REINSULATION OF THE REPLACED SECTIONS OF THE DAMAGED ZERO GRADIENT SYNCHROTRON RING MAGNET COIL*

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Abstract

The second aspect of the repair of the Argonne National Laboratory Zero Gradient Synchrotron Ring Magnet Coils was the reinsulation of the replaced damaged sections. The initial preparation of the sections, machining the existing insulation and installing the fitted insulation pieces, is described. A precision device for grinding the rigid insulation is detailed. The procedure for the two step vacuum impregnation of the reinsulated coil sections with epoxy is presented. Steps necessary to insure a good epoxy flow and a void-free impregnation are given in detail. The reinsulation techniques described appear to have been successful since the coils are in use again in the Zero Gradient Synchrotron Ring Magnet.

Introduction

When the exact location of the damaged section of the Zero Gradient Synchrotron Ring Magnet Coils was determined, the affected copper conductor sections were removed exposing the burned G-10[1] layer and turn insulation. After careful inspection of this insulation, it was decided to reinsulate the coil section in two phases: 1.) Lapping all joints between the old and new insulation to provide a long as possible breakdown path between conductors if insulation voids are present. 2.) Replacing the adhesive around the conductor sections in as void-free manner as possible to prevent corona and subsequent insulation deterioration.

The first phase of reinsulation was done in two parts: 1.) Relieving the replacement conductor sections for a "Kapton"[2] polyimide film wrap to provide laps at turn insulation joints. 2.) Slotting the old layer insulation and filling the slot with new insulation to provide laps at layer insulation joints.

The second phase was done by carefully impregnating the reinsulated coil sections in two stages: 1.) Impregnation around the reinsulated conductors themselves. 2.) Impregnation of the coil ground wrap. A vacuum-degassed epoxy formulation (100 parts by weight DER 332[3] epoxy resin, 30 parts by weight PGE[4] reactive diluent, and 70 parts by weight EM 308[5] epoxy resin curing agent) was pumped into the evacuated coil section at a rate determined to be less than the capillary wetting rate of the new insulation. An excess of the epoxy was pumped through the coil section, and atmospheric pressure was reapplied to the coil section to shrink and dissolve any remaining air bubbles. A description of the equipment and procedures involved in the reinsulation is given in the following paragraphs with special emphasis on insulation slotting and coil ground wrap impregnation.

Lapping Joints Between Old and New Insulation

Turn Insulation

Lapping the joints between old and new turn insulation presented little problem. The surfaces of the replacement conductor sections that were to be adjacent to other coil conductors were relieved 0.25 mm for a wrap of 0.127 mm thick "Kapton" polyimide film. This wrap, which extended beyond the ends of the old turn insulation, was applied to the relieved conductor areas; and the new turn insulation was butted against the old. The wrap thus provided the needed lap at turn insulation joints.

Layer Insulation

Lapping the joints between old and new layer insulation presented an interesting challenge that required the development of special equipment and procedures to grind a 0.38 mm wide, 6.35 mm deep slot into the center of the old 1.01 mm thick G-10 layer insulation. The slot was filled with a piece of 0.25 mm thick G-10, and pieces of 0.38 mm thick G-10 that butted against the old layer insulation were bonded to its top and bottom to provide the needed lap at layer insulation joints. (Figure 1 shows a top and a section view of a typical layer insulation slot. Figure 2 shows a cross section of a typical layer insulation repair.)

Slotting Equipment. A grinding machine, having a series of modules to satisfy the layer insulation slotting requirements at the different coil locations, was built. Basically, the machine was a precision high speed grinder with micrometer adjustments for the X direction (parallel with the side of the coil), the Y direction

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(perpendicular to the top or bottom of the coil), and the Z direction (perpendicular to the side of the coil). (Figure 3, a photograph, and Figure 4, a schematic drawing, show the slotting equipment in use.)

The main carriage or basic module was fitted with two ball bearing rollers to give smooth movement in the X direction. These rollers rode either on the conductors located above the insulation to be slotted or on a guide bar mounted across the coil parallel with the side of the coil. (If the conductors above the insulation were missing, the guide bar was used as a substitute for the missing conductors.) The carriage was held tight against the bottom of these conductors or guide bar (Y direction) by spring loaded ball bearings and against the side of the conductors or guide bar by a spring loaded ball bearing riding on a bracket mounted across the coil parallel with the conductors.

The top and bottom faces of the main carriage were made symmetrical so that other modules could be mounted on either face to grind into a right- or left-hand corner. Depending on the grinding function, the Y and Z directional traverse modules were mounted to the main carriage at one of several locations. The X directional traverse module, a lead screw half nut assembly, was also mounted to the carriage. A dc gear motor, operated by a variable speed control, was used to drive the lead screw via a roller chain drive.

