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William W. Salsig, Jr.

December 1955

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The advent of the polyester and epoxy resins has allowed a new design approach to many previously difficult and tedious problems in the construction of magnets, coils, and vacuum equipment for research in physics. High mechanical strength, excellent electrical properties, good vacuum characteristics (relative to other plastics) at pressures down to 10^{-6} mm Hg, and variety of application techniques enable one to provide much more compact, rugged, and dependable equipment.

A principal problem in research is that usually only a very few examples of a given design are manufactured. Thus, tooling must be held to a minimum. Fortunately several techniques exist for handling these plastics under such circumstances. The five examples that follow describe as many different ways of fabricating with these plastics.

Occasionally it is necessary to build a vacuum chamber which has electrically nonconducting walls (e.g., when the chamber is subject to changing magnetic fields which would generate eddy currents). Or perhaps the requirement is for a material that has a low atomic number. Where transparency is not a necessity, the superior temperature-creep, tensile-strength, and impact-resistance characteristics of polyester or epoxy resin laminates highly recommend them. Figures 1 and 2 show a vacuum pipe of rather unusual configuration used at pressures of the order of 10^{-3} mm Hg.

This part was made by wrapping ordinary 2-inch-wide unsized cotton tape on a mandrel formed to give the desired internal shape shown in Fig. 3. The aluminum mandrel was first covered with cellophane as a parting agent. In an effort to saturate the tape with plastic, it was passed through a series of squeeze rolls immersed in a bath of polyester syrup. This did not remove air bubbles at the surface of the tape. It soon became apparent that the best way to do the job was to smear the mandrel with plastic. The operator, with hands in rubber gloves, would then keep a pressure over the point of contact

