted on each system. The guns enable the deposition of four different materials without having to break vacuum to change source materials.

A source position indicator has been fabricated and installed on the systems. This enables the operator to know what source is in position at any time. An interlock has also been incorporated to turn to the Helmholz power supply when the NiFe source is in position.

An X-Y sweep has recently been installed on one system. The sweep enables the beam to be moved longitudinally and laterally over the crucible rather than being concentrated in one spot. The advantages of using such a device are: it breaks up the thin layer of oxide that covers the material, and that it will enable the deposition of materials that sublime (SiO, Cr, etc.). These materials can be deposited with a stationary beam but the beam burns (vaporizes) a hole through the material and then ceases to evaporate. The beam sweep overcomes this difficulty. In addition, a larger area is evaporating which gives a more even distribution of the film.

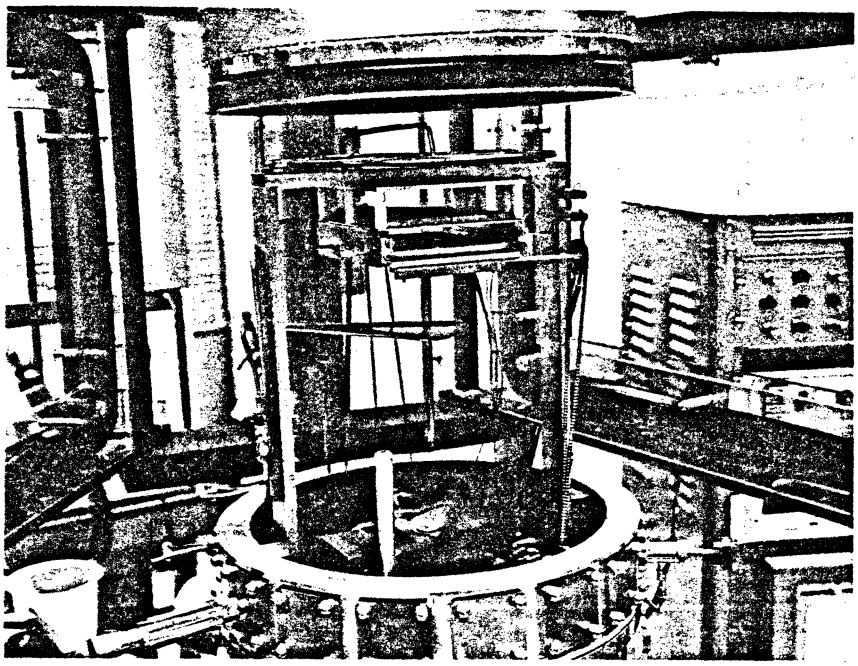


FIGURE 36

INTERIOR OF VACUUM CHAMBER

Helmholtz Coils - The two NRC systems have a pair of Helmholtz coils mounted on either side of the jar to orient the deposited NiFe film (see Figure 37). These coils are capable of 60 oe at the center of the jar. The coils measure approximately 2 X 3 feet and will cover about 6 X 6 inches.

The "home built" system has a pair of larger coils capable of over 100 oe. They measure 3 1/2 X 5 feet and will cover approximately 12 X 12 feet.

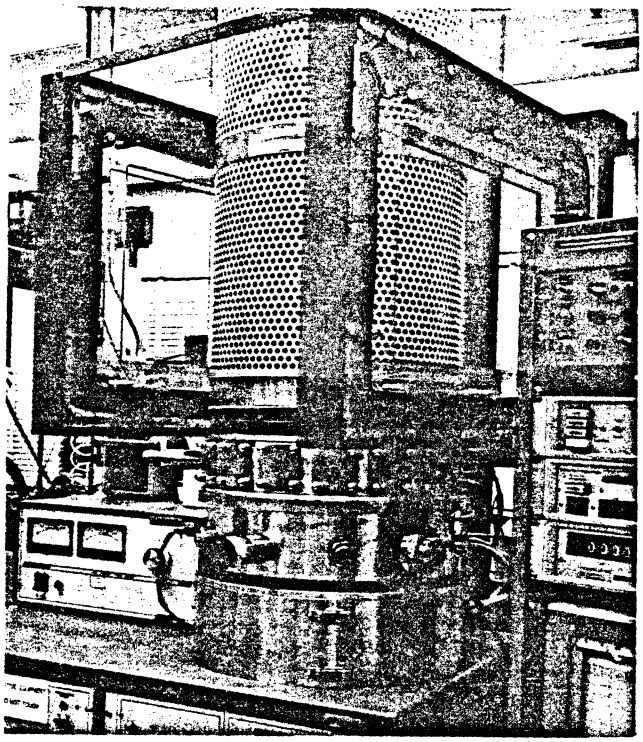


FIGURE 37

HELMHOLTZ COILS

Substrate Tooling - Present tooling is capable of producing seven read housings in two pumpdowns or 12 write housings in one pumpdown (the reason for the two pumpdowns on the read housing is that vacuum must be broken so a mask can be inserted before the final deposition of Cu (see Figure 38).

The substrate heater is able to raise the substrate to 300° C, using one-half power for approximately 10 minutes.

New tooling (installed but not functional because of lack of new heaters) can produce 20 housings (read or write) in one pumpdown. The new tooling incorporates a movable mask which is controlled from outside the chamber. In addition, five pilot process monitoring slides are incorporated in the new tooling (see Figure 38).

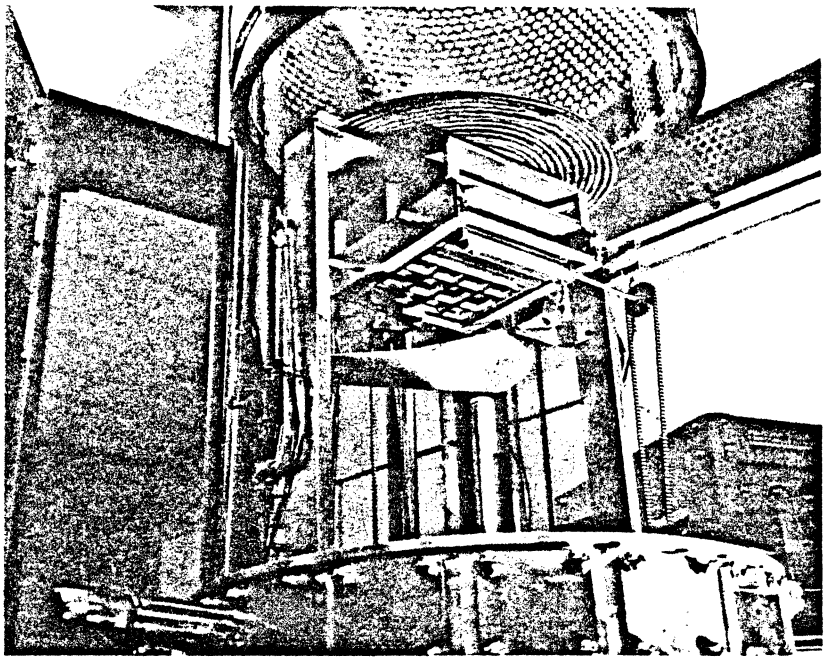


FIGURE 38

TOOLING FOR 20 HOUSINGS PER RUN

Cleaning - Parts are chemically cleaned in detergent, followed by a DI water rinse, then Freon dryed.

A 5000V, 500 ma, high voltage power supply is used to clean the substrates by "glow discharge" after they have been placed in the vacuum chamber. A needle valve allows the introduction of Argon into the chamber during the cleaning cycle.

Monitoring - Film deposition is monitored by, and the EB power supply controlled by, a Granville-Phillips Automatic Deposition System. This is a quartz-crystal oscillator monitor.

Deposition Process:

The following instructions apply to all substrates:

1. Wear nylon lint-free gloves to avoid skin contact with parts.

2. Clean all substrates per specified cleaning procedure.

3. Blow off loaded substrates with ionized dry nitrogen gas.

Read Housing:

1. Load substrates in substrate holder.
2. Pump down to low 10^{-5} Torr.
3. Backfill with Argon gas and "glow discharge" clean @ ≈ 2500 V and 250 ma for 5 minutes. Control power with gas flow.
4. Heat substrate to 150° C during pumpdown to 10^{-6} Torr region, using Meisner trap.
5. Deposit 1350 Å Ti.
6. Heat to 250° C.
7. Deposit 300 Å NiFe in 40 oe field at a vacuum of $< 2.0^{-6}$ Torr.
8. Cool substrate to 80° C. Open chamber and insert mask.
9. Pumpdown to 10^{-6} Torr region utilizing Meisner trap. Heat to 150° C.
10. Deposit 20 microinches of Cu.
11. Cool to 80° C and remove parts.

Write Housing:

1. Load substrates in substrate holder.
2. Pump down to low 10^{-5} Torr.
3. Backfill with Argon gas and "glow discharge" clean @ ≈ 2500 V and 250 ma for 5 minutes. Control power with gas flow.
4. Heat substrate to 150° C during pumpdown to 10^{-6} Torr region, using Meisner trap.
5. Deposit 500 Å Ti.
6. Deposit 1000 Å Cu.
7. Cool to 80° C and remove parts.

RESULTS AND ACCOMPLISHMENTS:

A "grand slam" experiment performed with SDD on 300 angstroms film, revealed a thickness deviation of 27 angstroms as measured by X-ray. Stoichiometry of the deposited film was within 1%. Temperature control was $\pm$ 2% @250° C.

Some experiments were performed concerning deposition through a mask. This procedure showed a great deal of promise. However, a complete read mask has not been obtained because of the difficulty encountered in trying to manufacture a mask from molybdenum.

Experimentation was performed involving deposition on a photo-resist pattern, followed by removal of the resist to leave the desired pattern. These experiments are still being conducted.

Considerable effort was expended on a resistance monitor. Head design required a certain resistance line, rather than a specified thickness. Many problems were encountered -- contact resistance for one was solved. However, the resistance versus temperature change was found to be very unreliable and not controllable. For these reasons, along with experience within the company, the idea was dropped.

In conclusion, all vacuum deposition head requirements were met and controlled. There is no reason to believe the AME vacuum deposition area could not meet the requirements of almost any head design developed.

COPPER ELECTROPLATING

Copper plating is required to produce the write tracks for the Newton head. The copper is deposited by an additive process which achieves maximum track definition and quality. The additive method of electroplating uses photoresist as a mask to define the track pattern. The photoresist is non-conductive and prevents the electro-deposit from forming on any surface which it covers. This technique produces conductors with finer detail than the conventional etching technique. A typical write track electroplated by this technique is shown in Figure 39.

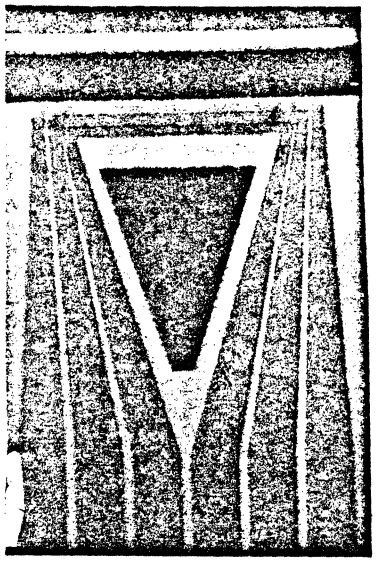
The requirements for copper deposits are a thickness of 90 $\pm$ 5 microinches and a conductivity of 70% or greater than OFHC copper. The copper is deposited on a metallized ferrite substrate which contains aluminum oxide wear bars and the photoresist pattern to define the tracks. The metallized layer consists of an initial vacuum deposit of 50 to 100 angstroms of titanium for adhesion and 1,000 angstroms of copper for conductivity. Following metallization, the photoresist is applied as described in the photolithography section to provide track definition. A cross-sectional sketch of the structure immediately following plating is shown in Figure 40.

Another important requirement for the copper deposit is that it be free of lumps or nodules which exceed the 90 $\pm$ 5 microinch thickness limit. Lumps cause closure problems because the face of the write section is positioned directly against the center section. When attempting to deposit 90 micro inches by vacuum deposition, lumps or nodules are frequently obtained. If a nodule is present, a wide gap proportional to the height of the defect will result. The lumps appear to be a copper oxide which are extremely difficult to remove by etching. The difficulty resulting from vacuum deposited copper and the superior line quality achieved with an additive process determined copper electroplating as the best method for processing write tracks.

Equipment

The copper is deposited in an electroplating module containing the copper electrolyte which was built exclusively for this application. The equipment used is represented in Figures 41 and 42. For development flexibility, the unit has been built to utilize either a copper or permalloy electrolyte. During operation, the temperature of the electrolyte can be maintained within $\pm$ 0.15° F.

FIGURE 39. TYPICAL PLATED WRITE TRACK



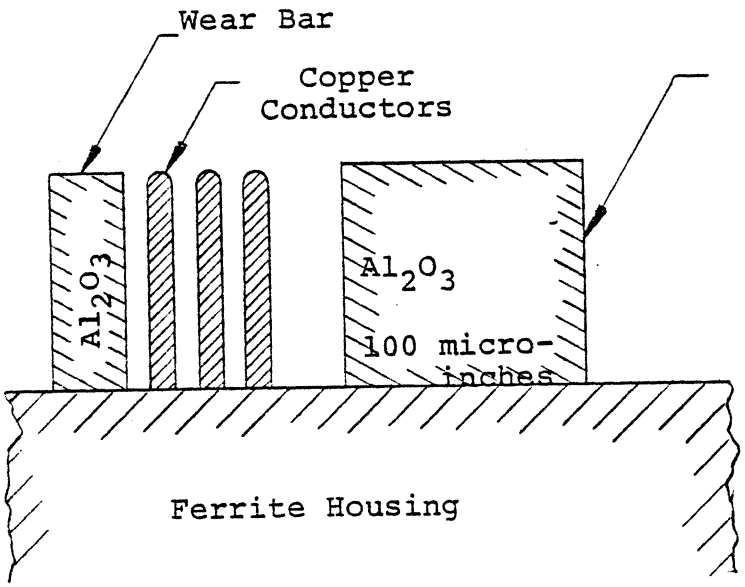


FIGURE 40. CROSS-SECTIONAL VIEW OF WRITE TRACK SECTION

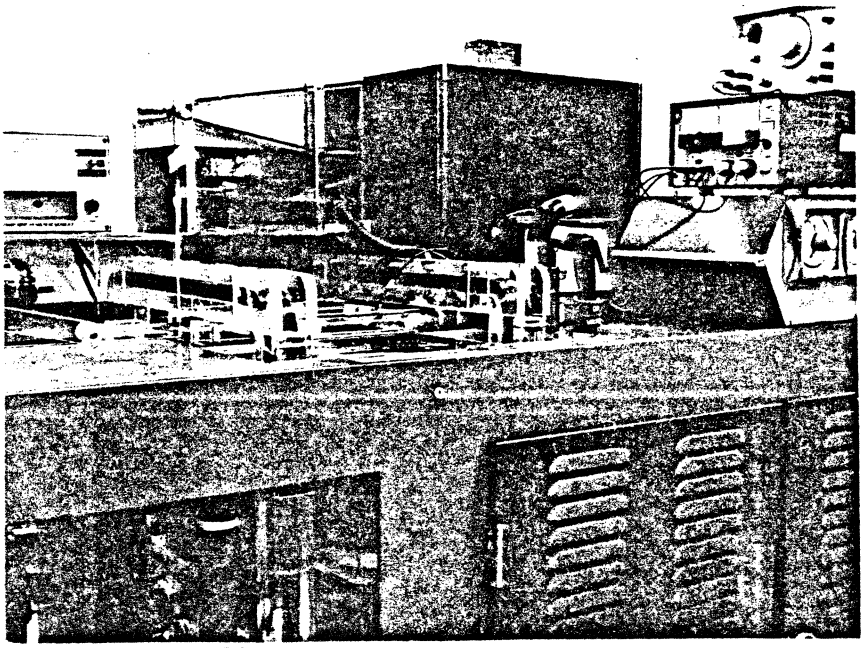


FIGURE 41. PLATING MODULE EQUIPMENT

Description of System (Refer to Figure 42):

The holding tank (A) contains both heating (A-1) and cooling elements (A-2). The temperature of the solution is precisely controlled by constantly cooling the electrolyte with cold water flowing through the cooling coil and heating with a pair of large heaters (A-1). Rapid thermal cycling is achieved using the continuous cold water flow as a heat sink to prevent the heaters from overshooting a given thermal set point. Mixing and agitation of the electrolyte is achieved by the large magnetic stirrer (A-3), and the flow of electrolyte in the bottom of the holding tank.

The spillway (B) provides a passage for the electrolyte to reach the plating cell. The spillway has a gradual ramp slope to provide thermal capacitance for the system. The ramp averages out any temperature fluctuations in the holding tank before the electrolyte reaches the plating cell. The spillway also provides a laminar flow of solution to prevent excessive air entrapment and bubbling from electrolytes containing wetting agents.

The plating cell (C) is designed to hold a cathode and anode in a vertical position and to agitate with a work rod agitator. Maximum uniformity and mixing of electrolyte is achieved by feeding solution into the bottom of the cell and overflowing from the top lip of the cell.

The filter pump (D) is positioned ahead of the filter and holding tank. Since pumping solution imparts energy into the fluid with a corresponding temperature rise, fluctuations in temperature in the plating cell are avoided by locating the filter pump at the overflow side of the cell.

The large filter (E) is used to remove any solid contaminates from the system.

The unit also contains a DI water level control system for maintaining a constant volume of solution. Helmholtz coils (F) are positioned around the plating cell for orienting magnetic permalloy films.

A digital DC power supply (G) is incorporated with the plating module to control the total coulombs for a plating cycle. Both current and plating time are programmed prior to the beginning of a cycle. The total coulombs are controlled within $\pm$ .1% of the total.

The plating fixture used to hold the housing during deposition is represented in Figure 43. Six write housings are held in the fixture for electroplating. Contact to each housing is made with spring loaded vlier screws in the fixture frame. Figure 43 shows a substantial thieve area which is plated with the parts to achieve thickness uniformity. After loading six parts in the fixture, it is positioned horizontally in the plating cell for plating.

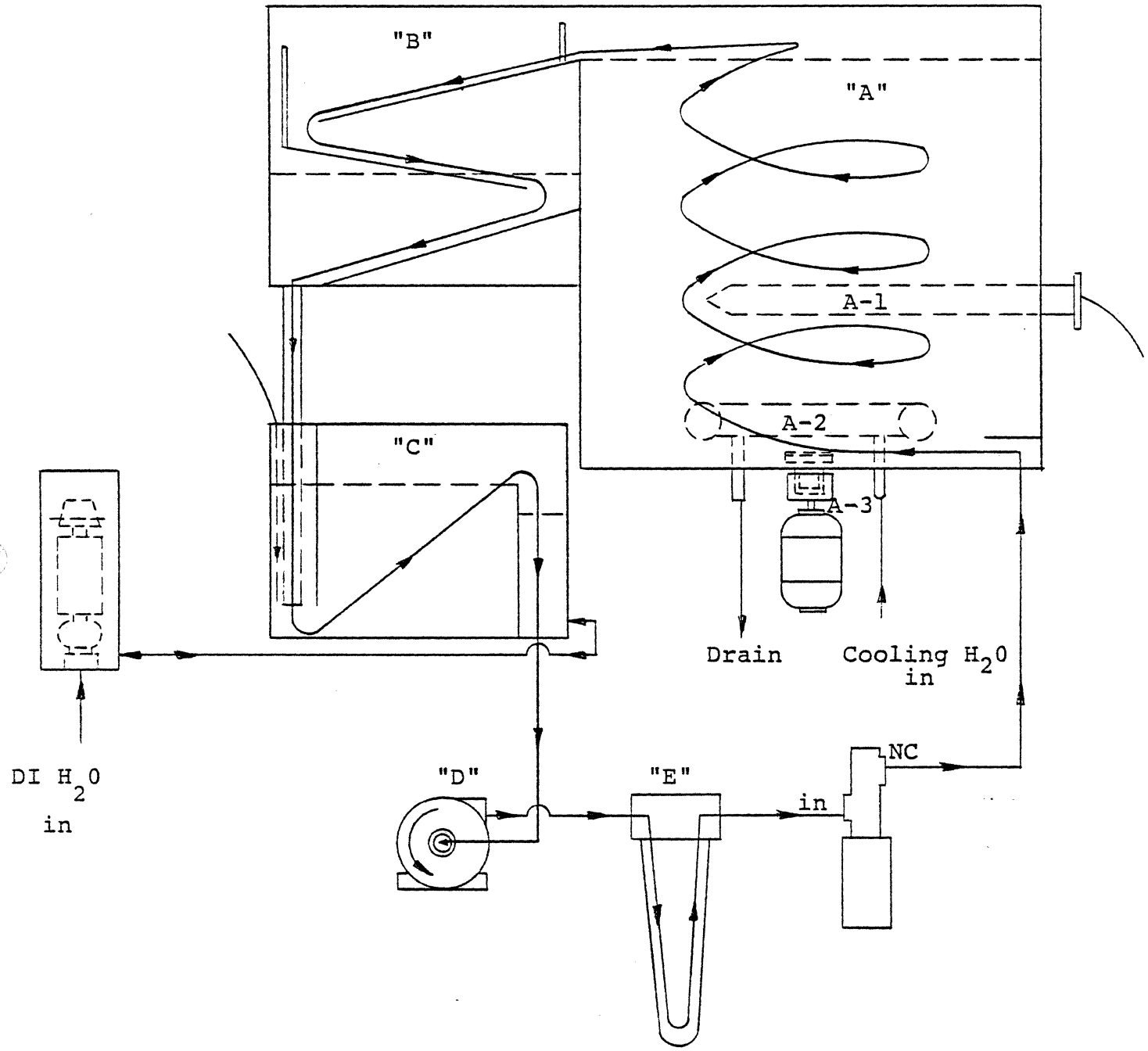


FIGURE 42 MODULE SCHEMATIC

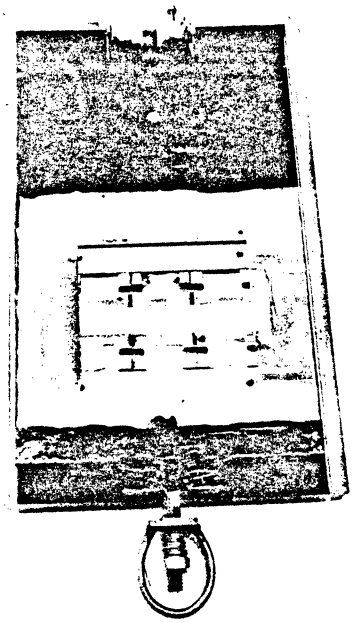


FIGURE 43

PLATING FIXTURE

Plating Process Parameters

Copper is deposited on the write housings from an Acid Copper electrolyte (see Table 1). The acid copper bath was chosen for this operation because of its chemical stability and deposit thickness uniformity.

Table 1. Deposition Conditions/Electroplating

Element	Quantity
Copper Sulfate - $Cu_2\ SO_4 - 5H_2O$	2/0 gm/l
Sulfuric Acid - $H_2\ SO_4$	28-5 gm/l
Chloride Ion - Cl^-	50.0 PPM
Ubach Brightener	5 Ml/l
CYCLE	
Current Density	.375/in^2
Plating Rate	100m"/3 min.
Temperature	75 $\pm$ .5° F
Agitation	Mechanical and Nitrogen

The Ubach brightener system was selected for its leveling characteristics and ability to produce a uniform thickness with good conductivity. The conductivity measured from this bath has a nominal value of 2.3 micro ohms/cm.

By maintaining the electrolyte within the limits specified in Table 1, a deposit is obtained which is free of nodules and has a plated contour as shown in Figure 44. This smooth contour is ideally suited for our application because it does not present a problem in closure during final assembly. Also, as can be observed from the trace, the thickness uniformity is very consistent from Track 1 through Track 9.

Each copper element builds perpendicular to the substrate surface which demonstrates the success of the additive photoresist process for providing sharp track definition.

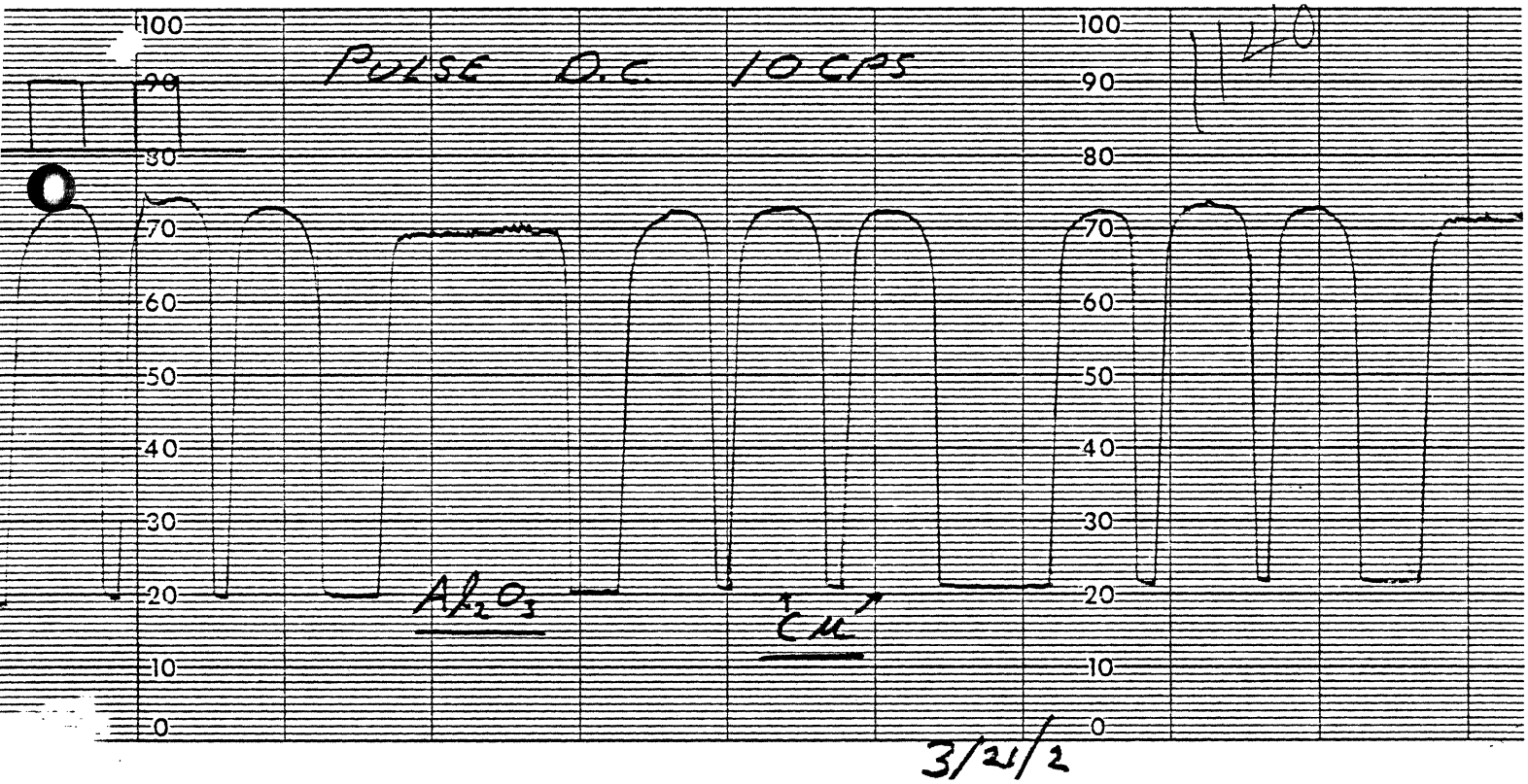


FIGURE 44

CONTOUR OBTAINED USING PULSE DIRECT CURRENT (50% DUTY CYCLE, 10 CPS)

DEVELOPMENT ACTIVITY

During the past year, our plating development efforts have been focused on additive plating, and developing alternatives for copper to achieve a hard wear resistant conductor. Our initial efforts with additive plating met with varied success. The development of the photoresist technique to provide an acceptable mask for plating is described in the photolithography section of this report.

Additive Plating

Initially, we attempted to electroplate the conductors with direct current and the bath composition listed in Table 1. The contour and thickness uniformity of the deposit was not acceptable (see Figure 45). The two most objectional characteristics of this deposit were the concave contour at the top of the land and the uneven thickness obtained. By increasing the current density of the direct current, this condition became even more pronounced. Some improvement was achieved by increasing the thieving area and decreasing the current density, but the irregular contour could not be eliminated.

After exploring the common variables with direct current plating with no success, we then investigated Pulse Plating. We evaluated a 50% duty cycle at varying frequencies. The optimum condition found was 10 cps at a current density of .375 amps/in^2. The deposits plated in this manner were uniform in thickness as shown in Figure 44. Also, the contour of the land was smooth and rounded, which is also desirable for closure during assembly. We did not investigate frequencies greater than 100 cps because satisfactory results were achieved at the lower value.

Resistivity of Copper Using Pulse and Direct Current Sources

The use of copper plated deposits for write track conductors requires a uniform and low resistance copper deposit. An experiment was performed to determine the resistivity of copper from the acid copper electrolyte having the composition listed in Table 1. Since pulse plating is being used, both pulse and direct current sources were evaluated. The substrates used were glass microscope slides (1 X 3 inches) which had been vacuum metallized with 50 angstroms of titanium and 1,000 angstroms of copper.

These substrates were then electroplated with approximately 90 microinches of copper. The actual thickness of plated copper was measured using X-ray flourescence and Tally-Surf techniques. The resistance was measured using a four-point probe technique. Both the thickness and the resistivity measurements were made by J. R. Depew in SDD.

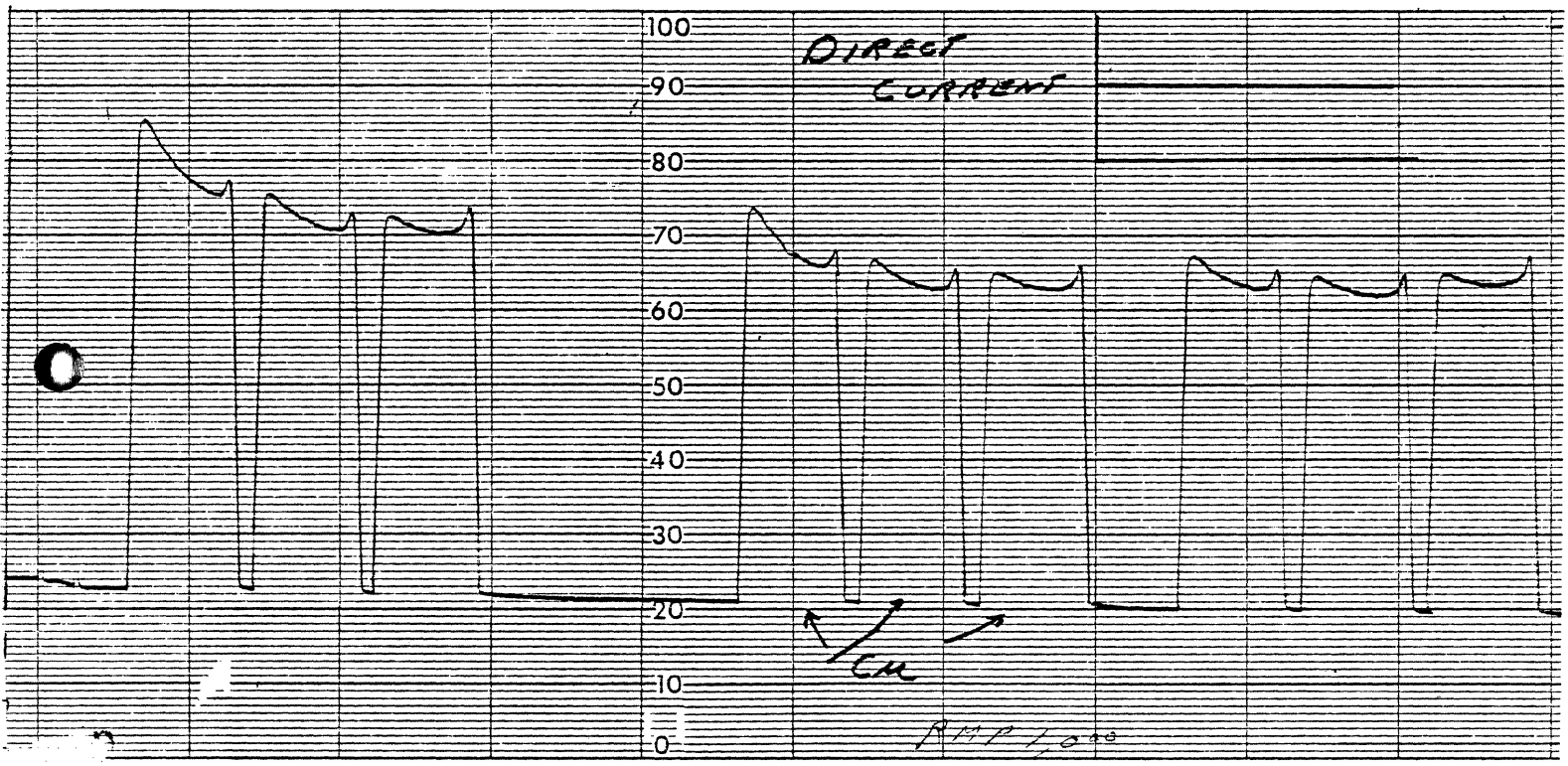


FIGURE 45

PLATING CYCLE
2.5 MINUTES AND 7.0 AMPS

The results obtained are listed in Table 2. The copper resistivity of deposits plated by pulse and direct current techniques were approximately the same. For both techniques, the plated copper had a resistivity approximately 25% higher than bulk copper (using a value of 1.71 micro ohm/cm for annealed bulk copper). Although the resistance is higher than bulk copper, the write head design permits use of a conductor cross-section great enough to carry the required current for writing. The values listed in Table 2 were consistent from batch to batch resulting in consistent values of resistance on completed write tracks.

Table 2. Resistivity Values

Sample No.	Thickness by Tally-Surf	Calculated (ρ) Resistivity
A-1	89 X 10^{-6} inches	2.3 micro ohm/cm
A-2	86 X 10^{-6} inches	2.2 micro ohm/cm
B-1	90 X 10^{-6} inches	2.2 micro ohm/cm
B-2	86 X 10^{-6} inches	2.2 micro ohm/cm

Samples A-1 and A-2 were DC Pulse Plated at .375 amps/in^2 using a 503 duty cycle.

B-1 and B-2 were plated using a normal DC output at .375 amps/in^2.

DEVELOPMENT ACTIVITY

Evaluation of Other Metals as Write Track Conductors

Copper, as used in the write gap, is placed beneath a strip of aluminum oxide. The housing is then ground until the aluminum oxide is exposed to the head surface. Copper cannot be used directly in the gap because it will smear and severely erode during use. The necessity of placing the copper track below the head surface causes considerable write efficiency to be lost. To produce a more efficient write head, we sought to electrodeposit a hard, conductive metal for use directly in the gap. The conductor used in this application must be ground with no chipping, and wear satisfactorily when used with magnetic tape. An evaluation was made of three different deposits: white gold, chromium, and rhodium. Although these metals are inferior to copper in conductivity, it was reasoned that being exposed on the tape head surface should still result in an overall improvement in write head characteristics.

Deposits of the three metals, 100 microinches thick, were supplied to SDD for wear evaluation. The deposits were electroplated on ferrite housings which had been metallized to provide a conductive surface. Both the white gold and the chromium were unsatisfactory. The chromium chipped badly and resulted in excessive edge breakdown of the ferrite housing. The white gold also performed poorly because of smearing and excessive erosion.

Rhodium electroplated samples were satisfactory for wear evaluation. The deposit provided good support to the ferrite housing and a minimal amount of chipping occurred. However, the plating process for rhodium was difficult to control. We were not able to consistently deposit rhodium through a photoresist mask. The rhodium electrolyte attacked the photoresist causing poisoning of the electrolyte.

Adhesion of rhodium to a metallized surface was also a problem. Conventional vacuum deposited combinations of Ti-Cu, Ta-Cu, and Cr-Cu to ferrite did not provide an adequate bond. The highly stressed rhodium lifted from these metallized substrates after a thickness of 20 microinches was deposited.

A method which did permit thick deposits was an intermediate layer of white gold as shown in Figure 46. The white gold alloy (80% gold, 20% Ni) is ductile and is able to absorb some of the stress in the plated rhodium. This method was used in plating several deposits on both glass and ferrite substrates with success. The write characteristics were effective enough to make this a satisfactory construction for production applications. The method was not thoroughly pursued because conventional write head construction of copper under an aluminum oxide wear bar worked exceptionally well.

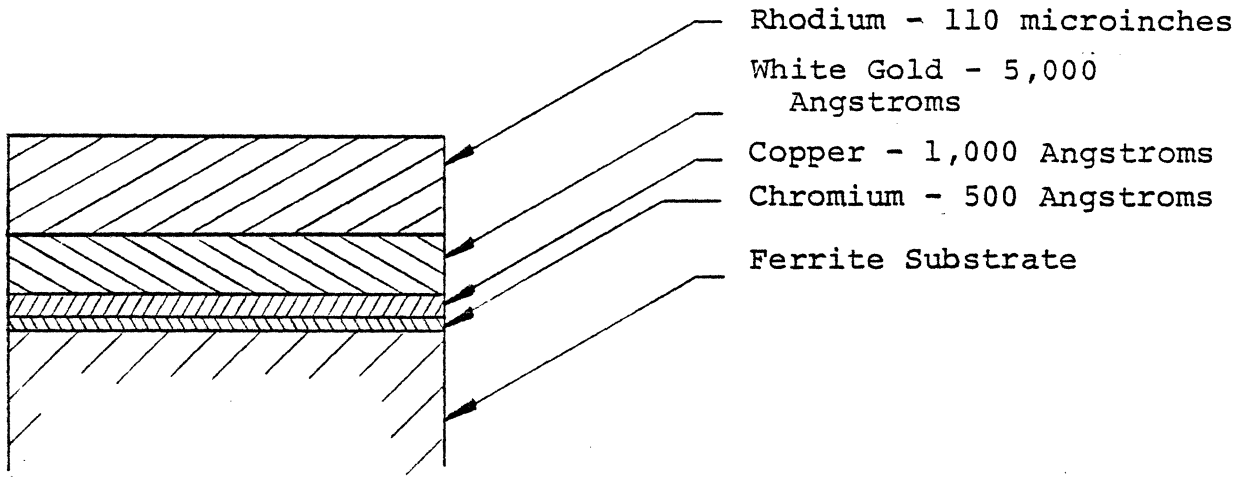


FIGURE 46

DEPOSIT USED TO IMPROVE ADHESION OF RHODIUM

PHOTOLITHOGRAPHY

The Newton film head presents a very difficult dimensional alignment problem in photolithography. The nine tracks on the read section and the write section must be aligned to the "X" and "Y" datum surfaces of the respective housings within ± 200 microinches, and must be parallel to the bottom datum surface within 100 microinches. This means that all of the tolerances associated with the artwork fabrication, visual alignment of the mask to the housing, and etching undercut, must be encompassed in the allowable locational tolerances.

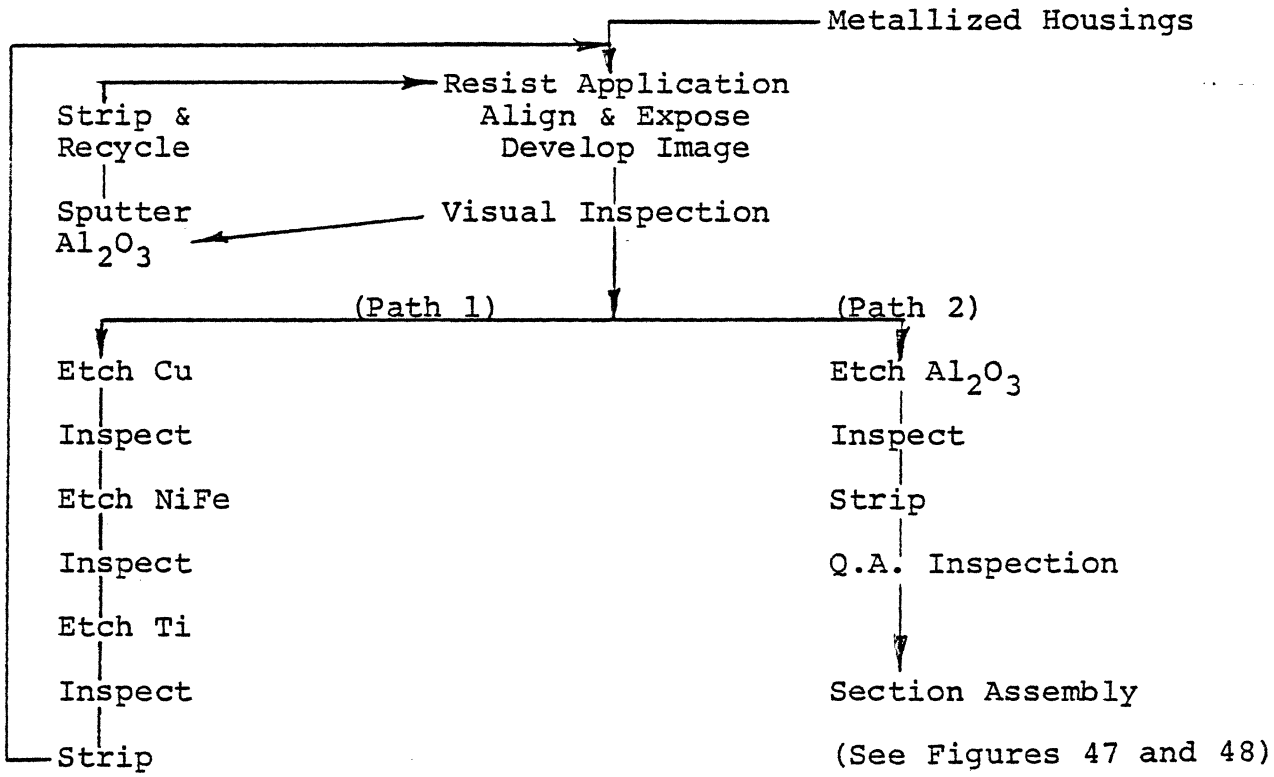
The Newton design requires etched line widths down to .001 of an inch and plate-thru resist line widths down to .0006 of an inch. The materials and thicknesses etched are listed below:

Table 3. Materials and Thickness

Material	Approximate Thickness
Permalloy	300 angstroms
Copper	25 microinches
Titanium	1350 angstroms
Aluminum Oxide	25 & 100 microinches

The following charts depict the photolithography process flow required in fabricating Newton read and write sections.