The grinding spindle, mounted on the Z directional traverse, consisted of a 4.76 mm diameter ground steel shaft riding on a pair of high speed ball bearings. The grinding wheel was mounted on one end of the shaft by a set screw that permitted rapid wheel changes. Machinists from the Argonne Central Shops Division made special grinding wheels, 0.25 and 1.27 mm thick, by cutting 38 mm diameter disks from 103 mm diameter rubber bound Al_2O_3 abrasive disks.[6] These disks were then bonded to brass hubs with Eastman 910[7] adhesive. The 1.27 mm thick wheels were used to true up the insulation surface before slotting, and the 0.25 mm thick wheels were used to make a 0.38 mm wide slot in the insulation. The Al_2O_3 abrasive wheels were used because the possibility existed that some of the abrasive particles might become embedded in the insulation providing a start path for electrical breakdown. The nonconductive property of the Al_2O_3 reduced the chance of this occurring.

The grinding spindle was powered by a 50 W, 524 rads/second motor operated by a variable speed control and was linked to the motor by a posi-drive nylon gear belt. The motor gear had 34 teeth while the spindle gear had 24 teeth, which gave a maximum spindle speed of 742 rads/second. The motor was equipped with a reversing switch for right- or left-hand grinding and was mounted to the main carriage via an adjustable mount that allowed motor and spindle alignment, regardless of the mounting position of the spindle, and adjustments for proper belt tensioning.

Slotting Procedures. Alcohol was used as a coolant for all insulation grinding because it evaporated rapidly, was nonconductive, had no solvent effect on the G-10, and left no residue to interfere with adhesion. The alcohol was applied to the grinding wheel before any insulation grinding was begun and was continued until the grinding had been completed. A lack of alcohol flow, for even a few seconds, would result in wheel burn-up.

The grinding spindle, with a 1.27 mm thick wheel, was positioned on the coil to true up the surface of the insulation to be slotted. Then with a 0.25 mm thick wheel, the spindle was moved to one end of the ground insulation, and its position was adjusted until the wheel was at the center of the insulation. The layer insulation consisted of two pieces of 0.505 mm thick G-10 bonded together, and the adhesive joint between the two pieces provided an excellent guide for proper wheel alignment. The grinding spindle was moved along the insulation, from one end to the other, while the wheel alignment was checked with a Zeiss Operation Microscope II.[8]

First, a 0.38 mm wide, 0.18 mm deep slot was made in the insulation, and its position was checked with the microscope. If adjustments were necessary, they were made. Next, the slot was made 0.18 mm deeper, and its position was rechecked with the microscope. If no adjustments were necessary, the slot was made 0.36 mm deeper. Otherwise, the slot was made deeper in increments of 0.18 mm until no further adjustments were necessary. In increments of approximately 0.36 mm, the grinding process was repeated - inspecting the slot after each pass of the grinding spindle - until a 0.38 mm wide, 6.35 mm deep slot was made in the insulation. The grinding equipment was then moved to another coil location, and this procedure was repeated until all the affected insulation had been slotted.

Replacing Adhesive in Reinsulated Coil Section

The new turn insulation was installed before the repaired conductors were relocated into the coil by spot bonding the insulation to the existing conductors with Eastman 910 adhesive. Because the repaired conductors had their surfaces relieved specifically for a wrap of 0.127 mm thick polyimide film, the wrap was applied and the layer insulation installed (as shown in Figure 5) after the conductors had been relocated into the coil.

Before installing the remaining conductor insulation (the 3.56 mm thick G-10 and the fiber glass tape, Style 520,[9] wrap around all the conductors), electrical tests were performed to check all turn-to-turn and layer-to-layer insulation qualities.

Conductor and Coil Ground Wrap Impregnations

After a final inspection of the reinsulation work, the coil impregnation fixture and equipment was installed for the first impregnation. Because the first impregnation (around the reinsulated conductors) and the second impregnation (of the coil ground wrap) used the same equipment and procedures, only the later impregnation will be described.

Seventy-two hours after the first impregnation was completed, the fixture was removed; the impregnation was carefully inspected; and the epoxy voids, if any, were repaired. The impregnated conductors were wrapped with half lapped 0.127 mm thick "Kapton" polyimide film (Figure 6) for added insurance against an impregnation failure. The remaining insulation and the anchor plates were installed, and the coil ground wrap (of the fiber glass tape used to wrap the impregnated conductors) was applied. The impregnation fixture and equipment were reinstalled for the second impregnation (as shown in Figure 7).

Impregnation Fixture. The impregnation fixture consisted of a top and a bottom plate of aluminum and two side plates of Plexiglas[10] that were bonded together around the reinsulated coil section and sealed together and to the rest of the coil with RTV-21[11] silicone rubber. The top plate had four vacuum ports, and the bottom plate had eight fill ports. Each vacuum port was located midway between two fill ports so that any air trapped in the fixture would be pushed out ahead of the epoxy, thus reducing the possibility of epoxy voids.