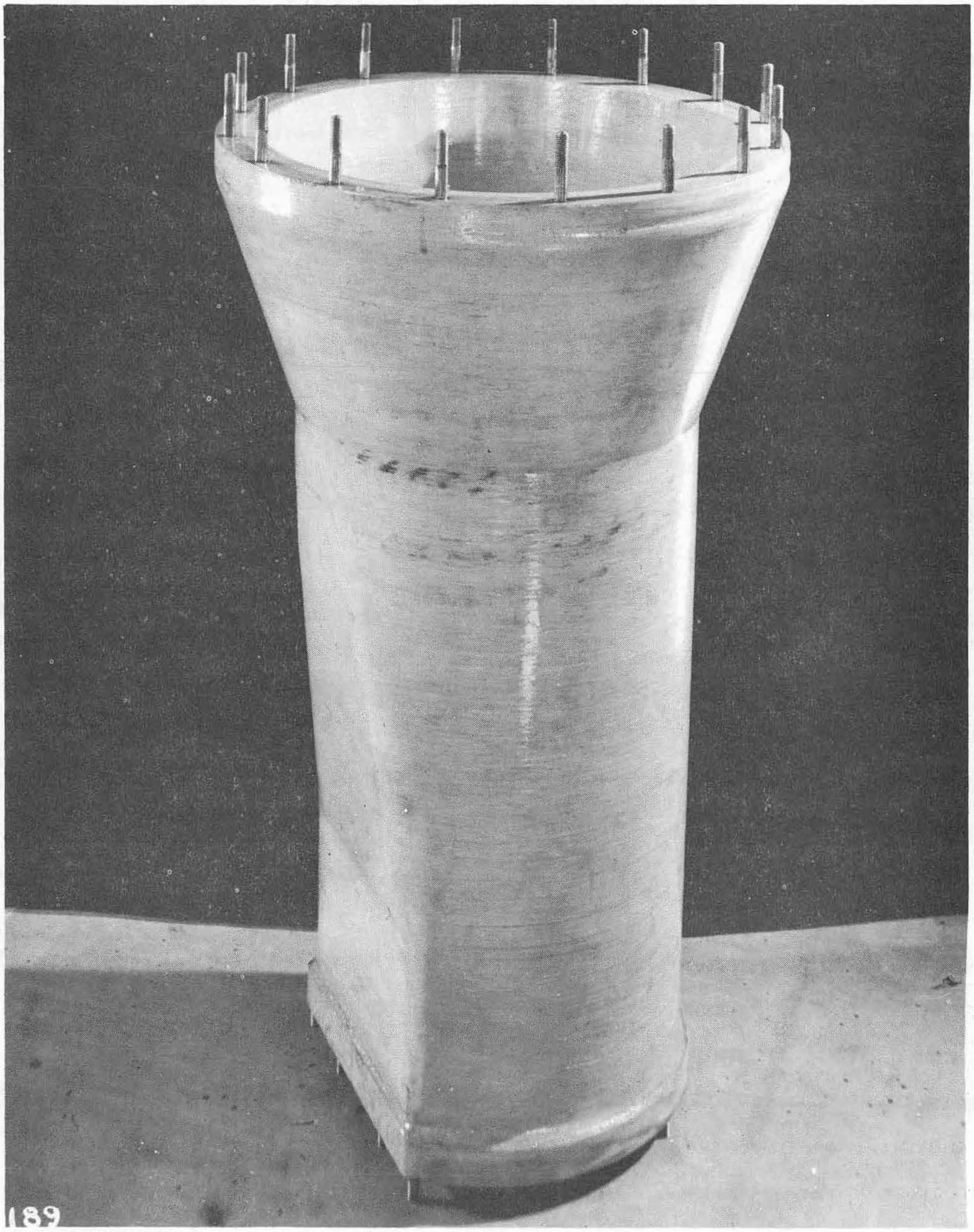

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Fig. 1. Eighteen-inch-diameter vacuum pipe fabricated from cotton tape and polyester resin.