Table 4. Read Sections



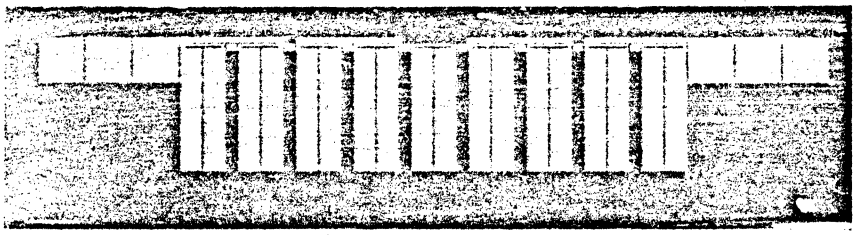


FIGURE 47

READ SECTION TRACKS

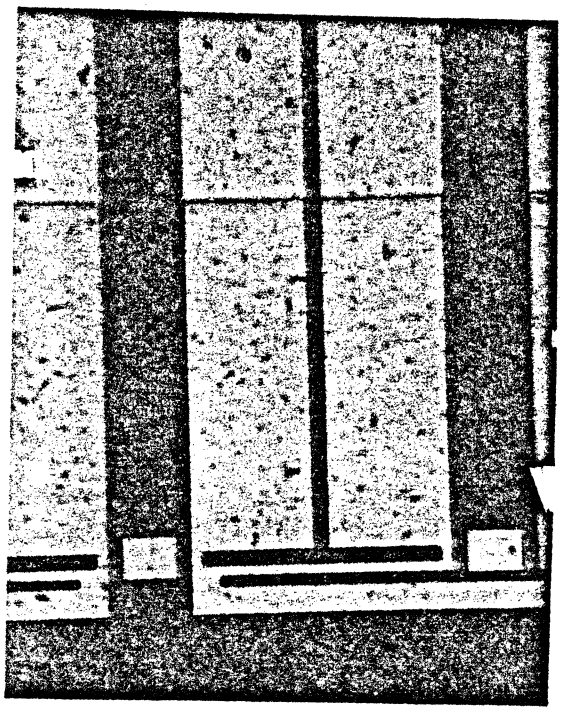
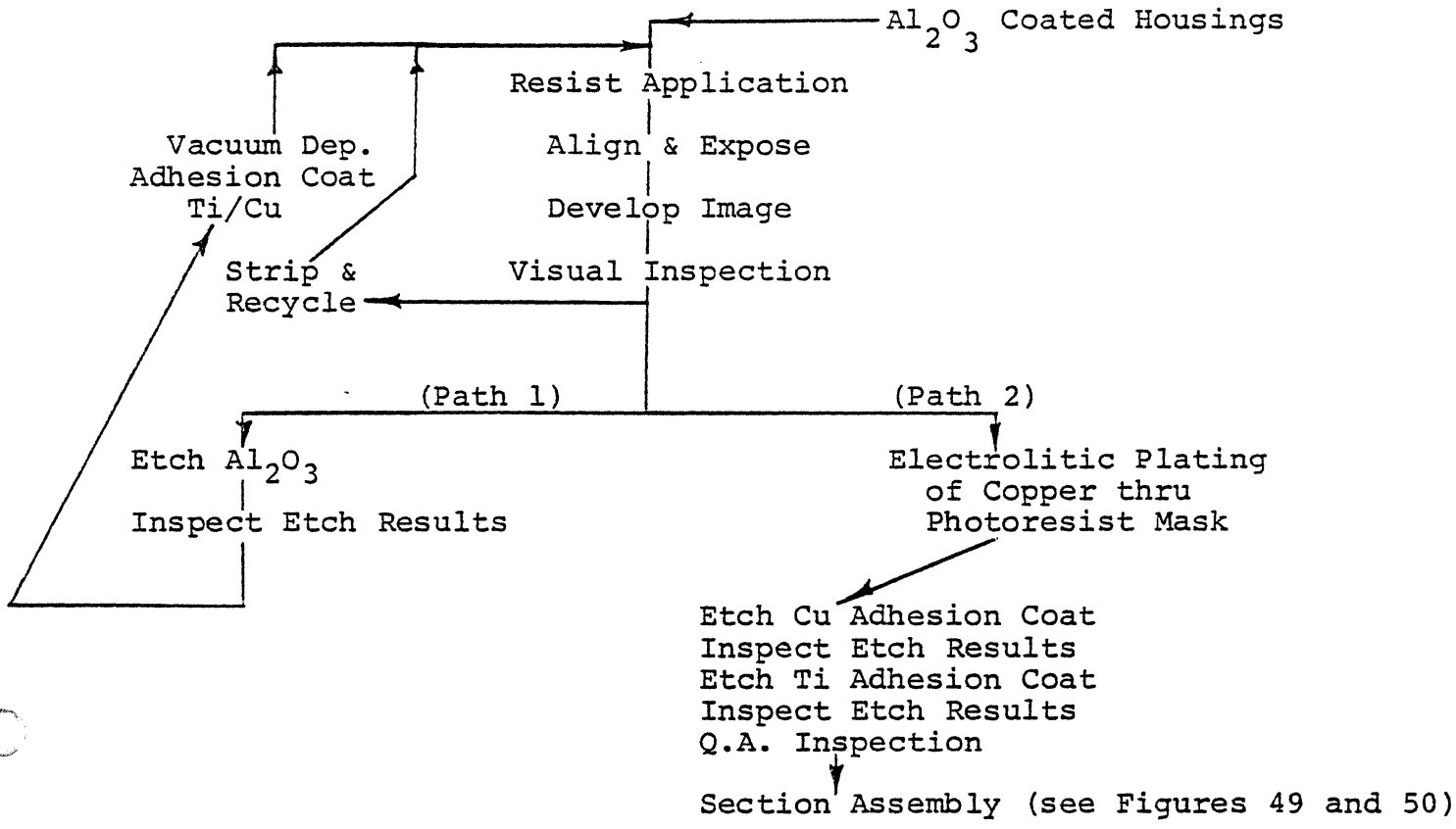


FIGURE 48

ENLARGED VIEW OF READ TRACK

Table 5. Write Sections



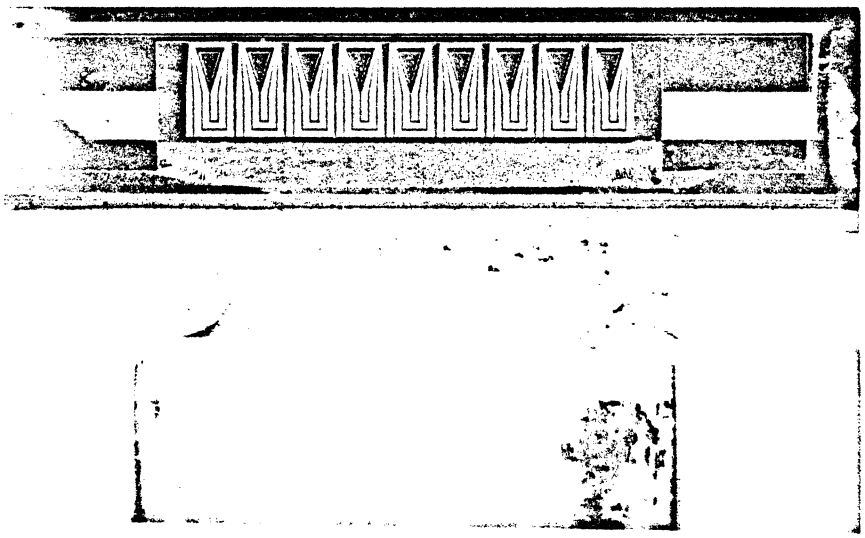


FIGURE 49

WRITE SECTION TRACKS

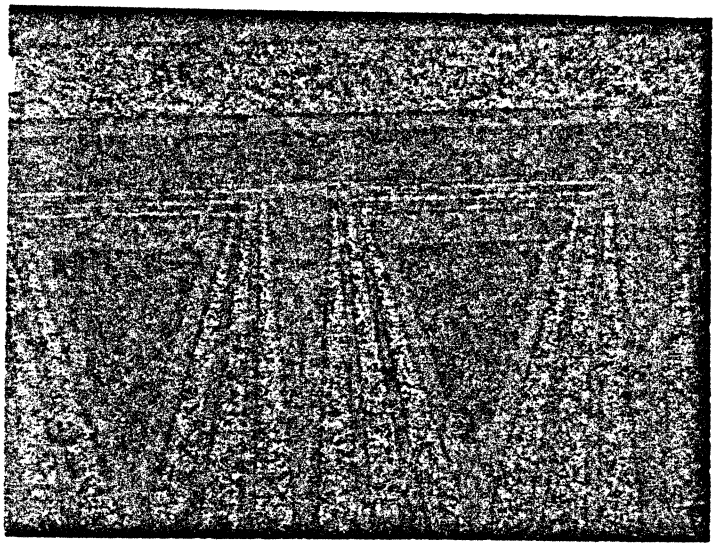


FIGURE 50

ENLARGED VIEW OF WRITE TRACK

The following is a brief outline of the basic photolithography processing steps used in the fabrication of the Newton film head:

Resist Application:

1. Place housing in 4-station spinning chuck on Headway* spinner.

2. Spin rinse with Freon TF* for 30 seconds at 1800 rpm.

3. With housings stationary, flood the ferrite surfaces with filtered Shipleys* AZ 1350-H photoresist and spin for 30 seconds at 1800 rpm.

4. Place the housings in the Gyrex* Infrared (IR) conveyor oven. Set heater on "1" and conveyor speed for 40 seconds' drying time (see Figure 51).

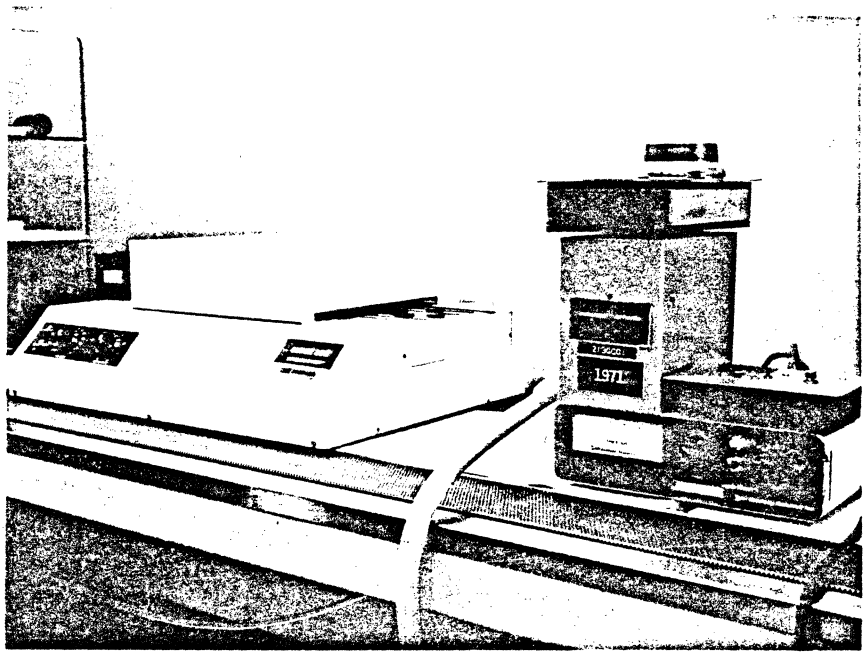


FIGURE 51

GYREX IR CONVEYOR OVEN

Align and Exposing:

1. Align the aligning marks on the photomask to the datum surfaces of the housing, using the Kasper* aligner (see Figure 52).

2. Expose with UV light for 15 seconds.

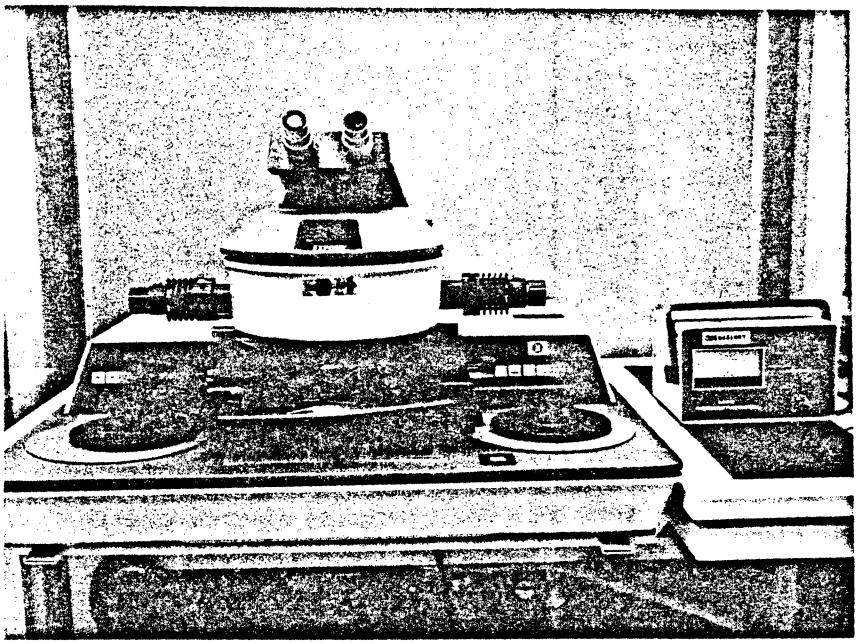


FIGURE 52

KASPER ALIGNER

Develop Image:

1. Place housing in Develop Tank 1 for 20 seconds, then in Develop Tank 2 for 20 seconds (AZ developer 1:1 with DI water) [see Figure 53].

2. Rinse in DI water until resistance level returns to normal.

3. Blow dry with dry N_2.

* Trade Name

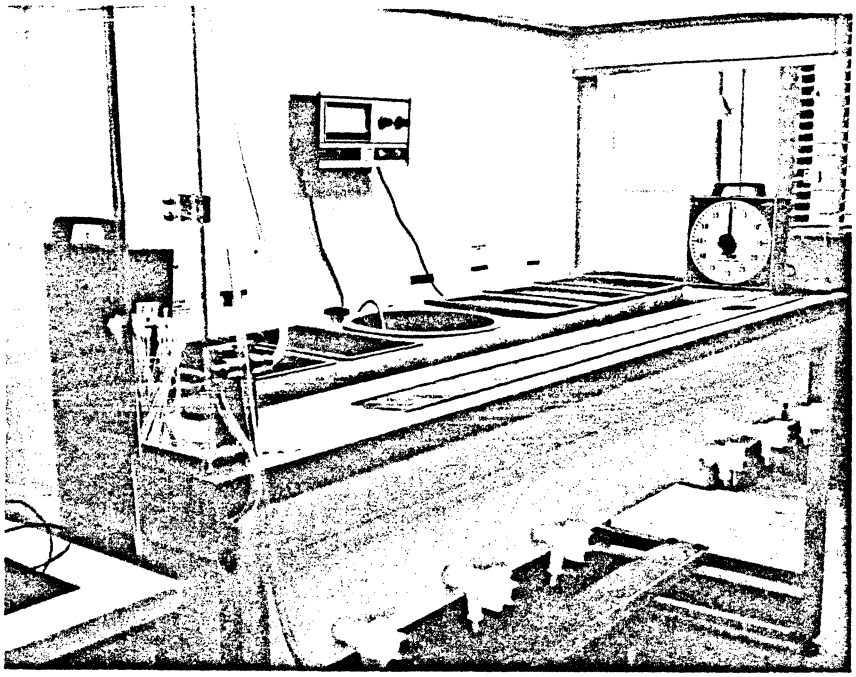


FIGURE 53

WETLINE BENCH

Visual Inspection:

1. Inspect image for resist quality:

   a. Pin Holes
   b. Poor Adhesion
   c. Scratches
   d. Complete Development

2. Measure on Lietz Toolmakers Microscope location of pattern on housing (see Figure 54):

   a. "Y" Dimension
   b. "X" Dimension
   c. Parallelism

   NOTE: STRIP AND RECYCLE HOUSINGS NOT MEETING VISUAL OR DIMENSIONAL PARAMETERS.

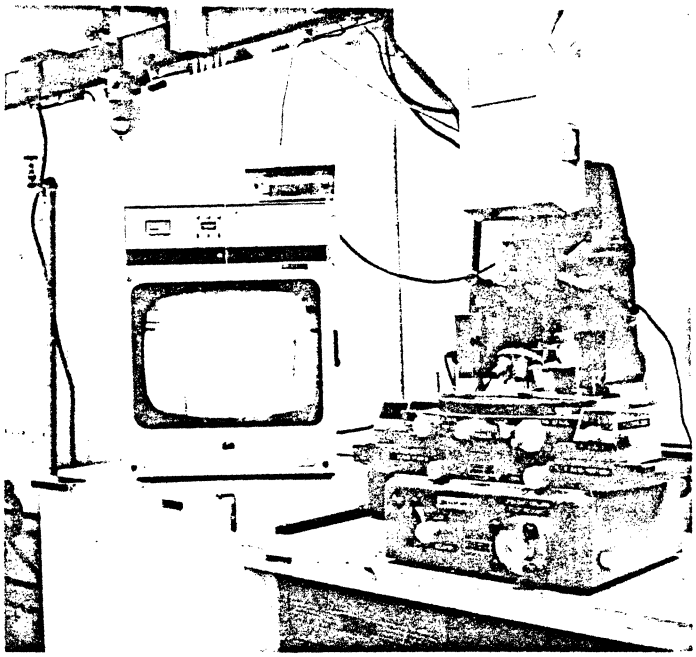


FIGURE 54

LIETZ TOOLMAKERS MICROSCOPE
WITH TV MONITOR TABLE

Etching:

1. Refer to Table 6 for etchants used and etch time.

2. Run one housing from each lot to establish the etch time for the lot. Inspect for completeness of etch and re-etch if necessary. Rinse in DI water after etching (refer to Figure 53).

Stripping:

1. Strip photoresist in two 30-second soaks in acetone baths.

2. Spray rinse with acetone and blow dry with filtered N_2 (refer to Figure 53).

Process development work in the photolithography area has been concentrated in three basic areas:

1. Resist Application
2. Alignment Aids, and
3. Etching

A summary of this work is listed below:

Resist Application

A high-speed camera, shooting approximately 2400 frames/second, was used to slow the motion of the spinner in order to observe the formation of resist pin holes and leveling. The film showed that loose surface contamination and air pockets that form during resist application, are pushed off the wafer during spinning. The pin holes that remain in the coated surface are usually caused by contamination that is firmly attached to the part, or irregularities such as bumps or depressions in the surface metal.

The photographs also showed the formation of an initial rim of photo-resist that appeared at the edge of the wafer. The rim slid off after a few revolutions of the spinner, but a small lump of photoresist remained after spinning. This lump causes distortion in the resist pattern and will not dry or develop out completely. The Newton design requires the pattern to be close to the leading edge of the housing (for cut-off and grinding). For this reason, the lump could not be tolerated. The problem was resolved by eccentrically spinning the housing rather than concentric spinning (see Figures 55 and 56).

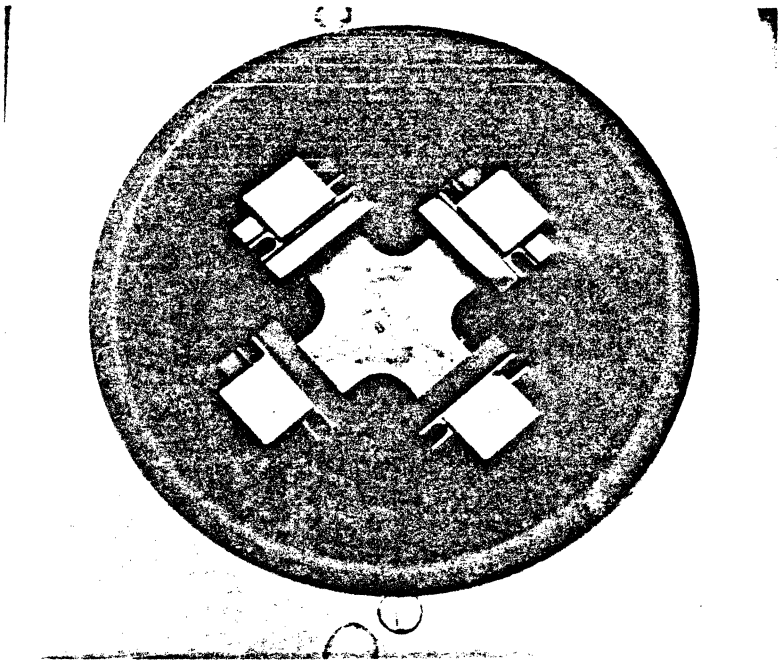


FIGURE 55

RESIST SPINNER

Table 6. Use and Etch Time for Etchants

SECTION	PATTERN ETCHED	MATERIAL	ETCHANT (MAKE-UP)	TEMP.	TIME* IN SEC.	EXPECT UNDERCUT IN MICROINCHES
Read	M/R Tracks	Cu	Cr-10A 1:1 w/H_2O	23°C	10- 13	150-200
Read	M/R Tracks	NiFe	$FeCl_3$ 1 part HCl 1 part H_2O 20 parts	23°C (Special Horizontal Spray Etcher is used)	6- 8	25- 75
Read	M/R Tracks	NiFe	2% HF	23°C	15- 18	25- 75
Read	Term Hole	Al_2O_3	H_3PO_4 1 part H_2O 1 part	85-90°C	45- 60	100-150
Write	Wear Bar	Al_2O_3	H_3PO_4 1 part	85-90°C	120-180	100-200
Write	Adhesion Coat	Cu	$FeCl_3$ 1 part $CrlO_A$ 5 parts HCl 1 part H_2O 35 parts	23°C	3- 5	N/A
Write	Adhesion Coat	Ti	2% HF	23°C	15- 18	N/A

* Actual time for each lot to be determined by trial part

Spraying AZ-1350H photoresist was also investigated. A Zicon* spraying booth was used, with Freon TF* as a carrier. The advantage of spraying photoresist rather than spinning is mainly in the high production capabilities. The edge effect previously discussed could also be reduced by spraying.

The experimentation showed a great deal of variation in the coating thickness (50 microinch variation in 100 microinch coatings). Another problem that made resist spraying undesirable for use in the laboratory was clogging of the spray nozzle between runs. The clogging caused extreme variation in coating thickness and could only be corrected by stripping the spray head down and cleaning in solvents. For these reasons, it was decided to reject this method for laboratory and "C" test use. It may be investigated at a later date when production quantities warrant it.

Different methods of drying positive photoresist were also investigated. The methods evaluated were:

1. Circulating Air Oven
2. Hot Plate Drying
3. IR (Infrared) Drying
4. Vacuum Oven Drying

The four methods were evaluated on the basis of exposed line resolution quality, using the USAF target patterns. All four drying methods produced comparable line resolution with thin resist coatings (50 microinches or less). When thicker coatings were dried, the circulating oven produced poorer results than the other methods. The other methods were equivalent in results.

However, for ease and speed of drying, IR drying was selected for use in the photolithography area.

A Gyrex* Micro-Dryer was selected for use in the AME Laboratory. This unit has reduced the resist drying time from 10 minutes (circulating air oven) to 40 seconds. The drying time is strictly controlled by the speed of the conveyor, making it very desirable for a production facility.

* Trade Name

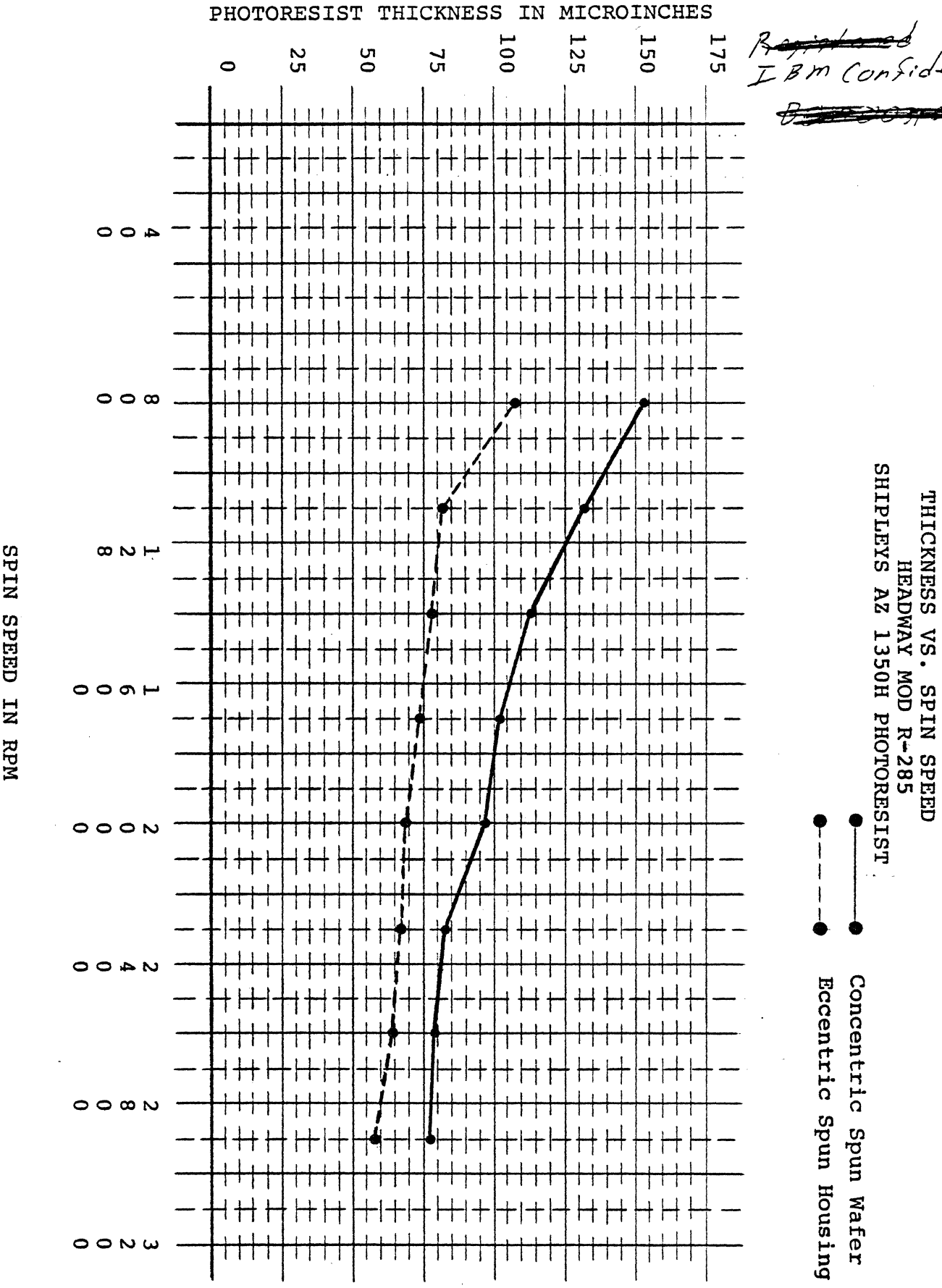


FIGURE 56

THICKNESS VS SPIN SPEED
HEAD WAY MOD R-285
SHIPLEYS AZ 1350H PHOTORESIST

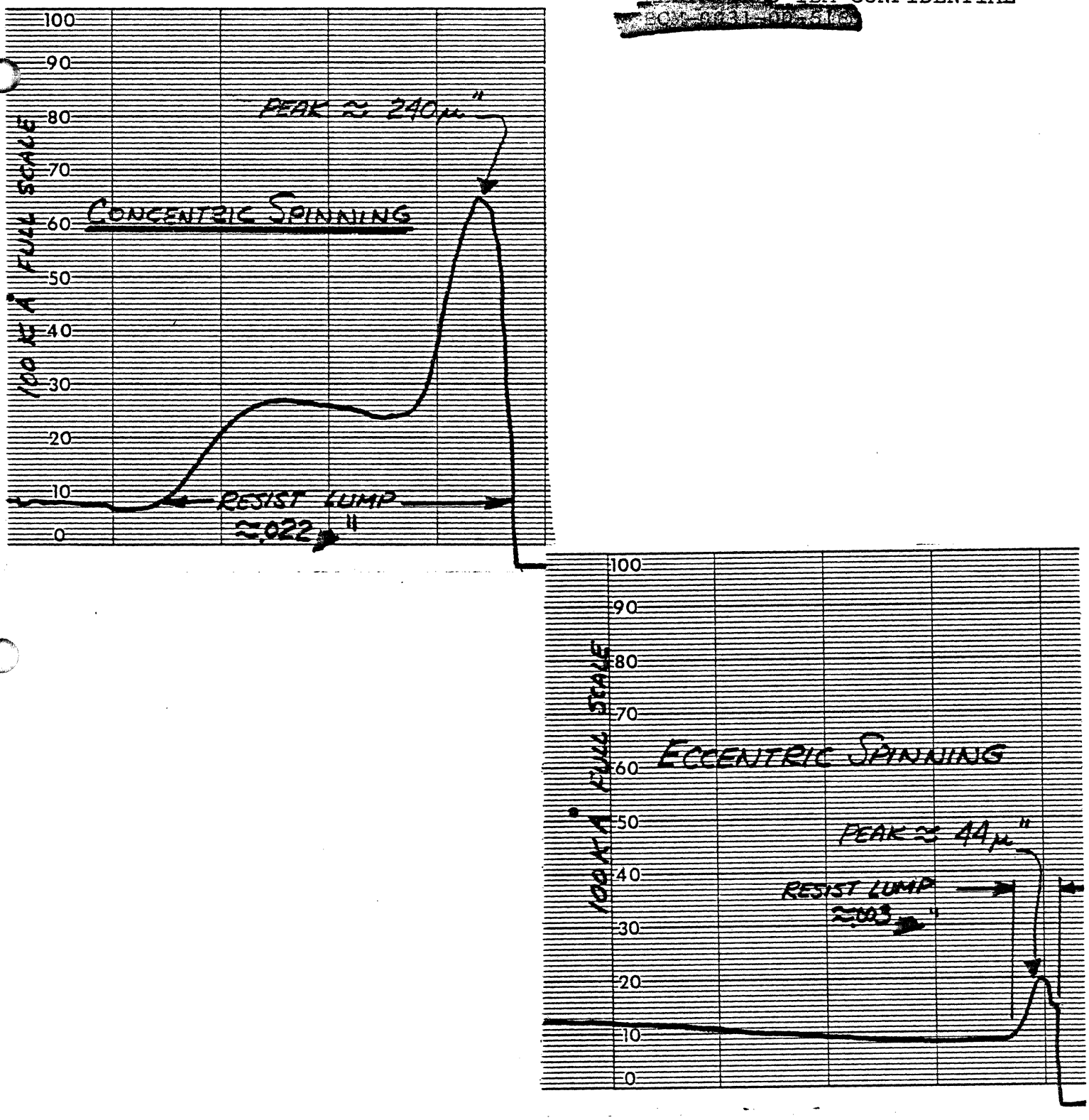


FIGURE 57

TRACES OF RESIST BUILDUP BY CONCENTRIC AND ECCENTRIC SPINNING

ALIGNMENT AIDS

As stated earlier, one of the biggest challenges in processing the Newton film head in the photolithography area is the dimensional alignment of the track pattern on the housing. A very simple approach was developed that has proven very reliable. The photomask is aligned to the housing, using three alignment marks. The marks are located to line up with the datum surfaces on the housing. The aligning marks on the photomask are more than .500 inch from the track features and are held to a tolerance of $\pm$ .000050 inch. Figure 58 shows the technique used to align the artwork to the housing.

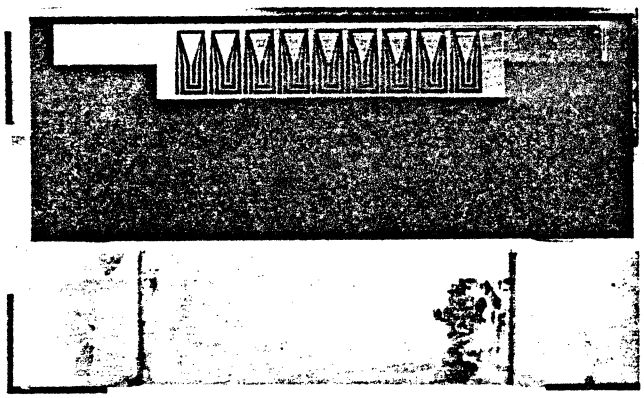


FIGURE 58

ARTWORK ALIGNMENT TO HOUSING

Two methods of optically aligning the marks to the housing have been tried. The first approach is to align the marks with the edge of the housing. The second is to place the housing in a tool that has reference edges ground on its surface and align the marks to the edges. This method is the least desirable of the two because the resist coated surface of the housing must be placed against a flat surface in order to make it flush with the tool. This damages the photoresist.

ETCHING

Two basic problem areas emerged in the development of the etching process for the Newton program:

1. Al_2O_3 Etching
2. Etching Thin Films of Permalloy

Etching of the other two materials (copper and titanium), involved in the Newton design, did not present any unusual processing problems and will not be discussed in this report (refer to Table 6 for all etchants and controls used in the process).

Etching Aluminum Oxide

The write section of the Newton head requires a 100 microinch thick wear bar along the write gap at the tape surface. The tolerance on the location of the edge of the bar is $\pm$ .0002 inch, thus limiting the undercut irregularity to .0002 inch (considering $\pm$ .0001 inch alignment tolerance).

Initial etching experiments were made using "P" etch:

300 parts H_2O

15 parts 48% HF

10 parts 70% Nitric Acid

Etch rates were unpredictable with undercut varying from .0002 to .0005 inch. Some resist breakdown was also experienced in longer etch cycles (5 minutes or more).

IBM San Jose supplied information on an etchant they use for Al_2O_3 films. The etchant they suggested was 85% H_3PO_4 mixed 1:1 with DI water and heated to 75-80° C. This etchant showed moderate improvement over the results obtained using "P" etch.

The etch rate and undercut still varied from lot to lot of housings. This variation indicated a strong relationship between etchability and sputtering parameters. Extensive experimentation was made into the effects of sputtering on etchability, which has resulted in Al_2O_3 films that have fairly predictable etching characteristics (see Section 4 of this report on sputtering Al_2O_3 for details). Undercut irregularity is now held to less than .0002 inch with an average undercut of .00015 inch.

Etching Thin Films of Permalloy

The very thin metallized layer of permalloy (300 to 1000 angstrom) coupled with the intricate geometry of the Newton design created unusual metal etching problems. At first, 42° Baume Ferric Chloride was used in a static dip etch. The results were very poor, with erratic undercut and bad line acuity (as much as .0002 inch variation). The etch time was extremely fast, less than 1 second, making precise control impossible.

Dr. L. T. Romankiw (Yorktown Research) suggested diluting 42° ferric chloride 1:5 with DI water and reducing the PH of this mixture to 0 using HCL. This etchant greatly improved the etch results, especially line acuity. Also, the dip etch time was extended to 5 seconds, which afforded more control over the etching.

Another problem experienced in etching the Newton design was etch rate variation due to pattern configuration. The narrow lines, .0002 inch or less, etch much slower the wider areas of the pattern. This caused more undercut on the metal edges adjacent to the wider areas.

Experimentation showed that spray etching, rather than static dip etching, greatly reduced this problem. However, conventional horizontal or vertical spray etching machines could not be controlled well enough to meet the etching requirements of Newton.

Through the joint efforts of AME and Equipment Engineering, IBM Boulder designed a Special Horizontal Etcher to meet the specialized requirements of the Newton program. The unique features of this machine are listed below:

1. Timer controlled etch and rinse cycles.

2. Instant quench (rinse) of parts in same chamber used for etching.

3. Rotating etchant spray headers and part holder.

4. Recirculating water rinse (does not require chemical drain).

The machine was fabricated by Western Technology Associates with IBM supervision (see Figure 59).

The parts are clipped to gears on a planatory gear rotating fixture. The speed of rotation is variable. The speed of the spray header rotation is also variable. This feature allows for leveling of the etching spray, illuminating rich and lean areas in the spray pattern.

The water rinse headers are located in the same chamber allowing instant quench of the etching at the completion of the etch cycle. Timers control the duration of the etch and rinse cycles. A large 3 inch quick-acting valve ports the drain to the respect etch or rinse reservoirs. Since the water rinse is recycled, chemical drains are not required in the immediate area.

Etching experimentation has just begun with this machine. Initial results are very encouraging. Undercut is very uniform on all edges of the pattern with much sharper line acuity than experienced in static etching. Spray etching allows greater freedom in design geometry since all line widths etch at approximately the same rate. This type of machine will be used for copper and permalloy metal etching in the production facility for the Newton head.

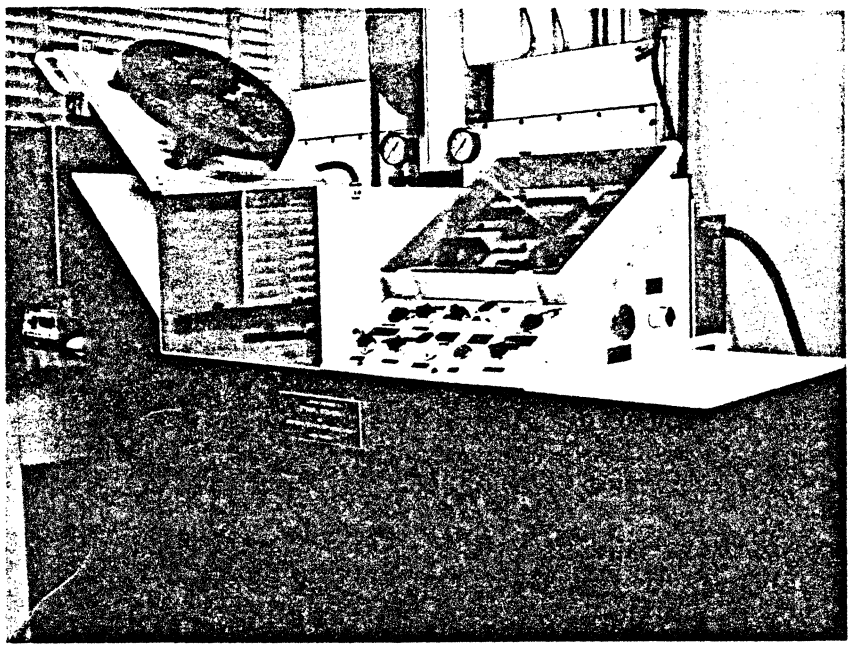


FIGURE 59

CUSTOM BUILT HORIZONTAL ETCHER

NEWTON INTERCONNECTIONS

The interconnection process developed for Newton is a refinement of the original process developed for the Oak program. [1] The process involves reflowing 63/37 Sn-Pb solder from a previously tinned wire onto (a) the head track extremities, or "legs"; followed by a similar reflow of the solder onto (b) the mating ribbon cable. The final interconnection for a head section involves soldering the ribbon cable to the pin block.

Process Selection

Soldering was chosen as the interconnection process for the "B" test program because of process versatility, repairability, and low development cost. Several different designs for both the read and write sections were evaluated during the "B" test program, requiring a versatile joining process. Further, the wettability of the head track metallization by the solder had been established (Figure 60 or Footnote 1).

Write Section Terminations

The write track consists of a 3-turn spiral, copper conductor element on ferrite. The pretinned wires were soldered to produce a 1-turn, 2-turn, or 3-turn head, as shown in Figure 60.

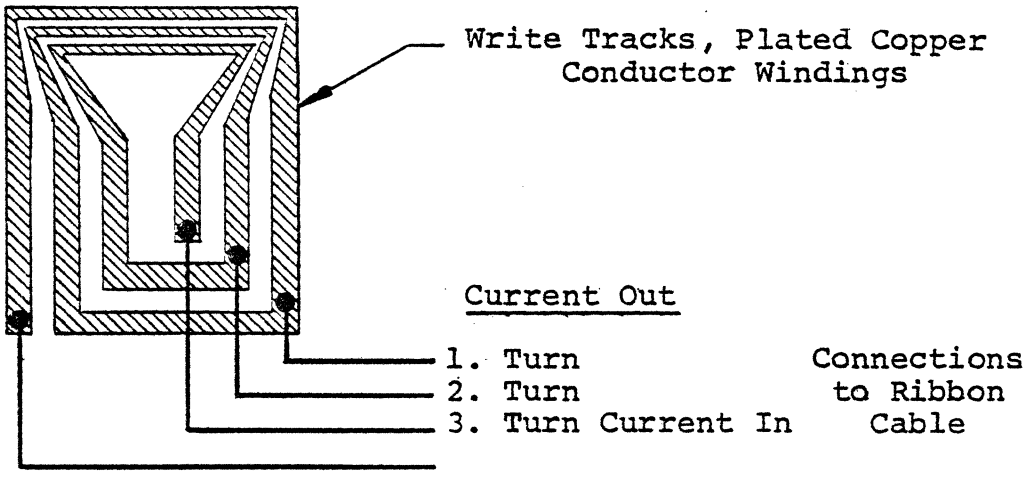


FIGURE 60

WRITE TRACK TERMINATION SCHEME

(1) Registered IBM Confidential Report BOM-0003-00-516, Boulder AME Thin Film Head Process Development, Pages 45 thru 53.

Write heads of all three configurations were made during the development program. However, the 2-turn configuration was selected for the "B" test schedule.

The ribbon cable is attached to the write section housing with pressure sensitive tape prior to interconnecting the tracks. Then the terminations are made to all nine tracks in the write section, followed by joining opposite ends of the wires to matching conductors in the ribbon cable.

Read Section Terminations

The read track is a one-turn Magnetoresistance (MR) element. The leg extremities are metallized with 20 microinches of copper, both to increase conduction of the read sense and bias currents, and to facilitate wetting by the solder. The interconnection scheme is as shown in Figure 61.

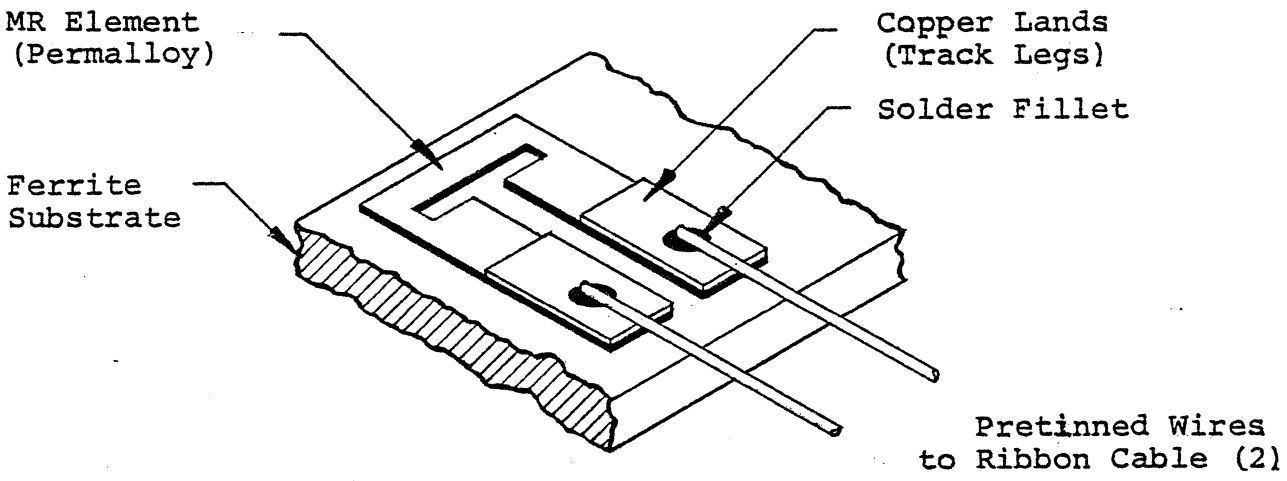


FIGURE 61

READ SECTION TERMINATIONS

Pin Block/Cable Terminations

Cables and pin blocks for both read and write sections are identical. To interconnect either assembly, the pins are inserted into the holes in the cable and are soldered in place with a standard soldering iron. In normal practice, the pin block/cable assembly is completed and attached to the appropriate section prior to terminating the head tracks. However, the cable can only be attached to the housing, the interconnections can be made, and the pin block can be installed last, if desired. (Refer to Figure 62)

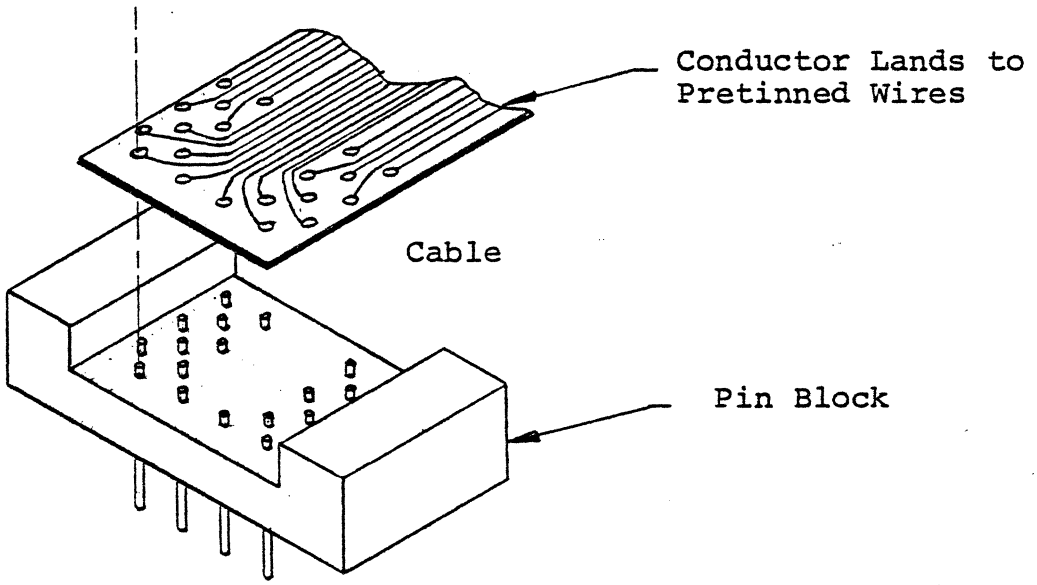


FIGURE 62

PIN BLOCK/CABLE INSTALLATION

EQUIPMENT DESCRIPTION

A memory transfer welder (TL #1376644) was modified for use as the Newton interconnection equipment (see Figure 63).