Impregnation Equipment. Four pumping stations, each supplying epoxy to two fill ports, were used. Figure 8 is a schematic drawing of a typical pumping station that consisted of: 1.) A water-cooled reservoir to increase the usable life of the epoxy supply. 2.) A heated vacuum-degassing column to facilitate the removal of the dissolved air introduced when the epoxy components are mixed and to keep the air solubility of the epoxy high so that any air bubbles would be dissolved when atmospheric pressure was reapplied to the epoxy. 3.) A heat exchanger to cool the heated degassed epoxy for more usable life. 4.) A hand operated peristaltic tubing pump to supply epoxy to two fill ports and to pump epoxy through the fixture. 5.) An epoxy sight gauge in each fill line to check the epoxy for air bubbles before the epoxy enters the fixture. 6.) A compound pressure gauge in each fill line to monitor the pressure of the epoxy during impregnation and to insure that the pressure of the epoxy never exceeded atmospheric pressure, which would stress the silicone rubber vacuum seals of the fixture in the wrong direction. 7.) A thermocouple vacuum gauge to check fixture vacuum before impregnation. 8.) A dual readout thermometer to monitor the temperature of the epoxy in the reservoir and in the degassing column. 9.) A sight gauge reservoir at the vacuum port to tell when the epoxy had been pumped through the fixture, to prevent epoxy from being pulled into the vacuum pump by any bubbles in the line, to provide a reservoir for the excess epoxy pumped through the coil section to further flush out air, and to provide a reservoir of epoxy for backfilling the coil section after the vacuum was removed.

Impregnation Procedure. The impregnation was begun when the fixture had been evacuated to 0.2 mm Hg at the fill ports. The degassing columns were heated to 32°C, and the chilled water (27°C) flow to the reservoirs was begun. The epoxy components, which had been degassed separately to reduce the amount of degassing that had to be done in the degassing columns, were then mixed and poured into the reservoirs. The epoxy was metered into the degassing columns slow enough to be completely degassed by the time it reached the bottom of the columns. At least 25.4 mm of epoxy was kept in the reservoirs at all times.

After 25.4 mm of epoxy had accumulated at the bottom of the degassing columns, the epoxy was pumped into the fixture at a rate of 13 cc per minute. The epoxy flow into the degassing columns was then adjusted to maintain the 25.4 mm epoxy level at the bottom of the columns. The gauge pressure of the epoxy entering the fixture, the temperature of the epoxy in the reservoirs, and the temperature of the epoxy at the bottom of the degassing columns were continually monitored.

If the epoxy pressure rose to 0 mm Hg gauge pressure, the epoxy pumping rate was decreased to keep the epoxy pressure always slightly negative. (A positive epoxy pressure might break the rubber vacuum seals of the fixture.) If the epoxy temperature rose above 37°C due to exotherm, the epoxy pumping rate was increased, unless the epoxy pressure was 0 mm Hg, to get the epoxy out of the degassing column and into the fixture quickly where the heat could be dissipated.

Each pumping station followed this procedure until its sight gauge reservoir had accumulated 25.4 mm of epoxy. The station then stopped pumping and waited until the other sight gauge reservoirs had accumulated 25.4 mm of epoxy. If during this time a sight gauge accumulated more than 25.4 mm of epoxy, it was isolated from the fixture, vented to atmosphere, and drained of the epoxy to prevent exotherm. The sight gauge reservoir was then refilled by pumping more epoxy through the fixture.

After all the sight gauge reservoirs had accumulated 25.4 mm of epoxy, the impregnation fixture was slowly vented to atmosphere to allow the epoxy in these sight gauges to flow back into the fixture to shrink and dissolve any remaining air bubbles. This venting operation was done with great care to prevent emptying the sight gauges completely. The epoxy was cured 72 hours at room temperature before the impregnation fixture was removed. During the first three hours of cure, periodic fixture checks were made for epoxy leaks.

After fixture removal, the impregnation was carefully inspected; all voids, if any, were repaired. The finished coil was cleaned and sized for reinstallation into the ring magnet. All electrical tests that could be done before the coil was reinstalled were carried out to indicate the quality of the repair.