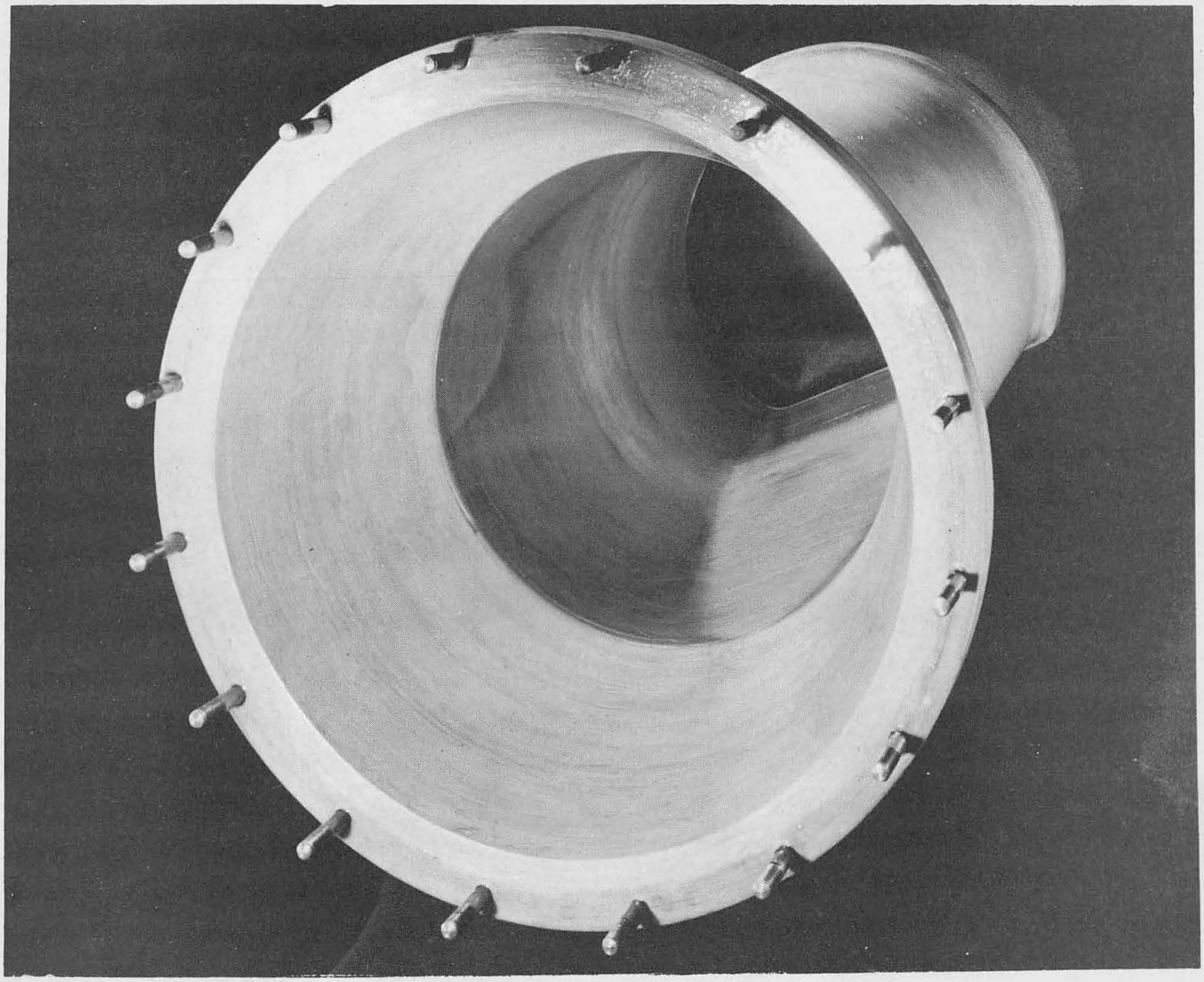

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Fig. 2. Eighteen-inch-diameter vacuum pipe, showing O-ring gasket surface and clean internal parting.