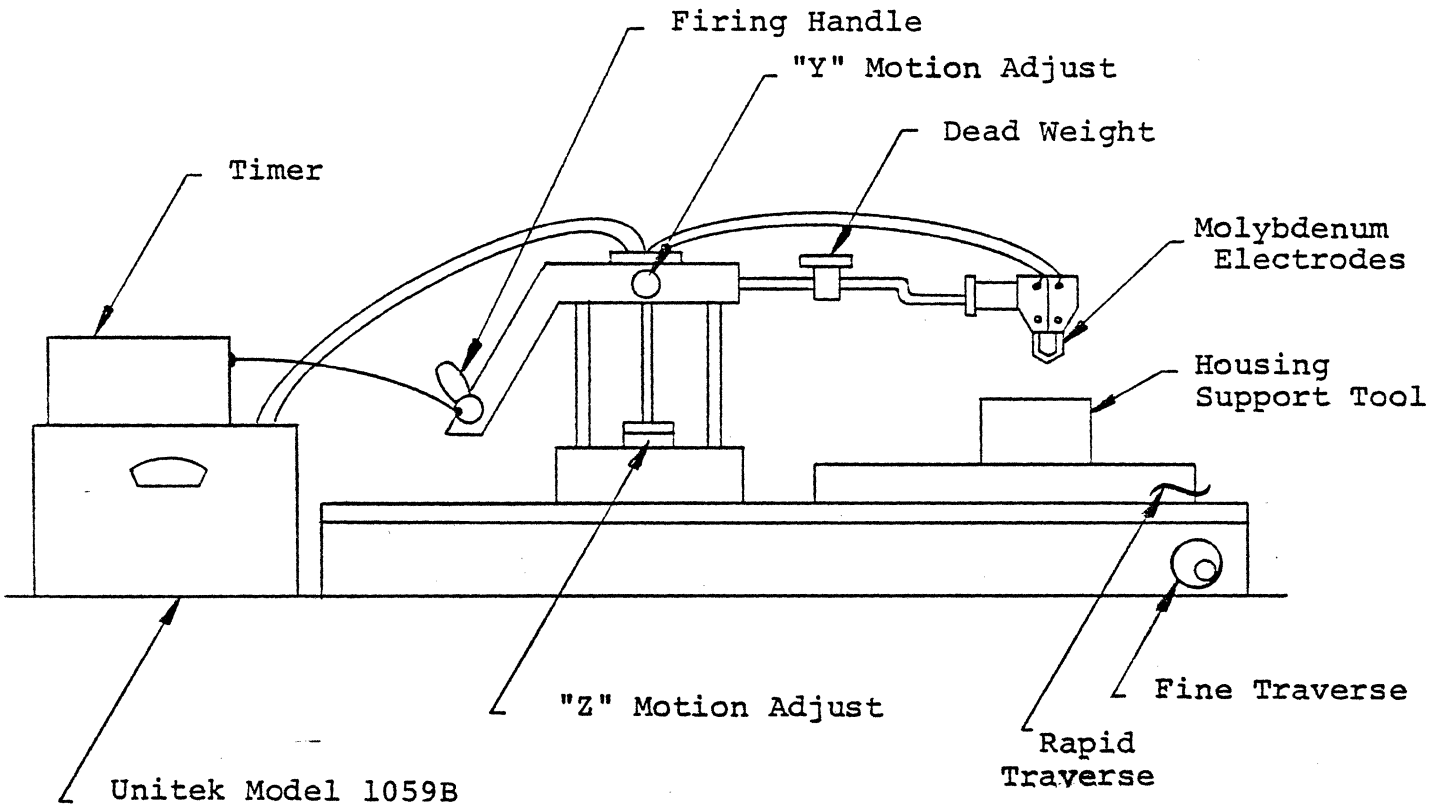


FIGURE 63

INTERCONNECTION EQUIPMENT

Power Supply

A capacitor discharge power supply was selected to avoid application of the reflow temperature to the head track for excessive periods of time. The power supply discharges in .0025 seconds (2 1/2 milliseconds) and the heat is rapidly removed through the molybdenum electrode after discharge.

Tooling

A platinum-rhodium electrode had been preferred in the prior Oak program, but further development showed the molybdenum electrode to be better. Molybdenum was chosen as the electrode material because it does not stick to the tinned wire. When sticking occurred, adhesion of the heads to the ferrite failed as the electrode was raised after soldering.

Precision dowelling techniques must be used in the housing support tool. If the housing moves during soldering, the wire and/or electrode becomes "off center," and a defective solder joint may result. Both the head housing and matching tool for Newton are designed to prevent any movement during the power supply firing cycle.

SOLDER PROCESS PARAMETERS

Some aspects of the Newton Program dictated that conventional soldering schemes could not be used. While adhesion of the metal layers on ferrite was good, it was sufficiently weak that all stresses imparted through the wires and joints had to be avoided. Yet, interconnecting the various prototype configurations required bending of the wires to mate with the cable conductors. Also, the use of any fluxes which either attacked the head elements or left a residue were to be strictly avoided. Because the read gap was 20 microinches, any contamination in the yoke area affected closure of the center section, thereby affecting the gap width.

Epoxy/Flux

Experiments with various materials led to the selection of an epoxy as flux. The viscosity could be controlled so that no epoxy would flow into the yoke area; thereby not affecting closure. Various epoxies and coating materials were evaluated, including the commercial grades EC 2290 (3M0), Easy Poxy (CONAP), and EPI-REZ (Shell). Fluxing agents were added to the above, as well as to the coating material by Poly Vinyl Alcohol. Upon curing, the additive generally corroded the head elements and this approach was abandoned. Ultimately, Epoxy 330 (Hughes Associates, Excelsior, Minn.) was selected as the flux.

After reflowing the solder from the wires onto all tracks, the read or write section is placed into an oven and the epoxy is cured at 80° C for 1 hour. Following this, the wires can be bent to mate with the ribbon cable without preloading the solder joint or affecting adhesion of the tracks.

For soldering the wire-to-cable and cable-to-pin block. Alpha 842 Organic Flux is used. The flux is removed with isopropyl alcohol after soldering. Standard 63/37 Sn-Pb solder is added to the cable-pin block joints.

After all joints are soldered, Epoxy 330 is applied as an over-coating and is recured. The wires are then encapsulated in epoxy, completely insulating the wires from each other as well as from other head components.

Total "build-up" of the encapsulated wires cannot exceed .020 inches. Otherwise, the center section would contact the epoxy and affect closure of the read/write (R/W) gap.

WIRE/CABLE

The interconnecting wires are .003 inch (3 mil) diameter, nickel plated, and tinned. The wire is purchased from the Nesor Corporation of West Caldwell, New Jersey. Wire specifications are shown in Table 7:

Table 7. Wire Specifications

1. .003 inch diameter OFHC copper.
2. Fully annealed, 65-80 Vickers hardness.
3. Ultimate strength 68-85 grams.
4. Nickel plated, 50 grams.
5. Tinned, 63/37 Sn-Pb solder, 200 hardness.
6. Uninsulated.

The cables are purchased from Electro Connective Systems in Brockton, Massachusetts. Both read and write cables are identical except for an external shield of 2 ounces copper which is added to the read section cable. The conductors are also made from 2 ounces OFHC copper.

INSPECTION/PROCESS CONTROLS

A primary inspection after soldering examines the joints for evidence of reflow (filleting) onto the tracks and cable conductors. Additionally, both pre-wire and post-wire resistance are measured so that the joint/wire/cable resistance increases, after interconnections, are controlled parameters. Shorts, opens, and epoxy flow characteristics are also examined visually.

Log sheet entries for the Computer Process Control System are shown in Table 2 (refer to Section 12.0 for Process Control).

Table 8. Process Control Entry Items

1. Pre-Wire Resistance (OHMS)
2. Post-Wire Resistance (OHMS)
3. Difference (2-1)
4. Gram Load (Typically 550 grams)
5. Epoxy Flux (330)
6. Power Setting (6.5 Watt-Seconds)
7. Flux (Wire-to-Cable and Cable-to-Pin Block)
8. Solder (Cable-to-Pin Block)
9. Epoxy Cure Cycles (Time/Temp)
10. Miscellaneous (Epoxy, Flux, Wire Lot Numbers, etc.)
11. Read/Write Section Numbers

Other process parameters are fixed by procedure (not variable) and are stored in the Newton data bank as a set parameter (i.e., Wire/Cable/ Electrode information).

RESULTS

Two read sections and two write sections were submitted to Quality Engineering for evaluation. The data was used to develop the "B" test engineering specification for the interconnecting process.

MECHANICAL PROPERTIES

Results of the study are shown in Table 3. Peel strengths of the write joints were greater than the read joints (8 grams difference). This was caused by the thicker, lower stressed copper (electroplated thru a mask, narrow conductors) as compared to the vacuum deposited, thinner copper for the read sections.

After aging the joints for 72 hours at 90° C, the joints were slightly weaker.

This indicates that some intermetallic compound formation and/or diffusion occurred during aging. The difference (2 grams) was not sufficient to be of concern about joint degradation.

FAILURE MECHANISMS

The failure mechanism of the peel test joints was identical for all samples, both before and after age (see Figure 64). All failures occurred at the ferrite/metallization interface and a portion of each head track remained attached to the wire at the solder joint.

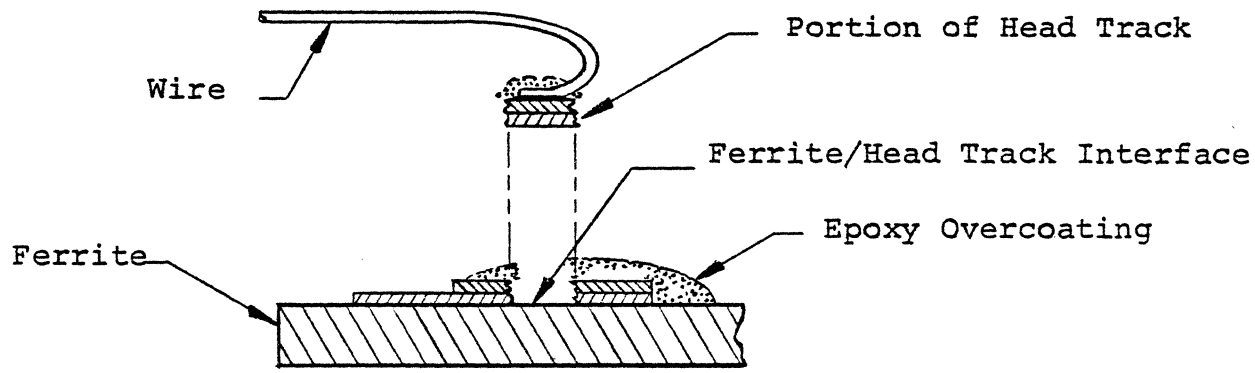


FIGURE 64

SOLDER JOINT FAILURE MECHANISM

A plot of the load versus time during testing (Instron Tester) showed the peel strength of the wire from epoxy to be slightly lower than the joint rupture strength (see Figure 65). The flat portion of the curve indicates the peel strength and duration of peeling prior to actual loading of the solder joint. All joints failed in this manner.

Table 9. Joint Certification Tests

		180° Peel Load, Grams [1]	
Head Sect No.	Track No.	After Solder Epoxy Cure [2]	After Age 72 Hrs @ 90° C [2]
R013	1	41	
	2	41	
	3	36	
	4		37
	5		35
	6		39
R029	1	35.5	
	2	38	
	3	44	
	4		39.5
	5		39
	6		36.5
Read, Avg.		39.3	37.7
W019	9	44.5	
	8	43	
	7	46.5	
	4		48.5
	5		40
	6		52
W050	9	51.5	
	8	46	
	7	56	
	4		48
	5		42.5
	6		41
Write, Avg.		47.9	45.3

1. Peel test was a 180° wire bend and peel load.

2. Average load of two readings (1 per each track leg).

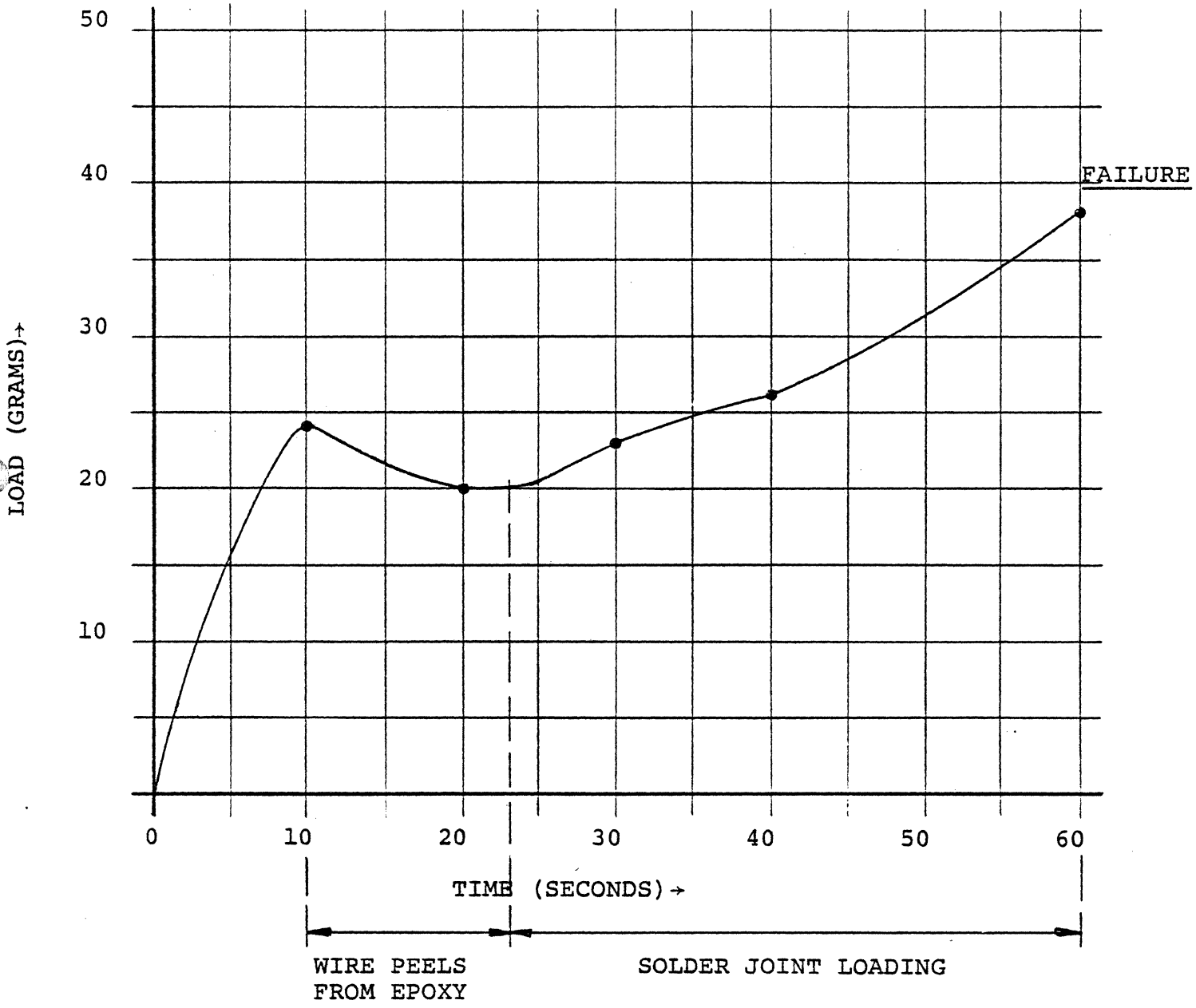


FIGURE 65

LOADING CURVE FOR PEEL TEST

METALLOGRAPHY

A photomicrograph of a typical wire-to-track joint cross-section is shown in Figure 66.

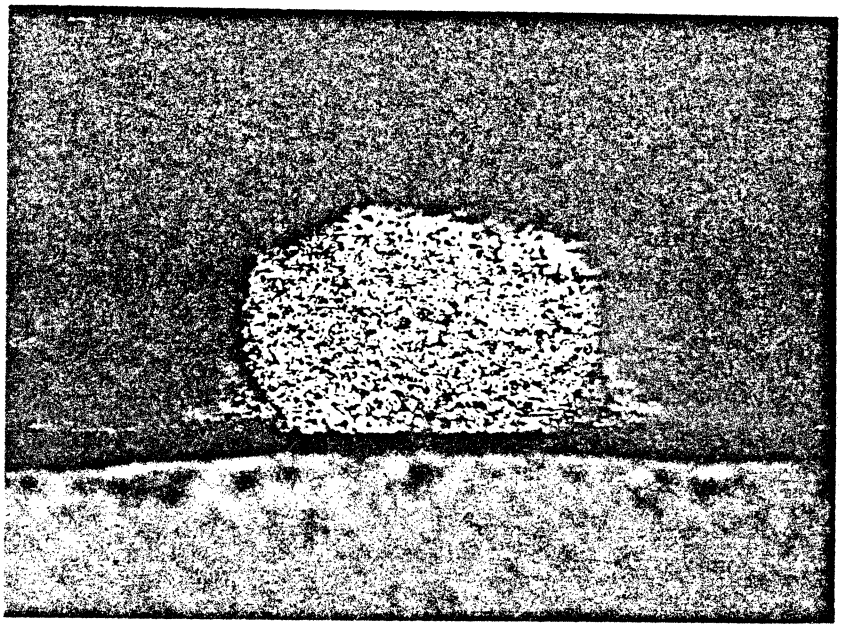


FIGURE 66

TYPICAL SOLDER JOINT CROSS-SECTION, UNETCHED (600X)

FUTURE DEVELOPMENT

Thermocompression (TC) Wire Bonding

A TC Bonder has been purchased and partially evaluated. This system will be implemented concurrent with the "C" test facility.

The failure mechanism of the TC bonds were identical to those for the solder joints. The preliminary results also indicate that gold plating of the copper legs is not necessary for good interconnections.

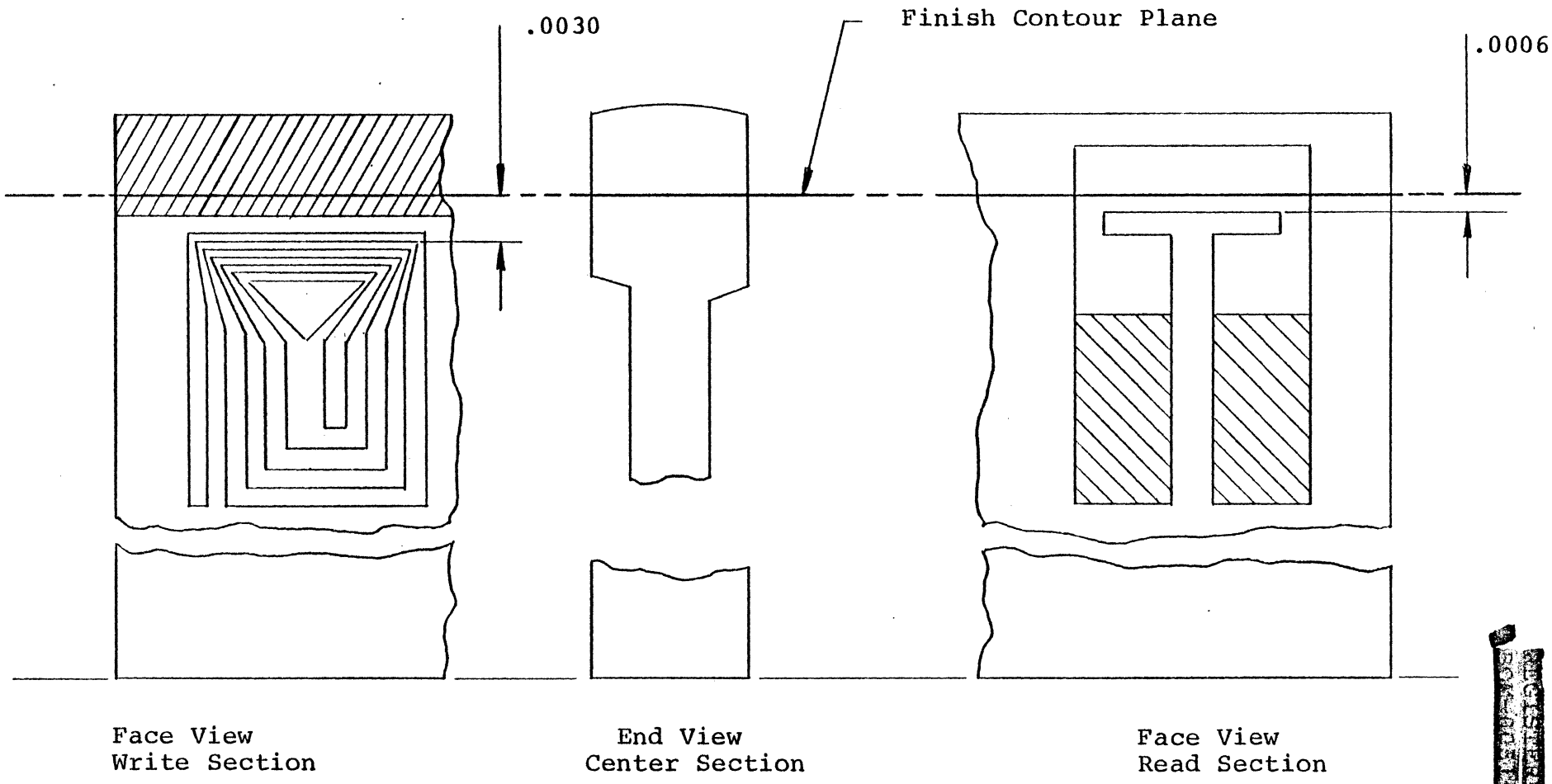
Decal Soldering

The Fishkill/Endicott decal soldering procedure offers many advantages if the process can be modified such that no fluxing is required. Little work has been done (by Boulder) in this regard, but may be evaluated in the future.

FINAL HEAD ASSEMBLY

This section covers the requirements of the head assembly process. This assembly consists of five sub-assemblies that are held together with two screws and epoxy. The main requirements for this process are to secure the sections into position within .0004 inch alignment on the DU1 surfaces, and alignment of ± .0005 from the DU2 surfaces. Each gap must also be force-closed (intimate contact between read, center, and write) within 10 microinches (Refer to Figures 67, 68, 69, and 70).

The relationship between the read and write sections is designed to allow .0028 inch from the bottom of the write track to the top of the contour, and .0004 inches from the bottom of the read track to the top of the contour (see Figure 67).



DU Alignment of Read and Write must be within .0004 inch.
DU Alignment of Read and Write to the center section must be within .002 inch.

FIGURE 67 DU ALIGNMENT OF READ, WRITE, AND CENTER SECTION

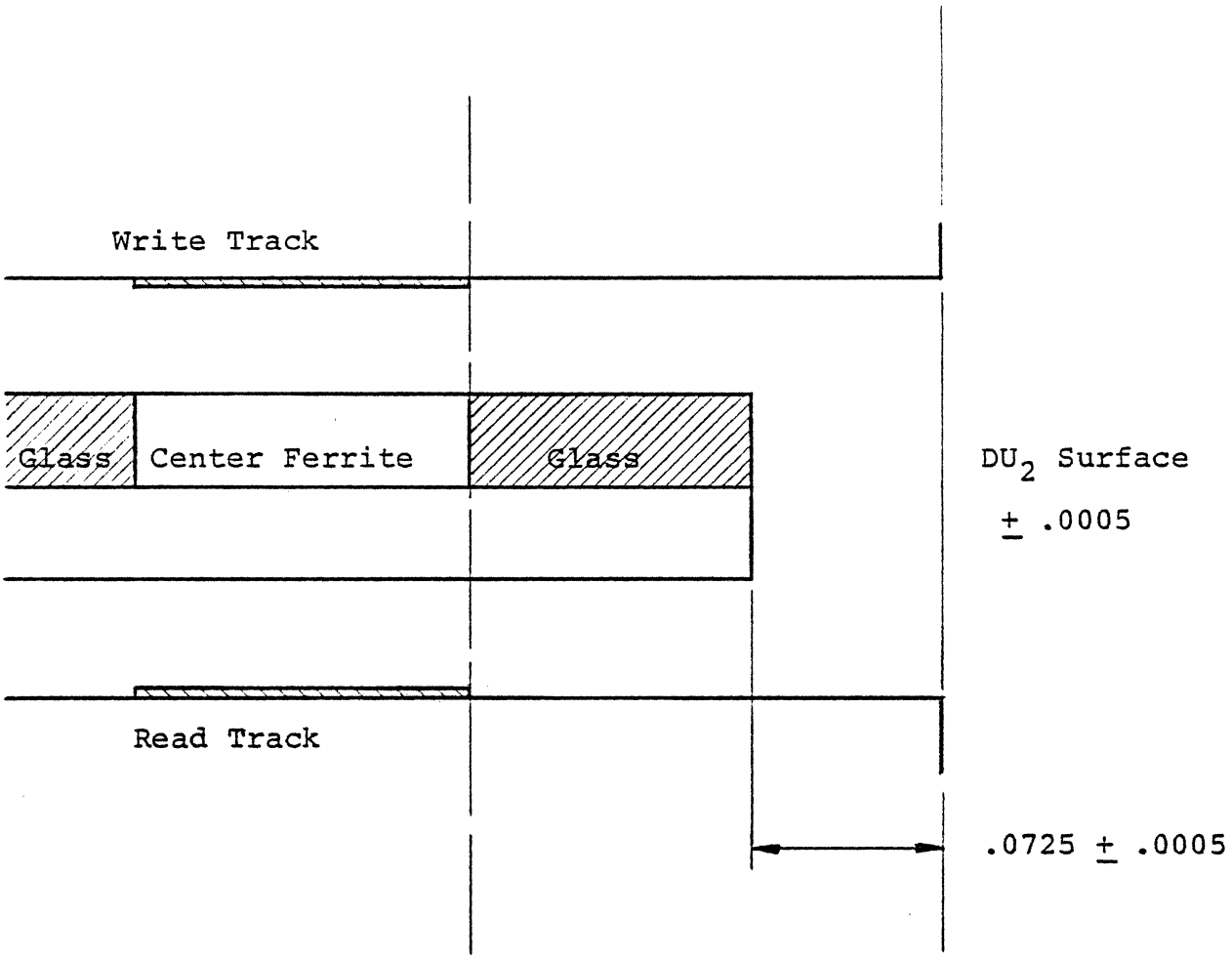


FIGURE 68

TOP VIEW OF READ, WRITE,

AND CENTER SECTION ALIGNMENT

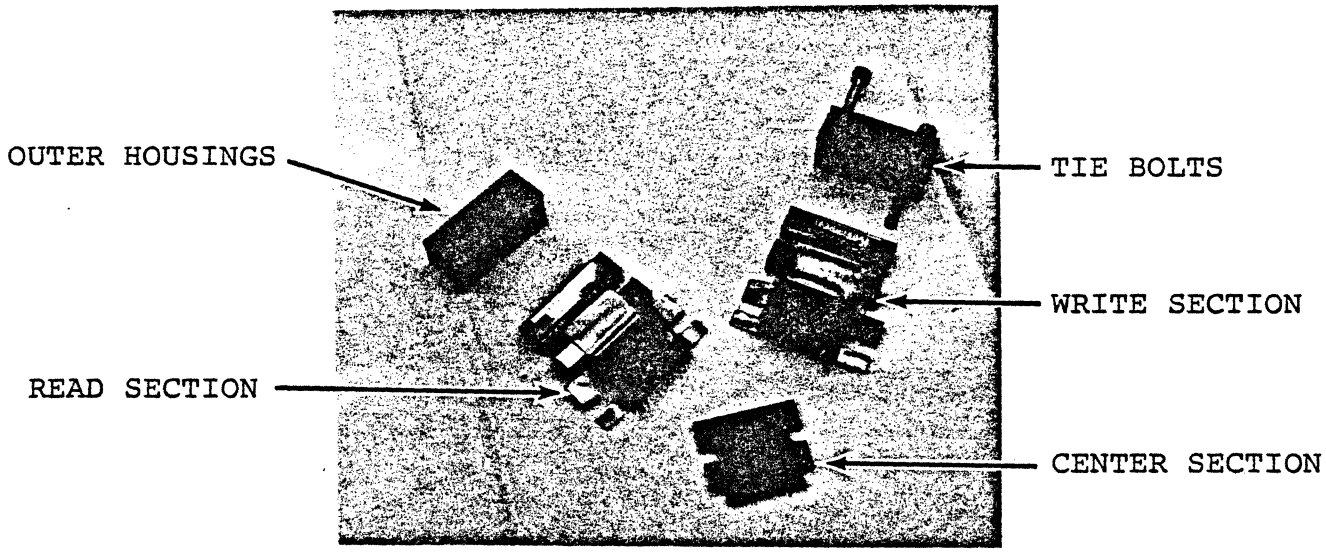


FIGURE 69

INDIVIDUAL SECTIONS OF TAPE HEAD

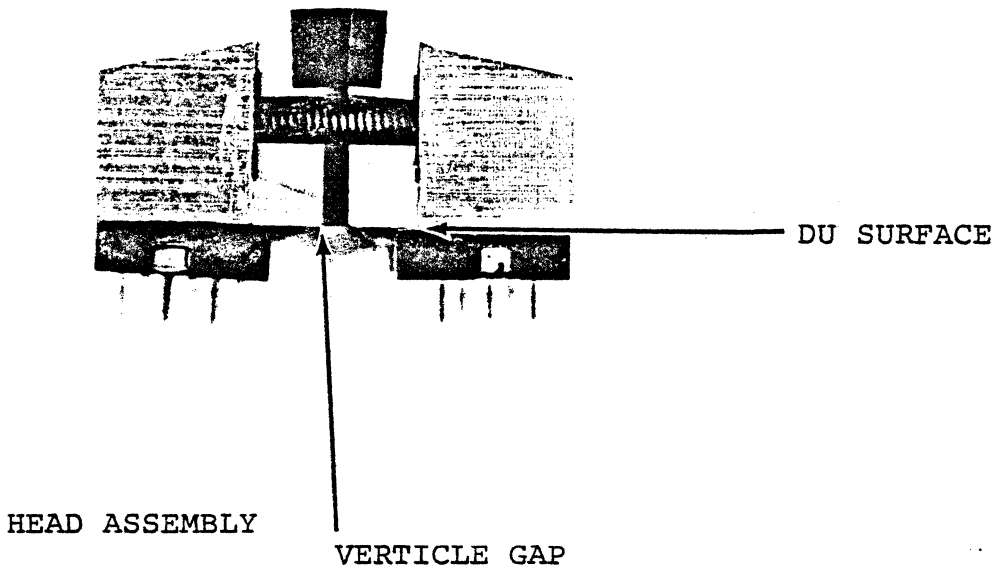


FIGURE 70

SIDE VIEW OF ASSEMBLED HEAD

EQUIPMENT USED

The assembly fixture is shown in Figure 71. All DU surfaces on this fixture are held to within .00005 inch alignment. No mounting surfaces are movable and the clamping mechanism is designed to assure a good closure between all sections.

The epoxy applicators are small injection needles and syringes (see Figure 72).

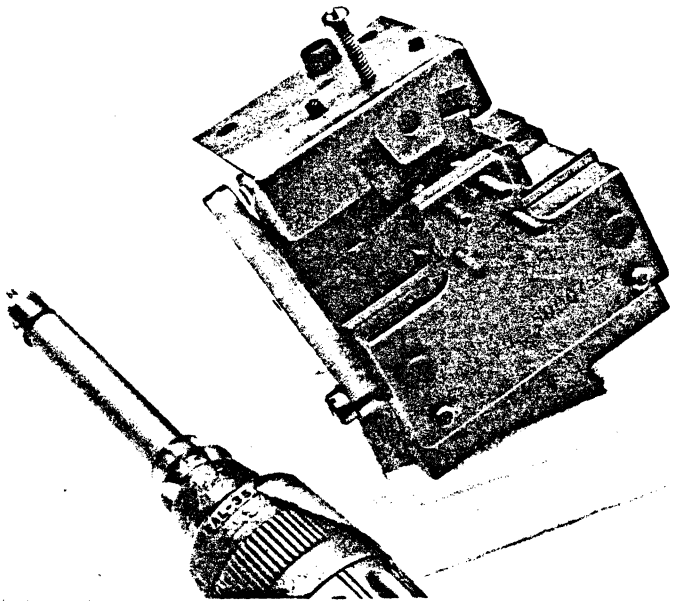


FIGURE 71

TAPE HEAD IN ASSEMBLY FIXTURE

The oven used for curing was a small 2.6 cubic foot circulating oven. The cycle required to get the head up to curing temperature is shown in Figure 73.

PROCESS

All sections are assembled into the fixture using the read gap to establish the plane that controls the squareness of DU1 surface to the gaps. The sections are held together with two screws that are torqued to five inch pounds each (Refer to Figure 70).

The part is then removed from the assembly fixture and placed in the potting fixture. Both sides of the head are potted with plater's putty to prevent the epoxy (placed in the head) from leaking out (see Figure 72). After the potting is complete, a retaining compound is placed along the top of the read and write gaps and allowed to work down into the gaps by capillary action. This compound is cured for 45 minutes in a circulating oven at 80° C (room temperature cure is possible but it requires 24 hours). Refer to Figure 73.

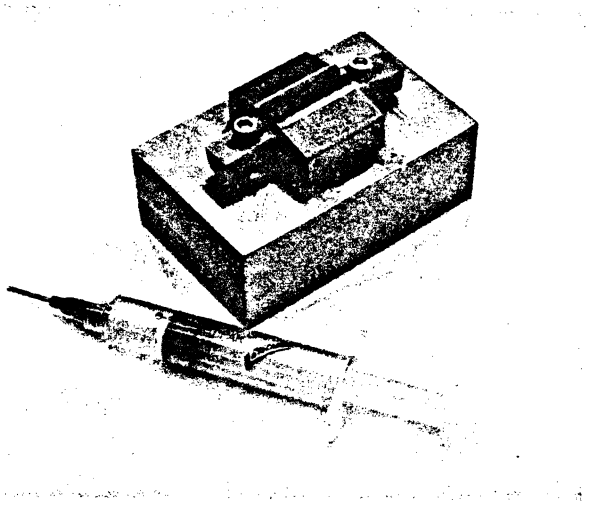


FIGURE 72

TAPE HEAD POTTING FIXTURE

This compound, as specified by Department 29S (SDD), has a viscosity of 12 cps and will creep down into the small cavities that are caused by voids, out of flat conditions, etc. The main purpose for this compound is to keep moisture (from the machining processes) out of the head.

The head cavities are then potted as specified (Engineering Spec 29T-1111) with epoxy and cured for six hours at 80° C. This epoxy keeps contamina out of the head cavities, and secures the read, write, and center sections together. The potting agent used is a 2-ethyl, 4-methyl imidazole cured bis phenol a epoxy resin (Epon 826), mixed with 4% of 2-ethyl, 4-methyl imidazole (EMI-24). Coefficient of thermal expansion for this epoxy is a maximum of 8.0×10^{-5} CM/CM/°C for under 70° C.

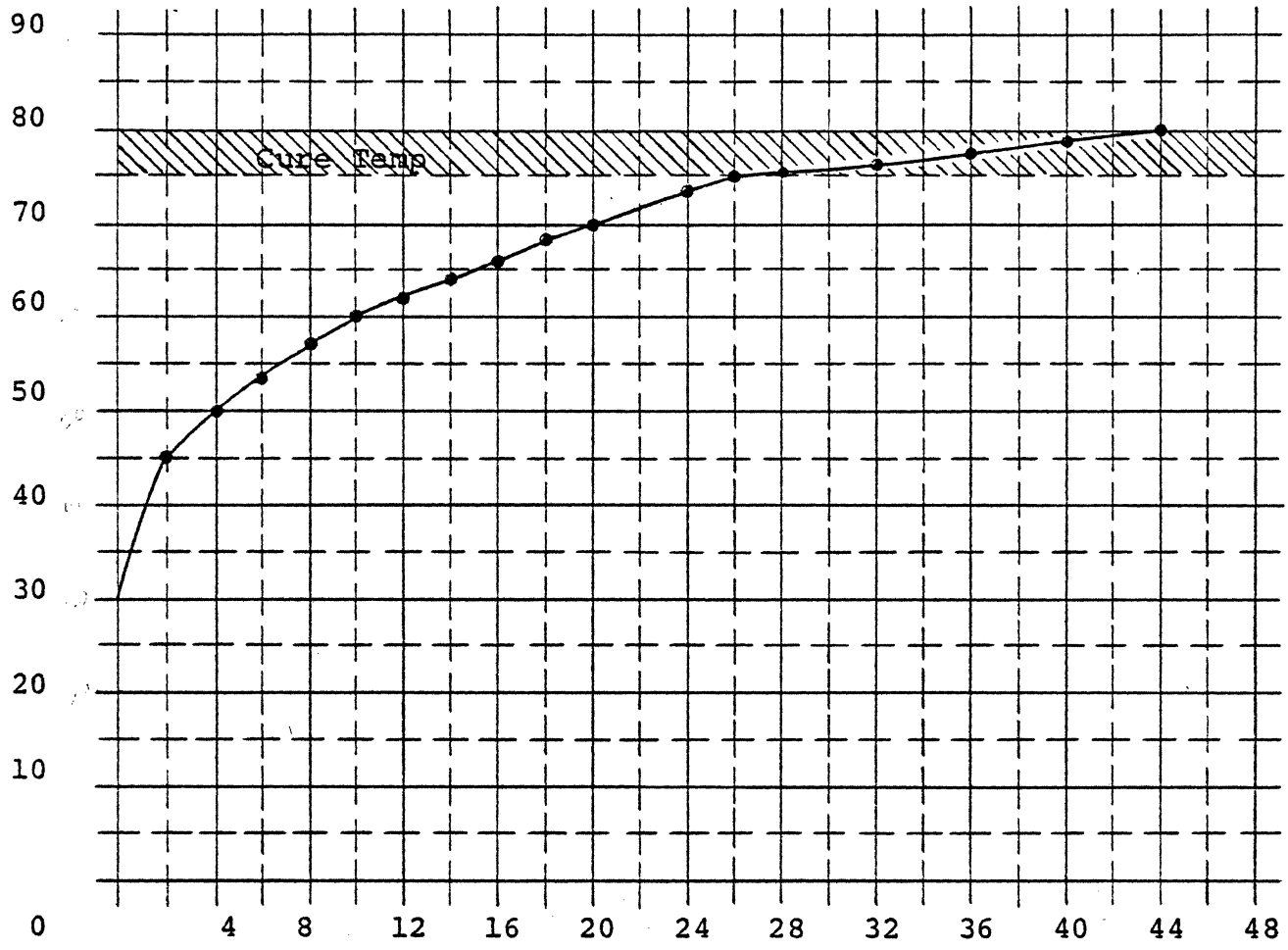


FIGURE 73

CURING CURVE FOR EPOXY

SIGNIFICANT PROBLEMS ENCOUNTERED

One of the most significant problems encountered at the assembly operation was to obtain a good closure. This problem was found to have three main contributors:

1. The pressure of irregularities in the copper surfaces of the tracks (see Figure 74). This problem was corrected by replacing the copper deposition process with an electroplating process.

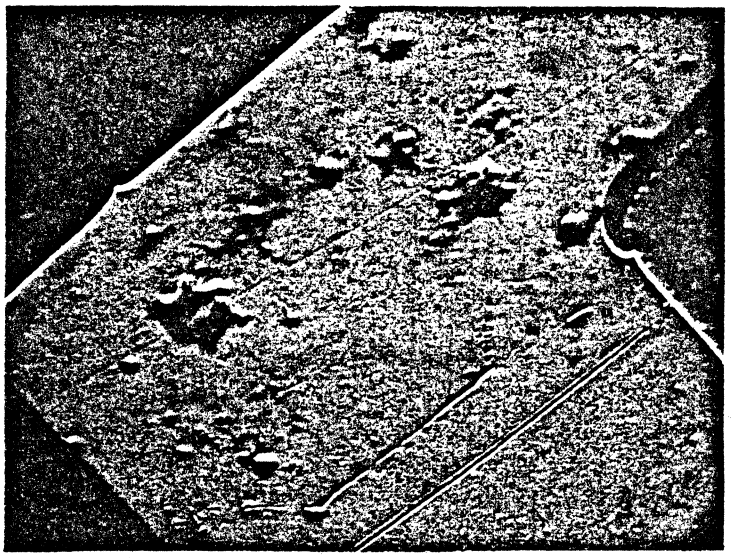


FIGURE 74

PICTURE OF COPPER IRREGULARITIES
(350 X)

2. Contamination on the Critical Surfaces:

   All assembly operations were performed in a class ten-thousand clean room. The main source of contamination came from the retaining compound (Lock-Tite 75). This type of compound required filtering to assure only a pure compound was applied to the surfaces. Extreme difficulty was experienced in using .25 micron filters and, as a result, there were problems with contamination. This compound had a viscosity of 125 cps.

   The corrective action was to assemble the head prior to applying the compound. A compound of 12 cps (Locktite AA) was then used and allowed to creep down into the gap by capillary action. This process provided its own filter.

3. Forces Holding the Gap Together Greatly Affected the Closure:

Early designs required the closure against each section to be made prior to wire bond to protect the tracks against soldering fluxes. Epoxy was used to hold this closure in place and it would not support the grinding forces. As a result, open gaps (causing chipping) occurred.

The corrective action was to design the head so the closure was supported with tie bolts. This positive mechanical force adequately supports the closure.

Several torques (2, 3, 4, and 5 inch pounds) have been verified. Adequate pressure to assure a good closure at each gap was obtained with 5 inch pounds. This torque also provides enough support to keep the gaps from chipping. Torques higher than 5 inch pounds indicate that too much stress is being applied to the ferrite causing it to fracture during the final contour grind operation. Enough force, however, is required to deform minute irregularities in the tracks and to deform the slight out-of-flatness of each section.

Another problem was openings in the track continuity which occurred during the assembly and machining processes. One of the main contributors for opens was the curing of the epoxy that filled the head cavities. Enough stress was put upon the internal wiring to cause openings. Two changes corrected this problem: The first change covered the internal wires with Epoxy 330* at the wire bond operation. This lessened the chance for the potting epoxy to directly stress each wire.

The second change was to use Epon 826 instead of Epon 828 to pot the cavities. This reduced the amount of internal stress on the wires and eliminated all opens at assembly.

Other opens have occurred during the grind operation because of gap chipping. This is discussed at the contour grind operation.

Chipping of DU surfaces has occurred while using ferrite and barium titnate ceramic (BTC). Had these material been required, it would have been necessary to place each head in a sub-fixture and remain in that fixture through all operations. This would eliminate most of the fatigure on these surfaces caused by clamping at each operation.

By using titanium as a housing material, all of the chipping problems were eliminated.

* Epoxy procured from Hughes Associates, Excelsior, Minnesota

DEVELOPMENT WORK

Some development work in Department 29K showed pressure effects on the MR elements. Results indicated that no effect on the MR was experienced up to approximately 11,000 psi. This experiment was conducted without the 15 microinch overcoat (it is still in design) on the MR element. If fractures were caused by the overcoat fracturing, the MR elements would be affected. However, heads built with this overcoat show no indication of a fracture problem.

Different materials have been used for outer housings to provide closure support. The material now being used is 416 stainless steel. SS416 material has a close expansion match to titanium, BTC, and ferrite which assures a good closure and causes minimum stresses during curing. SS416 is magnetic and does not function well with a permanent magnet design. Therefore, titanium outer housings are being evaluated. This could change the design to eliminate the two outer housings and incorporate them into the read and write housings.

Aluminum housings with brass screws were evaluated with negative results. Stresses caused by the high expansion rates of the aluminum broke several center sections (see Figure 75). When the torque was reduced to allow more room for expansion, there were problems maintaining a good closure.

Dimensional requirements have required locating planes to be established on each section. These planes are common locating surfaces for all operations such as photoetching, assembly, and contouring. This minimizes the locating surface errors such as flatness, squareness, etc.

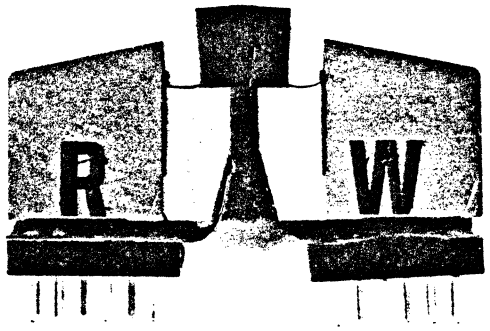


FIGURE 75

BISSECTED VIEW OF HEAD WITH ALUMINUM HOUSINGS

Figure 75 shows a bissected view of a head assembled with aluminum outer housings. Fractures in the BTC housings and ferrite center section were caused by the added stress from extreme rates of thermal expansion in the aluminum housings.

Reduced tension on the tie bolts eliminated this problem, but created closure problems.

CONTOUR GRINDING

This section covers the contour grinding process of the Newton head. This process must meet the following requirements per Engineering Spec 29T-1018 and applicable part prints:

The contour should be a 1.8 ± .3 inch radius symmetrical about both gaps.

The contour height of the tape head must measure within ± .001 inch.

The throat height of the read side must measure within .0001 as computed with a resistance measuring technique.

The write throat height must measure within ± .0012 inch.

Flatness measured parallel to the gaps must measure less than 150 microinches.

Ferrite pull-out (grain size particles of ferrite voiding) must be controlled to less than 100 microinches. The density-size ration must not exceed 10 voids per .100 inch if the size is greater than 50 microinches.

To meet these requirements, the part is rotated into a diamond cup wheel at a very slow rate. The grit of the diamond cup wheel is 20,000 (3 micron) and the table feed rate is as slow as 1/8 inch per minutes.

EQUIPMENT USED

The grinder and fixture used to generate the contour is shown in Figures 76 and 77. The fixture is designed to oscillate around a pivot point at varying ranges up to 350 cyles per minute.