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References

1. Manufactured by Taylor Corporation and the Richardson Company.

2. Manufactured by E. I. DuPont DeNemours and Company, Inc.

3. Manufactured by Dow Chemical Company.

4. Manufactured by Shell Chemical Company.

5. Manufactured by Thiokol Chemical Corporation.

6. Manufactured by the Machine Tool Division of C. A. Roberts Company.

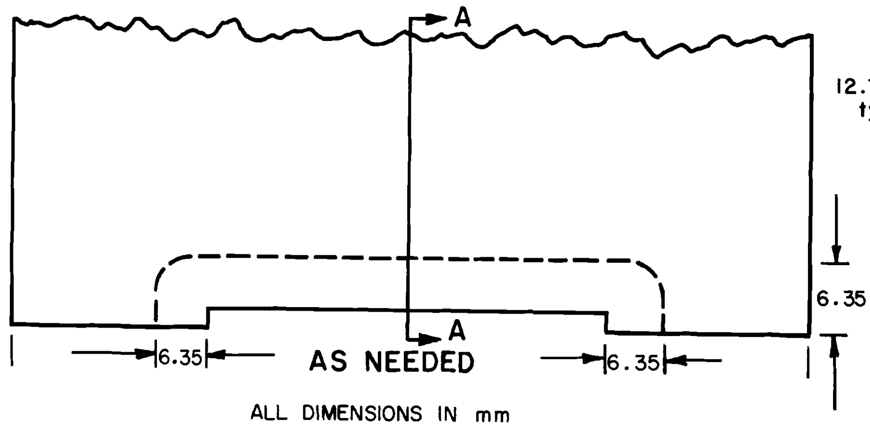
7. Manufactured by Eastman Chemical Products Company.

8. Manufactured by Carl Zeiss, Inc.

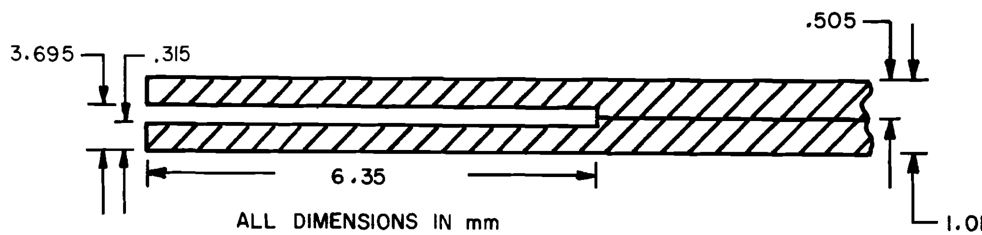
9. Manufactured by J. P. Stevens and Co., Inc.