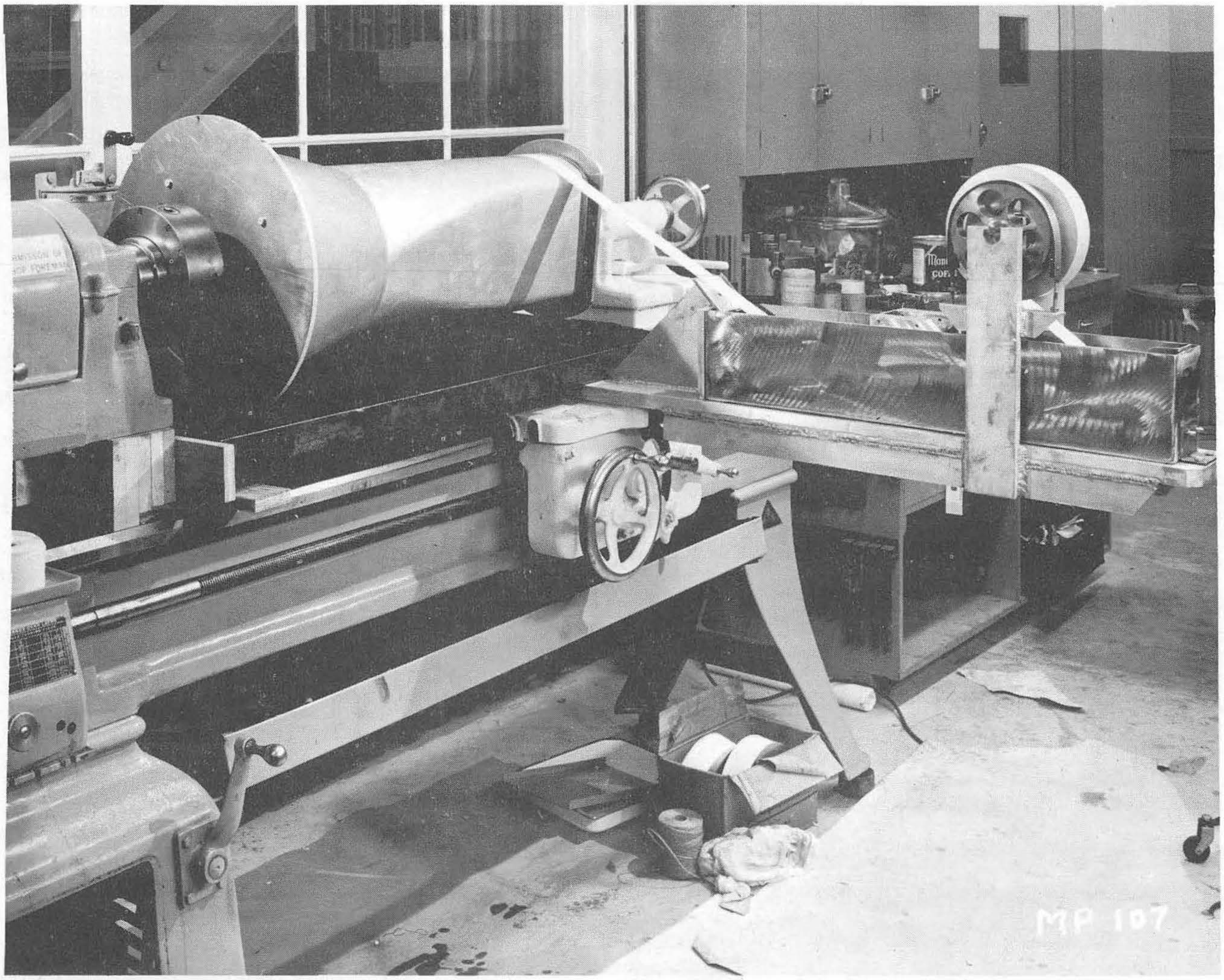

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Fig. 3. Winding setup used in fabricating 18-inch vacuum pipe.

as the tape wound onto the mandrel. Hand pressure plus tape tension forces the liquid on the mandrel up through the weave of the tape, insuring full saturation plus tight winding, layer to layer, and a very dense, sound, and good-looking job results. The operator should be provided with a respirator, and those few people who are allergic to these plastics should, of course, be kept away from such work, for the operator often comes out as well coated as the parts.

Approximately twelve hours were consumed in building up a 3/4-inch wall on the example illustrated. The part was then cured on the mandrel. After curing, the mandrel was withdrawn, the part was machined, and the stud holes tapped. The ends and outside were painted with polyester syrup, studs were installed in holes wet with the syrup, and the part was again cured. This last "varnishing" produces a dirt-resistant glaze seal and also provides an adequate gasket surface at the ends.

Example 2, described in photographs (Figs. 4, 5, 6, 7, 8, and 9), is an electromagnetic "motor" which drives the moving element of a large vibrating-blade capacitor. These blades are excited resonantly at 60 cycles per second to a tip amplitude of ± 1 inch. The motor is located just behind the vertical plates situated between the vibrating blades (Figs. 4, 5.) Design requirements here include (a) ability to withstand vibration, (b) good insulation between steel laminations, (c) adequate electrical insulation of exciting coil, (d) good mechanical and thermal bond between water-cooled coil and core, (e) operation in high vacuum (10^{-6} mm Hg) and (f) maintenance of close tolerances, particularly in straightness, at the blade face. Because of the close mechanical tolerances, and because ten motor halves were to be built, this job developed the most elaborate fixtures yet provided at UCRL for plastic work.

The 0.015-inch-thick steel laminations were sprayed with epoxy resin thinned with acetone, and then baked, one side at a time. The laminations were next dipped in epoxy syrup and stacked on the fixture shown in Fig. 6. Work and fixture were parted with silicone grease. During the early stages of the cure, the fixture was periodically removed from the oven, the bolts taken up until the final gage point lengthwise was reached, and the excess plastic thus squeezed out was wiped off. Continued baking then produced a unit core, straight, flat and with laminations flush to 0.003 inch.