The cam on the fixture is designed to provide the acceleration and deceleration in the positions where the wheel is not in contact with the tape head.

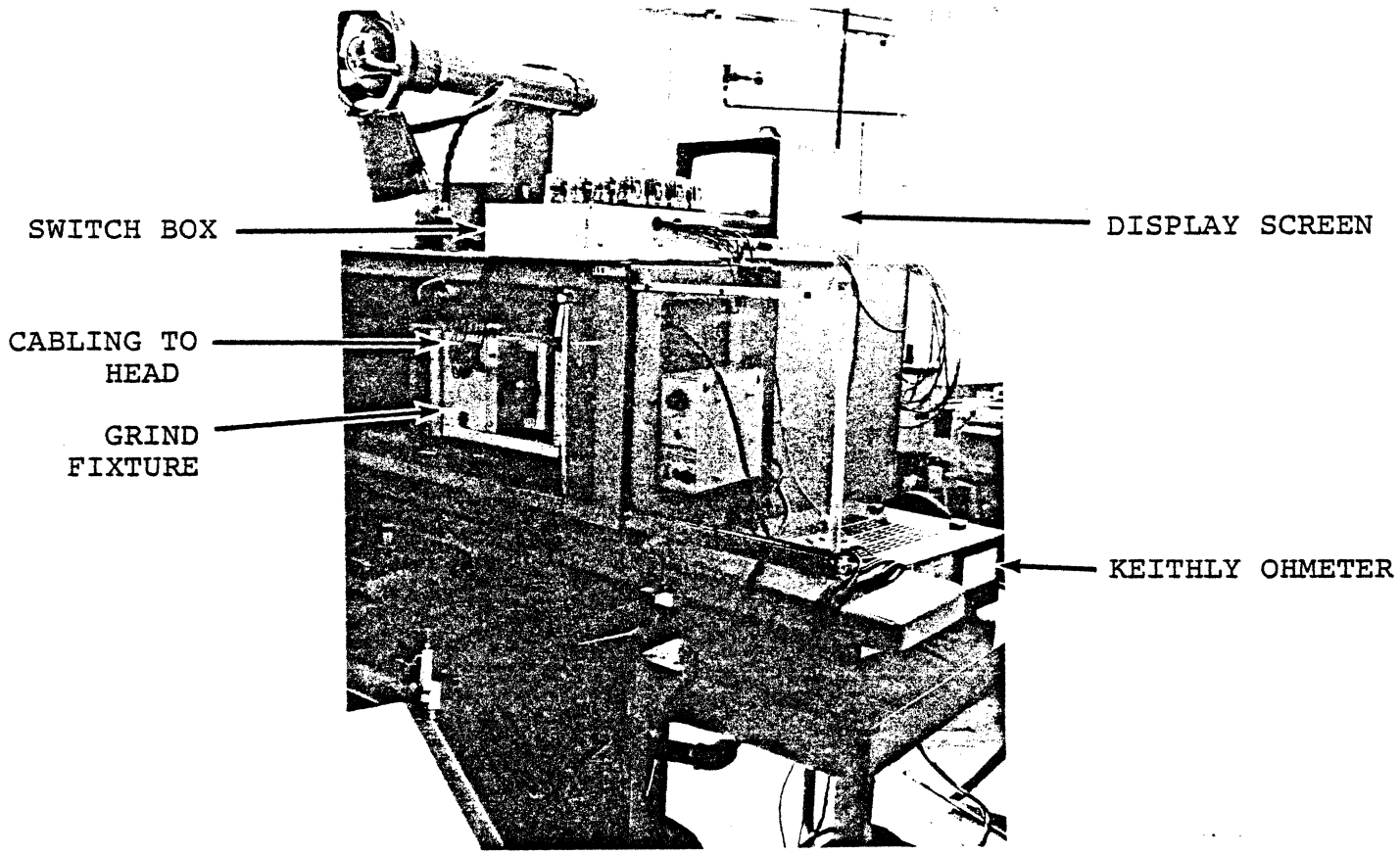


FIGURE 76

GRIND SETUP

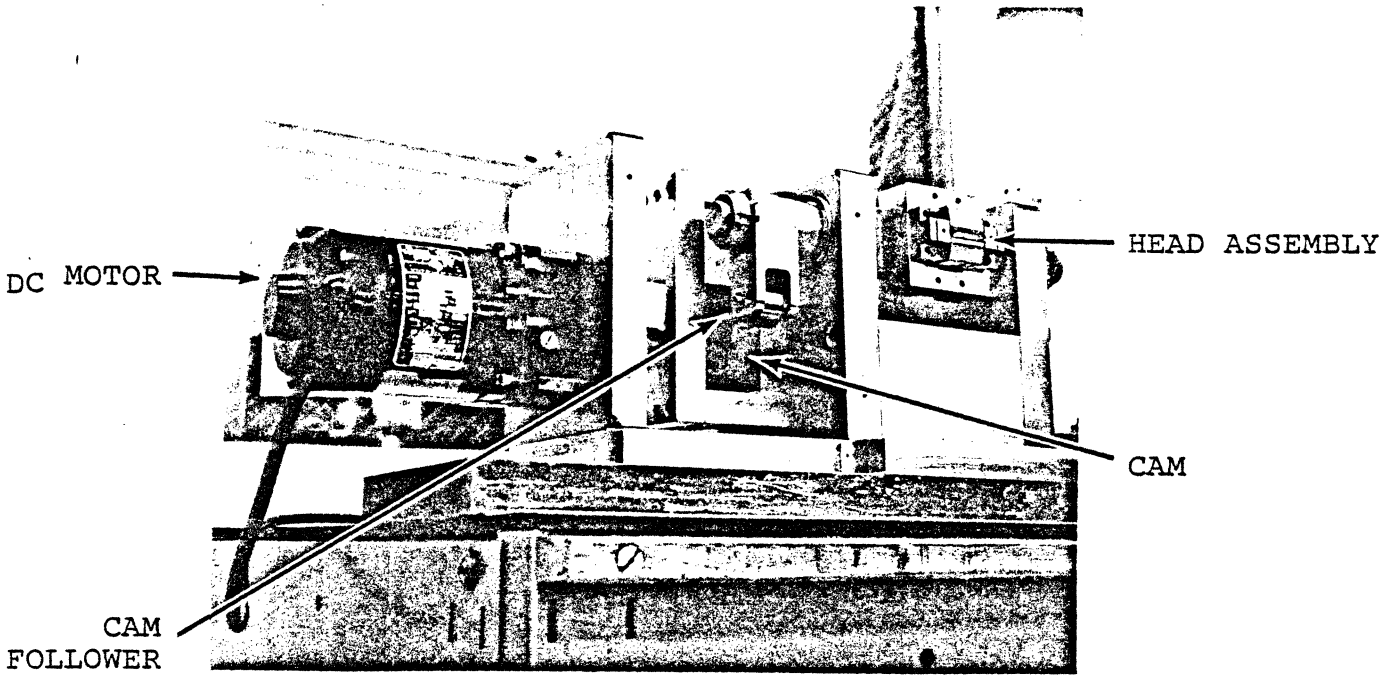


FIGURE 77

GRIND FIXTURE

Eighteen leads of cabling are routed through the grind fixture and plugged into the head assembly. The cabling comes from a switch box that uses a multiplexing relay to measure the resistance of all nine tracks. Constant current is supplied from the Keithley Ohmeter through the switch box and across each track.

A voltage drop is created across each track and is fed through the switch box to an 1800 computer. The computer compares the value of the voltage drop to a formula and prints out a comparison of resistance values and throat heights on a 1053 typewriter.

The print-out is monitored by a television camera that transfers this information through coax cabling to a display screen at the grind station.

A schematic of this process is shown in Figure 78 (this process was implemented with the combined efforts of Department 516 and 525).

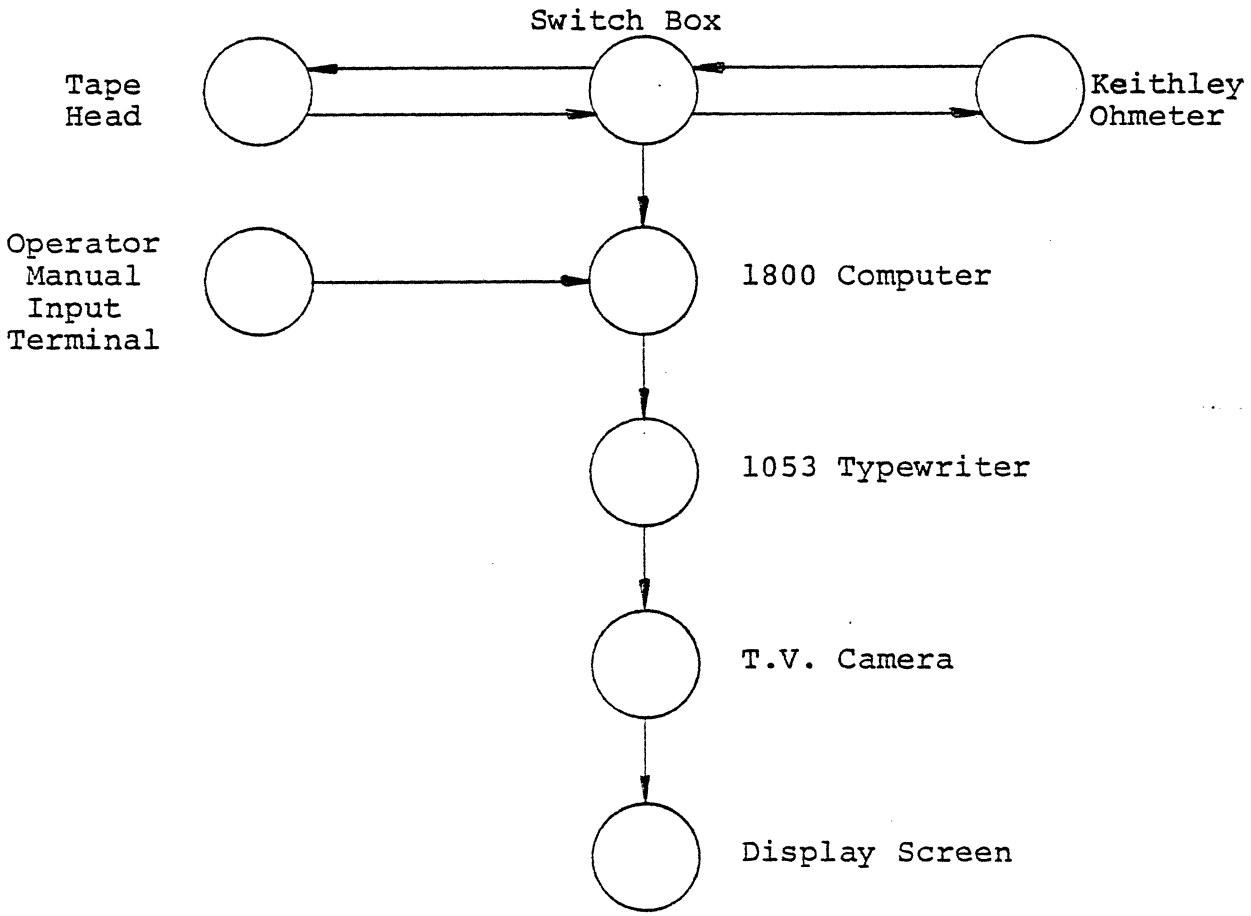


FIGURE 78

SCHEMATIC OF CONTROL SYSTEM

The contour grinder is a Do-All MTA 70 slicer equipped with a creep-feed which is required for this operation.

Several requests for quotation were submitted for a special grinder to provide the following specifications:

Variable	Original Spec	Revised Spec
Table Feed	1/4 to 20 IPM	Same
Spindle Run-Out	5 microinches	25 microinches
Table Run-Out	50 microinches	100 microinches
Spindle Speed	Variable 10,000 RPM Max	Variable 9,000 RPM Max

Costs up to $55,000 and lead times up to two years forced some compromises.

The final quote was selected on a Reid, Model 612-SG, indexing slicer for a cost of $15,000. This slicer is driven by DC motors for table feed and table indexing.

CONTOUR GRINDING PROCESS

The grind process rocks the head on a 1.8 inch radius. While it is rocking, the part is fed by a cup wheel at a very slow rate (Refer to Figure 79). Another method is a two-step grind operation described below:

Rough Contour Grinding:

Cup-Wheel	MD-400J-100 B 1/8 (6 inch O.D.)
Spindle RPM	4700
Grind Coolant	Johnson's 50 Cool
Table Feed	.5 I.P.M.
Fixture Rotation	200 C.P.M.
Depth of Cut	.0015 inch maximum

Each head is ground to within .002 inches of the final contour grind dimension. To control the grinding, the inner track network of the read side of the head is bridged between adjoining tracks (Refer to Figure 80). By measuring the resistance between tracks, the operator can determine the height of the bridge network. This network is ground until continuity is broken. At this point, the rough grind is terminated.

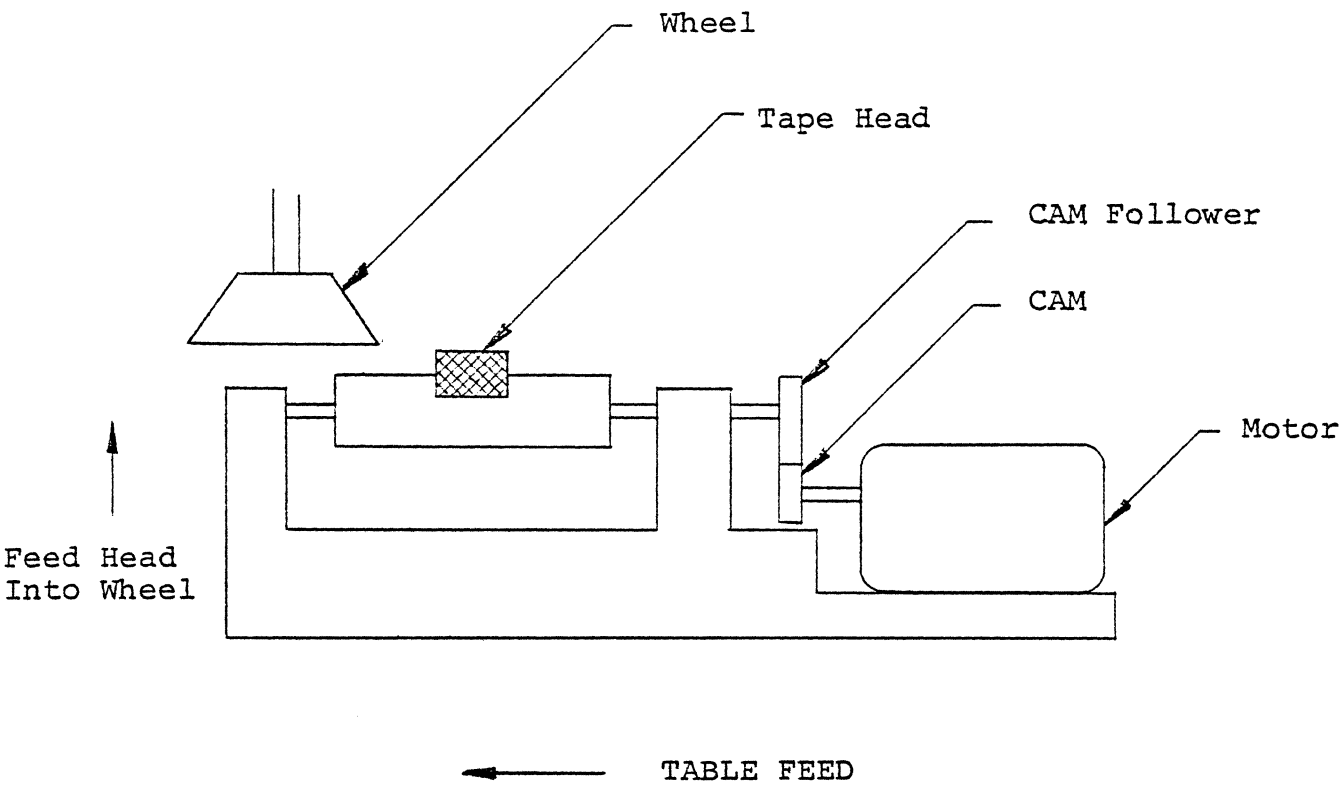
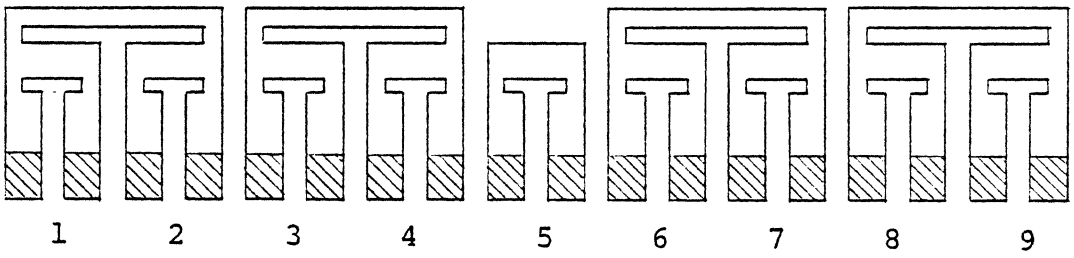


FIGURE 79

FUNCTION OF GRIND FIXTURE



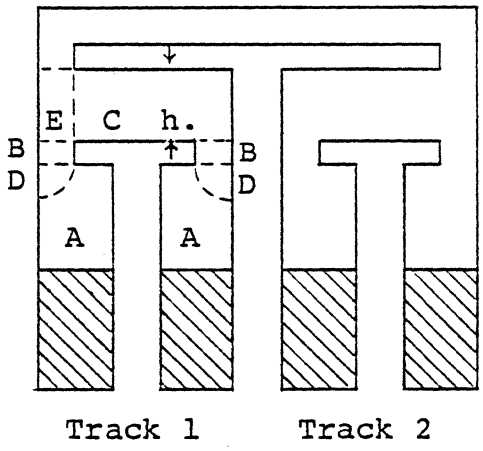


FIGURE 80

READ TRACK NETWORK

Finish Contour Grinding:

Cup Wheel	3 Micron Diamond*
Spindle RPM	4700
Grind Coolant	Johnson's 50 Cool
Table Feed	1/8 I.P.M.
Fixture Rotation	200 C.P.M.
Depth of Cut	.00010 inch max.

This grind wheel was manufactured in SDD Boulder from San Jose's manufacturing instructions.

Approximately .002 inches of stock must be removed with this process.

To control the grind process, the head is cabled to the 1800 computer as previously described.

Any time the operator wishes to measure the throat height, he pushes a button on the switch box. Each throat height is then displayed on the screen at the grind station.

Figure 81 shows a computer printout comparing the resistance with throat height.

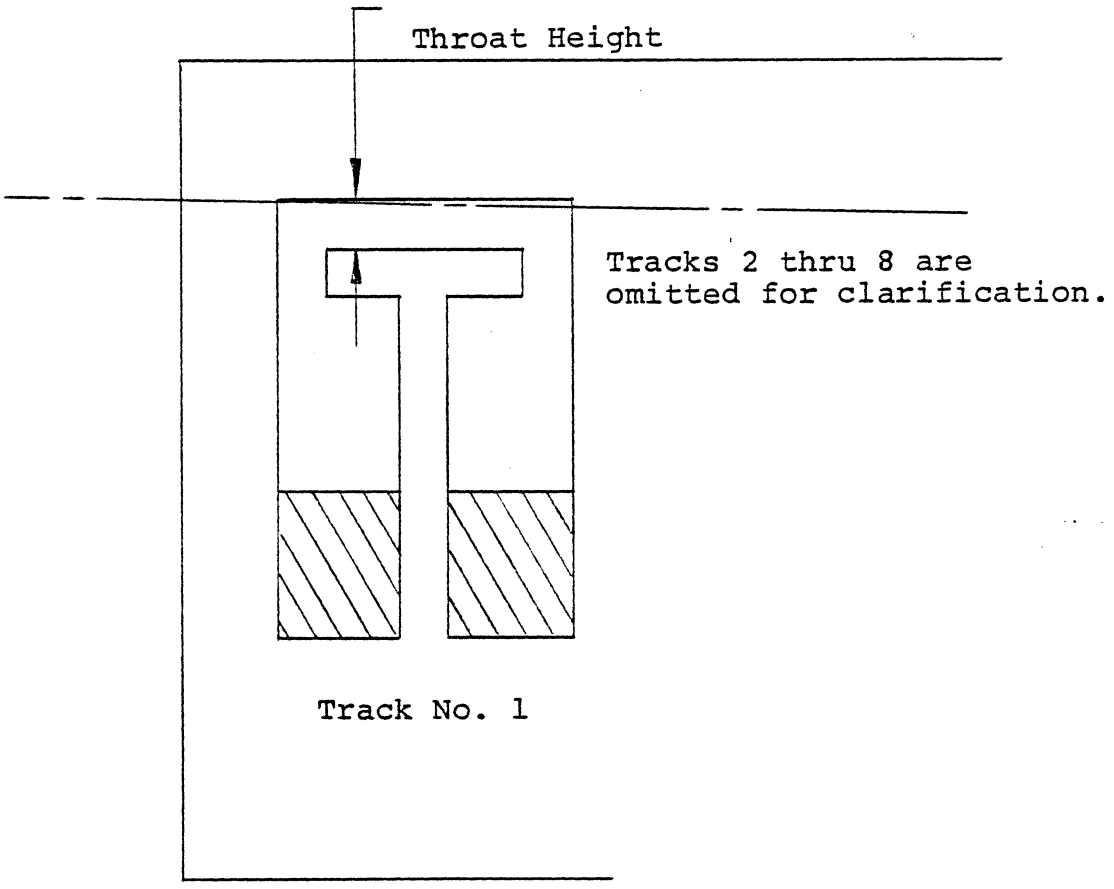


FIGURE 81

COMPUTER PRINTOUT: RESISTANCE AND THROAT HEIGHT

The concept of using resistance to control throat height is described under Patent Disclosure BO 871-48 with four authors from SMD and SDD. The following concept is used (Refer to Figure 80):

Input Required:

(S) Height of legs, from bottom of the throat to the top of the copper pads.

(ho) Initial throat height.

(Ro) Initial resistance.

Output Obtained:

(h) Calculated throat height (in inches).

(R) Measured resistance (in ohms).

Assumptions:

(1) The resistivity ÷ the thickness function of the high resistance portion of any element, is constant over the area of the element.

(2) The width of the two legs is constant.

Explanation

If $r = \frac{(\text{resistivity})}{(\text{thickness})}$ then the resistance of any strip "i"

$$Ri + r \frac{(\text{length } l)}{(\text{width } w)} \; i$$

The element is then divided as shown in Figure 81.

The formula for the initial condition will then read as such:

$$Ro = r \; 2 \frac{(l)}{(w)\; A} + 2 \frac{(l)}{(w)\; B} + \frac{(l)}{(w)\; C} + 2 \frac{(l)}{(w)\; D} + \frac{(l)}{(w)\; E}$$

If Ro is known (as measured) then r can be calculated:

$$r = \frac{Ro}{2 \frac{(l)}{(w)\; A} + 2 \frac{(l)}{(w)\; B} + \frac{(l)}{(w)\; C} + 2 \frac{(l)}{(w)\; D} + \frac{(l)}{(w)\; E}}$$

As the material is being ground from the top of the head, the bridge between tracks is removed (Region E) and the length of the throat "C" is increased to the full width of the track.

As the grind proceeds and we want to know the relationship showing the new resistance for any new value of height, the new resistance is:

$$R = r \quad 2\,\frac{(l)}{(w)\,A} + 2\,\frac{(l)}{(w)\,B} + \frac{(l)}{(w)\,C} + 2\,\frac{(l)}{(w)\,D}$$

Substituting the computed value for r, we get:

$$R = Ro \quad \frac{2\,\frac{(l)}{(w)\,A} + 2\,\frac{(l)}{(w)\,B} + \frac{(l)}{(w)\,C} + 2\,\frac{(l)}{(w)\,D}}{2\,\frac{(l)}{(w)\,A} + 2\,\frac{(l)}{(w)\,B} + \frac{(l)}{(w)\,C} + 2\,\frac{(l)}{(w)\,D} + \frac{(l)}{(w)\,E}}$$

During the grind process, a condition often occurs where there is a taper in the throat heights. This is illustrated in Figure 82.

```
      HTSMR
INITIAL RESISTANCE, OHMS
□:
      124
INITIAL HEIGHT, MILS
□:
      1.9
```

HEIGHT MILS	RESISTANCE OHMS	HEIGHT MILS	RESISTANCE OHMS
0.05	4266	1.00	225
0.10	2139	1.05	215
0.15	1430	1.10	205
0.20	1076	1.15	197
0.25	863	1.20	189
0.30	721	1.25	182
0.35	620	1.30	176
0.40	544	1.35	170
0.45	485	1.40	164
0.50	437	1.45	159
0.55	399	1.50	154
0.60	367	1.55	149
0.65	339	1.60	145
0.70	316	1.65	141
0.75	296	1.70	137
0.80	278	1.75	134
0.85	262	1.80	130
0.90	248	1.85	127
0.95	236	1.90	124

FIGURE 82

TRACK ALIGNMENT

Because of tolerances required for aligning the tracks to the bottom DU surface, (for assembling the read, write, and center sections, and for grinding the contour) it is sometimes required to position the head to grind more off of one end than the other. When this happens, the difference in throat height is measured by resistance.

This condition is corrected by rotating the part around Track 5 to skew the head. The accuracy is achieved because of a 60:1 ratio built into the fixture. The variation in throat height is detected by the resistance method.

Table 10 shows how the tolerances of each operation affect the final head tolerance:

Table 10. Effects of Tolerances on Final Head

		Tolerance Required	
	Operation	Write Section	Read Section
1.	Etching-Track Positioning & Alignment	± .0003	± .0003
2.	Head Assembly Positioning & Alignment	± .0001	± .0001
3.	Contouring	± .0001	± .0002

The above figures apply only to the .5 inch area of track, not the entire housing. There is a 2:1 advantage in using the outside edges of the housing to locate from.

During the grind operation, Items 1 and 2 can be eliminated from the read section by measuring the grind height of the read tracks only. This is done with the resistance method. In order to do this, however, the tolerance must be absorbed into the write section. This is exactly what happens when resistance is used to control the grind. The total variation in the read side of the head is then ± .0002, and in the write side is ± .0010 inch. Since the design permits this amount of variation on each side, it has proven satisfactory.

CONTOUR SCALLOPING

This process is used to grind small radiused grooves (parallel to the gaps) into the contoured surface. The process parameters are listed below:

Peripheral Diamond Wheel:	MD 1200 J 100 M 1/8
Table Feed:	1 1/2 IPM
Depth of Cut:	.0015 Max - .0005 Min.
Grind Coolant:	Johnson's 50 Cool
Spindle RPM:	4700

Figure 83 shows the scalloping operation set up on Do-All MTA 60 slicer:

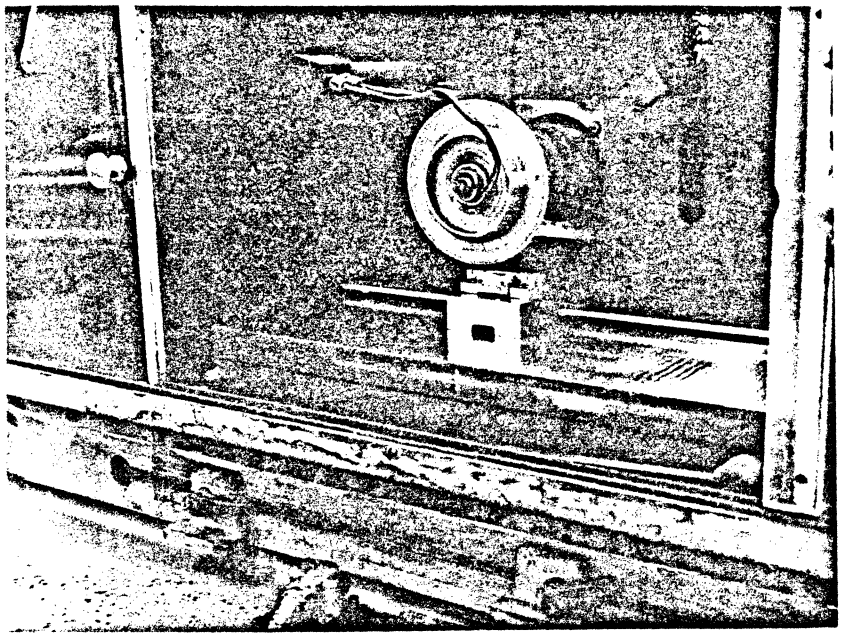


FIGURE 83

SCALLOPING EQUIPMENT

The scallop operation is set up on the centerline between the read and write gaps. Once the location is established, the table is indexed to the position for each scallop (refer to Figures 84 and 85).

Tape tolerance on the width of the groove and land must be controlled to $\pm$ .002 inch. This requirement is established by the abrasive tape lap operation and is discussed in that section.

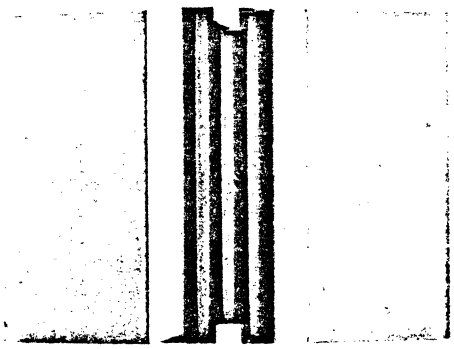


FIGURE 84

TOP VIEW OF SCALLOPS

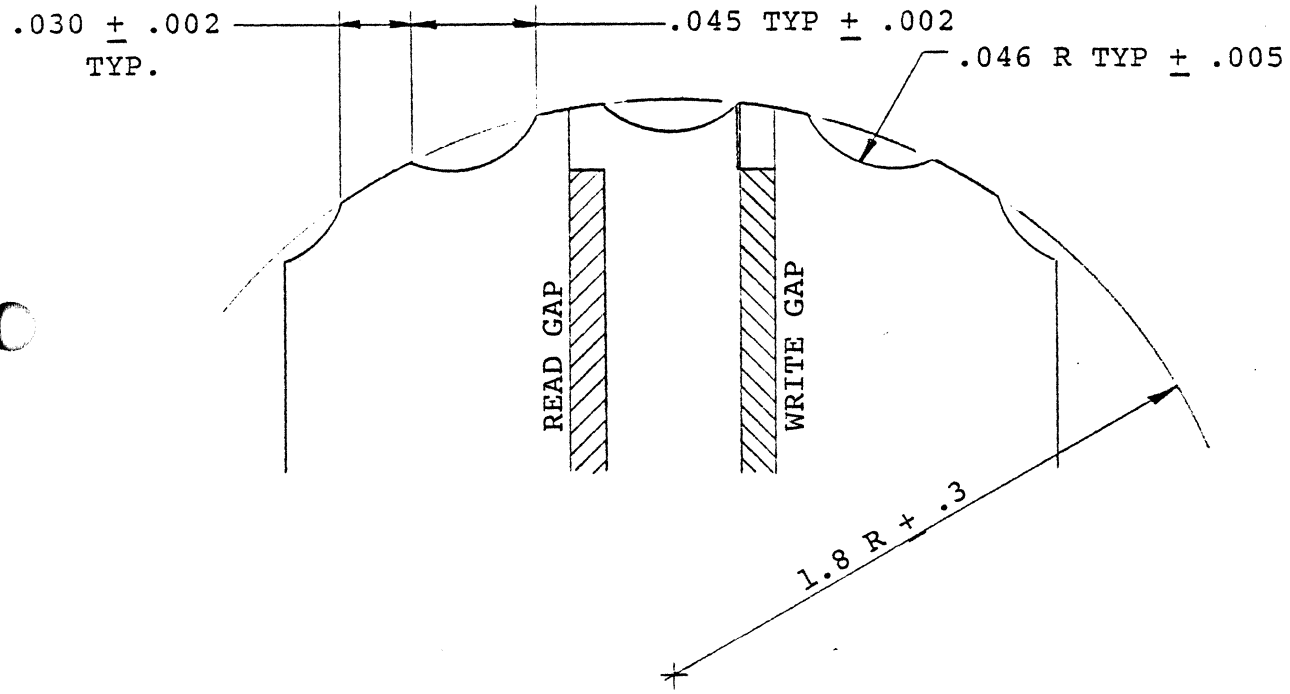


FIGURE 85

SKETCH OF SCALLOP CONTOUR

DEVELOPMENT

One of the major problems in machining ferrite is edge chipping and pull-out (grain size ferrite particles "popping out") of the ferrite. These problems are controlled by the following:

The type of ferrite used.

The cutting media.

Vibrations in equipment.

The grind coolant.

The type of material supporting the gap.

Three types of ferrite were evaluated by advanced technology in SDD:

1. Hot pressed,
2. Single crystal (Sony),
3. Cold pressed.

Hot pressed ferrite was characteristic of excessive pull-out and was used very little.

Single crystal ferrite seemed to have flaking problems during manufacturing.

Because of the availability of cold pressed ferrite from San Jose, the manufacturing processes were developed to handle this type of ferrite.

CUTTING MEDIA

Several different processes were evaluated to contour ferrite tape heads. Approximately .030 inch of material must be removed from the top surface of the head. This excess material removal is very time consuming on ferrite.

The first method used conventional contouring techniques on a G & L 350 surface grinder. The contour was dressed into an aluminum oxide or silicon carbide grinding wheel. Grinding with this method was slow, often taking 15 hours to contour a head. Several wheel dresses were required for each contour. Downfeed was difficult to control because of the cutting rate of the ferrite.

The downfeed was controlled, using an accelerometer reading into an oscilloscope. With each downfeed, the signal shown on the scope was generated from the forces of the wheel transferring to the accelerometer. When the signal became smaller, the wheel was lowered into the part again. Downfeed was set at 25 microinches and often 20 cycles of sparkout were required between each downfeed into the wheel.

Excess gap chipping and ferrite pull-out was experienced during this operation. This condition often requires lapping .003 inch from the ground surface. Some of the chipping was controlled by forming a mini-blip contour into the wheel (Refer to Figure 86). The mini-blip was a slightly raised area over the gaps. This area would lap off comparatively fast and leave a better finish on the gaps.

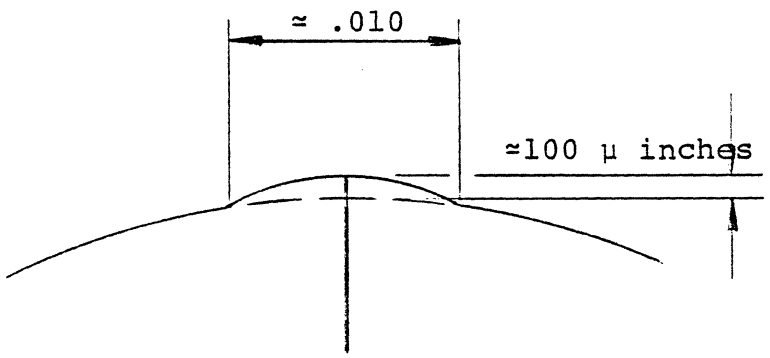


FIGURE 86

SKETCH OF MINI-BLIP

Illustrates the use of a mini-blip to provide extra stock to clean up the gap area.

Another process evaluated was to contour grind with a diamond peripheral wheel. Two different techniques were used:

1. To rotate the part into a peripheral wheel (see Figure 87).

2. To traverse the tape head under a contoured diamond wheel.

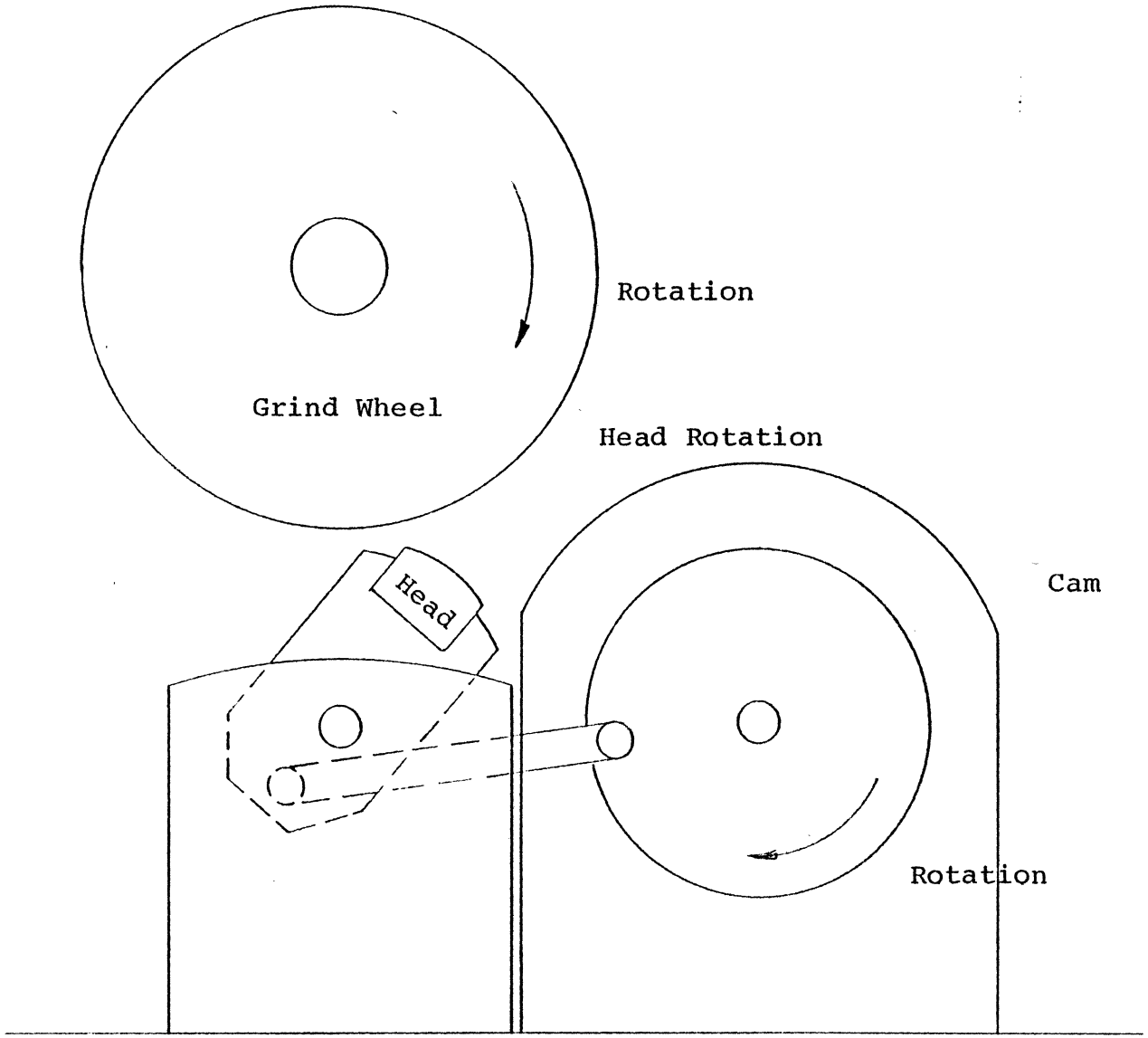
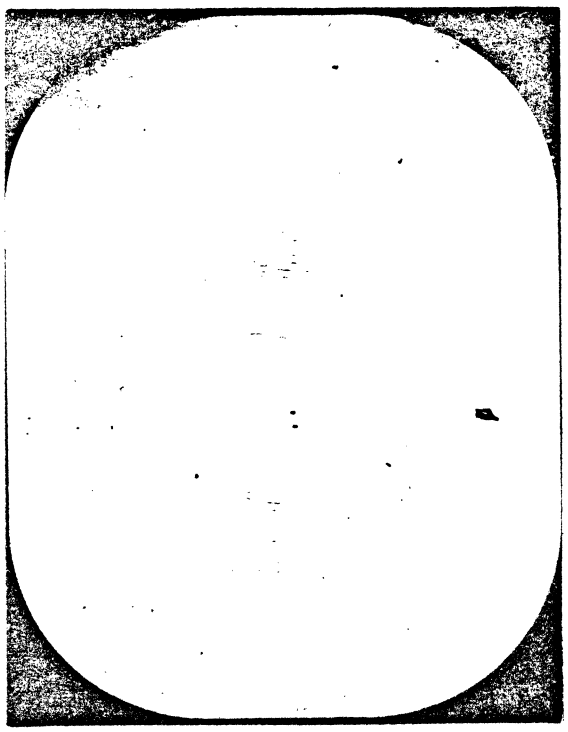


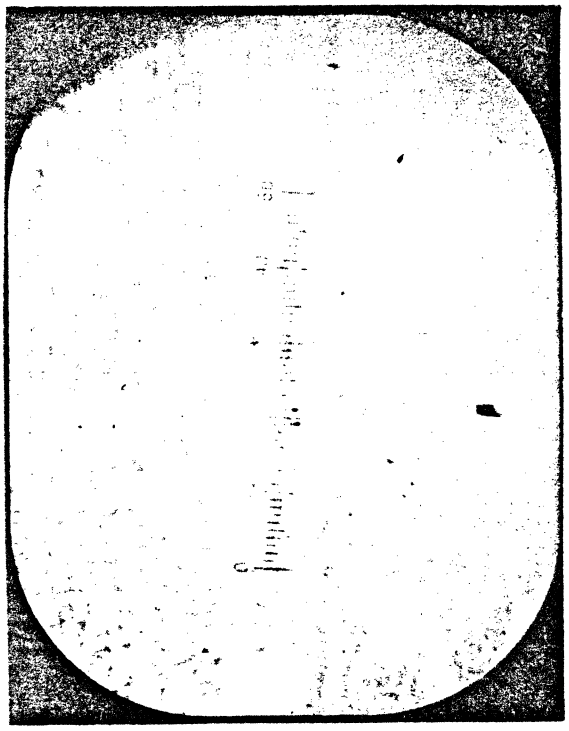
FIGURE 87 SKETCH OF RELATIVE HEAD AND WHEEL ROTATION

Illustration shows the head being rotated into the wheel. Table is locked into place with no table feed. The RPM of the motor controls the feed rate into the wheel.



1200 GRIT PERIPHERAL WHEEL
(DIAMOND)

1200 GRIT CUP WHEEL
(DIAMOND)



500 GRIT SILICON CARBIDE WHEEL

20,000 GRIT CUP WHEEL
(DIAMOND)

FIGURE 88

PHOTOMICROGRAPHS OF GROUND GAP

With both processes, excessive gap chipping and pull-out were present. Most problems with gap chipping and pull-out were related to the spindle run-out. Problems also existed in trying to keep the contoured wheel dressed.

The best process was to rock the tape head into a cup wheel. This process was then developed with assistance from Department 23L.

With any process used, diamond wheels provided the best results. Diamond wheels in grits of 400, 600, 1200, and 20,000 have been evaluated. Best results were obtained from roughing with 400 grit and finishing with 20,000 grit (the 20,000 grit wheel was manufactured in Department 23L using IBM San Jose formulation).

Material removal rate for diamond wheels ranges up to 15 times faster than with aluminum oxide or silicon carbide wheels.

Cup wheels cut much cleaner and produce a superior finish. Much of this is because spindle run-out is less critical.

Results at grind experiments on abrasives can be seen in Figure 88.

PLATE LAPPING TECHNIQUE

Prior to using the 20,000-grit wheel, a 1200-grit wheel was used. Approximately .0005 inch was required to be lapped from the contour, using a plate lapping technique (see Figure 89).