10. Manufactured by Rohm and Haas Company.

11. Manufactured by General Electric Company.



TOP VIEW OF A TYPICAL
G-10 LAYER INSULATION SLOT



SECTION AA

FIGURE 1

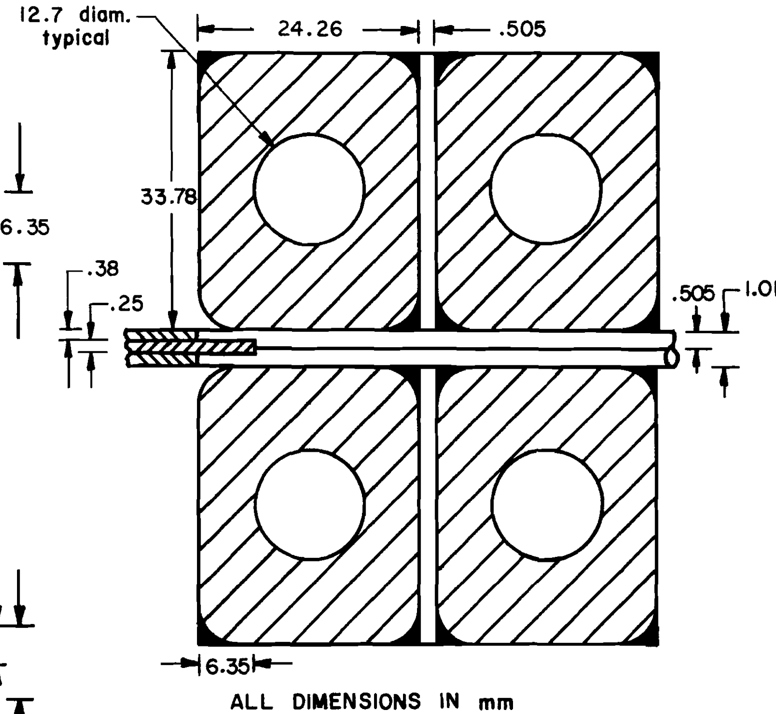