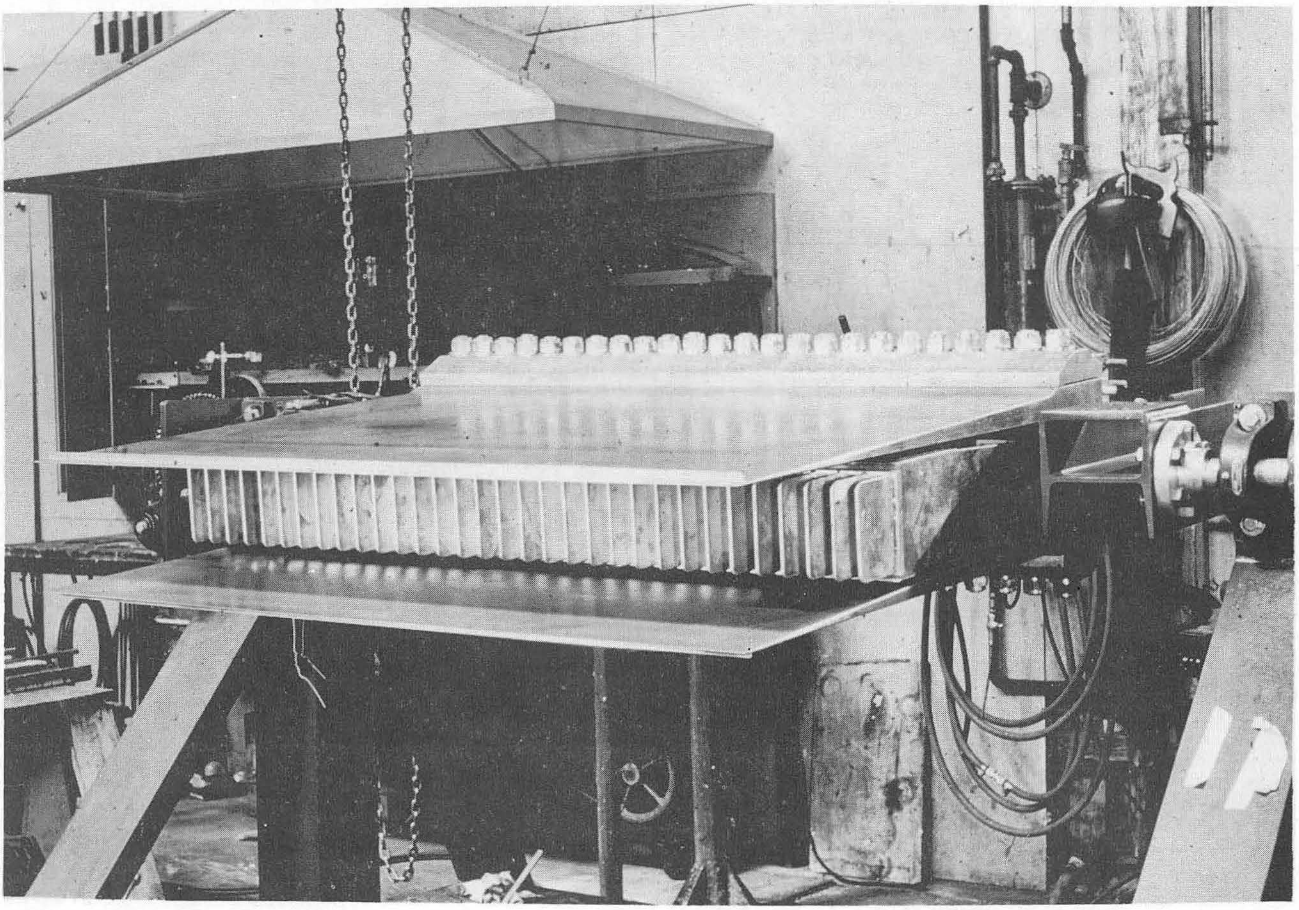

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Fig. 4. Vibrating-blade condenser element for 184-inch cyclotron. Blade is 32 in. long and 45 in. wide.