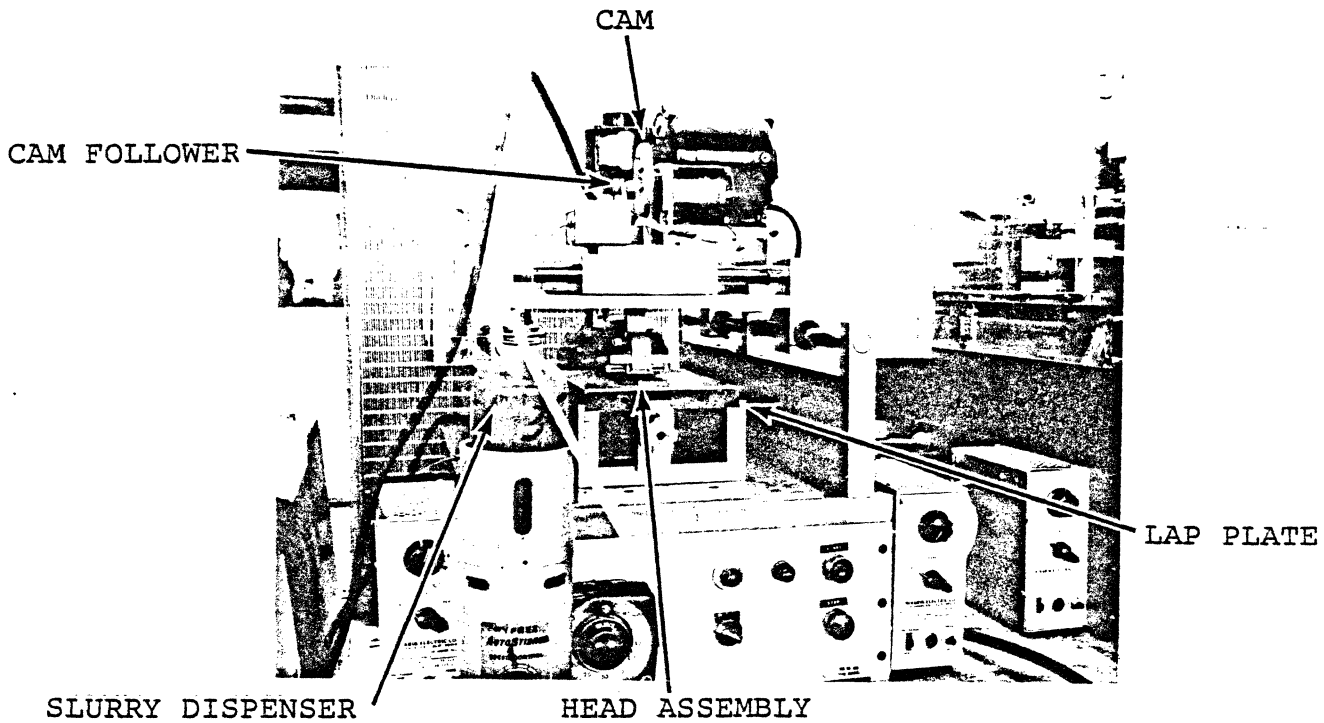


FIGURE 89

PLATE LAP EQUIPMENT

This technique used a cam to rotate the head around the radius while the head moved in a random motion on a tin lead plate (60% to 40%). The plate was charged with a 3-micron diamond slurry and the head was lapped to a resistance valve.

This technique presented problems in controlling the contour trueness because of the clearance of the fixturing. Traces taken along each part would resemble Figure 90.

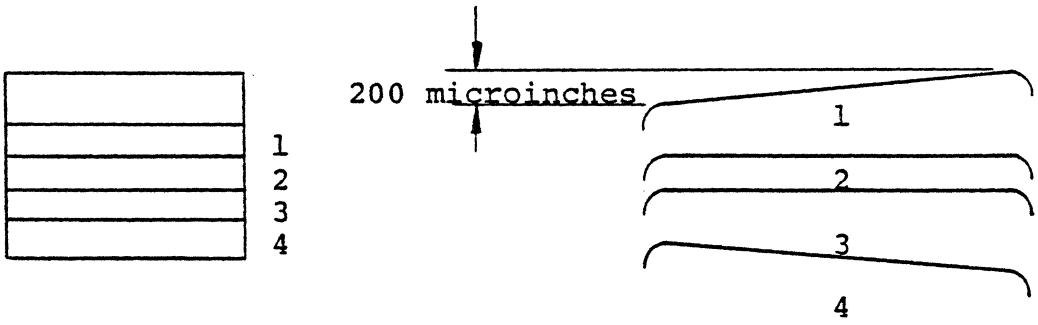


FIGURE 90

SKETCH OF CONTOUR TRUENESS

This operation was omitted with the use of the 3 micron diamond cup wheel.

One problem associated with the 3-micron diamond wheel is the removal rate. Amounts over .00005 inch per pass tends to crown the head. An example would be the trace shown in Figure 91, measured parallel to the gaps. Further experimentation is being done to eliminate this.

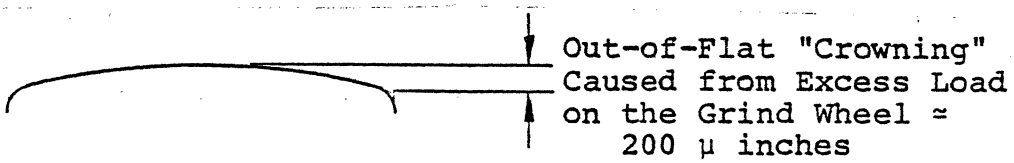


FIGURE 91

OUT OF FLAT CROWNING

ABRASIVE SLURRY GRINDING

Rough grinding this particular head is time consuming because of the amount of stock that must be removed (up to .030 inch). Advanced Technology's (SDD) experiments with abrasive slurry for rough contouring has shown promising results.

Removal rates of 1 inch per minute table feed and cutting .010 inch deep have proven successful. Some problems were encountered with gap chipping and glass erosion. However, by using this method as a roughing operation, the damaged surface could then be removed during the finish grind operation.

Gap Support

One of the most significant problems in contouring ferrite is chipping of the gap area. Although much work has been done with cutting media to reduce this problem, the important factor seems to be the type of material supporting the gap.

Several types of material have been evaluated for supporting the gap during the machining operations by both AME and Advance Technology. These materials include:

1. Copper
2. Glass
3. Chrome
4. Silicon Carbide
5. Aluminum Oxide

Two requirements for this material are: (1) adequate wear properties, and (2) proper gap support.

Aluminum oxide was the material that provided both requirements. It was also found that RF alumina provided much better support than F1 alumina (these types are defined in the sputtering section of this report).

Figures 92 through 97 display the effect that each gap material has upon the machined gap condition.

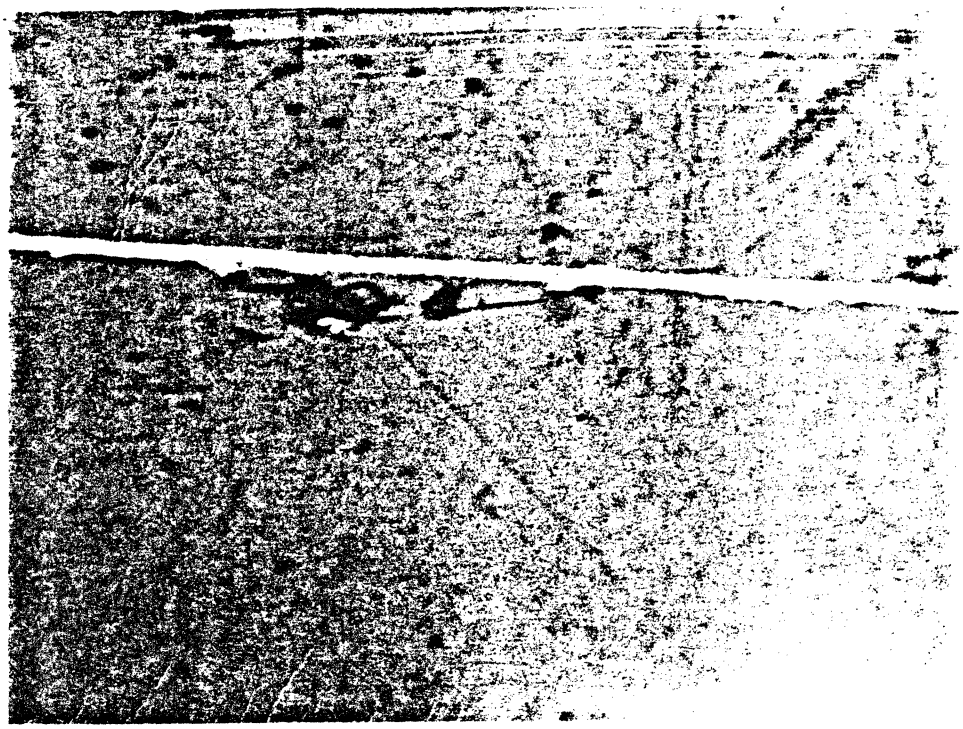


FIGURE 92

COPPER IN GAP (1000X)

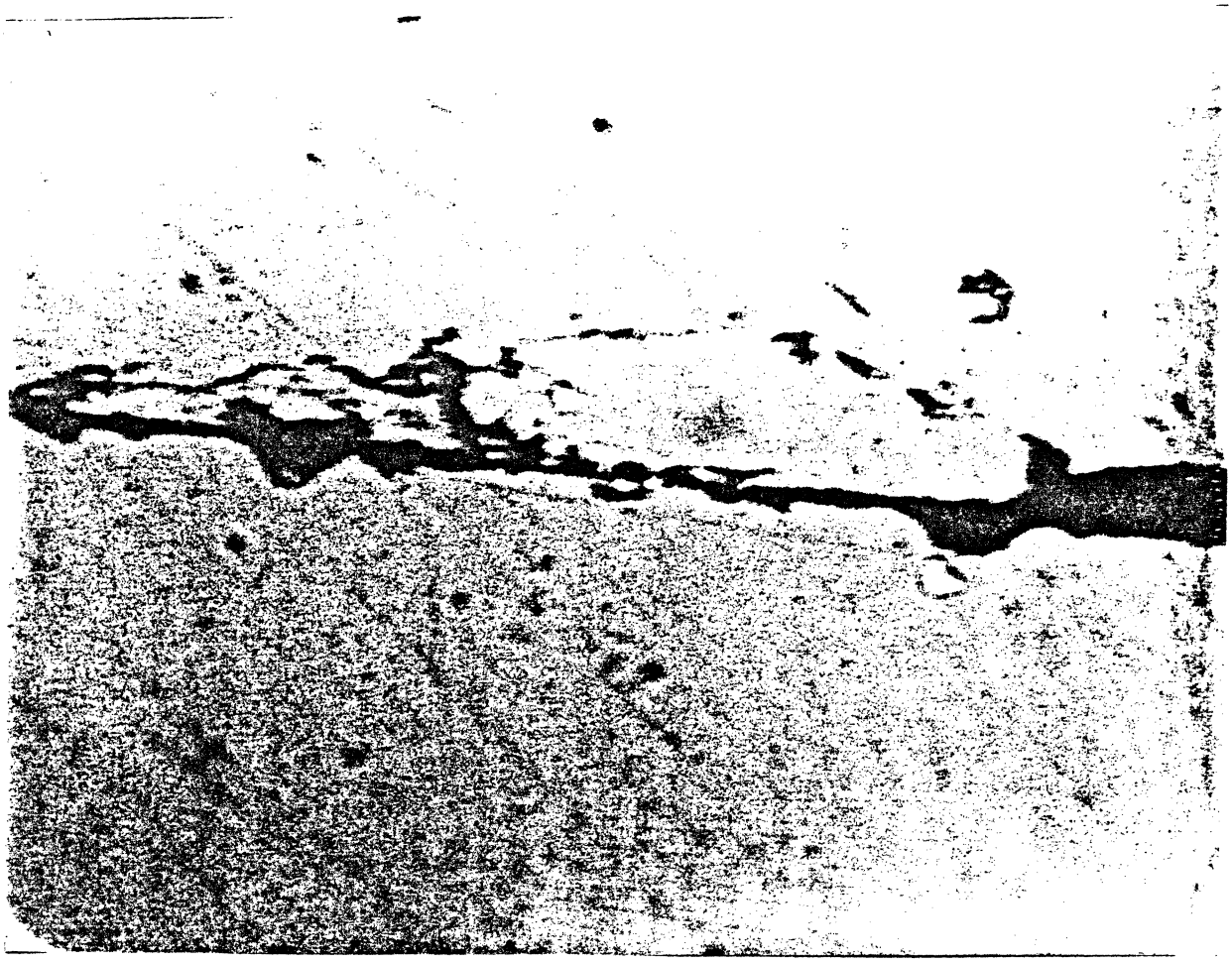


FIGURE 93

GLASS IN GAP (1000X)

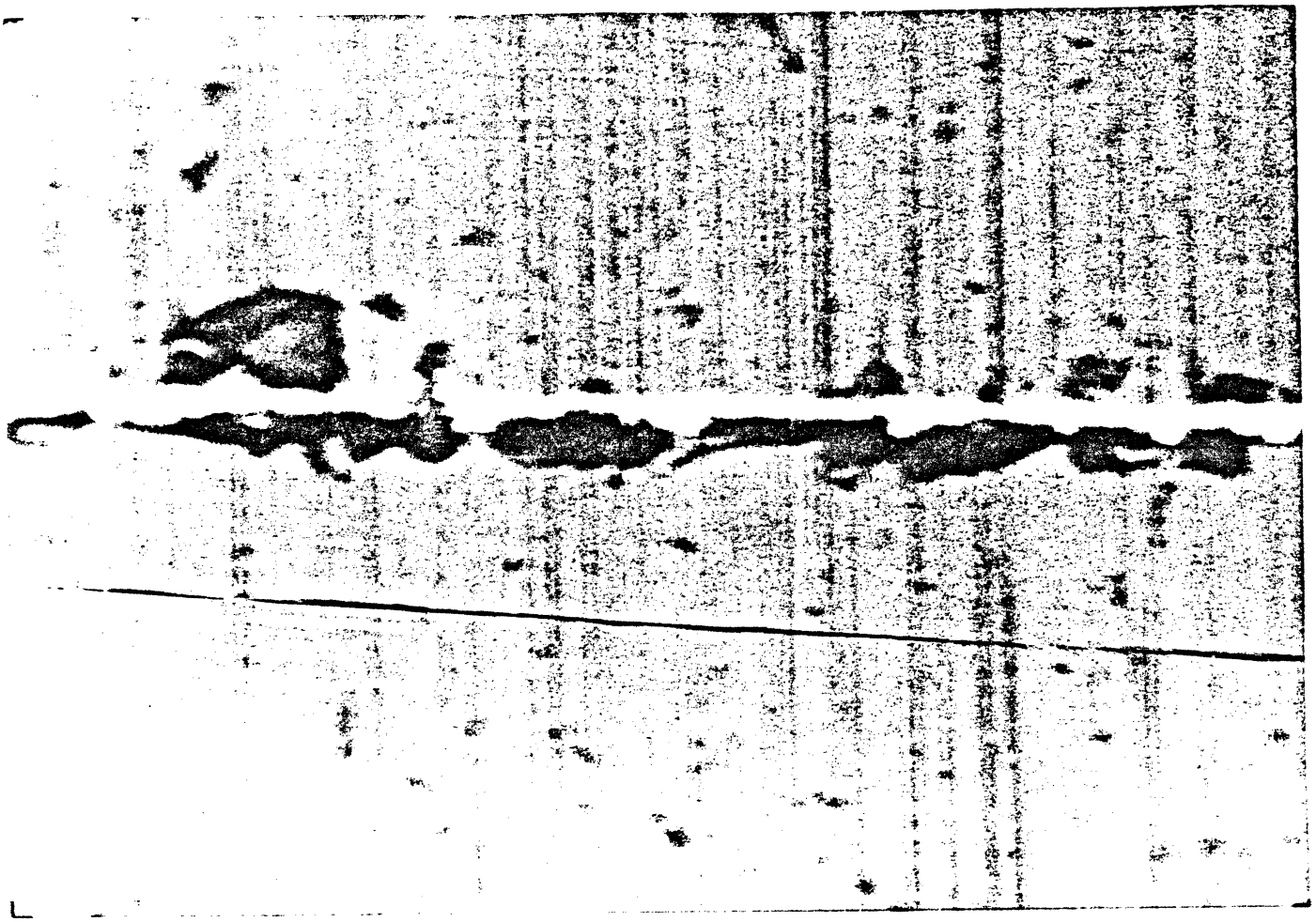


FIGURE 94

CHROMIUM IN GAP (1000X)

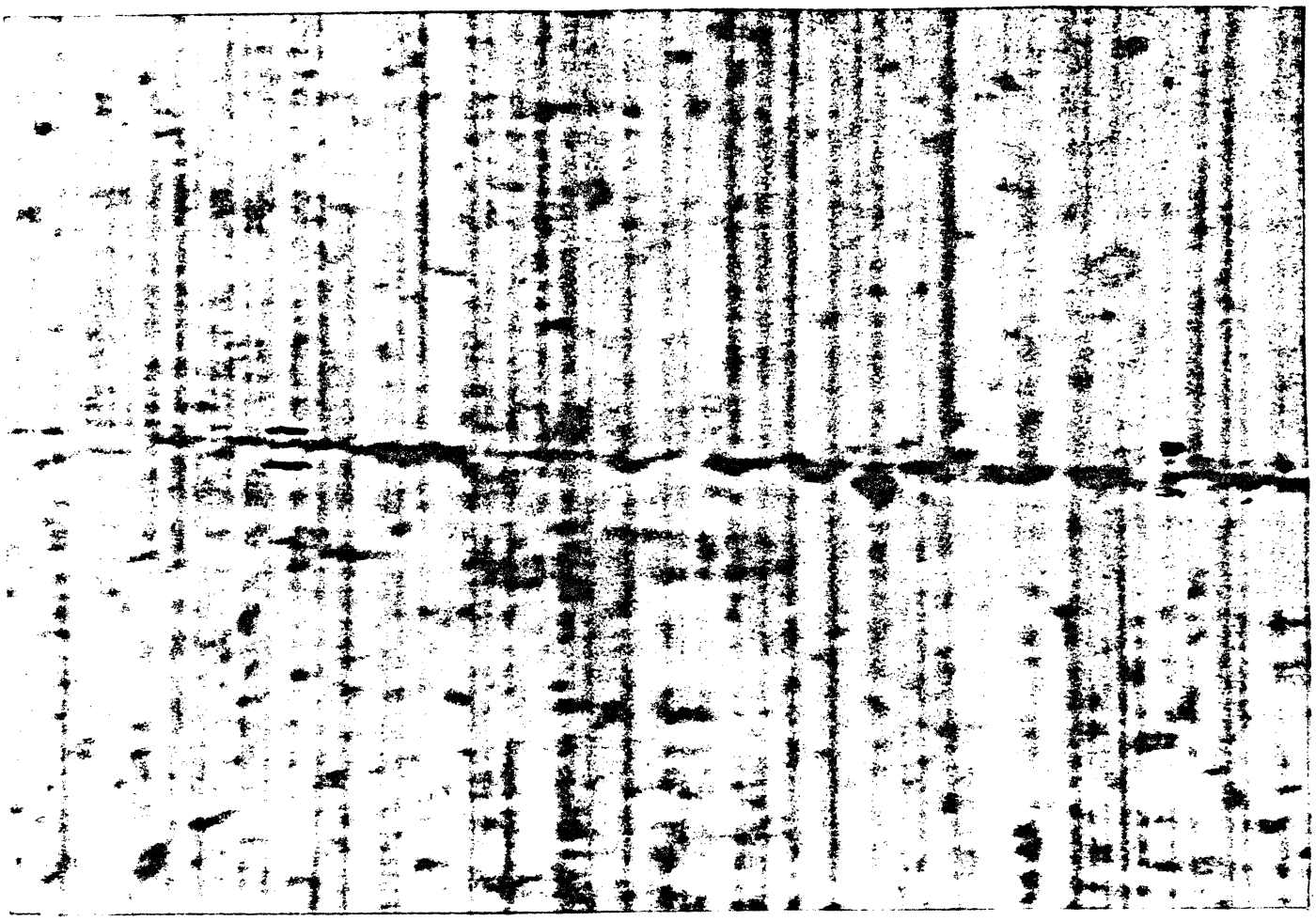


FIGURE 95

SILICON CARBIDE (1000X)

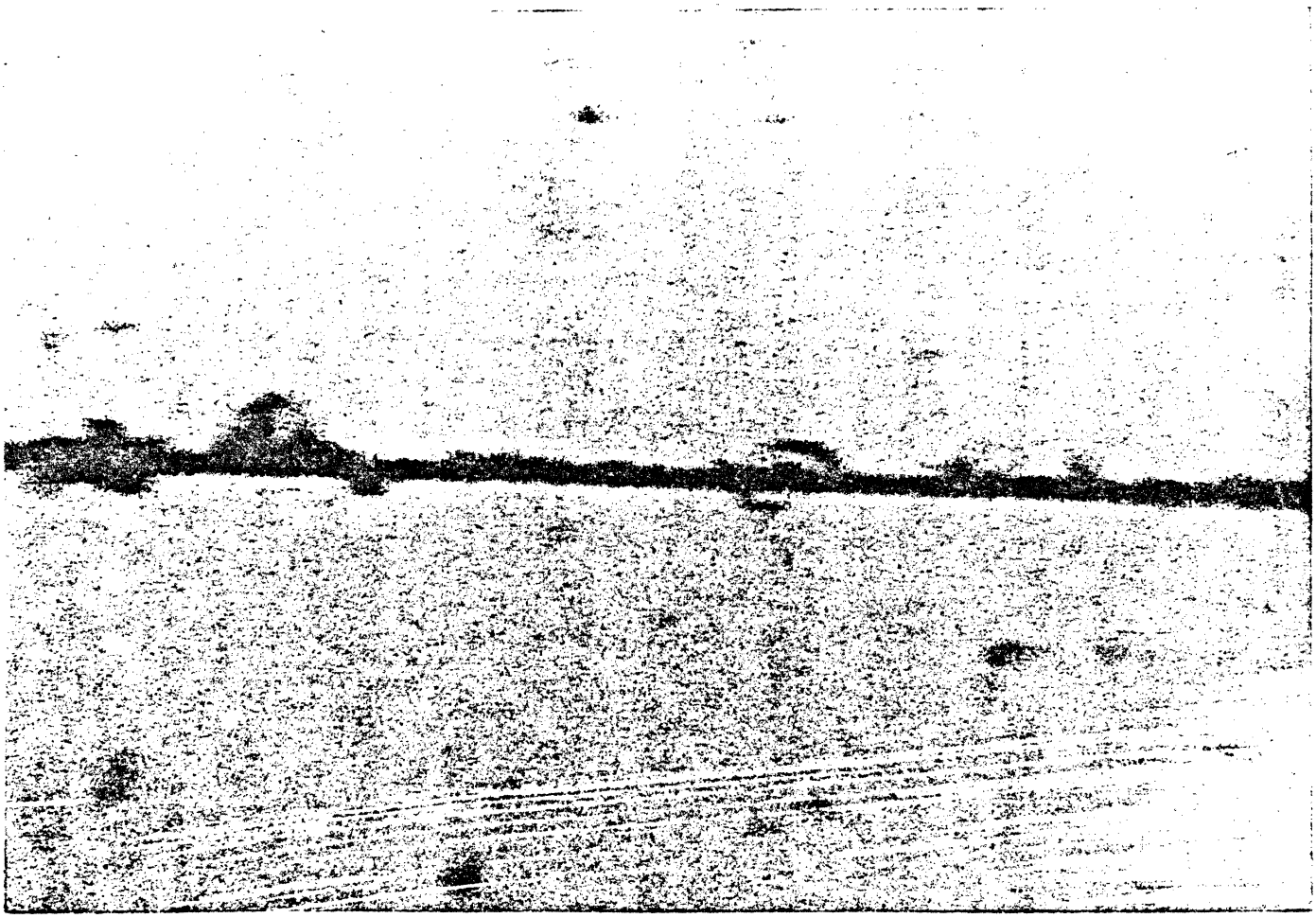


FIGURE 96

ALUMINUM OXIDE DEPOSITED IN
FLOATING MODE (1000X)

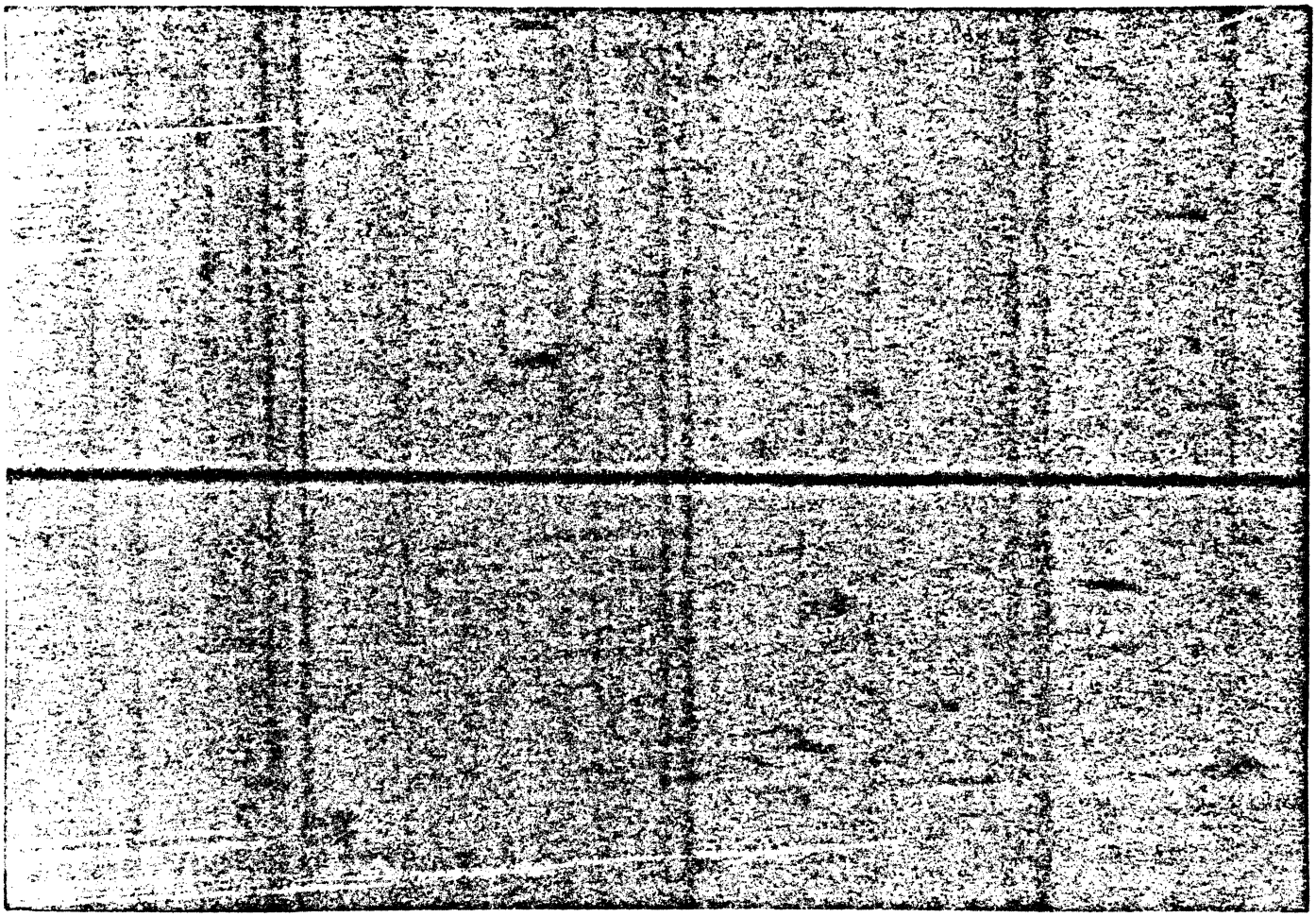


FIGURE 97

ALUMINUM OXIDE DEPOSITED IN
RF MODE (1000X)

OTHER CHIPPING PROBLEMS

Some gap chipping problems have been directly related to the glass ferrite edge on the comb structure of the write side. Directly opposite the glass/ferrite edge on the write side are conditions of excess gap chipping on the read gap (see Figure 98).

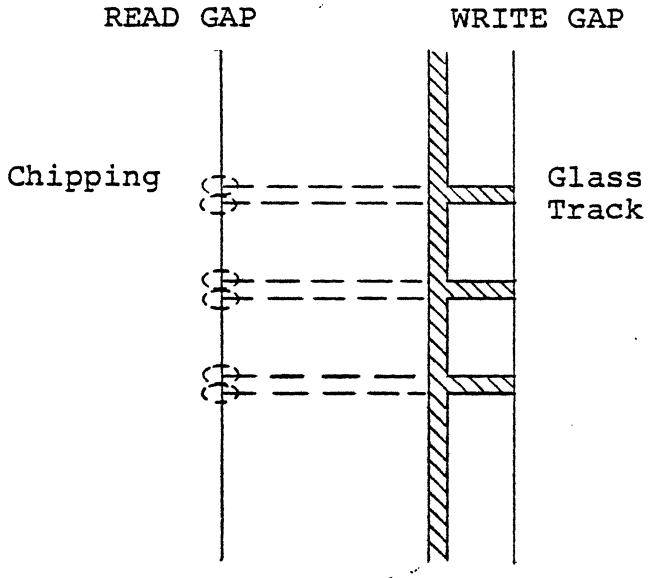


FIGURE 98

READ GAP CHIPPING

This problem is caused by damaged surfaces at both the section grind and glassing operations. The interface between these surfaces crumbles during the contour grind process. These particles lodge between the wheel and part causing damage to the gaps. This area is also located between the read tracks where the closure is not supported as well. The lesser support contributes to this problem.

GRINDING COOLANTS

Four different types of grinding coolants have been evaluated for contouring ferrite:

1. White and Bagley E-55 (waxed base) did not provide adequate lubrication for the technique used. Excess chipping and pull-out was experienced with this coolant.

2. Wheelmate (animal fat base) tends to break down during the finish grind operation. It was not compatible with the finish grind wheels (1200 grit to 20,000 grit). Excessive pull-out and chipping occurred.

3. Johnson's Millstream (water soluble oil base) foams excessively with the grinding technique used. This produces better results than the previous two coolants, but not as good as Johnson's 50 Cool.

4. Johnson's 50 Cool (water soluble oil base) produces adequate results, but not optimum results. Although this is the material being used, it tends to foam a small amount. The oil base tends to collect the ferrite particles and produces a contamination problem.

Factors Affecting the Resistance Measurement

One major factor affecting the accuracy of this method is our ability to keep moisture off of the critical surfaces. Three processes have eliminated this error:

1. A layer of Al_2O_3, 15 microinches thick covers the read tracks.

2. The retaining compound applied into the gaps, and

3. The potting epoxy filling the cavities of the tape head.

Additional error is introduced because of the varying temperature effects on the resistance of the material. This effect is small (2%) and is easily predicted and compensated for in each machining operation. However, if the accuracy is required, resistance wires or thermocouples could measure the temperature. This variable could be compensated for by using the computer to calculate the effect on the formula for comparing resistance and throat height.

$$R_\tau = Ro\ (1 + \alpha\tau)$$

where R_τ = effected resistance

Ro = initial resistance

α = temperature coefficient of resistance for each layer of metal in the track.

τ = change in temperature

SCALLOPING PROBLEMS

The major problem encountered with contour scalloping has been excessive wheel wear.

This wheel wear causes distortion in the radius (contour of the scallop). The major cause for uneven wear is the strip of copper-silver brazing material down the center of the center section. This material is difficult to machine with diamond wheels.

Several different grits of wheels (400, 600, and 1200) have been evaluated. Because of the small amount of material removed, it is impractical to run a rough and finish grind.

Various wheels from Norton and DuPont (Vespel) have been evaluated. Vespel wheels last approximately twice as long but cost 30% more.

Some work has been done with slurry abrasives by SDD. This process shows some encouragement. However, finish and edge chipping are a problem.

ABRASIVE TAPE LAPPING

Abrasive tape lapping consists of running abrasive lapping tape across the tape head in two directions until the desired characteristics are achieved. The lap drive used for this project is shown in Figure 99.

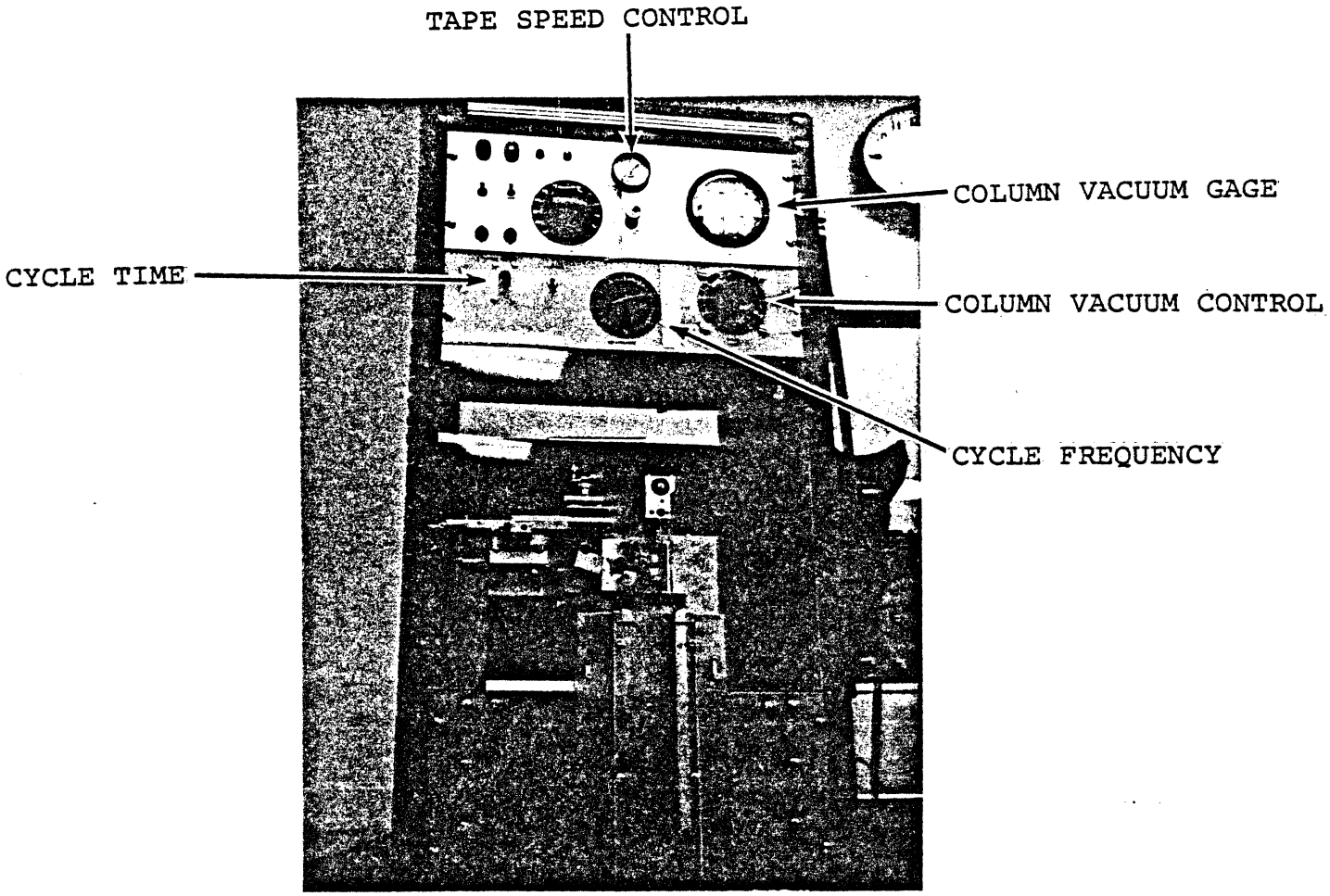


FIGURE 99

LAP DRIVE

The abrasive tape lap performs the following functions:

1. Produces a finish that will show good gap definition.
2. Produces desired run-in characteristics including the correct major/minor radius relationship shown in Figure 100 (discussed later).
3. Reduces the throat heights to the correct dimension.

EQUIPMENT

The lapping drive is a loop tester modified by Advanced Technology to control the tape tension by using a vacuum column. The tape speed and cycling frequency are also controlled on the machine.

The equipment is operated by placing a 24 inch loop around the spindle and into the vacuum column. The vacuum is increased until the required tension is reached. The length of lap time, cycling frequency, and tape speed are set with the controls. The machine will then run for the determined length of time, then shuts off automatically or it can be manually stopped at any time.

The abrasive tape consists of diamond particles held onto a Mylar backing by means of a binder.

The tape is formed into 24 inch loops and butt spliced with splicing tape for use on the drive.

A Dana 3800 Digital Ohmeter is used to measure the resistance of the tracks during the lap operation; however, the contour grinding technique (using the 1800 computer) could be applied.

PROCESS

The head is placed into the drive and tracks are connected to the digital ohmeter. Table 11 shows the machine settings:

Table 11. Machine Settings

	Lap No. 1	Lap No. 2
Tape Speed	1100 SFM	1100 SFM
Tape Tension	50 inches water	35 inches water
Cycling Frequency	10 seconds	5 seconds
Tape Thickness	.003 in.	.002 in.
Tape Particle Size	3 micron	3 micron
Length of Lap	.75 min. minimum	10 seconds
Wrap Angle	5.1° $\pm$ 0.3°	8°

During Lap 1, the operator watches the resistance of the tracks until the desired value is reached. At this point, the lap is terminated (from 1 minutes to 2 minutes). This lap removes the majority of the material, and the removal rate is approximately 50 microinches per minute, although it varies as the tape gets dull. Economical life of one loop of tape is about 3 minutes for 3 micron tape.

The purpose of Lap 2 is to round the edges of the contour scallops. This is measured as an edge break on the entry and exit loabs of the tape head, and as a minor radius over the two inner loabs. This edge break and rounding is required to reduce the contamination from magnetic tape to the tape head.

Problems and Development

Experiments have been run with various grits of abrasive lap tape in SDD with the following breakdown:

6-micron diamond abrasive tape does not produce an acceptable finish. Finishes of greater than 1 CLA are produced along with several random scratches up to 50 microinches deep.

3-micron diamond abrasive tape produces an acceptable finish of less than 1 CLA. Random scratches are reduced to 20 microinches deep. This tape is used because it most economically produces the acceptable finish.

1-micron and .5 micron diamond abrasive tape produce very good finishes. However, approximately twice as much tape is required. This tape was not as economical as the 3 micron.

7-micron aluminum oxide and silicon-carbide tape produced extensive pull-outs. The cutting rate for this tape was extremely slow and required approximately 50 times more tape than with diamond abrasives.

.5-micron chrome oxide produced an acceptable finish; however, it required up to several hundred times more tape to cut the ferrite. Operator and equipment time was prohibited.

The life expectancy of diamond tape has been a problem. Observations under magnification have shown only about 40% of the abrasive surface shows wear during the life of the tape. Efforts to recycle the tape after cleaning have failed. Because of the security problems, we have not been able to work with the tape manufacturer. It may be possible that a cleaning process or a different binder could be used to increase tape life.

The most significant problem encountered with abrasive tape lapping was to control the relationship of the minor radii with the major radius. The major radius is the radius of the arc across the entire contour while the minor radius is measured only over the read and write loabs (see Figure 100). The relationship between the radii is shown in Figure 101, where for each value of the major radius there is an upper and lower limit for the minor radius. The analysis for these requirements is found in Report No. N71-129, entitled "HTI Analytical Models."

ASSUMING A CONSTANT TOTAL TENSION

As the wrap angle (x) is increased, the tension (t_1^1) increases to (t_1) and the tension (t_2) decreases.

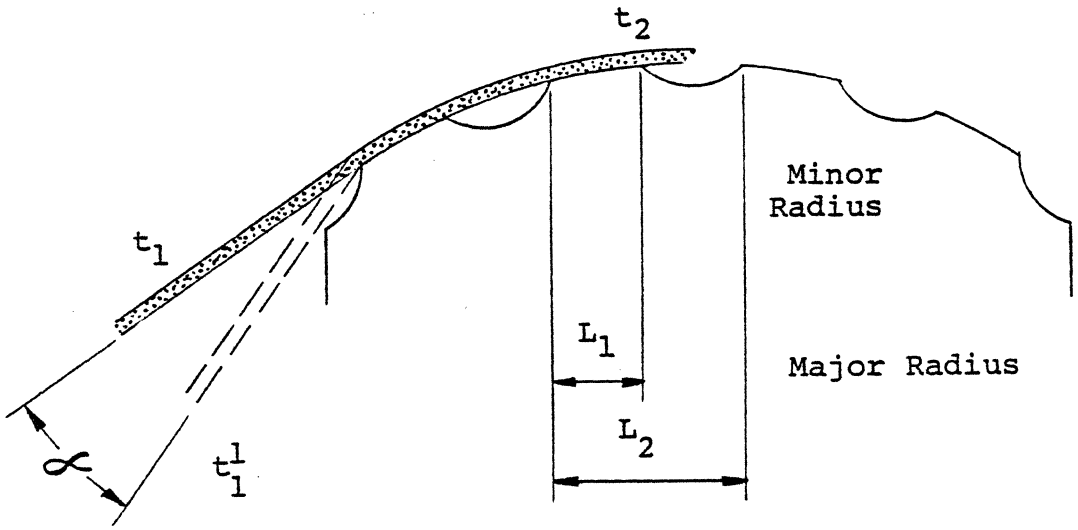


FIGURE 100

CONTOUR TAPE LAPPING

There are several factors which affect obtaining the minor radius. Among these are the tape stiffness, the tension on the tape, the size of the major radius, the tolerance between the scallops and the loabs, and the wrap angle of the tape to the head.

Tape stiffness is controlled by the thickness of the Mylar backing on the tape. Diamond tape is available in thicknesses of .001, .002, .003, .004, .005 inch. Figure 102 shows a method developed in SDD to determine tape stiffness of the tape.