FIGURE 2

CROSS SECTION OF A TYPICAL
COIL LAYER INSULATION REPAIR

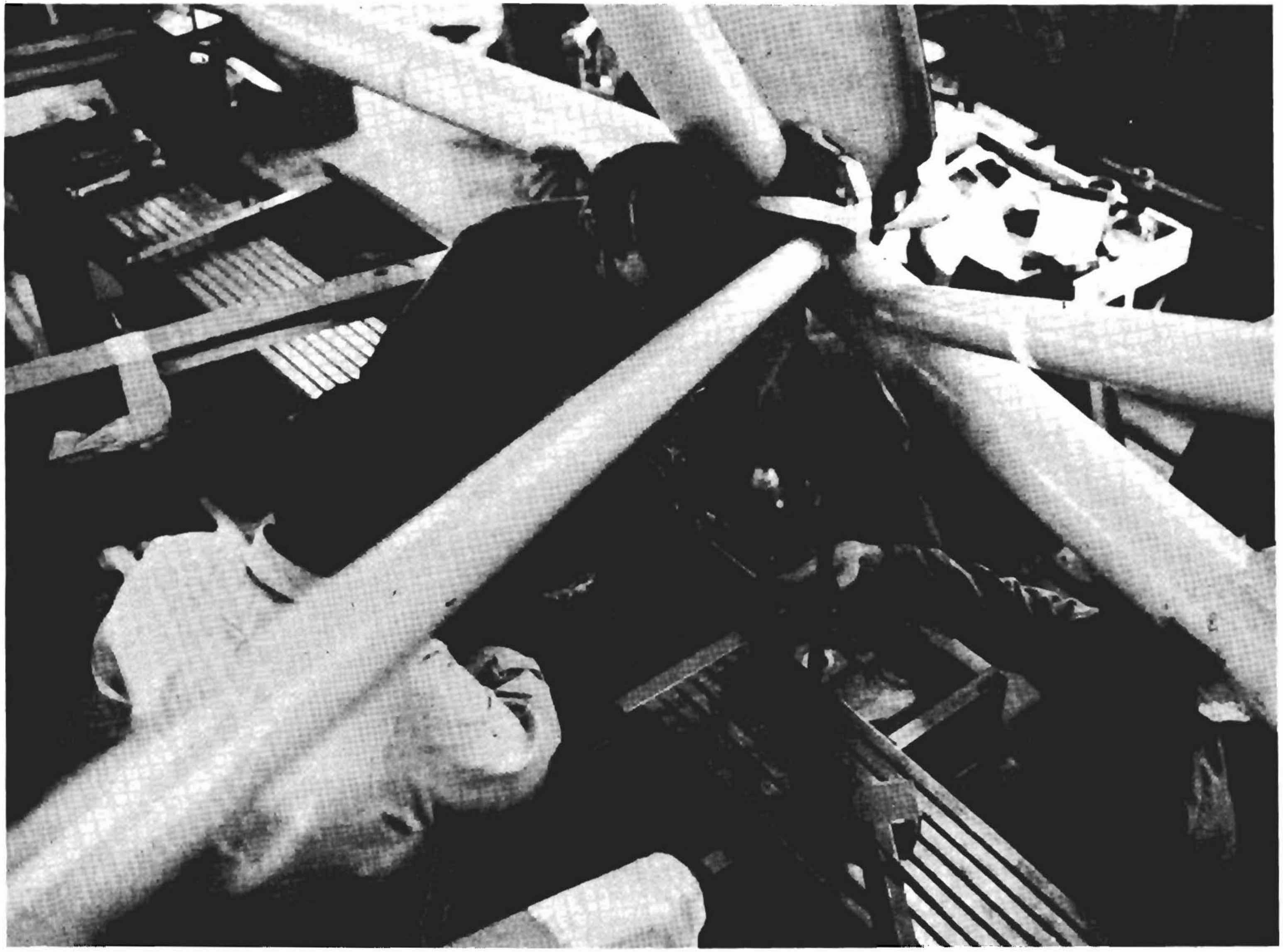


FIGURE 3

LAYER INSULATION SLOTTING EQUIPMENT IN USE

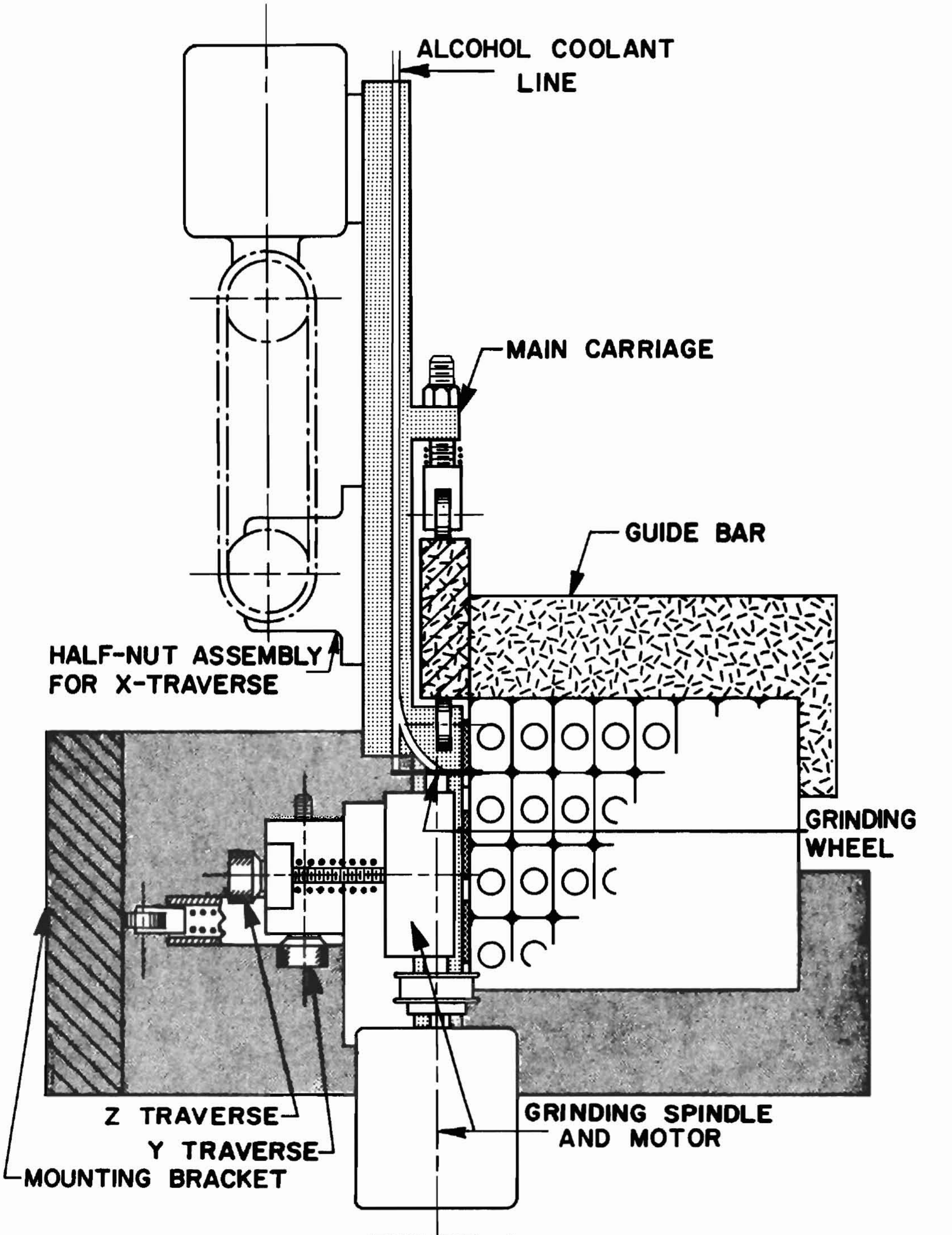