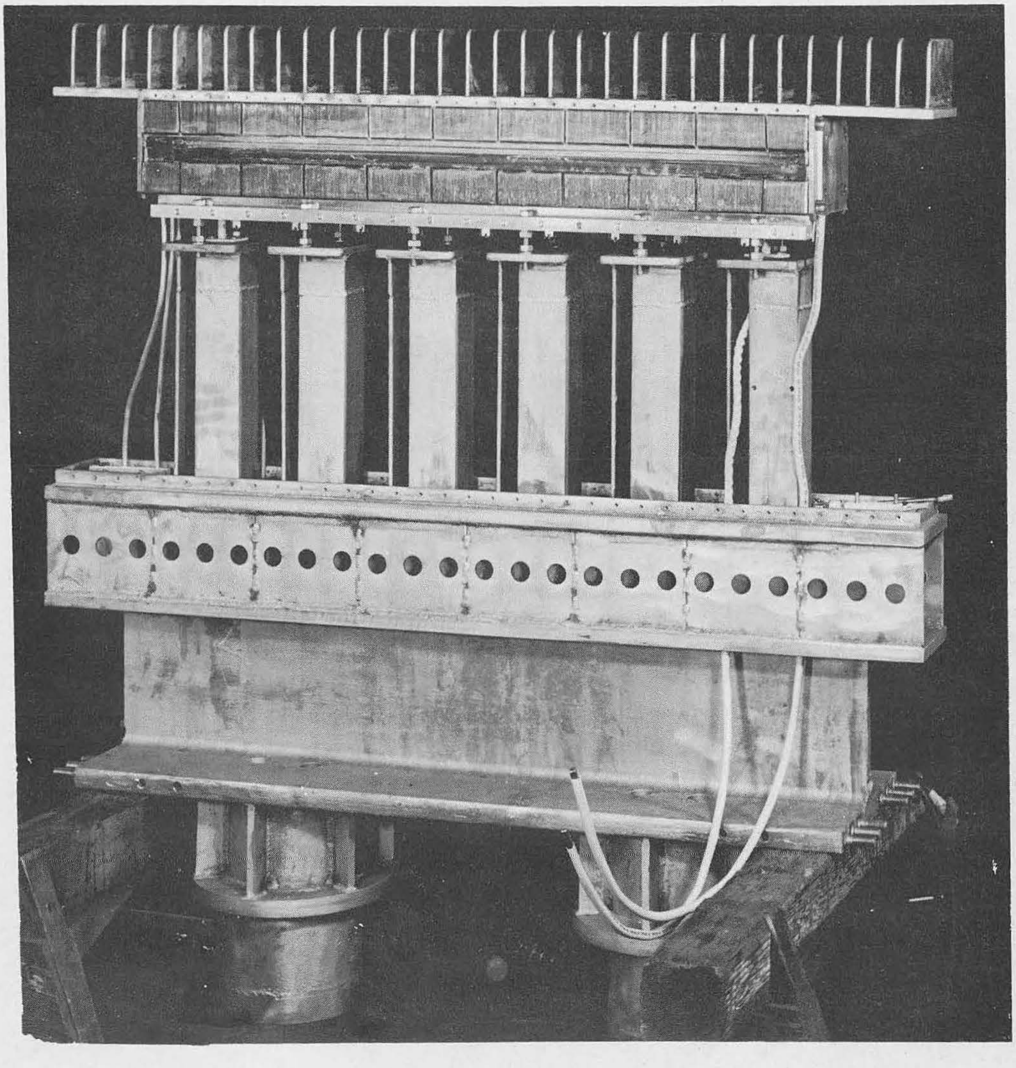

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Fig. 5. Vibrating-blade condenser (for 184-inch cyclotron) with blades removed to show motor installation.