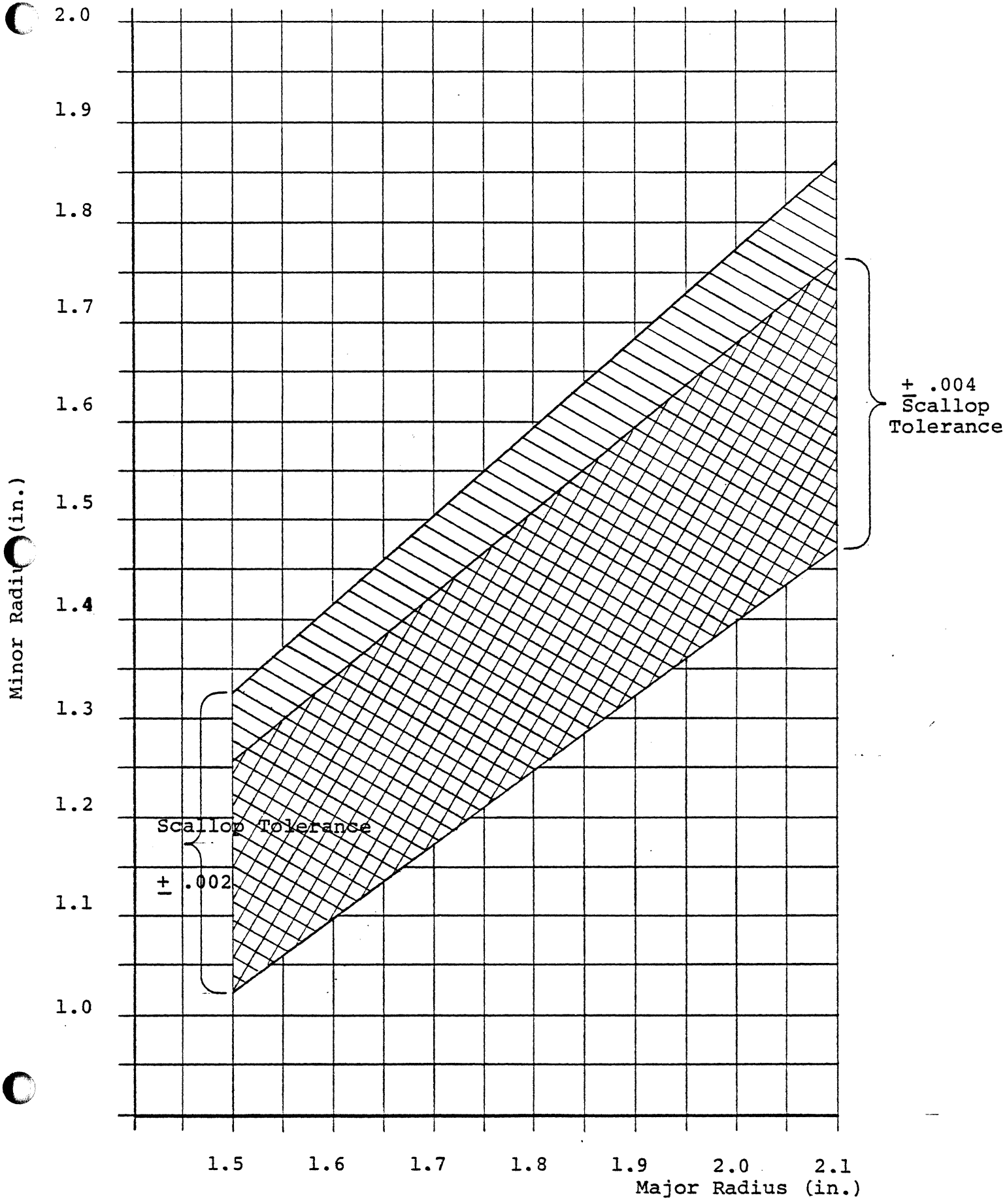
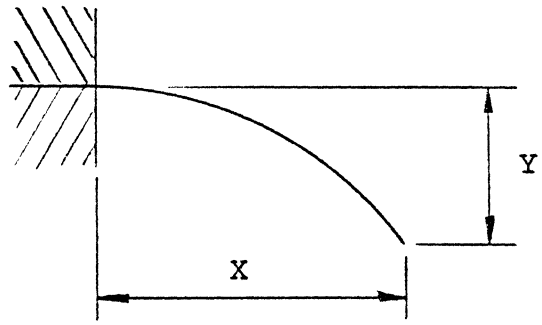


FIGURE 101 NEWTON HEAD TOLERANCES



B = Tape Stiffness - [LB_F - in^2]

L = Length of Cantilever - [inches]

W = Weight of Tape Per Inch [16_F/in]

$$B = \frac{L^3 W}{\sigma_1^3}$$

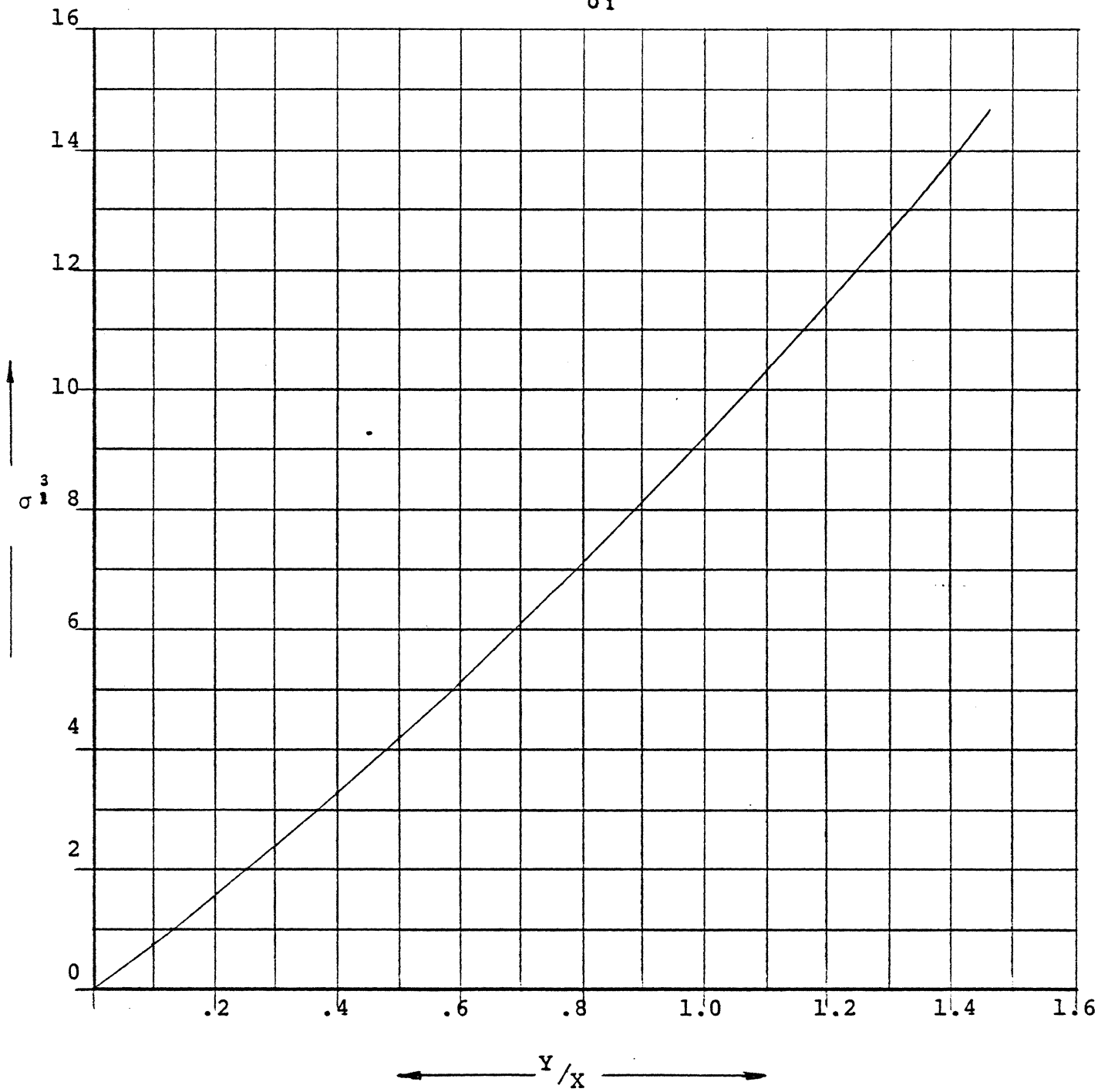


FIGURE 102 DETERMINATION OF TAPE STIFFNESS

The tension of the tape is controlled by the column on the tape drive. Capabilities of this drive are a maximum of 50 inches of water.

The size of the major radius is determined by the contour grind operation. It is changed by shimming the distance between the DU surface on the tape head and the rotation point of the contouring fixture.

The location and size tolerance of the loabs and scallops (per spec) is $\pm$ .004 inch. However, it has been determined necessary to maintain $\pm$ .002 inch to hold the tolerance on the minor radius. By observing Figure 101, one can see that the tolerance on the minor radius is increased by holding a tighter tolerance on the scallop dimensions. At the same time, the tighter tolerance has a very positive effect on the major/minor radius relationship at the tape lap operation.

The wrap angle of the tape entering and leaving the head also affects the minor radius relationship. The theory is that there is a tension drop between the tape entering the outer loab and the tape going across the head. As the wrap angle is increased, the tension drop increases also. By varying the wrap angle on one side of the head from that on the other side of the head, different minor radii can be produced. This is shown in Figure 100.

The effect that these variables have upon the minor radius can be approximated by the formula:

$$r = R \frac{(L1 + 2\sqrt{D/T})}{L2}$$

* From Report N71-129

where

r	=	minor radius
R	=	major radius
L1	=	Loab width
L2	=	Loab pitch
D	=	tape stiffness (in lbs) per unit width
T	=	tension on tape

Several experiments were evaluated in order to provide parts to specification; these experiments are documented below:

Table 12. Tape Lap Experiment Conditions

Variables	I	II	III	IV	V	VI
Tape Tension (In Water)						
1st Lap	35	35	50	50	50	50
2nd Lap	35	35	50	35	35	35
Tape Thickness						
1st Lap Cycle	.002	.002	.003	.003	.003	.003
2nd Lap Cycle (inches)	.001	.002	.003	.001	.002	.002
Scallop Tol. (inches)	±.002	±.002	±.002	±.002	±.002	±.002
Wrap Angle						
1st Lap	5.1°	5.1°	5.1°	5.1°	5.1°	5.1°
2nd Lap	8°	8°	8°	8°	8°	8°
Avg Maj Radius	1.6"	1.6"	1.6"	1.6"	1.6"	1.8"

The size of the vacuum column controlling the tension was .625 inches by 2.500 inches.

The effects that each of these processes had upon the minor radius were as follows:

These figures can be compared to Figure 101 for evaluation. The major radius value is the mean value for the sample size of each experiment.

Table 13. Tape Lap Experiment Results

Minor Radius	I	II	III	IV	V	VI
Max.	1.7	1.5	1.7	1.2	1.30	1.7
Min.	0.9	1.3	1.1	0.8	1.0	1.3
Range	0.8	.2	0.6	0.4	0.2	0.4
Mean	1.3	1.42	1.4	1.05	1.2	1.49
Std Dev.	0.23	*	0.15	*	0.06	0.11
Upper Contr Lim.	1.99	*	1.85	*	1.38	1.83
Lower Contr Lim.	0.61	*	0.95	*	1.02	1.15
% Yield	67	50	50	0	100	100

* Indicates sample size not adequate to compute statistical data. Experiment V had acceptable minor radii; however, some of major radii were undersize. The size of the major radius was increased for Experiment VI.

The conclusion of Experiments I through IV was that the processes were in statistical control, but were not producing parts within specification. This required a change in the process.

More encouraging results were seen in Experiment V when all minor radii met specification even though the statistical analysis indicated the lower control limit was below specification. In addition to this, approximately 4% of the parts were undersize on the major radius.

Experiment VI produced all good parts for major and minor radius to date. The basic difference between V and VI was the increase in the major radius by .200 inch.

Contamination of the contact surface from magnetic tape has been somewhat of a problem with this contour. Most of the work on this problem has come from Advanced Technology in SDD. Most of the contamination seems to be generated at the edges of the scallops on the tape head. Several projects to correct this problem have been pursued, but the problem, to some extent, still exists.

These projects included:

Varying the minor radius using different thicknesses of abrasive tape and different vacuums. This project was supported by AME. Variations in this experiment showed little effect.

SDD used slurry abrasives to round off the edges of the scallops. This experiment used a contoured wheel to cut scallops as shown in Figure 103.

FIGURE 103

VIEW OF SCALLOPS

Another experiment by AME is to lap the head with abrasive tape, parallel to the direction of the scallops. This concept is shown in Figure 105. It is felt that the pressure from the air manifold will increase the roll-off into the scallop and provide a smooth approach angle for the tape.

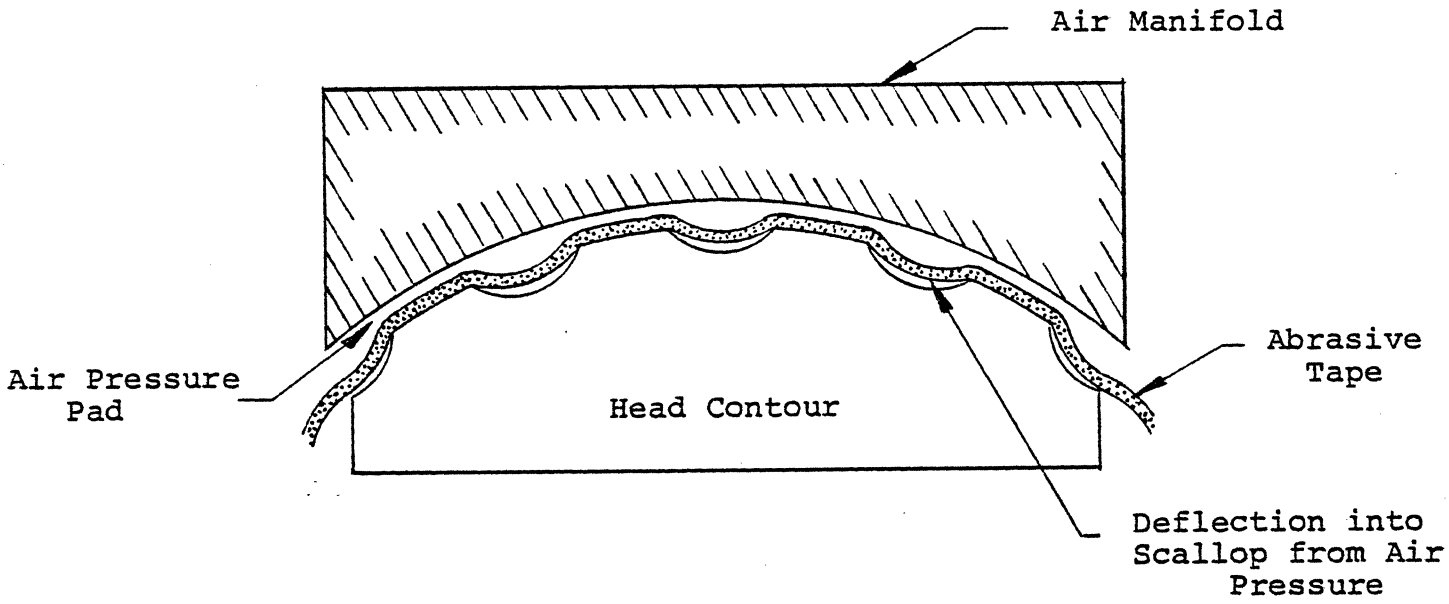


FIGURE 105

AIR MANIFOLD TECHNIQUE

(Abrasive Tape to Run in and out of Picture)

All contamination tests for these experiments were run in Advanced Sensor Technology (SDD). Problems with drive techniques and magnetic tapes make most of the data on these experiments inconclusive at this time.

IN-PROCESS TESTING OF MAGNETIC PARAMETERS

Magnetic parameters of the ferrite for both read and write heads are measured and specified by San Jose. Since SMD Boulder does not perform additional testing of the ferrite, no magnetic parameters of the write heads are measured at the "in-process" level. "In-Process" resistance measurements are discussed in other sections of this report.

The two test methods discussed are:

Kerr Magneto-Optic Testing (KMOT), and

Magnetoresistance (MR) Testing

Both tests are performed on the evaporated permalloy films of the read section.

KMOT

The KMOT (Tool Number 399024) was obtained from IBM Burlington and is documented in CD Procedure 484-4238-001. A mechanical schematic is shown in Figure 106. A test sample of the film on a glass disk is placed on the table in the zero position, as indicated by the graduated vernier.

Dispersion (α) and skew (β) measurements are taken first, using the transverse coils. Skew is then "zeroed" in the easy direction, the longitudinal coils are energized, and coercive force (Hc) of the film is measured. Following this, the table is rotated 90° and the anisotropy field (HK) is measured. The four parameters are shown in Figures 107, 108, 109, and 110.

MR Test

The magnetoresistance tester (Tool Number 1440922) is used to measure the change in resistance of the read head element in the presence of an applied magnetic field. The read housings are heated to 130° C, approximately 5° C above the Curie temperature of the ferrite, so the permalloy element can be tested magnetically, independent of any magnetic influences of the ferrite. The resistance of the read element is measured; (a) at room temperature, (b) at 130° C, and (c) under the influence of a magnetic field applied at a planar right angle to the easy direction of the element magnetization.

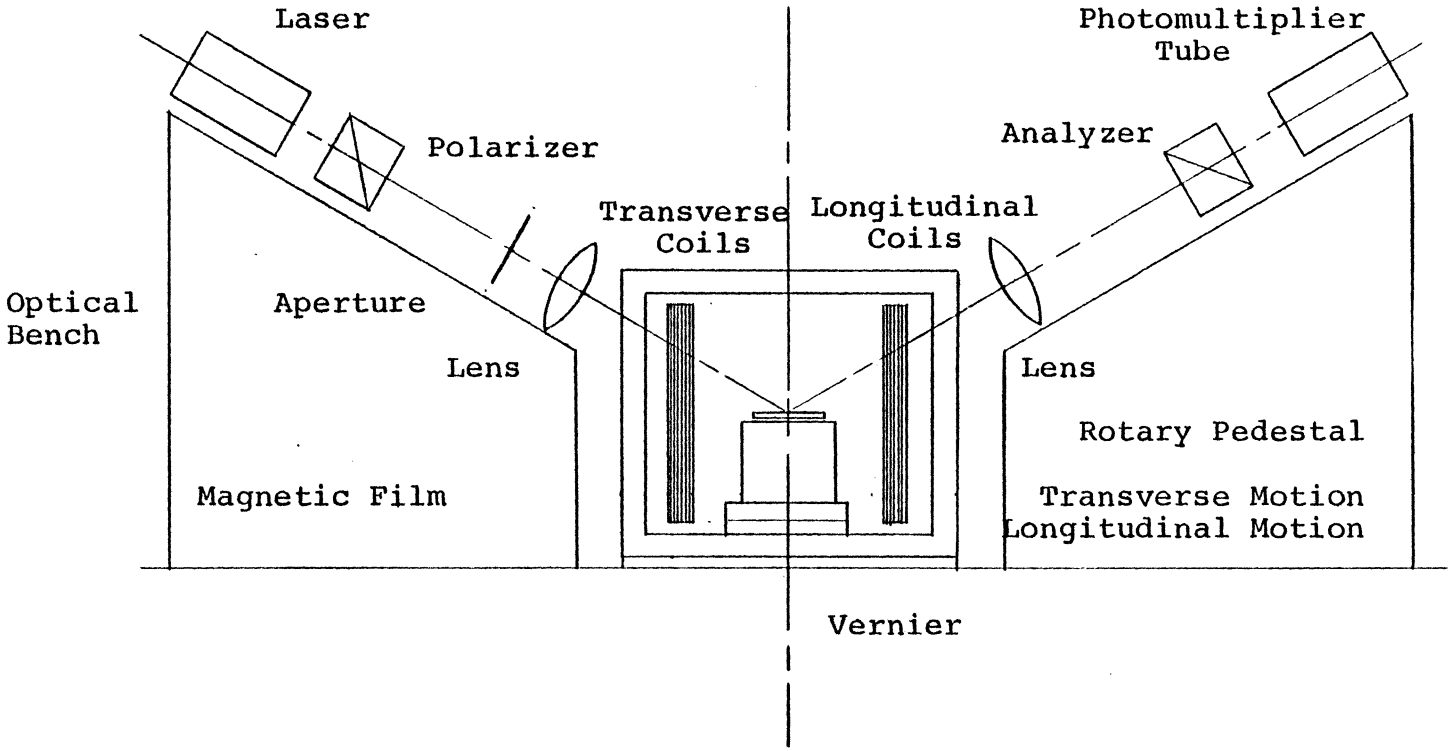


FIGURE 106

MECHANICAL SCHEMATIC OF MAGNETIC-OPTICAL ASSEMBLY

(The transverse and longitudinal coils are designated as to the direction of the magnetic field produced, not by the physical position of the coils (i.e., the longitudinal coils are mounted transverse to the light beam).

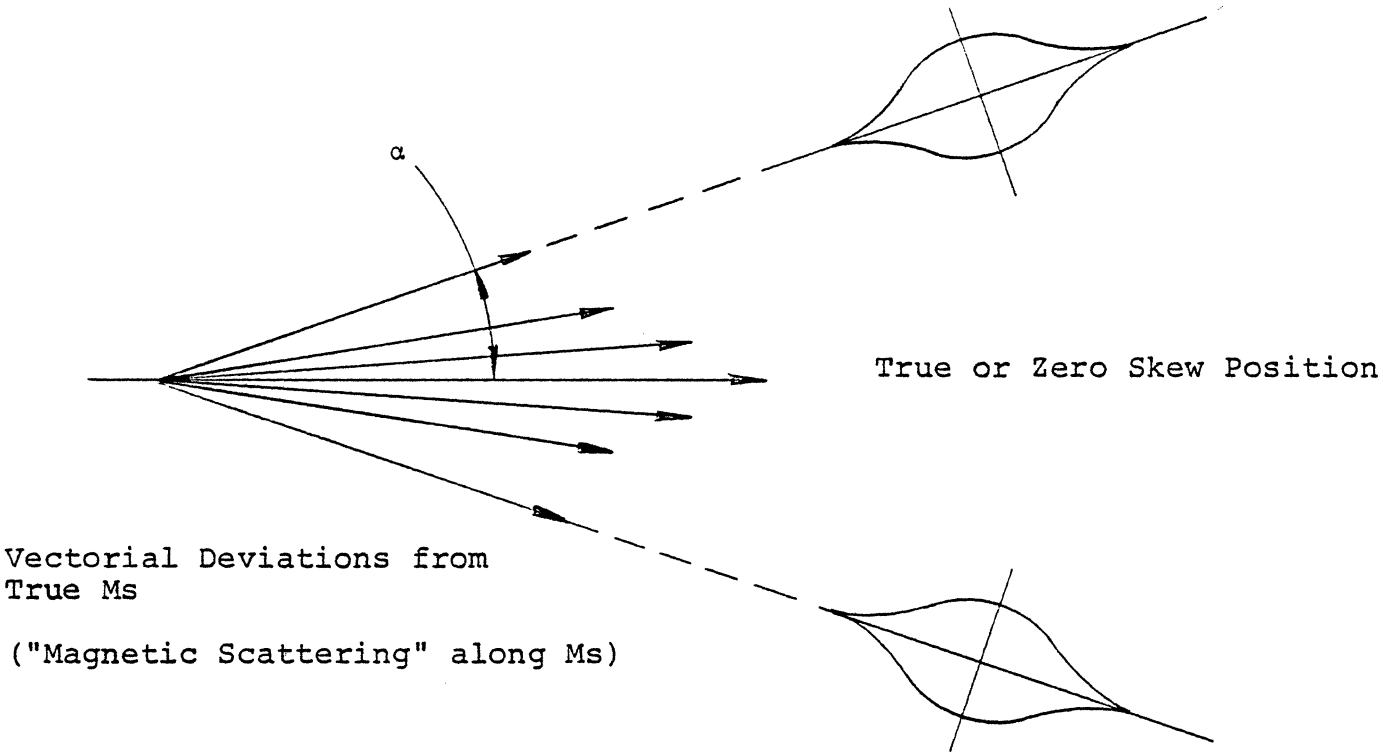


FIGURE 107 DISPERSION α

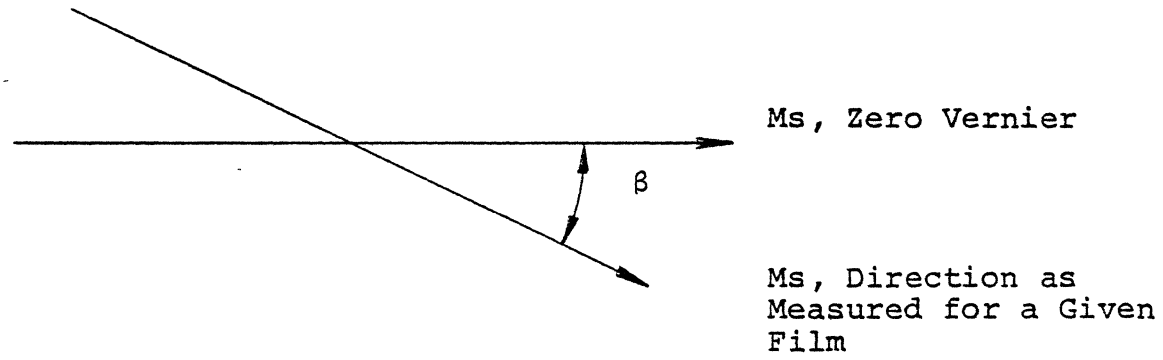


FIGURE 108 SKEW β

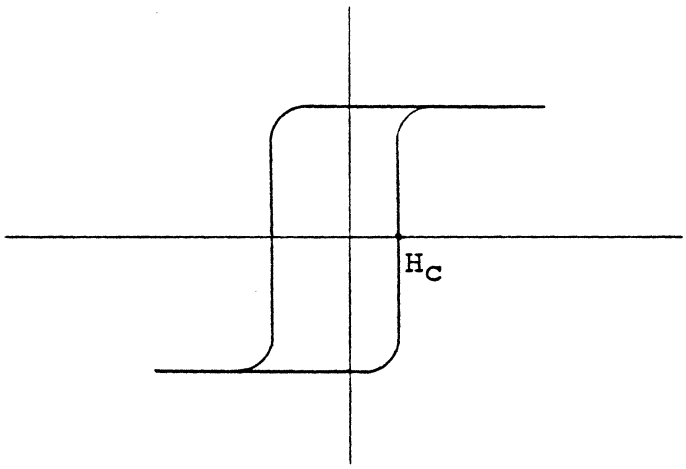


FIGURE 109

EASY DIRECTION LOOP

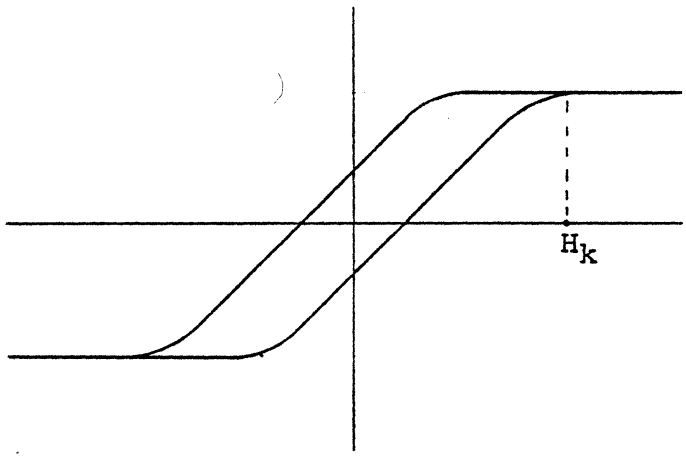


FIGURE 110

HARD DIRECTION LOOP

Figure 111 shows the MR parameters that are measured. The tests are performed on each read head track. Resistances (R and delta R) are measured in ohms and other parameters (linear bias range, peak separation, etc.) are in oersteds.

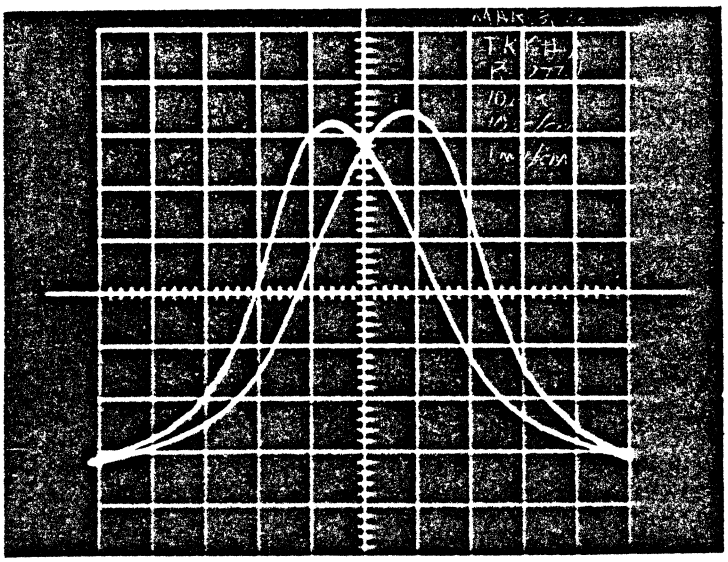


FIGURE 111

GRAPH OF RVS H

EQUIPMENT DESCRIPTION

The magnetoresistance behavior of various materials, as well as the Kerr effect, is contained in the literature and will not be presented here. This equipment section concerns the hardware to measure the observed effects.

MR Test

The tester was designed and built by Yorktown Research and is shown in Figure 112. A sense current of 10 milliamperes is applied through the read tracks. The resistance of the element at both room temperature and at 130° C is measured. Thereafter, the Helmholtz coils are energized to produce a cross-field and the entire R vs H curve is displayed on an oscilloscope (Tektronix Type 536 with 1A7A and Type W plug-in units). All parameters are taken from the displayed curve.

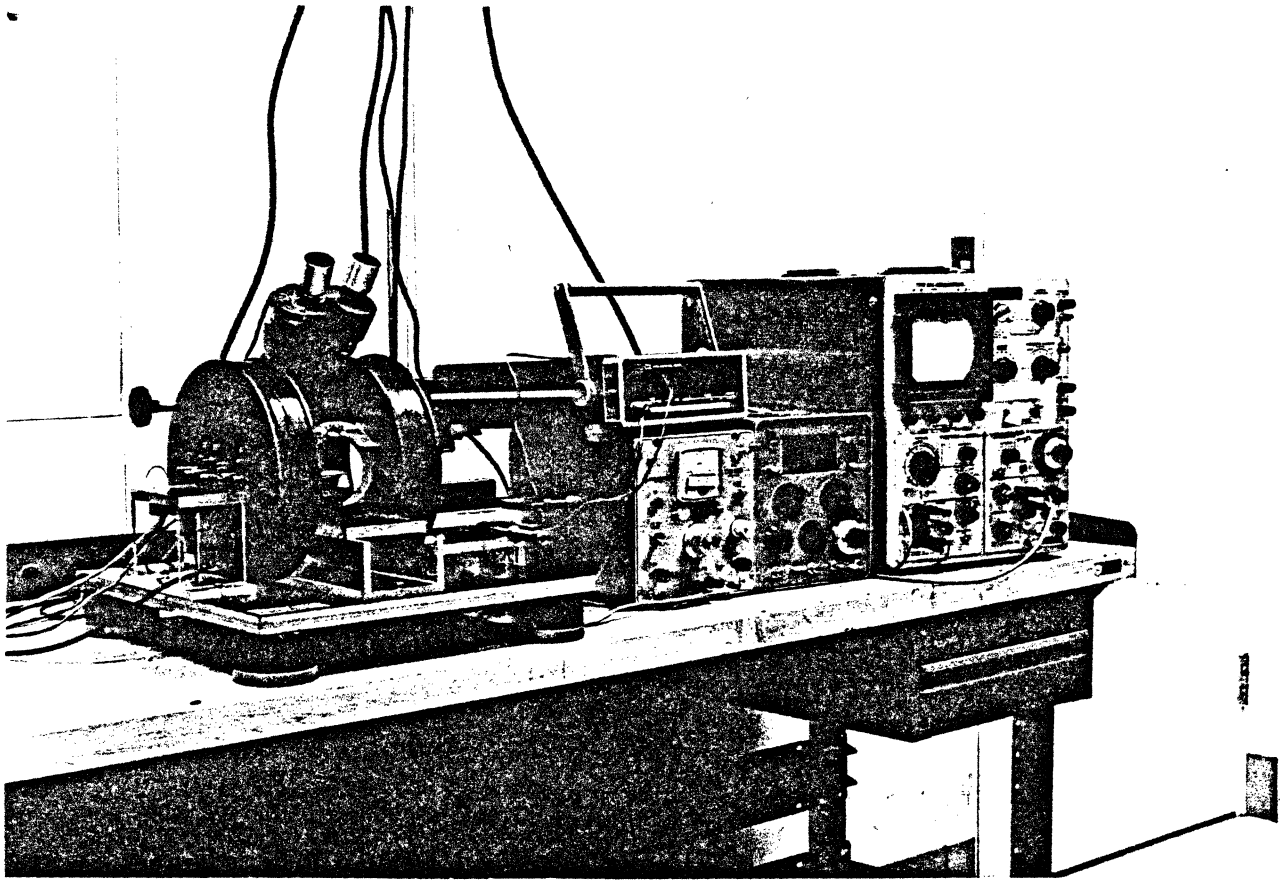


FIGURE 112

MAGNETORESISTANCE TEST EQUIPMENT

KMOT

The Kerr Magneto-Optic Tester is shown in Figures 113 and 114. A Spectro-Physics 15 milliwatt Helium-Neon Laser produces the polarized light which is deflected from the test sample into the photo-multiplier tube (PMT). The PMT signal is monitored on a Tektronix Model 561A oscilloscope with Types 3A72 and 3A6 plug-in units.

The horizontal and longitudinal Helmholtz coils are used both to zero the effects of the earth's magnetic field and to provide the magnetizing field for the test sample. A standard sample obtained from Burlington is measured as a calibration check prior to testing any test samples. During an actual test sequence, the room lights are turned off to avoid any stray incident light into the PMT.

The KMOT was converted to the visual Kerr configuration by replacing the PMT with a closed circuit television (CCTV) system. Magnetic domains were observed in this manner, but the information (domain size) field relationship, and switching behavior, etc., was not quantized or characterized into retrievable data.

PROCESS CONTROL

Record log sheets were developed to input the test information into the Computer Process Control System. The KMOT data is input by Deposition Lot Number, but may be retrieved by the serial number of any or all heads made from that lot of material. The MR test data is entered by Head Serial Number and the data is collected for all nine tracks on the head.

KMOT Data Entry

Coercivity (Hc) of the standard sample (4.8 oersteds) is a fixed value input to the process control system. The test equipment is calibrated, or adjusted, to this value before the actual test samples are measured. Thereafter, skew (β), dispersion (α), coercivity (Hc), and anisotropy field (H_k) for the test sample are input to the control system.

MR Test Data Entry

Fixed data items for the MR test are:

Al_2O_3 Coating

Housing Material (BTC or Titanium)

10 Milliamperes Sense Current

Room Temperature, 23° C, and

50 Oersted Field Sensing, Plus to Minus

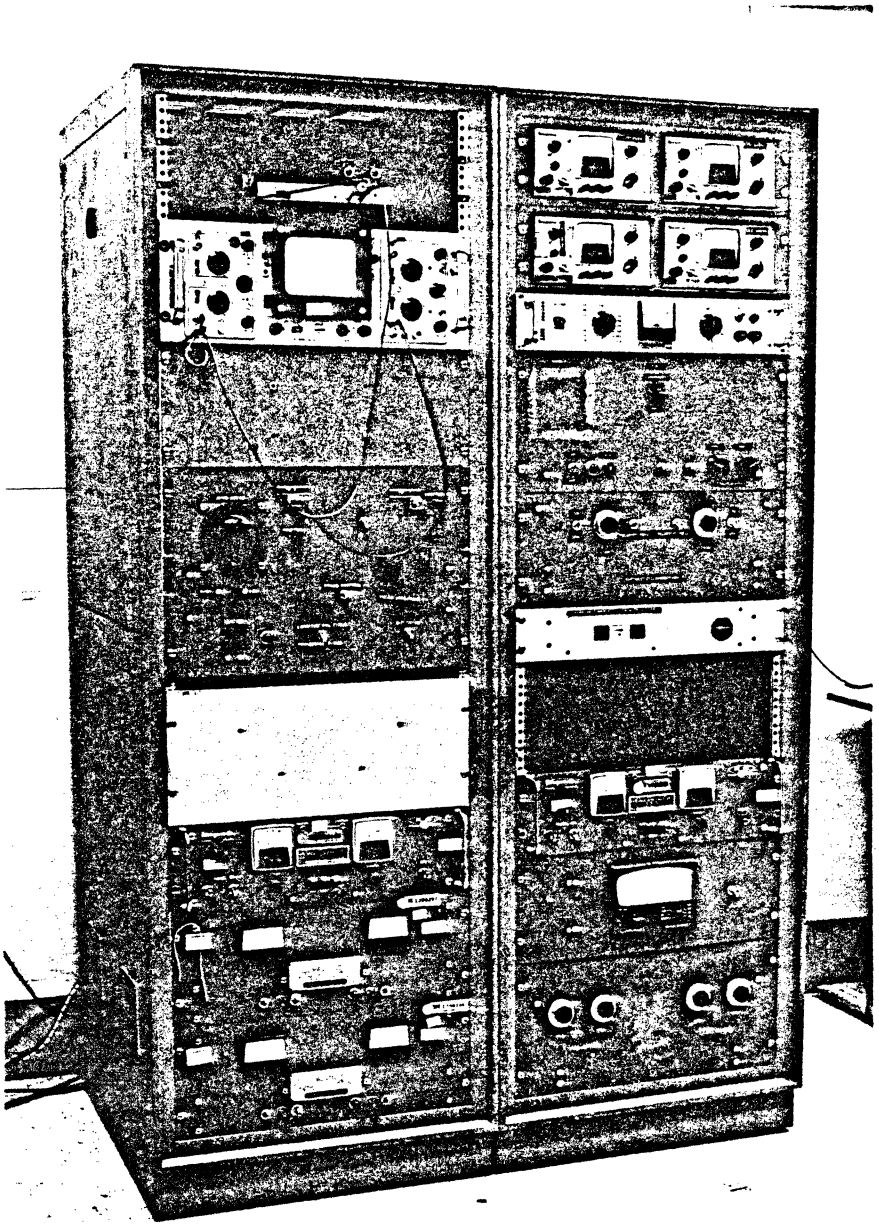


FIGURE 113

KERR MAGNETO-OPTIC TEST EQUIPMENT

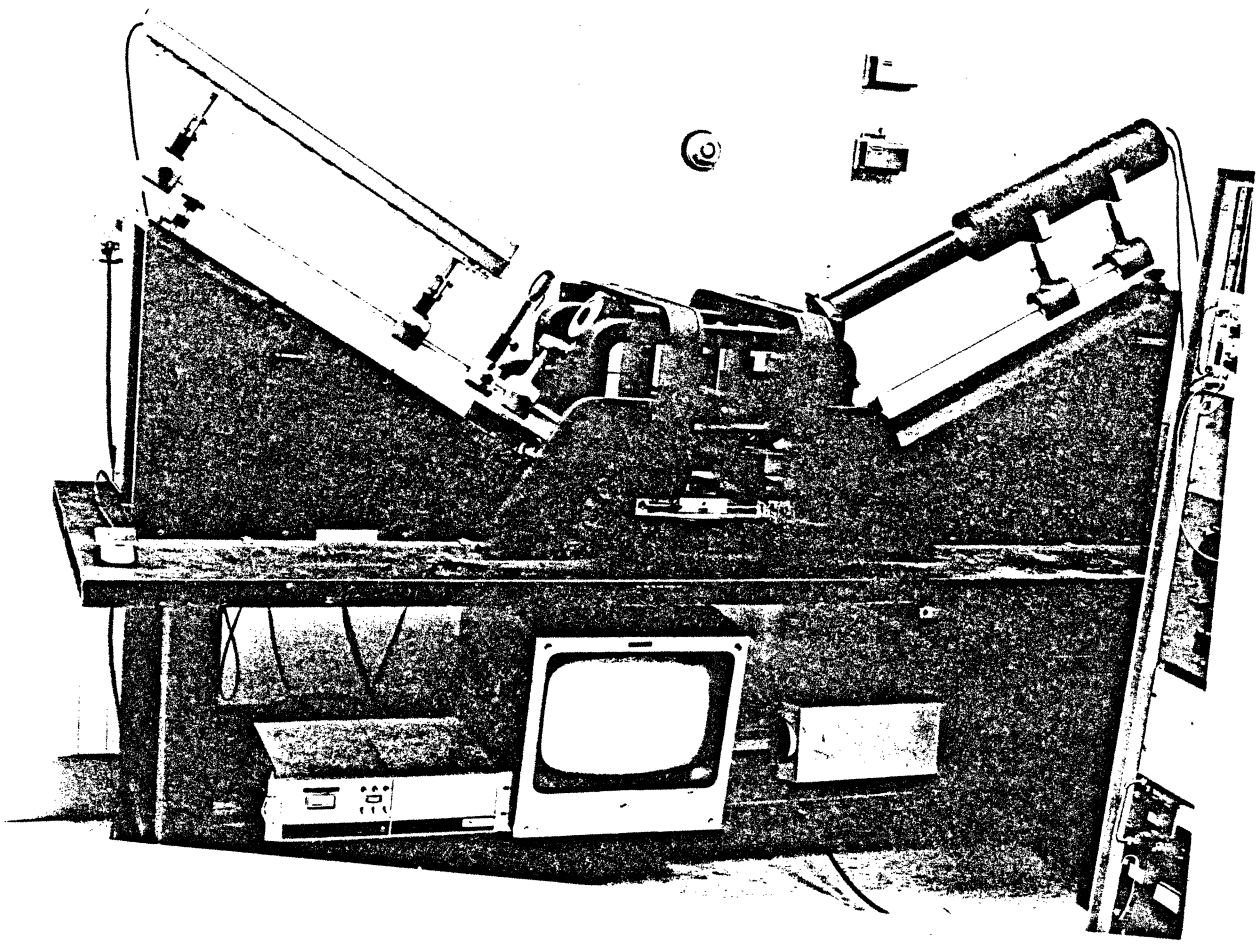


FIGURE 114

KMOT OPTICAL BENCH

The measurements taken for each read track (9 tracks per head) are as follows:

Track resistance @ room temperature (ohms)

Track resistance @ Curie temperature (130° C ohms)

Change in resistance with applied field (ohms)

Change in resistance with applied field (%)

Linear Bias Region (ohms, vertical axis)

Linear Bias Region (oersteds, horizontal axis)

Linear Bias Slope Calculation

Peak Separation (oersteds)

RESULTS AND DISCUSSION

Prior to depositing permalloy films for head build, a matrix experiment was performed to correlate various deposition process parameters with the resulting magnetic properties. The films were deposited on glass microscope slides. Two samples were prepared for each set of conditions, one for KMOT evaluation and one for MR evaluation.

Detail results of the experiment will be included in a later report by SDD Boulder and will only be partly summarized here (refer also to the Vacuum Deposition section of this report for a discussion of the deposition parameters). For the selected deposition process conditions, sample test results were as follows:

Hc	1.8 oer
Hk	3.0 oer
Skew	4°
Dispersion	3.8°
Resistance	1.6 ohms
$\Delta R/R$	2.6%
Peak Separation	3.7 oer

It should be noted that these values are for a test sample which is not the same configuration as a track element. These values are not to be compared to later results for actual head tracks. Major differences were: (a) test sample element was .005 inches wide, (b) no shunt bias metallization was used, (c) a different MR tester was used.

Magneto-Optical Properties

The thickness measurement samples, deposited simultaneously with all "head build lots," were used for testing. Test results are shown in Table 14.

Table 14. KMOT Test Results

Lot #	Hc, Oer	H_k Oer	Skew (β) (Degrees)	Dispersion (α) (Degrees)	Remarks
3	2.5	5.0	34.0	2.0	
8	5.7	5.7	37.0	6.0	
9	22.1	22.8	-	40.0	Almost Isotropic
21	2.3	3.7	64.0	6.0	
22	35.9	35.9	-	-	Isotropic
28	4.3	4.8	75.0	11.0	
29	17.6	17.6	-	-	Isotropic
47	2.6	3.7	8.0	7.5	
48	2.2	3.3	15.0	5.5	
49	4.0	3.3	14.0	12.5	Inverted
50	4.6	3.6	25.0	15.0	Inverted

The above values are for those lots from which read sections (heads) were made. A variety of permalloy film thicknesses and underlying titanium metallization thicknesses are also represented in Table 14.

The variability of the data could not be traced to variations in deposition process parameters. High dispersion and skew suggest that the film orientation coils are ineffective. However, a study by SDD did not confirm this. Wide variations in Hc and H_k did not correlate with thickness or composition changes. It was finally decided (jointly by both Boulder and Yorktown) that the titanium metallization caused the random magnetic variations. Data to support this decision is shown in Table 15. The data shows consistently increasing values for Hc, H_k , and dispersion with titanium metallization thickness.

The mechanism of the Ti/NiFe magnetic interactin is not understood, and no mention of the effect could be found in the literature. Most sources state that the properties of permalloy on titanium are the same as those for permalloy on glass. It appears the interaction is concerned with the deposition pressure (1×10^{-6} Torr) and the gettering of residual oxygen from the evaporation chamber by the titanium. However, there is no proof that this is the case; it may be some unexpected diffusion or lattice phenomena.

Table 15. KMOT Data (Variations in Magnetic Parameters vs Titanium Metallization Thickness)

Film Description	Sample (Mask Position)	Hc Oer	H_k Oer	Skew (Deg)	Dispersion (Deg)
350 NiFe No Ti	3	1.4	4.0	5	1
	4	1.2	4.2	6	1
	9	1.2	4.2	6	1
320 NiFe On 990 Å Ti	3	3.5	4.2	5	5
	4	3.6	3.8	15	9
	5	7.1	8.2	9	11
335 NiFe On 1085 Å Ti	3	7.4	7.1	5	6
	4	7.2	9.1	11	16
	5	12.4	14.9	3	12
350 NiFe On 1210 Å Ti	2	18.9	21.7	0	23
	3	12.6	14.7	7	22
	4	12.1	11.3	13	24

MAGNETO RESISTANCE PROPERTIES

Data is presented only for those later lots from which heads were made. Results are shown in Table 16. As before, a wide range of thickness combinations, track geometries, and changed process conditions existed for the different lots such that the data cannot be compared for lot-to-lot variations of the parameters.

Table 16. Magnetoresistance Properties of "Head Build" Lots

Lot #	R, Avg (Ohms)	ΔR, Avg (Ohms)	Peak Sep'n Avg (Oersteds)	Bias Offset Avg (Oer)	Remarks
8	200	.67	20	10	
21	178	.75	9	6	PM Bias*
22	150	.44	5	2	
28	81	.53	-	0	
29	47	.18	10	0	
38	38	.08	19	0	
44	55	.21	11	0	
45	258	.64	27	15	PM Bias
47	47	.11	29	0	
48	195	.68	11	10	PM Bias
49	94	.27	-	0	
50	52	.17	-	0	

* PM denotes permanent magnet was used for biasing. The material was: 70/30 Iron Cobalt, 600 Å thick.

FUTURE DEVELOPMENTS

A hot stage will be added to the KMOT so that magnetic properties of films on ferrite can be evaluated. An inductive loop tracer is also being built for Boulder by Yorktown. This tester, along with a "four bar probe" device will be used to characterize the magnetic and magneto resistance properties of bulk films, prior to photoetching the head tracks.

The matrix experiment, previously known as "Grand Slam" will also be repeated for films on Ferrite and Silicon instead of glass. The effects of metal underlayers and stress in the permalloy films will be added as parameters in the new experiment.

FINAL HEAD TEST

The final Newton head assembly is delivered to SDD for evaluation. Therefore, final head test is SDD responsibility but is being summarized in this report to better define the SDD/AME interface. The test results are also input to the AME process control system.

ELECTRICAL SPECIFICATION

Engineering Specification 28N-1349, issued by SDD, defines the Newton head operating parameters. The specification is outlined below:

Test Criteria:

1. Demagnetization
2. Tape Velocity
3. Tape Tension
4. Wrap Angle
5. Tape Erase
6. Write Density
7. Write Current Waveform
8. Read Sense Current
9. Read Test Chain Parameters
10. Tape Specification

Read Voltage Amplitude:

1. Test Conditions
2. Peak-to-Peak Amplitudes
3. Dynamic Range
4. Forward-to-Backward Ratio

Saturation Test:

1. Test Conditions
2. Voltage Amplitudes

Read Linearity (Undefined)

Read Skew:

1. Test Conditions
2. Test Instructions

Write Skew:

1. Test Conditions
2. Test Instructions

Feedthrough:

1. Test Conditions
2. Densities
3. Feedthrough Voltage Limits

Crosstalk:

1. Test Conditions/Write Current Waveform

Peak Shift:

1. Test Conditions
2. Peak Shift Limits

Downward Compatibility (Undefined)

Data for many sections of the specifications are not available since operating limits for the heads have not yet been determined. The report to be issued by SDD at a later date will contain these detailed operating limits.