FIGURE 4
SCHEMATIC OF LAYER INSULATION SLOTTING EQUIPMENT

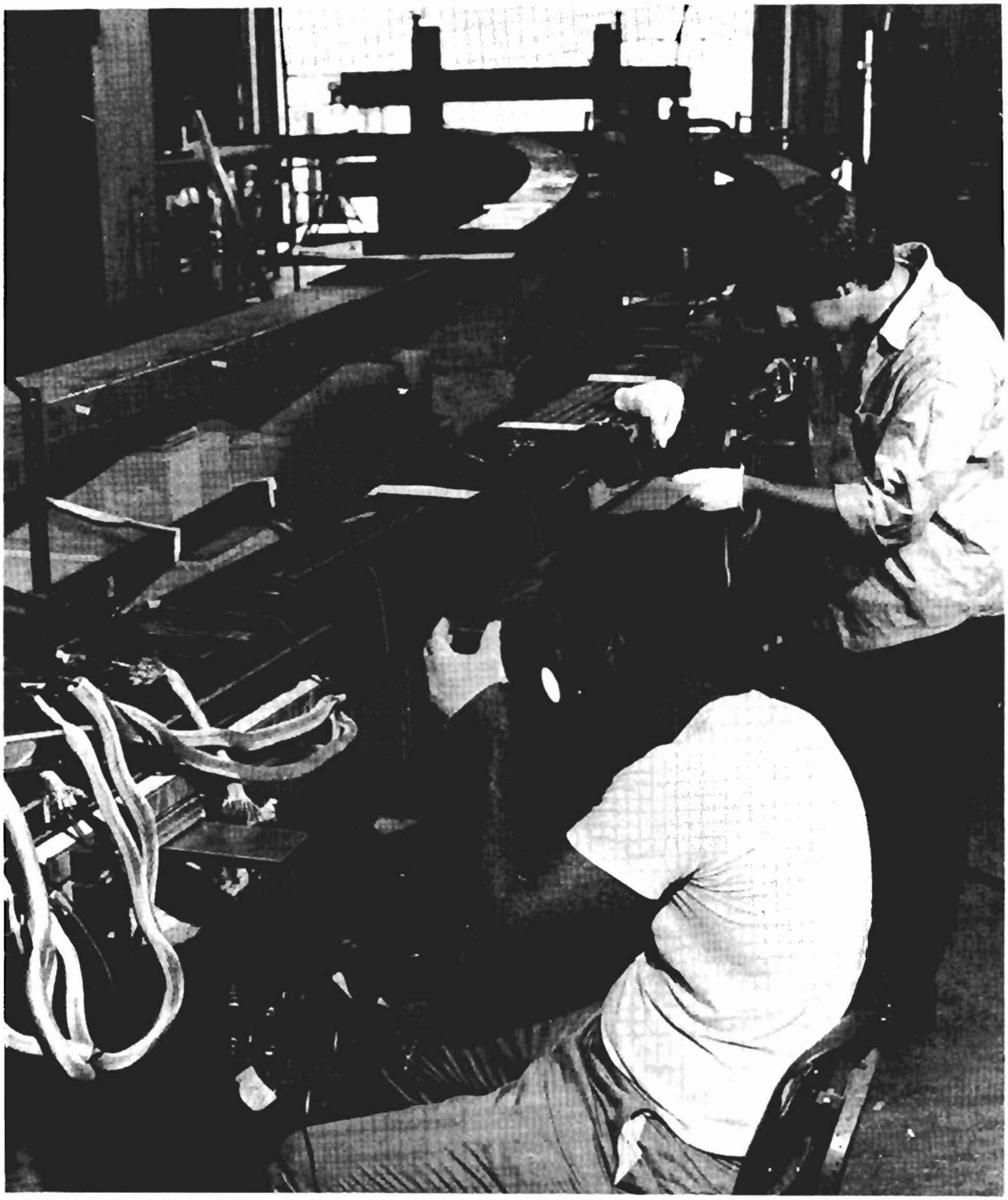


FIGURE 5
INSTALLING INSULATION AROUND REPAIRED CONDUCTORS

FIGURE 6

WRAPPING THE IMPREGNATED CONDUCTORS WITH POLYIMIDE FILM