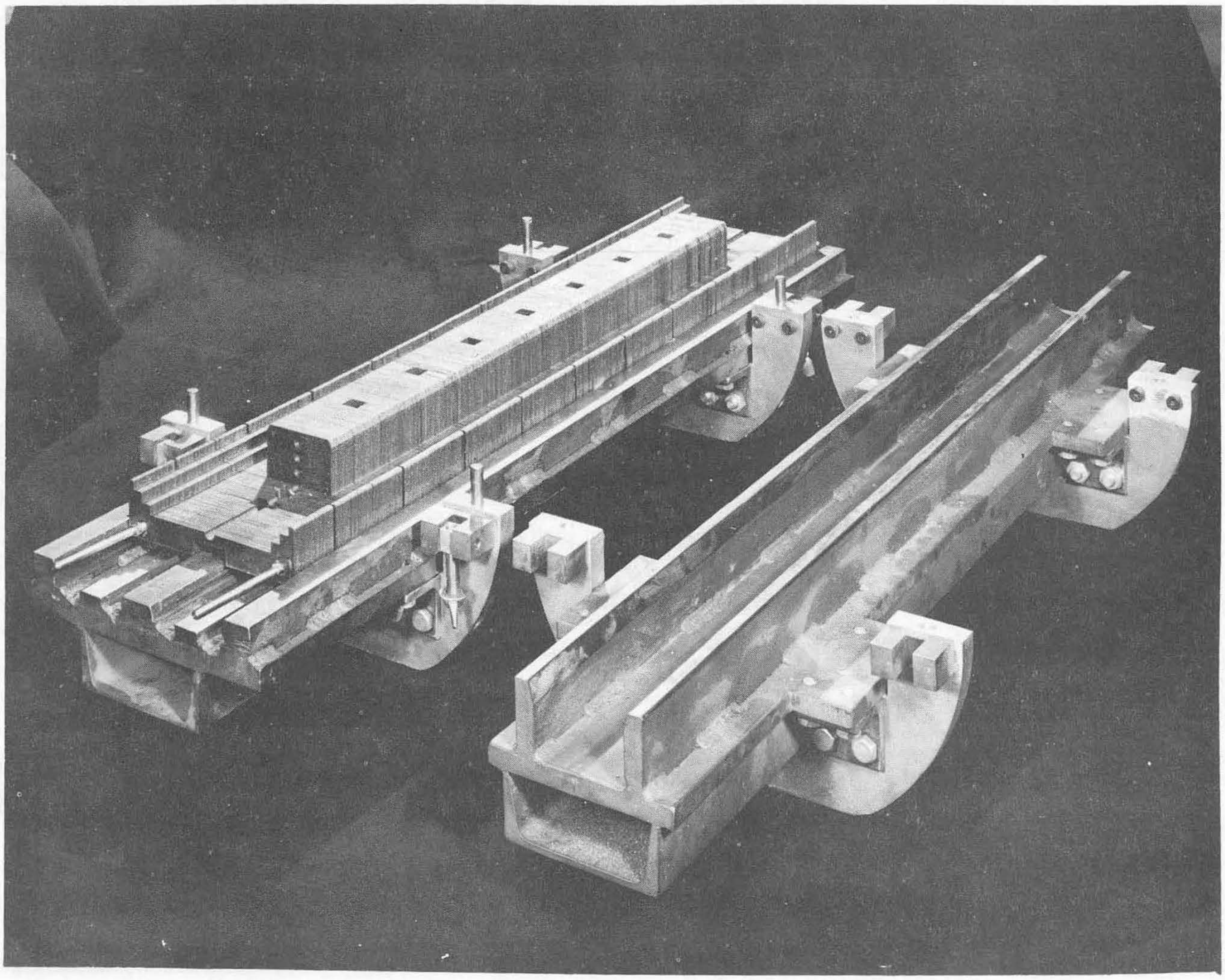

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Fig. 6. Fixture for bonding steel laminations of 184-inch cyclotron vibrating-blade motor.