Final test log sheets are completed for each head delivered. The log sheets are designed so average limits can be determined for those items listed in the engineering specification. The design criteria and operating limits determined to date will not be presented here.

PROCESS CONTROL

The Newton program would involve extensive development of new technology. A Process Control Plan was needed to assist engineers in defining and controlling relationships between process and functional parameters.

The approach and specific capabilities developed to meet this need are described in the following subsections:

Process Control: Concept and Technique
"B" Test Capabilities
Plans for "C" Test and After
Examples of Process Data Reports and Analysis

Process Control: Concept and Technique:

The concept of control implies that actual results are to be controlled (maintained) within some range of an acceptable standard (i.e., we expect some degree of deviation between the desired and the actual).

The above concept is general and may be applied to any of the manufacturing process requirements; namely, quality, schedule, cost, safety, and ecology. Distinction among different types of control must therefore be based on what is being controlled and techniques for doing it.

> FOR PROCESS CONTROL, THE OBJECTIVE IS TO CONTROL (MAINTAIN) THE VALUES OF CRITICAL PROCESS VARIABLES WITHIN ACCEPTABLE LIMITS.

To support this objective, an effective information system was needed. Emphasis for this system, as shown in Figure 115, was to provide process data feedback for the engineering analysis as a basis for action. Later, after acceptable limits for critical variables had been defined, the plan would include automated facilities for direct feedback control where technically and economically desirable.

* Acknowledgement and thanks are due Messrs Tom Cree and Russ Farnsworth, Department 525, for completing software required to implement the capabilities described in this chapter.

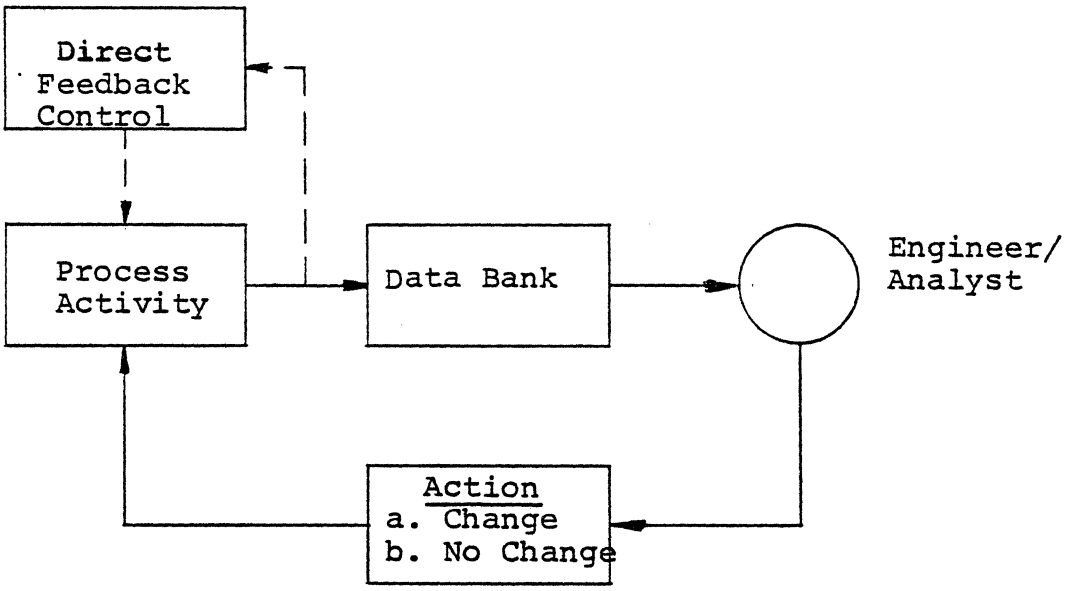


FIGURE 115

INFORMATION FLOW FOR PROCESS CONTROL

Capability objectives of this system were:

Provide a documented history of how a particular product unit was built, along with in-process and final test results.

Data retrieval and analysis to identify critical variables and establish acceptable limits (specifications) for them.

Monitor on-going process performance in terms of average, dispersion, and stability for any given parameter.

Provide first time and rework yields on a daily, lot (batch), or cumulative basis along with defect reporting.

"B" Test Capabilities:

The following capabilities were developed and implemented to meet the low volume changing conditions of the "B" test environment:

Log Sheet Data Collection System:

Computerized log sheets for data posting keypunch entry into ME Mod 50 system.

Data Retrieval Capabilities:

Retrievals can be generated by sorting on serial number, parameter value (range), lot number, time period, parameter number, or any combination theory.

Analysis and Reporting Capabilities:

Serial Number History Report

Data Listings

Descriptive Statistics

Histograms

Regression Analysis

"F" Tests, "T" Tests, Chi-Sq. Tests, etc.

Process Control Charts ($\bar{X}$ and s)

Yield and Defect Reports

Of particular value was loading the entire Newton data base into the Product Test Laboratory APL System, providing engineers with direct terminal access to data. After retrieval, the data can be submitted to an entire library of quantitative and graphical routines, including descriptive statistics, curve plotting, regression analysis, etc. A special "Short Course Text" was prepared to assist all concerned in learning how to use the APL facility.

Figure 116 illustrates how the above capabilities were combined to meet the "B" test process control objectives.

Plans for "C" Test and After:

Process control for "C" test and manufacturing would involve increasing volumes of data. To reduce costs for data collection, a more automated facility was needed.

Concurrent with this need was the Process Control Committee investigation of a "Common Data Collection and Response System (CDCRS)" to replace various existing systems throughout the Boulder Manufacturing facility. The Newton process was an excellent opportunity to size the requirements of such a system, and to justify a sound return on the investment. A system proposal was therefore developed as illustrated in Figure 117. Important features of the proposed system were:

Common Facility:

Labor claiming, quality, production control, and variable process data are all collected via one system. Once collected, data can be shipped wherever needed for storage, analysis, and reporting per each user's needs.

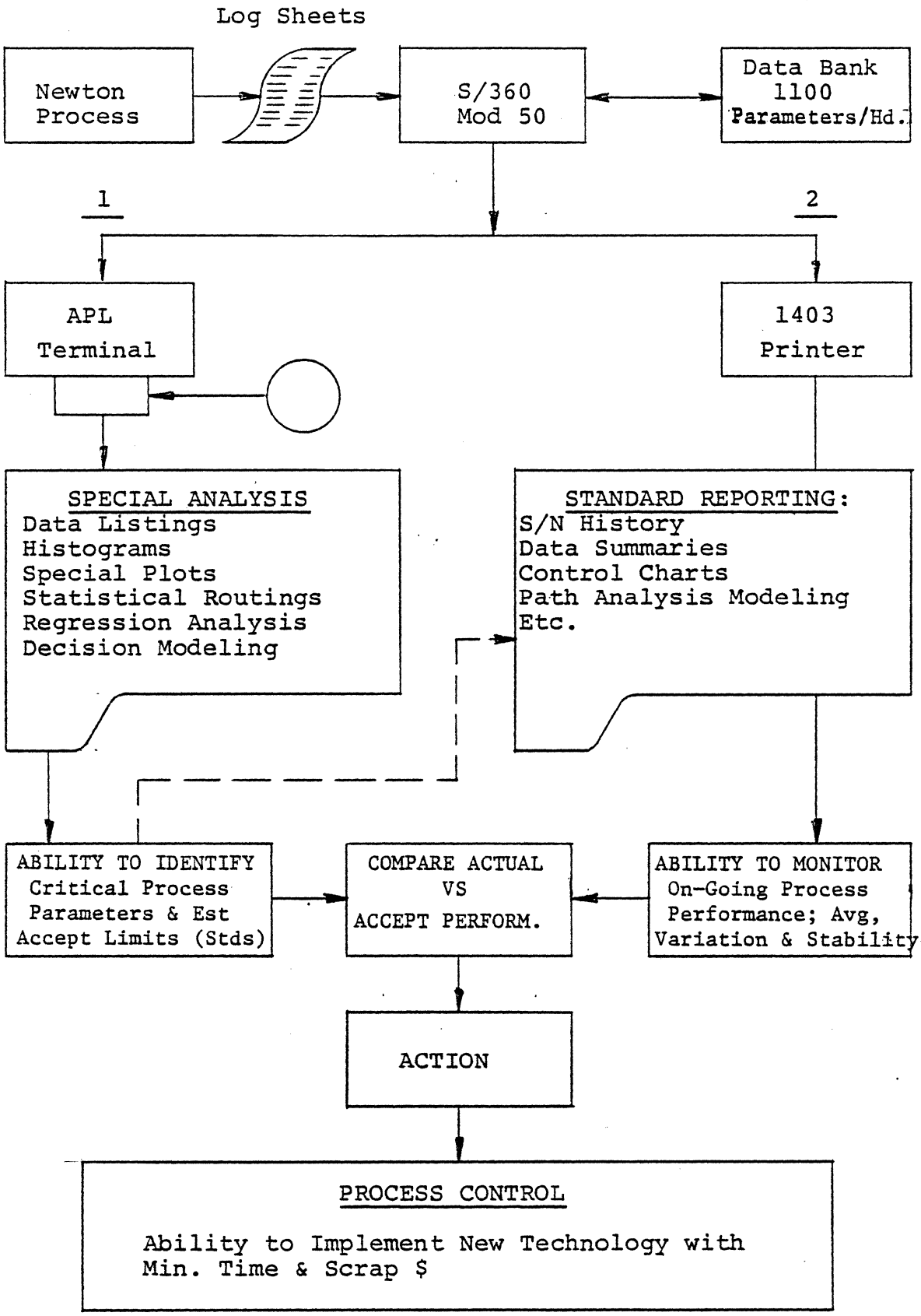


FIGURE 116

INFORMATION SYSTEM FOR "B" TEST PROCESS CONTROL

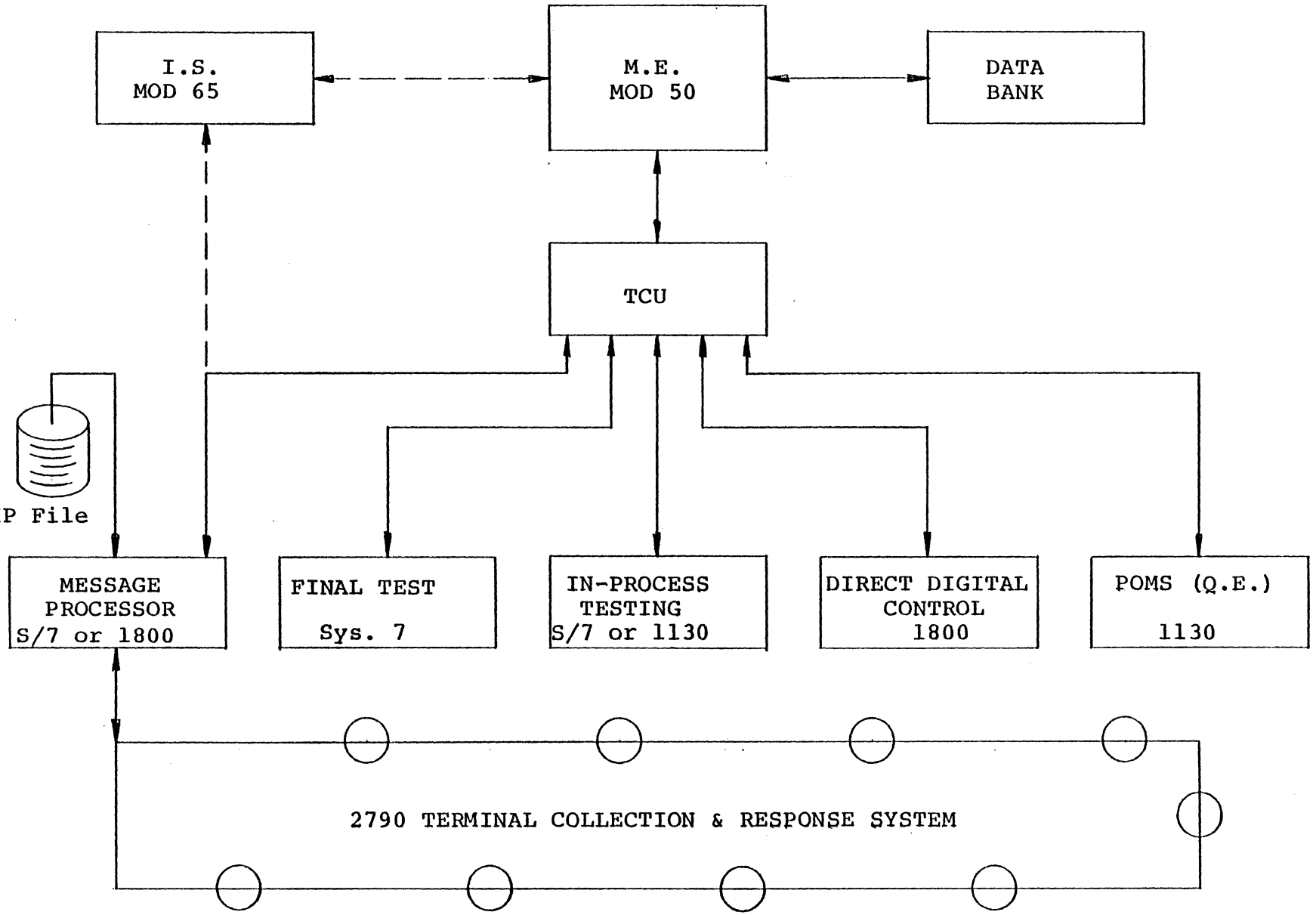


FIGURE 117

PROPOSED "COMMON DATA COLLECTION & RESPONSE SYSTEM (CDCRS)

FOR "C" TEST AND MANUFACTURING FACILITIES

Reduced Labor Cost, Flexibility and Expansion:

The 2790 Terminal Collection System provides a variety of labor saving data entry devices including Alpha-Numeric keyboard, precoded switches, punched card readers, badge readers, direct digital inputs, etc. Expansion is achieved by simply adding more terminal loops.

Verification and Inquiry Response:

Identification of data entries can be verified against a work-in-process (WIP) file to assure accuracy of part number, serial number, EC number, lot number, etc. This file also makes it possible to provide real time hard copy inquiry response regarding status of in-process parts.

Retrieval, analysis, and reporting capabilities for "C" test and manufacturing would be same as for "B" test except that special analysis, modeling and reporting programs would be added as needed. Particular emphasis was to be placed on separation of fixed versus variable cost factors in order to provide engineers with more timely and accurate feedback on cost consequences of process changes.

Examples of Process Data Reports and Analysis:

This subsection consists of the following examples of data reports and analysis:

Figure No	Description
118	Serial Number History Report
119	Quantity of Parts Good and Bad (By Operation)
120	Summary of Failures by Operation/Parameter
121	Using APL for Data Retrieval and Analysis

SERIAL	OPER	PRM	SEQ	DATA										
F007	Z230	DIM	005	+0000.04330	G									
F007	Z230	DIM	006	+0000.04470	G									
F007	Z230	DIM	007	+0000.02980	G									
F007	Z230	DIM	008	+0000.03020	G									
F007	Z230	DIM	009	+0000.02170	G									
F007	Z230	DIM	010	+0000.02230	G									
F007	Z230	DIM	011	+0000.07170	F									
F007	Z230	DIM	012	+0000.07170	F									
F007	Z230	DIM	013	+0000.07330	F									
F007	Z230	DIM	014	+0000.00330	G									
F007	Z230	DIM	015	+0000.00300	G									
F007	Z230	DIM	016	+0000.00330	G									
F007	Z230	DIM	017	+0000.00030	G									
F007	Z230	FRI				QTY GOOD=0001	0000=QTY BAD							
F007	Z230	FRI	001	+0001.00000	G									
F007	Z230	MRM				QTY GOOD=0001	0000=QTY BAD							
F007	Z230	MRM	001	+0000.00450	G									
F007	Z270			PROCNO	DATE	TIME	GOOD	FAIL	LOTNUM	PARTNUM	ECNUMB	EXPERN	C	EQUP
				100501	72054	0000	0000	0000						
F007	Z270	C01				QTY GOOD=0000	0000=QTY BAD							
F007	Z270	C01	001	MOUNTING PLATE NOT GROUND										
F007	Z310			PROCNO	DATE	TIME	GOOD	FAIL	LOTNUM	PARTNUM	ECNUMB	EXPERN	C	EQUP
				101001	72054	0000	0000	0000						
F007	Z310	C01				QTY GOOD=0000	0000=QTY BAD							
F007	Z310	C01	001	PLATE NOT ASSEMBLED TO HEAD										
F007	Z330			PROCNO	DATE	TIME	GOOD	FAIL	LOTNUM	PARTNUM	ECNUMB	EXPERN	C	EQUP
				102003	72054	0000	0022	0000						
F007	Z330	CNT				QTY GOOD=0001	0000=QTY BAD							
F007	Z330	CNT	001	+0002.00000	G									
F007	Z330	C01				QTY GOOD=0000	0000=QTY BAD							
F007	Z330	C01	001	USED .003 THICK TAPE FOR LAP NO 1.										
F007	Z330	RES				QTY GOOD=0009	0000=QTY BAD							
F007	Z330	RES	001	+0341.00000	G									
F007	Z330	RES	002	+0336.00000	G									
F007	Z330	RES	003	+0333.00000	G									
F007	Z330	RES	004	+0331.00000	G									
F007	Z330	RES	005	+0350.00000	G									
F007	Z330	RES	006	+0326.00000	G									
F007	Z330	RES	007	+0319.00000	G									
F007	Z330	RES	008	+0310.00000	G									
F007	Z330	RES	009	+0311.00000	G									
F007	Z330	THT				QTY GOOD=0009	0000=QTY BAD							
F007	Z330	THT	001	+0000.70000	G									
F007	Z330	THT	002	+0000.70000	G									
F007	Z330	THT	003	+0000.70000	G									
F007	Z330	THT	004	+0000.75000	G									
F007	Z330	THT	005	+0000.70000	G									
F007	Z330	THT	006	+0000.75000	G									
F007	Z330	THT	007	+0000.75000	G									
F007	Z330	THT	008	+0000.75000	G									
F007	Z330	THT	009	+0000.75000	G									
F007	Z330	TIM				QTY GOOD=0001	0000=QTY BAD							
F007	Z330	TIM	001	+0001.00000	G									

FIGURE 118

SERIAL NUMBER HISTORY REPORT

TOTAL WEEKS RUN FOR 'B' TEST FOR HARLEY LYONS

QUANTITIES OF PARTS GOOD ANC BAD BY OPERATION

OPERATION = T070	QUANTITY GOOD =	31.	QUANTITY BAD =	0.	TOTAL QUANTITY =	31.	% YIELD =	100.000
OPERATION = T160	QUANTITY GOOD =	7.	QUANTITY BAD =	64.	TOTAL QUANTITY =	71.	% YIELD =	9.859
OPERATION = V010	QUANTITY GOOD =	29.	QUANTITY BAD =	0.	TOTAL QUANTITY =	29.	% YIELD =	100.000
OPERATION = V130	QUANTITY GOOD =	99.	QUANTITY BAD =	0.	TOTAL QUANTITY =	99.	% YIELD =	100.000
OPERATION = V150	QUANTITY GOOD =	196.	QUANTITY BAD =	0.	TOTAL QUANTITY =	196.	% YIELD =	100.000
OPERATION = V270	QUANTITY GOOD =	45.	QUANTITY BAD =	0.	TOTAL QUANTITY =	45.	% YIELD =	100.000
OPERATION = V310	QUANTITY GOOD =	45.	QUANTITY BAD =	0.	TOTAL QUANTITY =	45.	% YIELD =	100.000
OPERATION = V390	QUANTITY GOOD =	34.	QUANTITY BAD =	0.	TOTAL QUANTITY =	34.	% YIELD =	100.000
OPERATION = V430	QUANTITY GOOD =	51.	QUANTITY BAD =	0.	TOTAL QUANTITY =	51.	% YIELD =	100.000
OPERATION = V530	QUANTITY GOOD =	17.	QUANTITY BAD =	25.	TOTAL QUANTITY =	42.	% YIELD =	40.476
OPERATION = W010	QUANTITY GOOD =	36.	QUANTITY BAD =	0.	TOTAL QUANTITY =	36.	% YIELD =	100.000
OPERATION = W110	QUANTITY GOOD =	36.	QUANTITY BAD =	0.	TOTAL QUANTITY =	36.	% YIELD =	100.000
OPERATION = W150	QUANTITY GOOD =	32.	QUANTITY BAD =	0.	TOTAL QUANTITY =	32.	% YIELD =	100.000
OPERATION = W210	QUANTITY GOOD =	32.	QUANTITY BAD =	0.	TOTAL QUANTITY =	32.	% YIELD =	100.000
OPERATION = W250	QUANTITY GOOD =	17.	QUANTITY BAD =	0.	TOTAL QUANTITY =	17.	% YIELD =	100.000
OPERATION = W270	QUANTITY GOOD =	25.	QUANTITY BAD =	0.	TOTAL QUANTITY =	25.	% YIELD =	100.000
OPERATION = W310	QUANTITY GOOD =	23.	QUANTITY BAD =	0.	TOTAL QUANTITY =	23.	% YIELD =	100.000
OPERATION = W390	QUANTITY GOOD =	10.	QUANTITY BAD =	6.	TOTAL QUANTITY =	16.	% YIELD =	62.500
OPERATION = X010	QUANTITY GOOD =	2.	QUANTITY BAD =	69.	TOTAL QUANTITY =	71.	% YIELD =	2.816
OPERATION = X130	QUANTITY GOOD =	3.	QUANTITY BAD =	0.	TOTAL QUANTITY =	3.	% YIELD =	100.000
OPERATION = Y050	QUANTITY GOOD =	12.	QUANTITY BAD =	2.	TOTAL QUANTITY =	14.	% YIELD =	85.714
OPERATION = Y070	QUANTITY GOOD =	85.	QUANTITY BAD =	1.	TOTAL QUANTITY =	86.	% YIELD =	98.837
OPERATION = Y100	QUANTITY GOOD =	38.	QUANTITY BAD =	0.	TOTAL QUANTITY =	38.	% YIELD =	100.000
OPERATION = Y110	QUANTITY GOOD =	38.	QUANTITY BAD =	0.	TOTAL QUANTITY =	38.	% YIELD =	100.000
OPERATION = Y130	QUANTITY GOOD =	24.	QUANTITY BAD =	0.	TOTAL QUANTITY =	24.	% YIELD =	100.000
OPERATION = Y150	QUANTITY GOOD =	16.	QUANTITY BAD =	1.	TOTAL QUANTITY =	17.	% YIELD =	94.117
OPERATION = Y170	QUANTITY GOOD =	39.	QUANTITY BAD =	0.	TOTAL QUANTITY =	39.	% YIELD =	100.000
OPERATION = Z070	QUANTITY GOOD =	14.	QUANTITY BAD =	1.	TOTAL QUANTITY =	15.	% YIELD =	93.333
OPERATION = Z090	QUANTITY GOOD =	16.	QUANTITY BAD =	0.	TOTAL QUANTITY =	16.	% YIELD =	100.000
OPERATION = Z110	QUANTITY GOOD =	26.	QUANTITY BAD =	4.	TOTAL QUANTITY =	30.	% YIELD =	86.666
OPERATION = Z130	QUANTITY GOOD =	16.	QUANTITY BAD =	0.	TOTAL QUANTITY =	16.	% YIELD =	100.000
OPERATION = Z170	QUANTITY GOOD =	15.	QUANTITY BAD =	1.	TOTAL QUANTITY =	16.	% YIELD =	93.750
OPERATION = Z190	QUANTITY GOOD =	11.	QUANTITY BAD =	6.	TOTAL QUANTITY =	17.	% YIELD =	64.705
OPERATION = Z210	QUANTITY GOOD =	6.	QUANTITY BAD =	4.	TOTAL QUANTITY =	10.	% YIELD =	60.000
OPERATION = Z230	QUANTITY GOOD =	16.	QUANTITY BAD =	0.	TOTAL QUANTITY =	16.	% YIELD =	100.000
OPERATION = Z330	QUANTITY GOOD =	11.	QUANTITY BAD =	5.	TOTAL QUANTITY =	16.	% YIELD =	68.750
OPERATION = Z350	QUANTITY GOOD =	1.	QUANTITY BAD =	15.	TOTAL QUANTITY =	16.	% YIELD =	6.250
OPERATION = Z370	QUANTITY GOOD =	2.	QUANTITY BAD =	0.	TOTAL QUANTITY =	2.	% YIELD =	100.000
OPERATION = Z470	QUANTITY GOOD =	4.	QUANTITY BAD =	0.	TOTAL QUANTITY =	4.	% YIELD =	100.000

FIGURE 119

QUANTITY OF PARTS GOOD AND BAD (BY OPERATION)

TOTAL WEEKS RUN FOR '8' TEST FOR HARLEY LYONS

SUMMARY OF FAILURES BY OPERATION/PARAMETER

OPERATION = X010	PARM = DIM/001	26.	PARM = DIM/007	13.	PARM = DIM/008	31.	PARM = VDC/001	19.
	PARM = PAR/001	28.	PARM = DIM/005	11.	PARM = DIM/009	6.	PARM = DIM/003	19.
	PARM = DIM/006	1.	PARM = DIM/004	14.	PARM = FLT/002	9.	PARM = DIM/002	13.
	PARM = DIM/010	4.	PARM = SQR/001	24.	PARM = FLT/001	7.	PARM = DIM/015	9.
	PARM = DIM/016	9.	PARM = LGN/001	3.	PARM = DIM/017	2.	PARM = DIM/013	6.
	PARM = DIM/014	2.						
OPERATION = Z350	PARM = GAP/002	11.	PARM = SPE/001	12.	PARM = DPE/001	11.	PARM = SPE/002	12.
	PARM = MRT/001	4.	PARM = MRT/003	4.	PARM = MRT/005	3.	PARM = MRT/002	4.
	PARM = MRT/004	4.	PARM = MRT/006	4.	PARM = TRF/002	2.	PARM = TRC/001	2.
	PARM = TRC/002	2.	PARM = GAP/001	3.	PARM = DPE/002	1.	PARM = MXV/001	5.
	PARM = TRF/008	1.	PARM = SPE/003	6.	PARM = DPE/003	4.	PARM = DEN/001	1.
	PARM = CWT/001	1.						
OPERATION = Z330	PARM = RES/002	4.	PARM = RES/003	3.	PARM = RES/004	3.	PARM = RES/005	2.
	PARM = RES/006	2.	PARM = RES/007	3.	PARM = RES/008	2.	PARM = RES/009	3.
	PARM = RES/001	2.						
OPERATION = Z210	PARM = RES/002	3.	PARM = RES/003	3.	PARM = RES/004	3.	PARM = RES/005	2.
	PARM = RES/006	2.	PARM = RES/007	3.	PARM = RES/008	2.	PARM = RES/009	3.
	PARM = RES/001	1.						
OPERATION = Z190	PARM = RES/002	3.	PARM = RES/003	2.	PARM = RES/004	2.	PARM = RES/005	1.
	PARM = RES/006	1.	PARM = RES/007	1.	PARM = RES/008	1.	PARM = RES/009	3.
	PARM = WOP/001	1.	PARM = RES/001	1.	PARM = WSH/001	1.	PARM = DIM/001	1.
OPERATION = Z170	PARM = IPN/001	1.						
OPERATION = Z110	PARM = RES/003	2.	PARM = RES/004	2.	PARM = RES/005	1.	PARM = RES/007	1.
	PARM = RES/008	1.	PARM = RES/009	2.	PARM = RES/001	1.	PARM = RES/002	1.
	PARM = BCS/001	1.	PARM = DUA/002	1.				
OPERATION = T160	PARM = DIM/006	13.	PARM = DIM/012	51.	PARM = DIM/020	30.	PARM = DIM/003	2.
	PARM = DIM/011	3.	PARM = DIM/014	4.	PARM = DIM/015	2.	PARM = DIM/016	5.
	PARM = DIM/021	5.	PARM = FLT/001	12.	PARM = LGN/001	6.	PARM = SQR/003	7.
	PARM = DIM/001	20.	PARM = SFD/003	6.	PARM = DIM/005	2.	PARM = DIM/018	1.
	PARM = DIM/022	3.	PARM = PAR/001	10.	PARM = SQR/002	3.	PARM = DIM/013	1.
	PARM = FLT/002	2.						
OPERATION = V530	PARM = DIM/001	22.	PARM = DIM/002	1.	PARM = DIM/003	21.	PARM = DIM/004	8.
OPERATION = W390	PARM = DIM/001	1.	PARM = DIM/004	5.	PARM = DIM/003	1.		
OPERATION = Y050	PARM = RES/002	1.	PARM = RES/003	1.				
OPERATION = Z070	PARM = PAR/002	1.						
OPERATION = Y070	PARM = CRA/001	1.	PARM = CRA/002	1.	PARM = CRA/004	1.	PARM = CRA/009	1.

FIGURE 120

SUMMARY OF FAILURES BY OPERATION/PARAMETER

USING APL FOR DATA RETRIEVAL & ANALYSIS

```
      )LOAD NEWTONDATA
SAVED  15.48.48 05/22/72

      2▼DATA
```

S/N Index	Y1	Y2	Y3	Y
1.00	573.68	573.67	573.65	532.27
2.00	573.15	573.02	573.20	532.02
3.00	573.98	574.01	574.06	532.54
4.00	573.20	573.26	573.35	532.57
5.00	573.09	573.10	573.01	532.34
6.00	573.35	573.42	573.45	531.91
7.00	573.19	573.15	573.15	532.31
8.00	573.09	573.08	573.07	532.38
9.00	573.25	573.18	573.25	532.20
10.00	573.48	573.43	573.27	532.18
11.00	573.62	573.62	573.60	532.05
12.00	573.40	573.47	5	

```
      ⍴DATA
33  5
```

A matrix named "DATA" has been loaded and displayed from workspace "NEWTON DATA." DATA consists of 33 rows by 5 columns; only 12 rows are shown.

X and Y are measurements of track locations from DU surfaces on Write Sections.

```
      DSTAT Y1
SAMPLE SIZE -          33
MAXIMUM                573.98
MINIMUM                573.09
RANGE                  0.89
MEAN                   573.51
STANDARD DEVIATION     0.24474
THREE SIGMA LIMITS 572.77  574.24
```

The function"DSTAT" is used to compute summary statistics for the values of Y1.

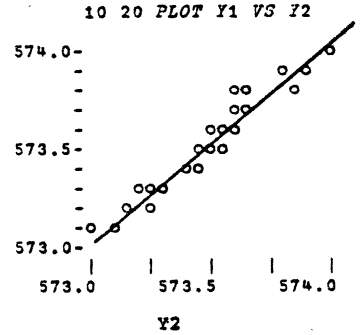
```
      572.8 .1 13 2 RHIST Y1
.       TT
.       TT
.      TTTT
.    TTTTTTT
.    TTTTTTT
.  TTTTTTTTTT
.  TTTTTTTTTT
.  TTTTTTTTTT
.............
```

```
      2▼T
```

Cell No.	Cell Limits LL	UL	Freq	% Freq
1.00	572.80	572.90	0.00	0.00
2.00	572.90	573.00	0.00	0.00
3.00	573.00	573.10	2.00	6.06
4.00	573.10	573.20	3.00	9.09
5.00	573.20	573.30	3.00	9.09
6.00	573.30	573.40	4.00	12.12
7.00	573.40	573.50	5.00	15.15
8.00	573.50	573.60	5.00	15.15
9.00	573.60	573.70	4.00	12.12
10.00	573.70	573.80	3.00	9.09
11.00	573.80	573.90	2.00	6.06
12.00	573.90	574.00	2.00	6.06
13.00	574.00	574.10	0.00	0.00

The function "RHIST" is used to plot a histogram of the Y1 values. The left arguments of RHIST specify the lower end of 1st cell, cell increment, number of cells, and vertical height of the histogram, respectively. "T" is a frequency table prepared by RHIST and displayed with 2 decimal places.

```
      10 20 PLOT Y1 VS Y2
```



The function "PLOT" is used to display a scatterplot of Y1 vs Y2. A freehand line has been fitted to the data, indicating a positive linear relationship exists. The function "STREG" could be used to compute the equation of the best fit line.

FIGURE 121

USING APL FOR DATA RETRIEVAL AND ANALYSIS

QUALITY ASSURANCE

Quality Assurance (hereafter known as QA) support of the Newton program encompasses such areas as raw chemical and material analysis, process analysis and control, electrical subassembly testing, precision dimensional measurements, artwork inspection, and functional testing.

The following presents, in more detail, QA's support of the Newton program.

Quality Responsibilities

QA objectives are to remain heavily involved as an ME-QE member in the early Newton build process to understand, follow, and contribute to process development. Our purpose is to identify and reduce in-process and finished product failure for ultimate reduction of total product cost while achieving ultimate product quality. Specifically, QA has tried to achieve its objective by developing non-electrical measurement concepts and methods, both for the manufacturing and inspection processes. It plans to carry this responsibility into the production environment from the pilot line environment. Further, QA will participate with Manufacturing Engineering in collecting data on critical process materials and procedures. For both product and process materials, procurement specifications will be developed with the Manufacturing Engineer.

Since Manufacturing Engineering is responsible for developing the pilot and manufacturing processes (where there are many measurement requirements, diversified in type, and extremely precise), it is logical to consider the measurement area as a process in itself. Thus, the ME-QE process team concept is a logical approach to obtain lowest product cost, best quality, and quantity. The team concept provides a mutual check and balance between the Manufacturing Engineer and the Quality Engineer assigned to a given operation. The ME will play an evaluation role in the process measurement methods while the QE will play an evaluation role in the basic process.

When the Newton build process reaches production level, QA will audit to assure process controls continue to maintain adequate yield and reliability.

Finally, QA will be concerned with final functional test certification and correlation of test with process parameters.

During the "B" test and "C" test preparation stages of the Newton program, QA will assist in establishing and evaluating process control parameter history for the purpose of process control and improvement.

Process Inspection Objectives

All critical process variables will continue to be monitored and/or measured. The following addresses those variables which had no established measurement as of January 1, 1972:

ELECTRO-CHEMICAL PROCESS CONTROLS

Thermal Cleaning

Thermal cleaning basically involves the variables of time, temperature, and amount of vacuum when a vacuum furnace is used. For temperature measurements, non-contacting infrared temperature monitoring was considered. The observed furnace temperature should be compared with furnace strip chart recorder values in a production environment.

Sputter Etch

Sputter etch variables of concern are time, vacuum level, plate current, and voltage. No additional measurement development efforts were required to monitor this part of the process. The operation control charts on the sputter equipment provides control data recording. Minimum operator training is required to monitor the control variables of this process.

Sputter Al_2O_3

This operation involves five process control variables: time, substrate temperature, plate current, voltage, and system pressure, as well as part parameters of thickness and adhesion. Process variable measurement techniques exist at present. A program is currently being developed to monitor the Argon content and the etch rate of the sputtered Al_2O_3. Argon content will be measured using the X-ray flourescence vacuum spectrograph.

Kerr-Magneto-Optic Testing (KMOT)

Four film characteristics are of concern in the KMOT: dispersion, skew, Hc (coercive force in the "hard" direction). Test equipment in SDD will be used to test all "B level" hardware. Another portion of this report describes KMOT in further detail.

Wire Bonding

Wire bonding will require monitoring of the wire to pad resistance via pre-wire and post-wire measurements. Visual examination of the reflowed solder for well rounded solder fillets is performed before post-wire measurements are made. Precision four-terminal resistance measurements utilizing current reversal made for both pre-wire and post-wire tests are performed by the Metrology Laboratory. Figure 122 shows the pre-wire/post-wire resistance probe test station. Figure 123 shows the probe contact method.

Magneto-Resistance Tests

As in the case of KMOT, "B" test level parts will be measured with the SDD tester. Another part of this report describes this measurement in further detail.

DIMENSIONAL/PHYSICAL PARAMETER CONTROL

Receiving Inspection - Raw Material

All raw materials are to be evaluated and analyzed in the QA Lab relative to procurement specifications. No special equipment or training is required.

Housings - Sourced In-Plant and San Jose

One hundred percent (100%) inspection of all specifications of all out-plant sourced parts is to be performed. This inspection plan rate will be converted to sampling as confidence is established in the acceptability of these parts.

Strength Testing - Braze of Ferrite to Titanium

Test samples brazed in conjunction with production parts are tested to destruction with existing equipment and procedures.

Center Section Assembly

Flatness, parallelism, and surface finish measurements are made with the same equipment as used for housings: (standard inspection equipment already available for these dimensions).

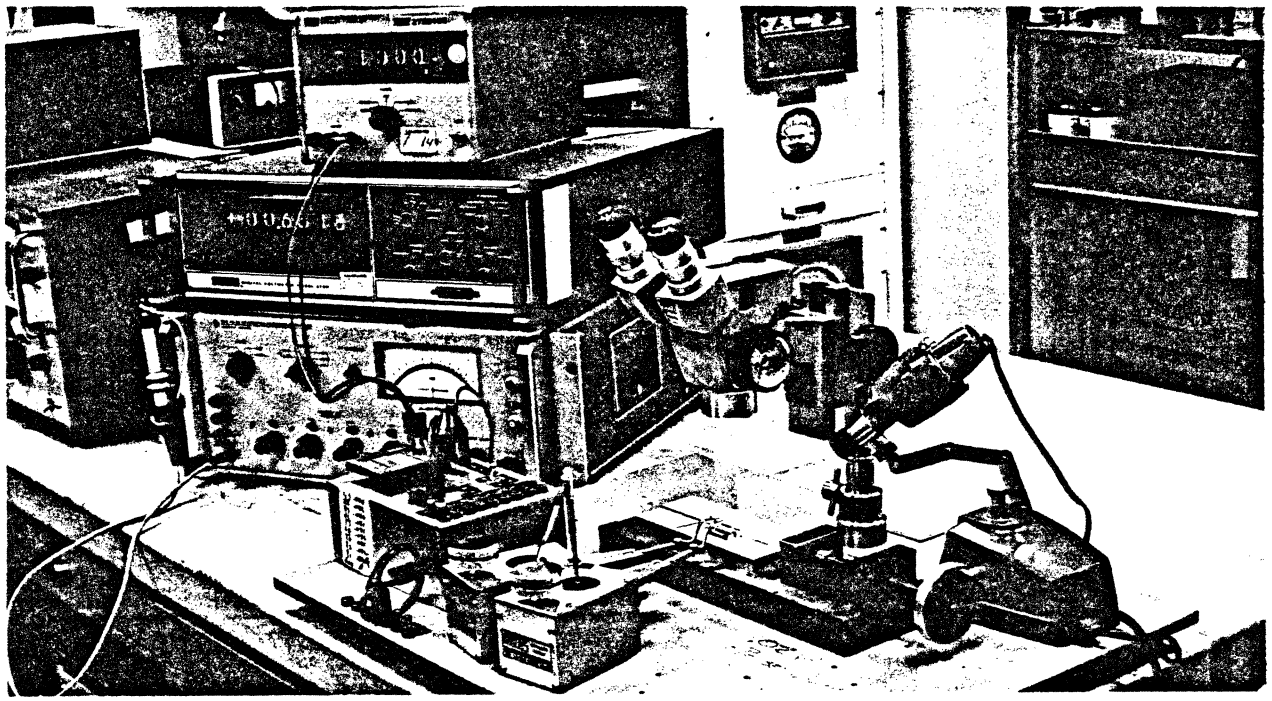


FIGURE 122

PRE-WIRE/POST-WIRE RESISTANCE PROBE TEST STATION

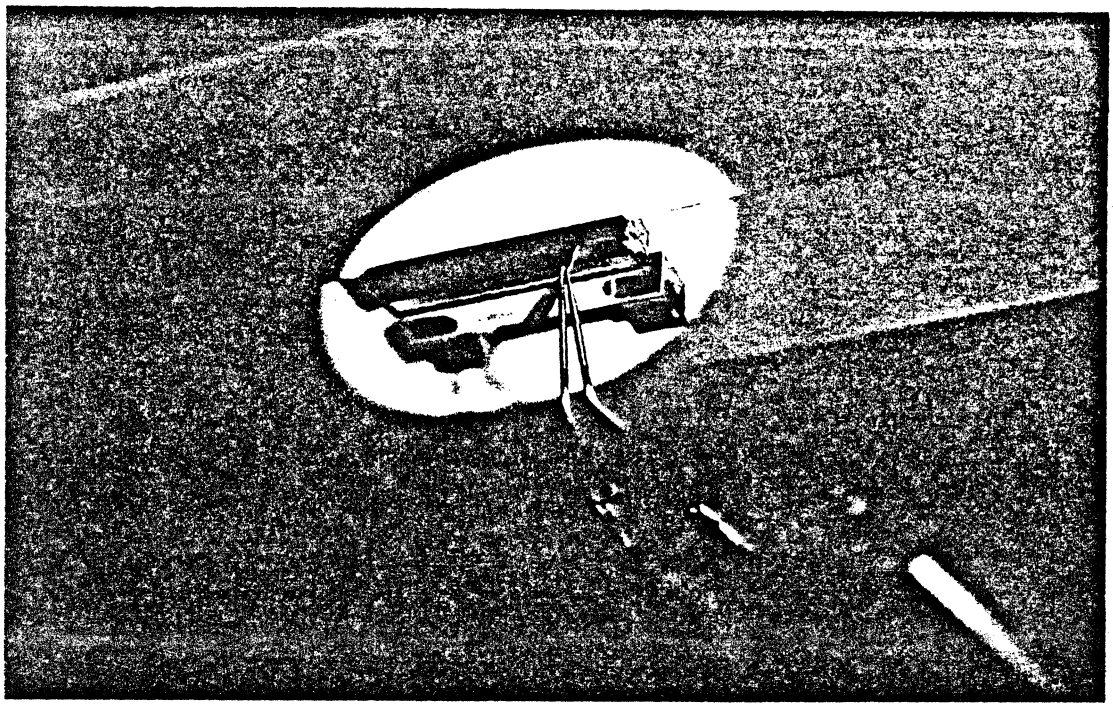


FIGURE 123

PROBE CONTACT METHOD

Final Head Assembly

Existing standardized laboratory inspection equipment will be used for "B" test heads.

ARTWORK/DEPOSITED FEATURE CONTROL

The basic objectives in artwork and product inspection are as follows:

Measurement of artwork for read and write sides. Data collection of the measured parts is inherent to the inspection.

Measurement of deposited features. This includes dimensional characteristics, voids, pinholes, and undercutting. Data collection is a part of this inspection.

The objectives will be satisfied in two phases: Phase I will support B/C test activity; Phase II will be an automated system to support full production.

The Phase I system is operational now. It consists of the Moore Model B measuring machine fitted with a TV camera and Edge Detector as pickup devices. The edge detector will be used exclusively for artwork inspection and for patterns that are relatively simple. The TV system can be used for either artwork or product inspection. The features can be magnified to 400X and observed on the TV monitor. The TV system will permit inspection of the total feature for bridging, etc. It will not detect undercut; this will be inspected in B/C test by the Leitz toolmakers' microscope currently in the AME Lab. Figure 124 shows the Moore Optical Measuring System.

The Phase II system is dependent on product schedules for justification. Envisioned is an X-Y table that is computer-controlled and a TV system that will be used for feature edge detection. The inspection machine will be used as a production tool and will be part of the manufacturing process. The language to define pattern layout has already been implemented; modification of this language is required for computer control of the measuring process.

MATERIAL AND CHEMICAL PROCESS CONTROL

Within this category, the major objective is to establish the material and chemical variables in the Newton process, to determine which variables are necessary for process control, and how these variables can be measured. Another objective is to determine if it is economical to automate those measurements found to be necessary.

Copper Plating

Existing plating process variables were evaluated theoretically to establish whether or not control functions could be related to required product characteristics. Measured product characteristics are plating thickness and appearance, which are related to process evaluations of current and plating bath composition. Process measurements are pH, total sulfate concentration, chloride concentration, and cupric concentration. It was found that current process laboratory measurements were adequate and that more detailed controls were not economically justified.

ETCHANTS

Laboratory experiments are conducted to establish controls for certain chemicals as follows:

Phosphoric Acid

This chemical is purchased per ACS specifications (85%). Control properties are established by plotting etch time versus Al_2O_3 loading versus pH. Temperatures are monitored and reviewed to maintain the necessary rate during etchant deterioration. Contamination is controlled by grade of Al_2O_3, ACS specification, and organics tests. All initial tests per ACS specifications are conducted at a one to one (1 to 1) concentration.