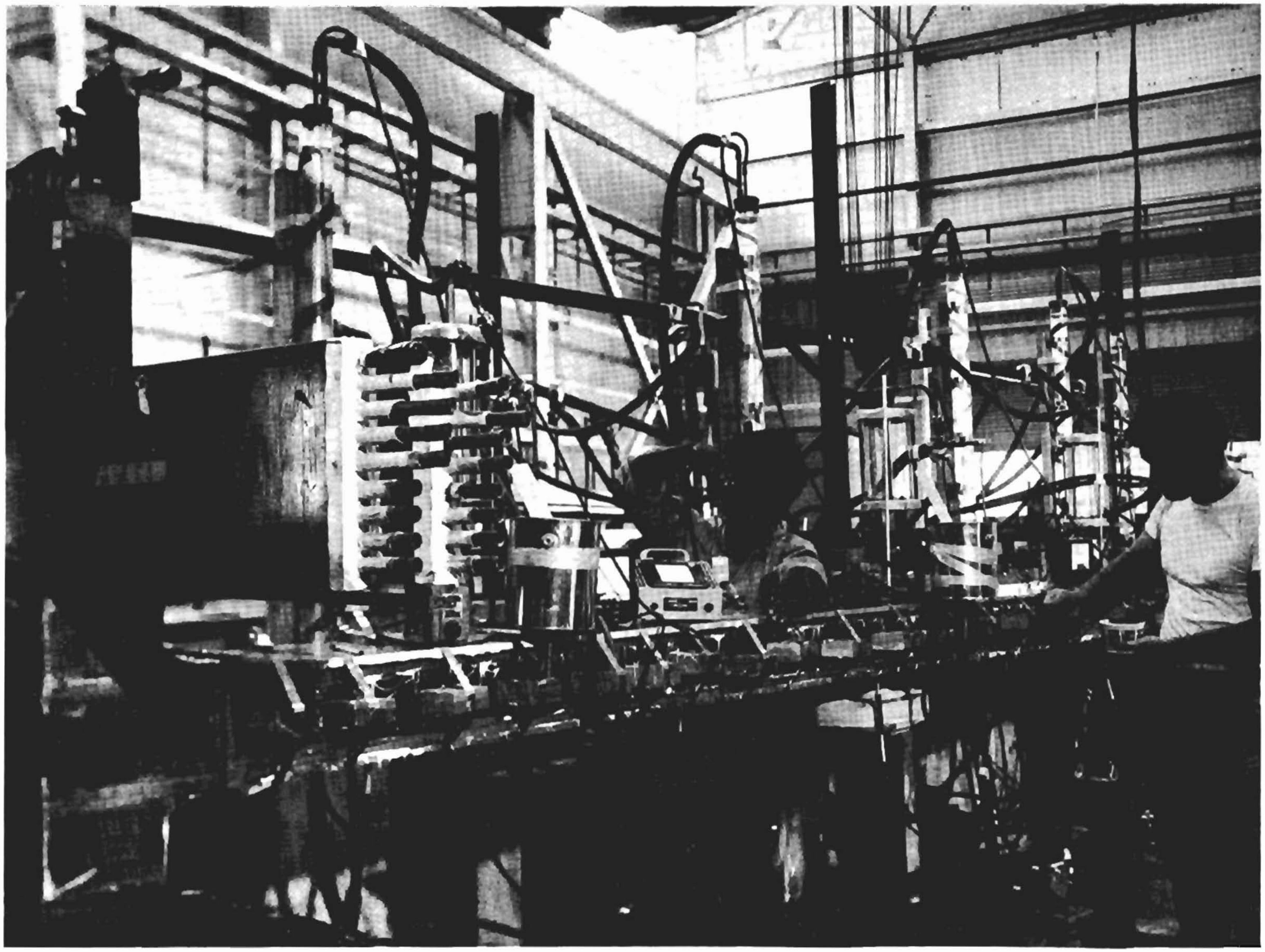


FIGURE 7

INSPECTING AND SEALING COIL IMPREGNATION FIXTURE

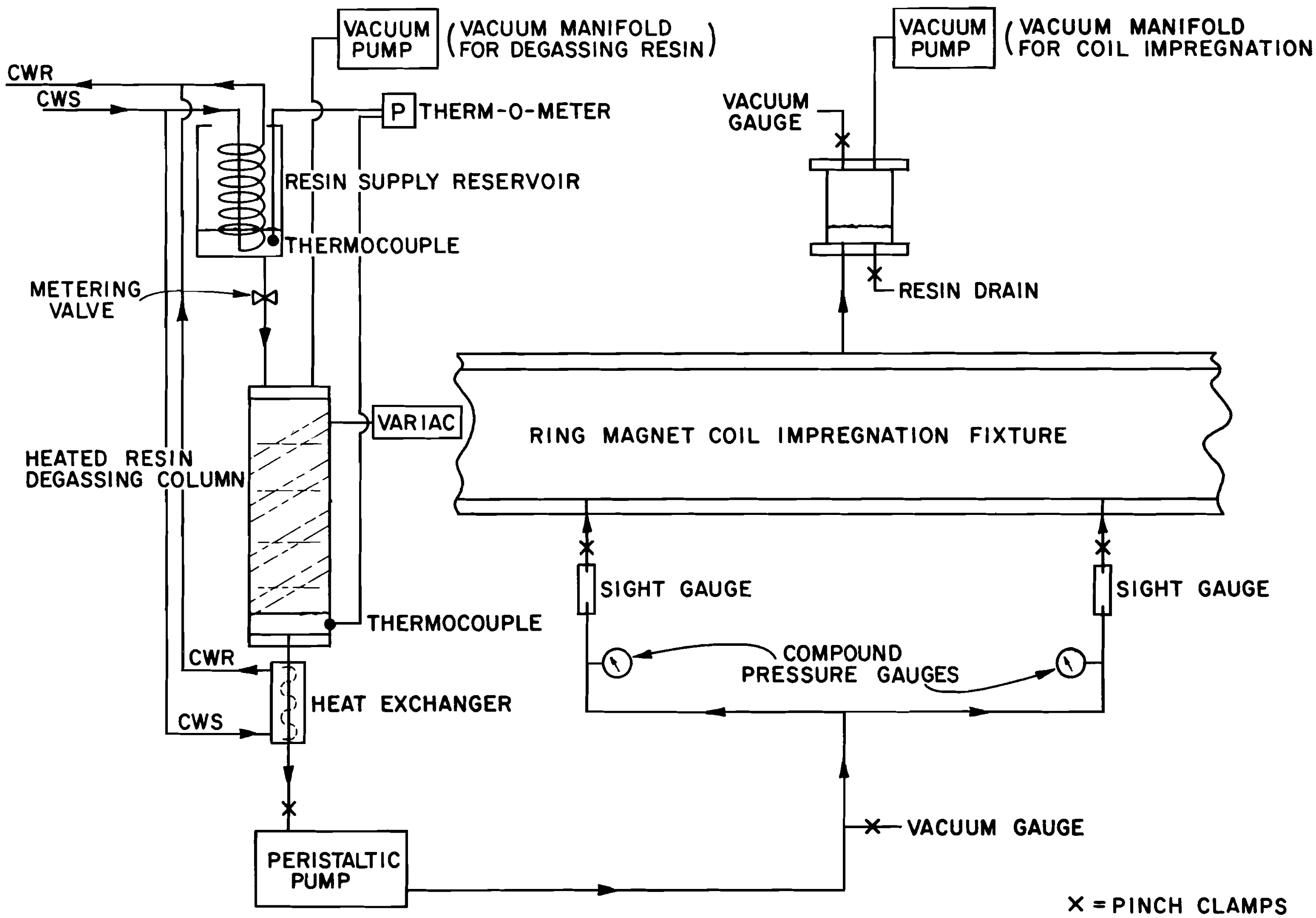


FIGURE 8

SCHEMATIC OF A TYPICAL PUMPING STATION