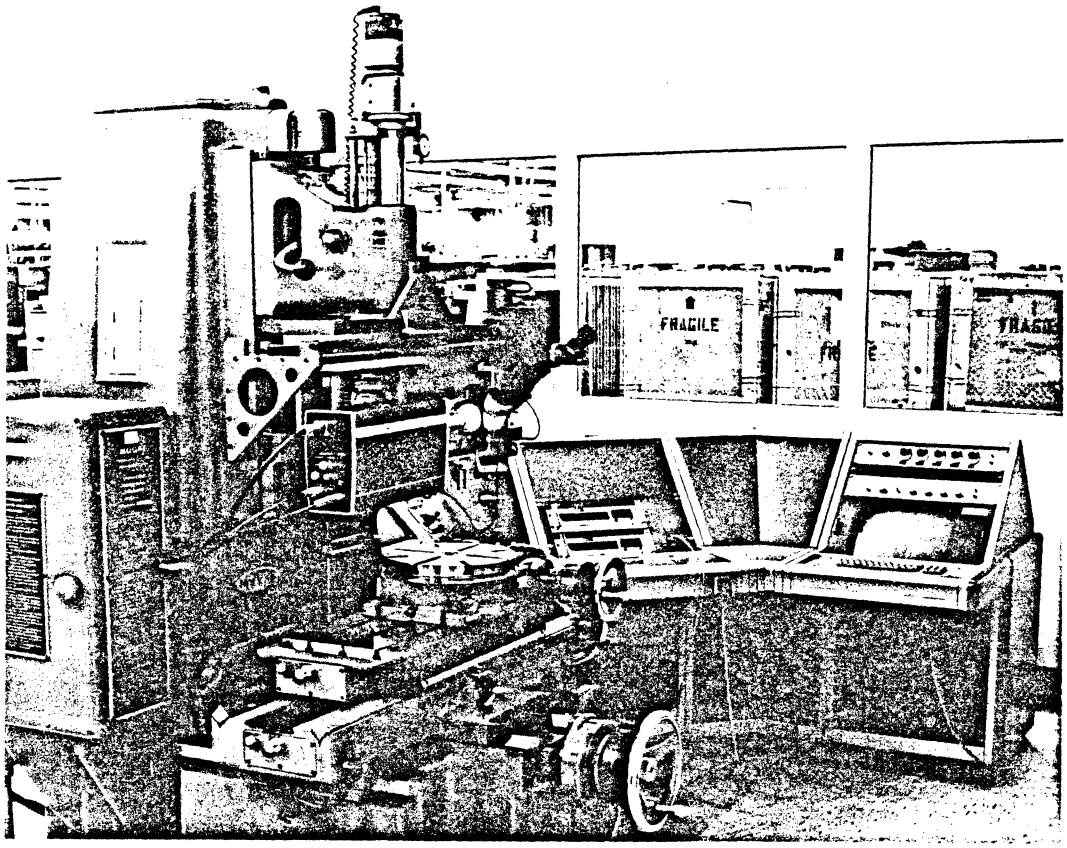


FIGURE 124

MOORE OPTICAL MEASURING SYSTEM

Cr-10A

Control functions are determined by correlation of loading versus etch time versus pH. The effect of temperature will also be investigated. Contamination will be monitored via the plating analyzer, and trace metal contamination will be monitored via emission spectroscopy. Evaluation of process variables used as a spray should be completed by September, 1972. Procurement specifications for Cr-10A will be determined at a dilution of one to seven (1 to 7).

Ferric Chloride

This chemical is purchased per local procurement specifications. Control functions are determined by correlating the plots of loading versus temperature versus pH. The ferric chloride purchased is 42° Baume, and all specifications are determined at this Baume. The main source of contamination is the etchant itself which is monitored via emission spectroscopy. Current specs are adequate. Investigation of use of etchant grade for use is under investigation.

Hydroflouric

Hydroflouric will be procured and tested per ACS specifications. Contamination will be controlled per ACS specifications and emission spectroscopy. Hydroflouric purchased to ACS specifications is 48% minimum/57% maximum. This concentration will be diluted, one to forty-nine (1 to 49) or 2% with water. All further control tests will be made at this concentration. Generally, the QA Lab planned to determine if all etchants could be functionally controlled. Two specific methods evaluated were etchant conductivity and resistivity measured during spraying. It has generally been determined that functional control is unnecessary and it is not technically or economically justified.

Photo-Resist

Data required to develop procurement specifications is complete. Resist sensitivity detection and control was studied for time dependency and application. Ultra-violet spectroscopy and refractive index was used for determining sensitivity. The degree of resistive cure was determined by monitoring cure by: (1) infrared, (2) ultra-violet, and (3) refractive index.

BTC

A Boulder Engineering Specification has been written and reviewed at San Jose.

Adhesives

Several available commercial specifications were reviewed. Adhesive materials were evaluated relative to the available specifications.

Aluminum Oxide

Procurement specifications were developed after SDD engineering specifications were released.

Glass/Ferrite

Engineering specifications have been issued and were reviewed at San Jose. Procurement specifications will not be necessary since the materials are procured IPT.

Evaporative Coatings

Procurement specifications were developed for copper, titanium, aluminum oxide, permalloy. Coating thickness was determined by X-ray flourescence, beta-transmission, and reflectance.

Wire Bonding

A flux specification presently exists. The possible effect of EC-2290 on resist and resist removal was determined. The engineering specification has established the solder joint and test procedure specification. An evaluation of these specifications and procedures was completed.

Thin Film Adhesion

An evaluation of scratch and mechanical tests is still under investigation.

Thermal Analysis

Tests were made to determine coefficient of expansion and stress/strain characteristics for metal films. Adhesives will be evaluated for expansion coefficients, glass transitions, cure optimization and stress/stain relationships.

Water (Distilled)

Organic, inorganic, and bacteriological tests were performed on distilled water. All background data is available.

FUNCTIONAL TESTING

All "B" level and development level parts are tested by SDD. Quality Engineering follows those tests and will participate in test specification pre-analysis. After engineering release of specifications and as the "C" test level test and tester concepts are developed by Manufacturing Engineering, Quality Engineering will define the certification ground rules and procedure.

DATA COLLECTION AND PROCESS CONTROL

QA had the responsibility for assuring that all process and inspection data was keypunched and stored on tape or disc file. The Data Entry Department has provided the keypunch support of log sheet deliveries made on a daily basis. As a result, process data has been available for retrieval for most process steps within 3 or 4 working days - earlier if required. As of this writing, data is on file for head serial numbers up through F034. Functional test data from SDD has been sketchy due to the variety of heads to be tested. It is planned that eventually, process data and functional test parameters may be comparable via APL techniques.

FUTURE PLANS

Upon product commitment to Newton and subsequent release of capital funds, higher volume and inspection enhancement equipment will be procured. This equipment is planned for production line support and is more specifically identified in the Quality Capital budget.

NEWTON MANUFACTURING FACILITY

Determination of Physical Requirements

The overall objective in planning any manufacturing process is to arrange the facilities and personnel so the manufacturing process may be carried out in an effective manner as possible. This objective calls for a minimum of movement on the part of both materials and personnel, and a minimum of time in process for any individual part. In accomplishing this objective, the facilities plan must also consider employee safety, convenience and comfort, and provide adequate security measures.

With these objectives in mind, the first step in determining the Newton facilities requirement was to define, by operation, each step of the head assembly process. This process flow is shown in Figures 125, 126, and 127.

The introduction of thin film technology brought new and unfamiliar processing techniques to Boulder (in respect to equipment, installation requirements, process area relationships, etc.). This technology had been well established at East Fishkill and Burlington. Therefore, it was decided that a visit to these facilities would be beneficial in that we could utilize their experience in layout design and equipment installation for thin film processing. The visit proved to be very valuable. From the observations made and the discussions with personnel at Burlington and East Fishkill, we were able to establish general facilities design criteria and develop specific objectives for our facilities.

The general facilities design criteria are listed as follows:

Clean Room Concept

All operations would be done within a clean room environment of class 100,000 except for the grinding, slicing, and slurry operations. All critical operations requiring better than a class 100,000 level would be done in a class 100 laminar flow clean bench.

Sputtering and vacuum deposition equipment would be under class 100 laminar flow hoods.

Parts handling between critical operations would be in portable clean hoods.

READ/WRITE HOUSING PREPARATION

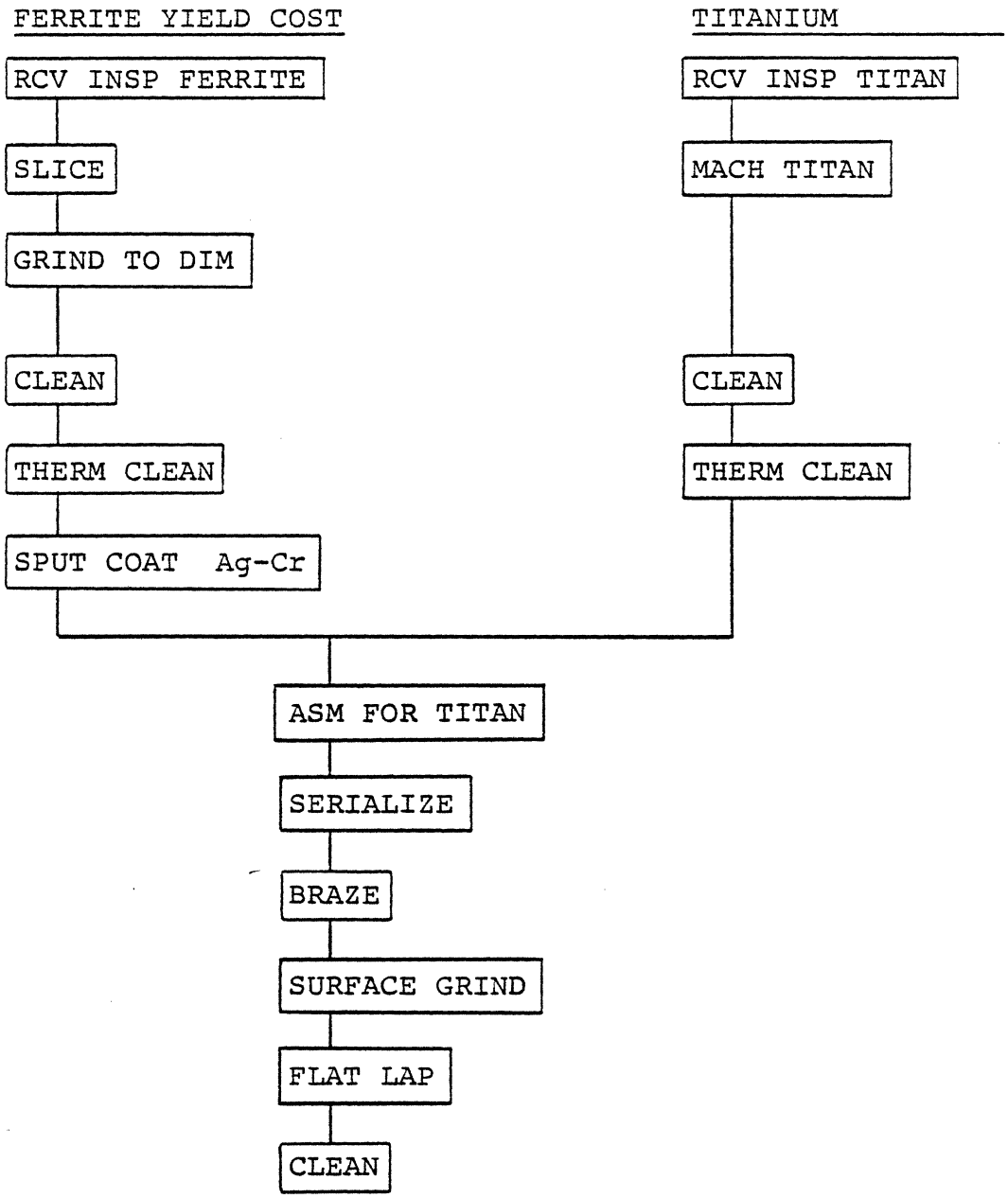


FIGURE 125

HOUSING PREPARATION

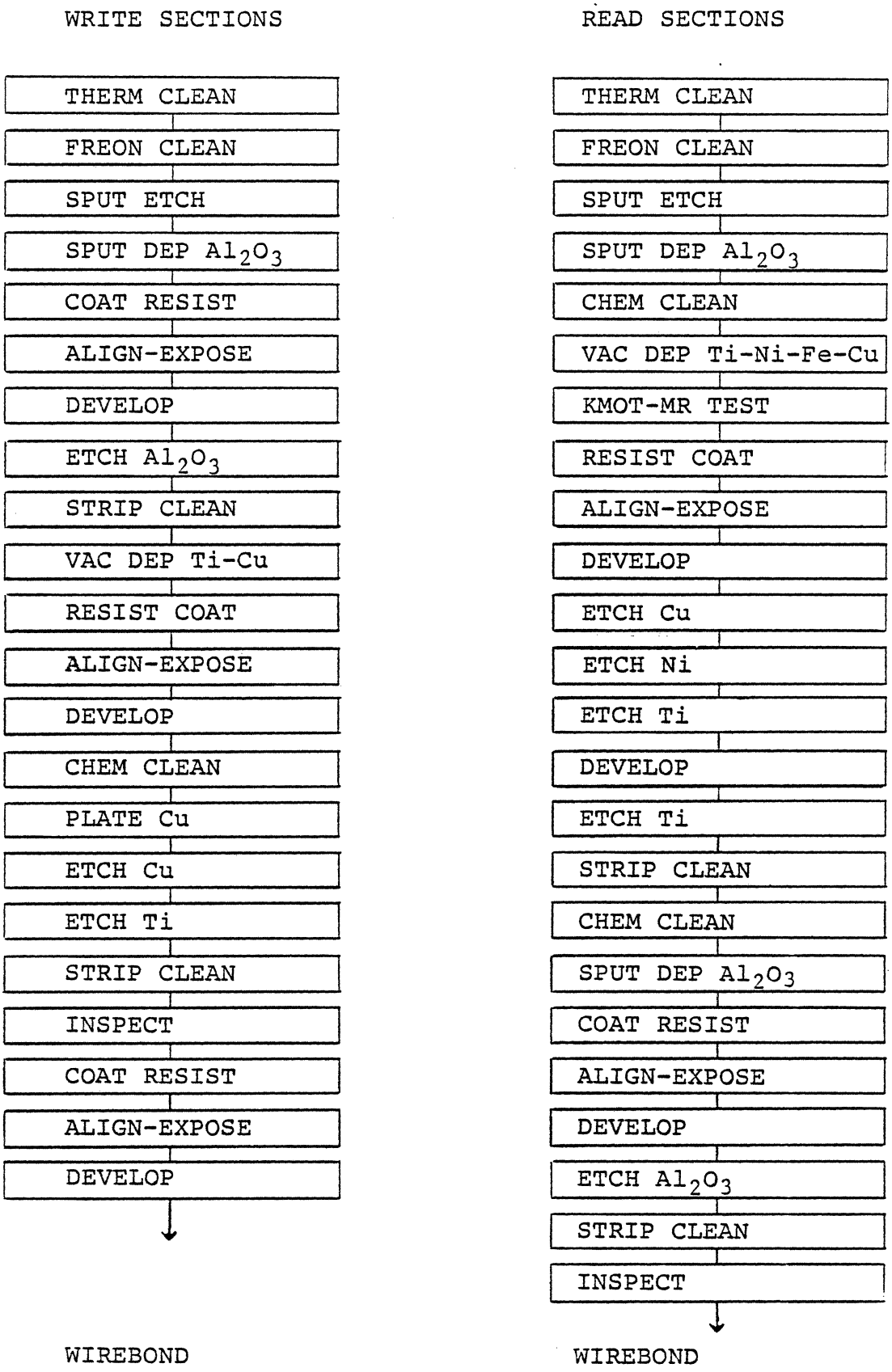


FIGURE 126 TRACK DEPOSITION

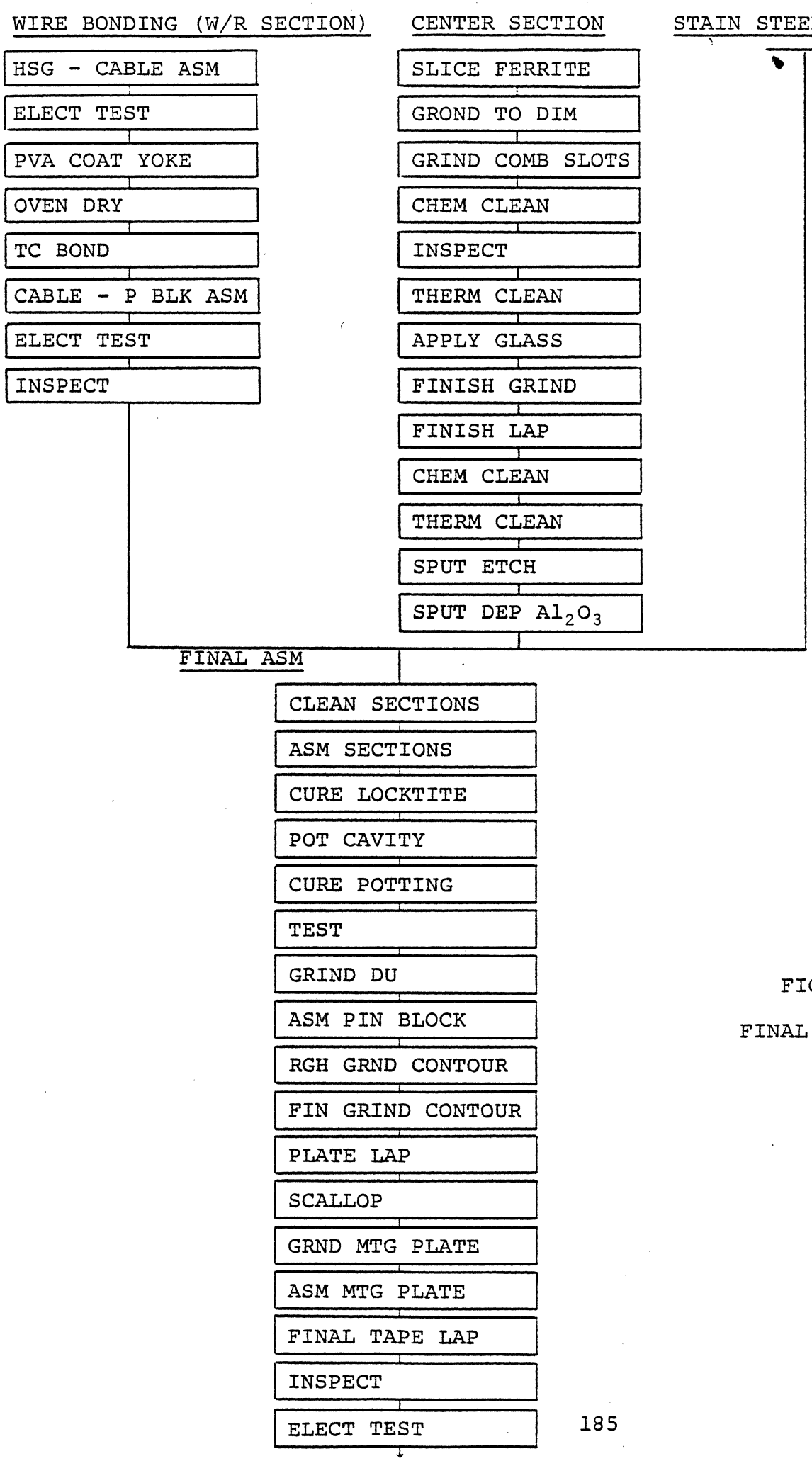


FIGURE 127

FINAL ASSEMBLY

Core Concept

This concept refers to the location of all plumbing, wiring, pumps, gas bottles or any equipment that contributes to contamination that could be remotely located from the operator, within an enclosed cubicle referred to as a core. The core area also allows free access for maintenance work without disturbing the contamination level in the manufacturing area outside the cubicle (see Figure 128).

Adjacent Facilities Maintenance Area

Vacuum deposition and sputtering equipment require constant support from maintenance personnel which is in addition to the normal maintenance support required by the other processing operations. Therefore, to minimize downtime and reduce contamination generated by maintenance operations, a separate maintenance area, adjacent to the vacuum deposition and sputtering area, would be provided.

Distribution of Supplies and Chemicals

Provisions would be made for safe and economical storage and distribution of supplies and chemicals to usage areas with a minimum of traffic through the manufacturing area. The storage area would be capable of handling up to seven days' supply of chemicals and be provided with equipment for cleaning containers to prevent the introduction of contamination into the manufacturing area. The majority of chemicals would be stored and supplied by the Chemical Storage Department and shipped to the manufacturing area in five-gallon or smaller containers, packaged in plastic bags.

Centralized Vacuum System

A centralized vacuum system with a port convenient to each work station is essential for contamination control for clean room areas. Portable vacuum systems, even though well filtered, tend to introduce contamination back into the area.

Centralized N2 System

Dry N2 gas is required for the vacuum deposition and sputtering operations, parts storage cabinets, and at work benches for dry blow-off of parts. N2 terminals are to be located where required to draw N2 from existing centralized N2 supply system.

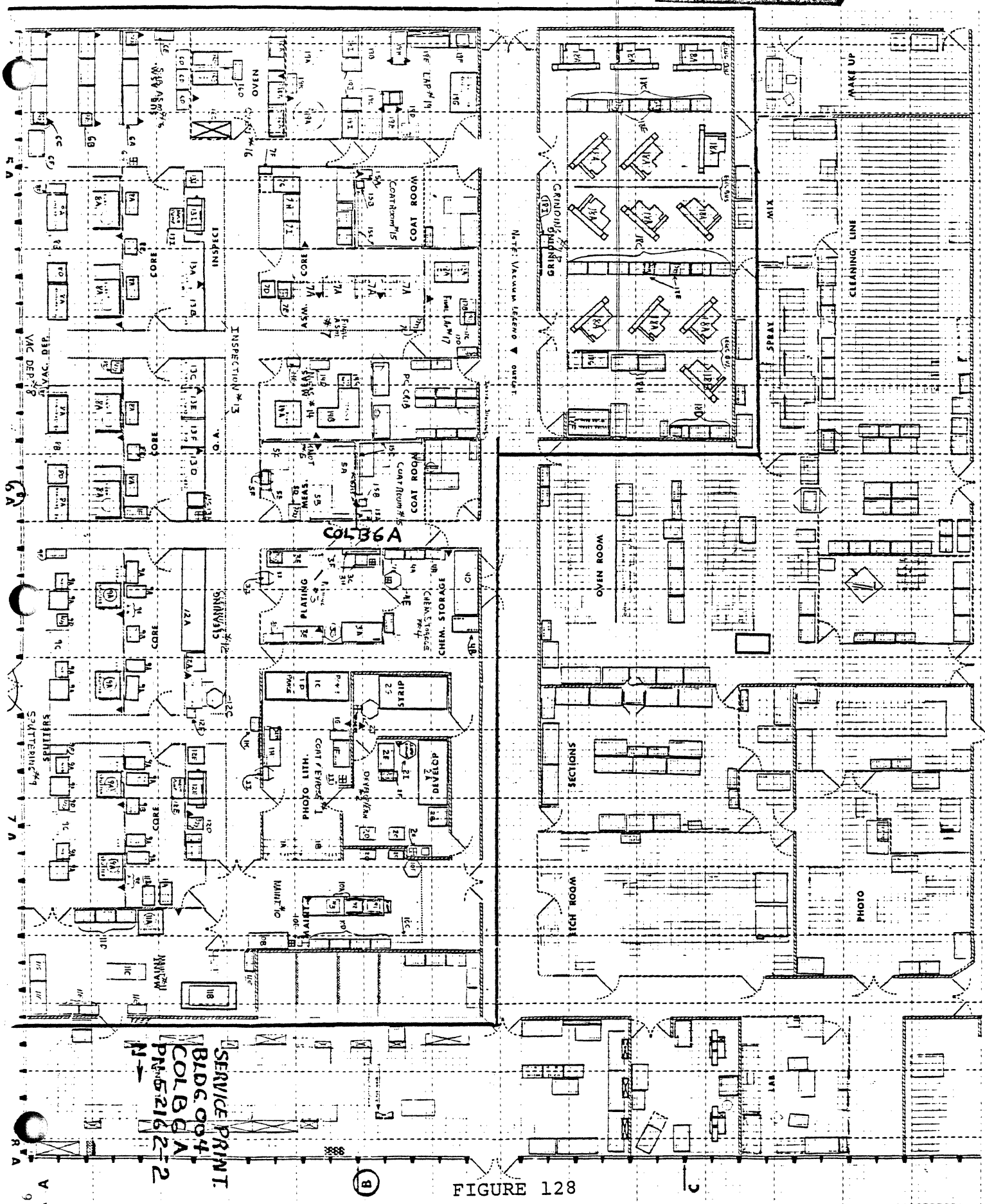


FIGURE 128

FACILITIES LAYOUT

Centralized Liquid Nitrogen (LN2) System

The usage of liquid nitrogen by vacuum deposition, sputtering and leak detection equipment has been estimated at 108.4 liters/hour. This volume justifies the installation of a centralized system. The design and installation would be the responsibility of Facilities Engineering.

Centralized City Water Coolant

The estimated usage of city water for the Newton facility is approximately 32,580 gal/day. The cost of this water, if used once, amounts to $1.28/K gallon or $41.60/day. Approximately 80% of this water would be recirculated through a cooling tower at a savings of approximately $25/day.

Centralized DI Water Supply

The existing DI water facility would be expanded to handle thin film processing requirements of approximately 5 gpm. The expansion would also include bacteria control and monitoring equipment.

Centralized Chilled Water

Approximately 40 gpm of chilled water for the DI recirculators would be piped from the chilled water system installed for plastics manufacturing.

The next step in the facilities design was to determine the equipment, manpower, square footage, and work area layout for each operation, based on a given schedule. This step involved extensive interviewing with each engineer to define these parameters and to establish other facilities design criteria such as power requirements, water usage, chemicals, air and nitrogen usage, clean room requirements, and contamination control measures. These parameters are tabulated in IE Transmittal #52162-2.

With all of the above information collected, we were able to begin the floor plan layout. Scaled layout templates were then laid out on a large grid of the same scale. The templates were placed in various positions so that area relationships and product flow patterns could be studied. By rearranging the templates, different patterns were evaluated until the optimum compromise was achieved.

After the overall floor plan concept was completed, it was necessary to fit it to some location within an existing building. The Newton manufacturing facility was assigned to be located in the northeast corner of Building 004. The final layout, adjusted to fit this location, is shown in Figure 128. This layout involved a complete rearrangement of the existing head assembly facilities to accommodate the Newton facilities (see IE Transmittal #162-2).

CLEANLINESS AND CONTAMINATION CONTROL

Cleanliness and contamination control is a very broad and sometimes controversial subject. The scope of this report does not justify mentioning all of the ramifications pertaining to this subject in respect to thin film processing. Refer to NASA Technical Publications, #SP-5045 and #SP-5074, for a detailed treatment on contamination control.

For our manufacturing area, it was decided that class 100,000 cleanliness level, with critical operations performed under class 100 laminar flow benches, would be sufficient.

The facility was designed with contamination control measures in mind, such as:

1. Central vacuum system with outlets at most work stations.
2. Tile floors.
3. Drop ceilings in all areas with sealed ceiling tile.
4. Special entry for personnel clean room preparation (shoe cleaner, garments, etc.).
5. Positive air pressure in clean room areas.
6. Special core area for plumbing, wiring, and contaminate generating equipment and maintenance.
7. Adjacent maintenance area to handle maintenance work removed from the clean room area.
8. Receiving area for chemicals and supplies for special preparation to remove contamination prior to distribution into the manufacturing area.
9. Special cleaning consoles for parts cleaning.
10. Relationship of manufacturing operations located to minimize operator activity.
11. Rules concerning wearing apparel and personnel practices would be adopted to prevent migration of contamination into the area and to control generation of contamination within the area.

COST ANALYSIS

The following outline lists the attached tables of schedules, equipment, and cost information upon which the manufacturing facility was sized:

Table 17	Head Build Schedule
Table 18	Equipment List & Capacity Schedule
Table 19	Phase 0 Labor & Material Cost Summary
Table 20	Newton SMD Cost Summary (Ø-0)

Table 17. Newton Head Build Schedule With Est. Yields & Start

	'72	'73	'74	'75	'76	'77	'78	'79	Total
OAK			235	2,288	4,651	6,318	3,963	2,162	19,617
Oak Yield (Thru Wire Bonding)			20%	25%	30%	35%	35%	35%	
Final Asm Yield			30%	35%	40%	50%	50%	50%	
Process Starts			1,175	9,152	15,503	18,051	11,323	6,177	
Rate Per Day Starts			5	38	65	75	47	26	
Final Asm Starts			783	6,537	11,626	12,636	7,926	4,324	
Rate Per Day Starts			3.2	27	48	53	33	18	
BIRCH	37	1,818	5,973	7,531	2,804	587	222	0	18,972
Birch Yield (Thru Wire Bond)	10%	25%	35%	40%	42%	42%	42%		
Birch Yield Final Asm	30%	40%	55%	60%	68%	68%	68%		
Process Starts	370	7,272	17,066	18,828	6,676	1,398	529	-	
Rate Per Day Starts	123	4,545	10,842	12,552	4,124	863	326		
RPD Starts	.5	19	45	52	17	4	1.4		
Total Beginning Starts/Day	1.5	30	76	115	93	81	49	26	
Total Final Asm Starts/Day	.5	19	48	79	65	57	35	18	

Table 18. Manufacturing Facility Equipment List and Capacity Schedule

Oper	Equipment	No RQD	Cost Ea. $K	Cost Total	Cycle Parts/Hr.	Capacity Per 8-Hr Shift
Read/Write Hsg Prep						
Ferrite-Tit.	1. Slicer	1	16.0	16.0	590/hr.	3,820 fer. pieces
Machining	2. Tooling		3.0	3.0		
Grind	3. Slicer	1	16.0	16.0	590/hr.	3,820 fer. pieces
	4. Tooling		2.0	2.0		
	5. ECM	1	20.0	20.0	120/hr.	780 fer. pieces
	6. Tooling		6.0	6.0		
	7. Vac Furn*	1	-		1,000/hr.	6,500 fer. pieces
	8. Sputter	1	25.0	25.0	666/hr.	4,300 fer. pieces
	9. Exp Tools		3.0	3.0		
Fer-Tit. Asm.	1. Tooling		6.0	6.0		
Braze	2. Vac Furn		25.0	25.0		
	3. Exp Tools		2.0	2.0		
Grind	1. Surf Grinder	1	16.0	16.0	33/hr.	216 hsgs
	2. Fixt.		5.0	5.0		
	3. Surf Plate		2.5	2.5		
	4. Insp Equip		2.0	2.0		
	5. Exp Tools		3.0	3.0		
Lap	1. Lapmaster		10.0	10.0	182/hr.	1,180 hsgs
	2. Lap Fixt.		2.0	2.0		
	3. Exp Tools		3.0	3.0		
Photolithography						
Clean	1. Clean Console	1	30.0	30.0	180/hr.	1,080 sect
	2. Lam Flow Hood	1	5.0	5.0		
	3. Exp Tools		3.0	3.0		

* IBM Loc at Vendor or Design at Vendor

Table 18. Manufacturing Facility Equipment List and Capacity Schedule (Cont'd)

Oper	Equipment	No RQD	Cost Ea. $K	Cost Total	Cycle Parts/Hr.	Capacity Per 8-Hr. Shift
Therm Clean	1. Vac Furn	1	25.0	25.0	1,000/hr.	6,500 sect
	2. Exp Tools		2.0	2.0		
Sput Etch	1. Sputter	1	25.0	25.0	100/hr.	650 sect
	2. Lam Flow Hood	1	2.0	2.0		
Sput Deposit	1. Sputter Al_2O_3	1	25.0	25.0	40/hr.	260 read
	2. " "	1	25.0	25.0	15.4/hr.	100 write
	3. Lam Flow Hoods	3	2.0	6.0		
	4. DI Recirculator	2	3.0	6.0		
	5. Clean Bench	2	2.5	5.0		
	6. Interferometer	1	3.0	3.0		
	7. Tooling		10.0	10.0		
	8. Exp Tools		3.0	3.0		
Vac Dep	1. Evaporator	4	40.0	120.0	2 loads @ 20/load	120/3 mach read
	2. EB Pwr Supply	2	35.0	70.0	2 loads @ 60/load	120/1 mach write
	3. DI Recir	2	3.0	6.0		
	4. Clean Bench	2	2.5	5.0		
	5. Interferometer	1	3.0	3.0		
	6. Tooling	4	7.5	30.0		
	7. Lam Flow Hoods	3	2.0	6.0		
	8. Exp Tools		5.0	5.0		
KMOT (Test)	1. KMOT	1	20.0	20.0	12/hr.	78 samples
	2. MR Test		7.0	7.0		
	3. Tooling		5.0	5.0		
	4. Gauss Meter		3.0	3.0		

Table 18. Manufacturing Facility Equipment List and Capacity Schedule (Cont'd)

Oper	Equipment	No RQD	Cost Ea. $K	Cost Total	Cycle Parts/Hr.	Capacity Per 8-Hr. Shift
Resist Coat	1. Spin Coater	1	7.0	7.0	83/hr.	540
	2. IR Dryer	1	7.5	7.5		
	3. Clean Bench	3	3.2	9.6		
	4. Tooling		5.0	5.0		
	5. Exp Tools		3.0	3.0		
				493.1		
				660.6	Cumulative	
Expose	1. Prace Align & Expose	2	10.0	20.0	71/hr.	460
	2. Light Table	1	.3	.3		
	3. Scope	1	14.0	14.0		
	4. Tooling	1	2.0	2.0		
	5. Masks		250.0	250.0		
Develop	1. Develop Console	1	30.0	30.0	143/hr.	930
	2. Scope		14.0	14.0		
	3. Tooling		2.5	2.5		
Etch	1. Spray Etcher	1	7.0	15.0	47/hr.	300
	2. Tooling		5.0	5.0		
	3. Gaging (Dev Etch)		16.0	16.0	26/hr.	170
Strip-Clean	1. Prec Meas Mach	1	45.0	45.0		Mask Measuring
	2. Tooling		5.0	5.0		
Q.E. Inspect	1. Lam Flow Clean Bench	7	3.2	22.4		
	2. Vib Isol Table	1	2.0	2.0		
	3. Brush Analyzer	1	12.0	12.0		
	4. Interferometer	1	In-House			
	5. Scopes		3.0	3.0		
	6. Comparator		IPT	-		
	7. Dektak	1	In-House			

Table 18. Manufacturing Facility List and Capacity Schedule (Cont'd)

Oper	Equipment	No RQD	Cost Ea. $K	Cost Total	Cycle Parts/Hr.	Capacity Per 8-Hr. Shift
Plate	1. Plate Console	1	10.0	10.0	40/hr.	260
	2. Clean Bench	1	2.5	2.5		
	3. Tooling	1	3.0	3.0		
	4. PH Meter	1		5.0		
	5. Exp Tooling		5.0	5.0		
				516.7K		
				1,187.3K		
Center Section						
Slice Ferrite	1. Slicer*	1		-	60/hr.	390 sect
	2. Fixt	1	2K	2.0		
Grind	1. Slicer*	1		-	60/hr.	390 sect
	2. Fixt	1	2K	2.0		
	3. Surf Plate	1	2.5	2.5		
	4. Insp Equip	1	2.0	2.0		
Grind Slots	1. Slicer*	1			6/hr.	39 sect
	2. Fixt	1	2K	2.0		
Inspect	1. Insp Equip	1	2.5	2.5		
Therm Clean	1. Vac Furn*	1	IPT	-	1,000/hr.	6,500 sect
Finish Grind	1. Grinder*	1		-	28.6/hr.	185 sect
	2. Fixt	1	3.0	3.0		
	3. Surf Plate	1	2.5	2.5		
	4. Insp Equip	1	2.0	2.0		
Finish Lap	1. Lapmaster	1	10.0	10.0	24.4/hr.	154 sect
	2. Fixt		2.0	2.0		
	3. Surf Plate	1	2.0	2.0		
	4. Insp Equip	1	1.5	1.5		
	5. Exp Tools			4.0		

Table 18. Manufacturing Facility Equipment List and Capacity Schedule (Cont'd)

Oper	Equipment	No RQD	Cost Ea. $K	Cost Total	Cycle Parts/Hr.	Capacity Per 8-Hr. Shift
Sput Etch	1. Sputter*	1	-	-	100/hr.	650 sect
Sput Dep	1. Sputter*	1	-	-	50/hr.	325 sect
				40.0		
				1,227.3K Cum.		
Wire Bond						
Hsg Cable Asm.	1. Tooling	2	5.0	5.0	20/hr.	140 sect
Elect Test	HVS R Continuity TSTR	1		19.5	100/hr.	650 sect
Solder Block	1. T.C. Bond Mach	2	3.0	6.0	33/hr.	428 sect
	2. Wave Solder		10.0	10.0		
Cable-Pin Block Asm.	1. Tooling	1	3.0	3.0	33/hr.	214 sect
Elect Test	1. Final Tstr	1	172.0	172.0	100/hr.	650 sect
	2. Processer	1	28.0	28.0		
Final Asm & Mach						
Section Asm	1. Tooling	3	3.0	9.0	4 hds/hr	78 hds
	2. Clean Bench	4	3.2	12.8		
	3. Inspect Equip	1	4.0	4.0		
	4. Oven	1	IPT	-		
Pot Cavity	1. Tooling	150	.2	30.0	4 hds/hr	52 hds
	2. Oven	2	IPT	-		
Grind DU	1. Grinder	1	ETA	-	20 hds/hr	70 hds
	2. Fixt	2	1.5	3.0		
	3. Surf Plates	1	ETA	-		
	4. Insp Equip	2	1.5	3.0		
	5. Exp Tools			8.0		

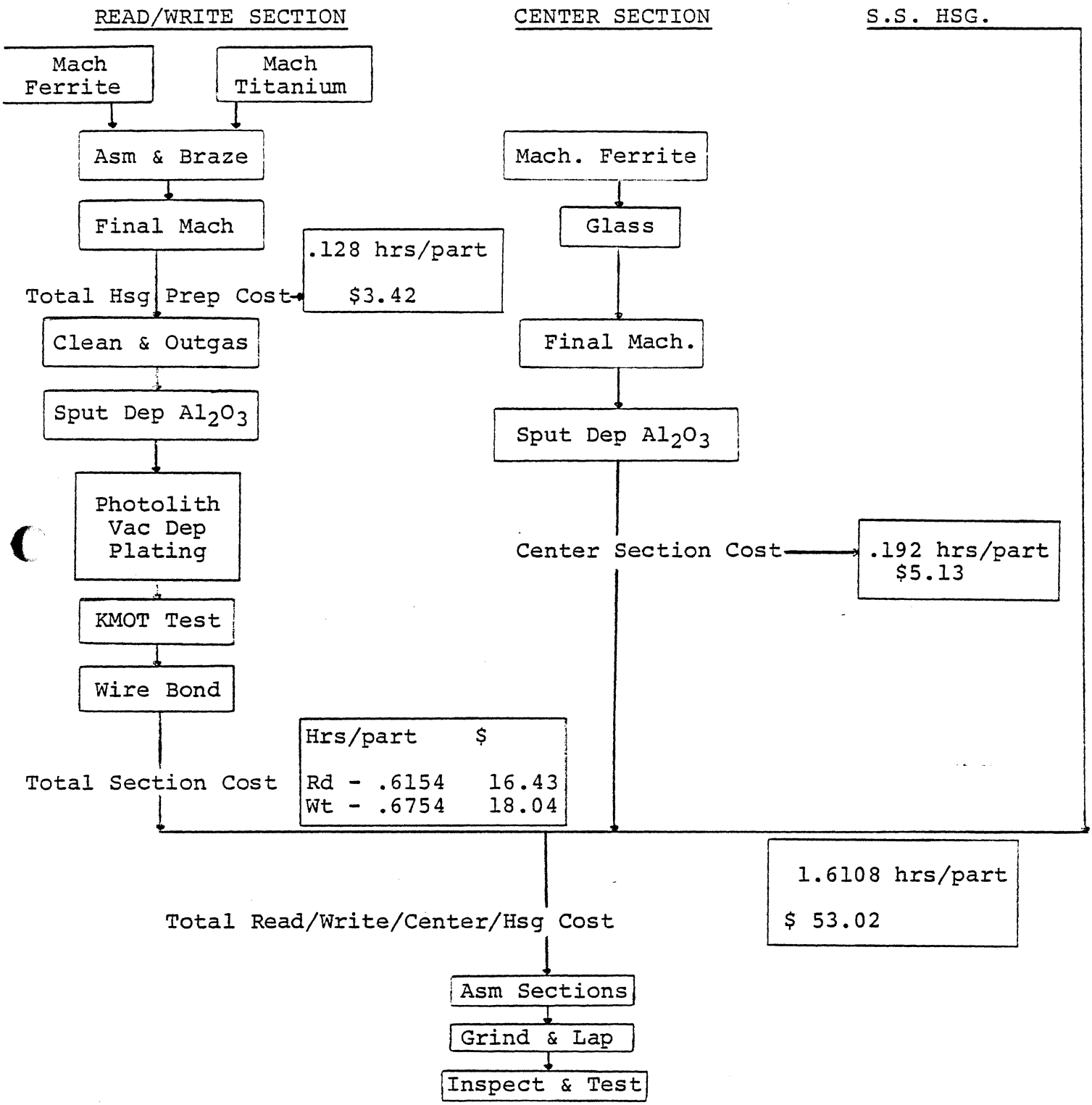
Table 18. Manufacturing Facility Equipment List and Capacity Schedule (Cont'd)

Oper	Equipment	No RQD	Cost Ea. $K	Cost Total	Cycle Parts/Hr.	Capacity Per 8-Hr Shift
Rgh Contr Grind	1. Grinders	2	15.0	30.0	4 hds/hr	52 hds
	2. Fixtures	2	7.0	14.0		
	3. Surf Plates	1	3.5	3.5		
	4. Insp Equip	2	2.0	4.0		
	5. Exp Tooling			5.0		
				388.7		
				1,616.0K Cum.		
Fin Grnd Contr	1. Grinders	3	24.0	72.0	2 hds/hr	39 hds
	2. Fixtures	3	7.0	21.0		
(Includes 1 QE)	3. Surf Plates	5	ETA	-		
	4. Insp Equip			7.0		
	5. Comparator	1	16.0	16.0		
Plate Lap	1. Lapmasters	3	7.5	22.5	1.85 hds/hr	36 hds
	2. Fixtures	3	2.6	7.8		
	3. Surf Plates	1	2.5	2.5		
	4. Insp Equip	1	2.0	2.0		
	5. Clean Equip	1	3.0	3.0		
	6. Vert Mill	1	6.0	6.0	(Not for parts)	Production Support
Grnd Mtg Plt	1. Grinder	1	ETA	-	66/hr.	430 plates
	2. Tooling	1	1.5	1.5		
	3. Vac Pump	1	ETA	-		
Final Lap	1. Lap Drive	2	12.0	24.0	10 hds/hr	130 hds
	2. Tooling	2	3.0	6.0		
Final Insp	1. Vib Isol Table	1	1.5	1.5		-
M.E.	2. Brush Analyze	1	12.0	12.0		-
	3. Resist Fixt	2	1.0	2.0		-
	4. Scope	1	14.0	14.0		-
500 ohmeter	5. Insp Fixt			5.0		

Table 18. Manufacturing Facility Equipment List and Capacity Schedule (Cont'd)

Oper	Equipment	No RQD	Cost Ea. $K	Cost Total	Cycle Parts/Hr.	Capacity Per 8-Hr Shift
Exp Tools All Machining				20.0		
Maintenance						
	1. Sputter Base	1	15.0	15.0		
	2. Leak Det.	1	10.0	10.0		
	3. Degreaser	1	10.0	10.0		
	4. Crane	1	1.5	1.5		
	5. Big Joe	1	IPT	-		
	6. Degreaser	1	3.0	3.0		
	7. Test Equip	1	15.0	15.0		
	8. Spectroph.	1	3.0	3.0		
	9. Pump Speed Ind	1	10.0	10.0		
	10. Exp Tools		10.0	10.0		
			TOTAL	$1,946,800		
			Expense	64,000		
			Capital	1,882,800		
				1,946,800		
	Class 100,000 Clean Room			250,000		
	Equipment Install			170,000		
			TOTAL	$2,366,800		

Table 19. Phase-0 Labor and Material Cost Summary



Approx Overall Yield →	42%
Total Hrs/Part →	4.406
Total Labor Cost →	$ 117.835
Total Purch Parts →	$ 16.72
TOTAL HARDWARE COST →	$ 134.555

Table 20. Total SMD Newton Cost Summary (Ø-0)

4th Element	$ 235.00
Hardware (w/o Cont)	134.00
Q.A.	60.00
TOTAL (W/O CONT)	$ 429.00