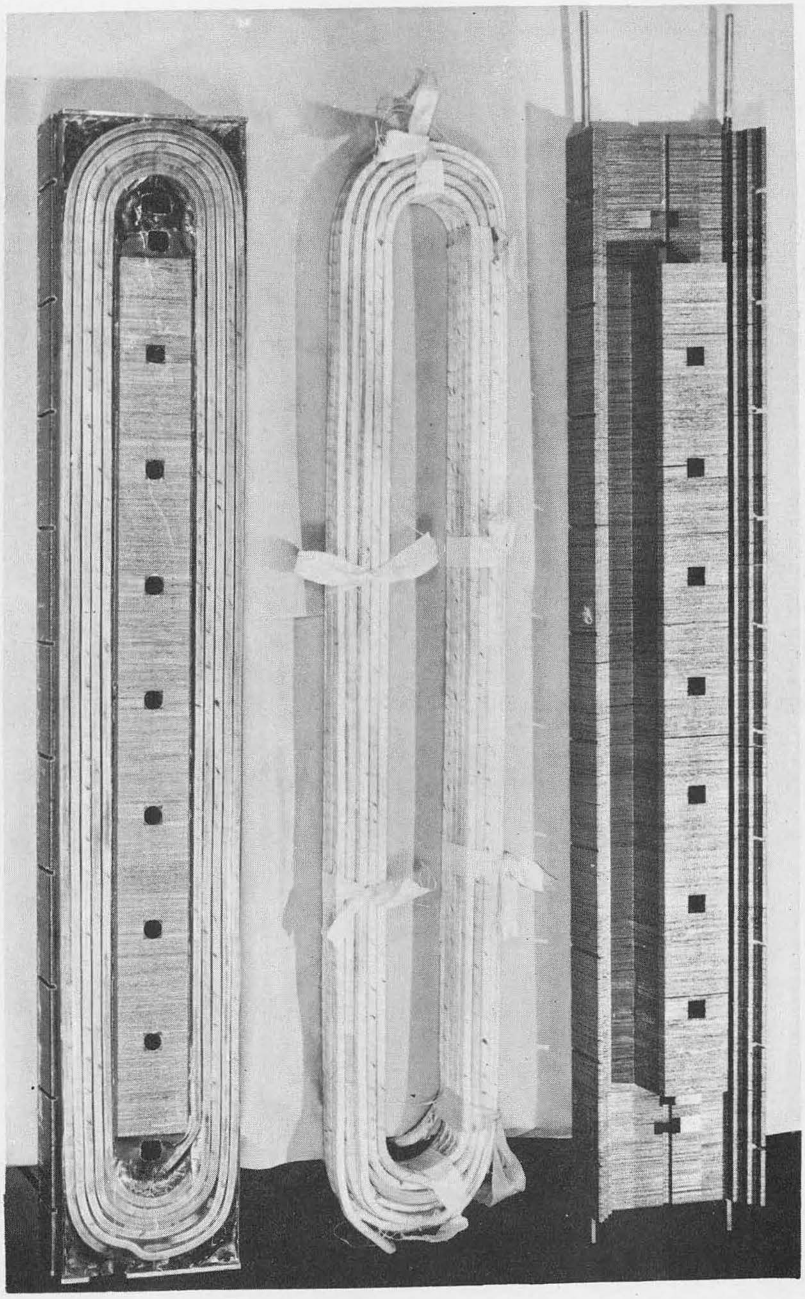

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Fig. 7. Potting coil to core for 184-inch cyclotron capacitor motor.

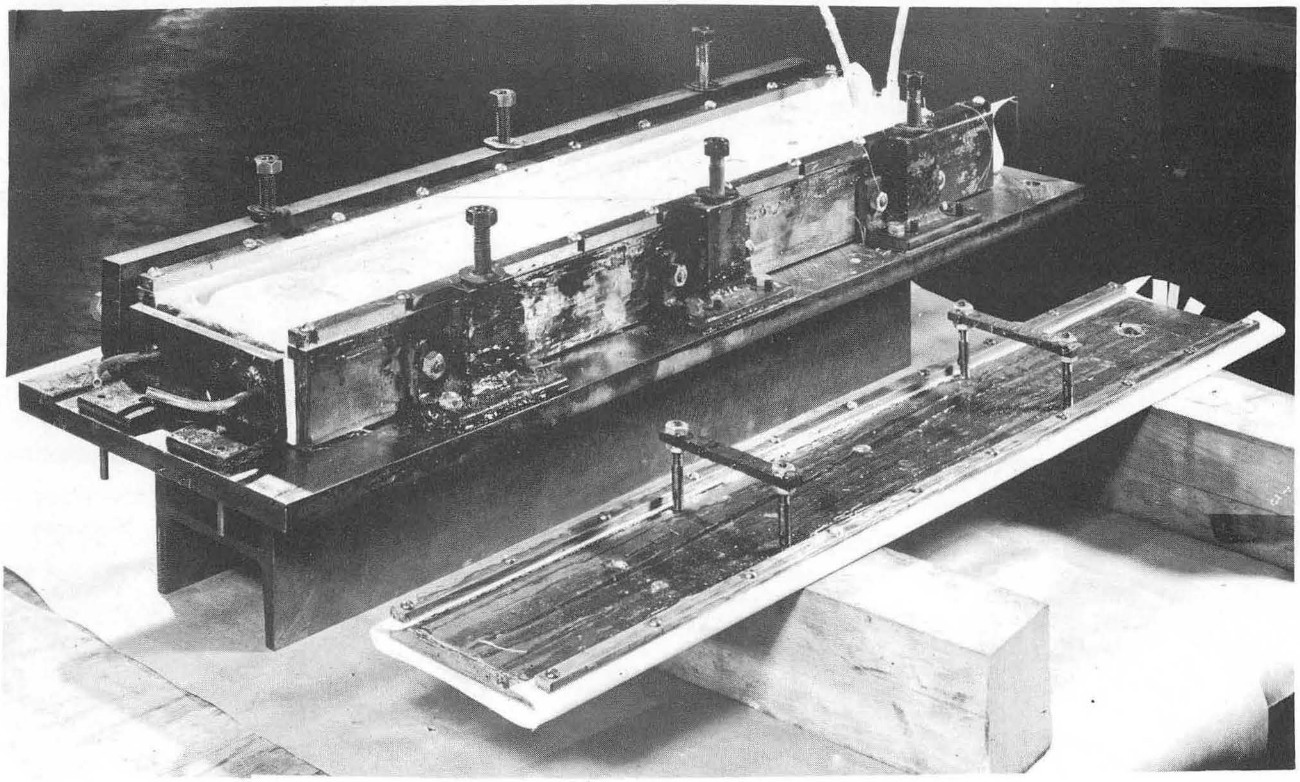

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Fig. 8. Potting fixture for bonding coil to core, 184-inch cyclotron capacitor motor.

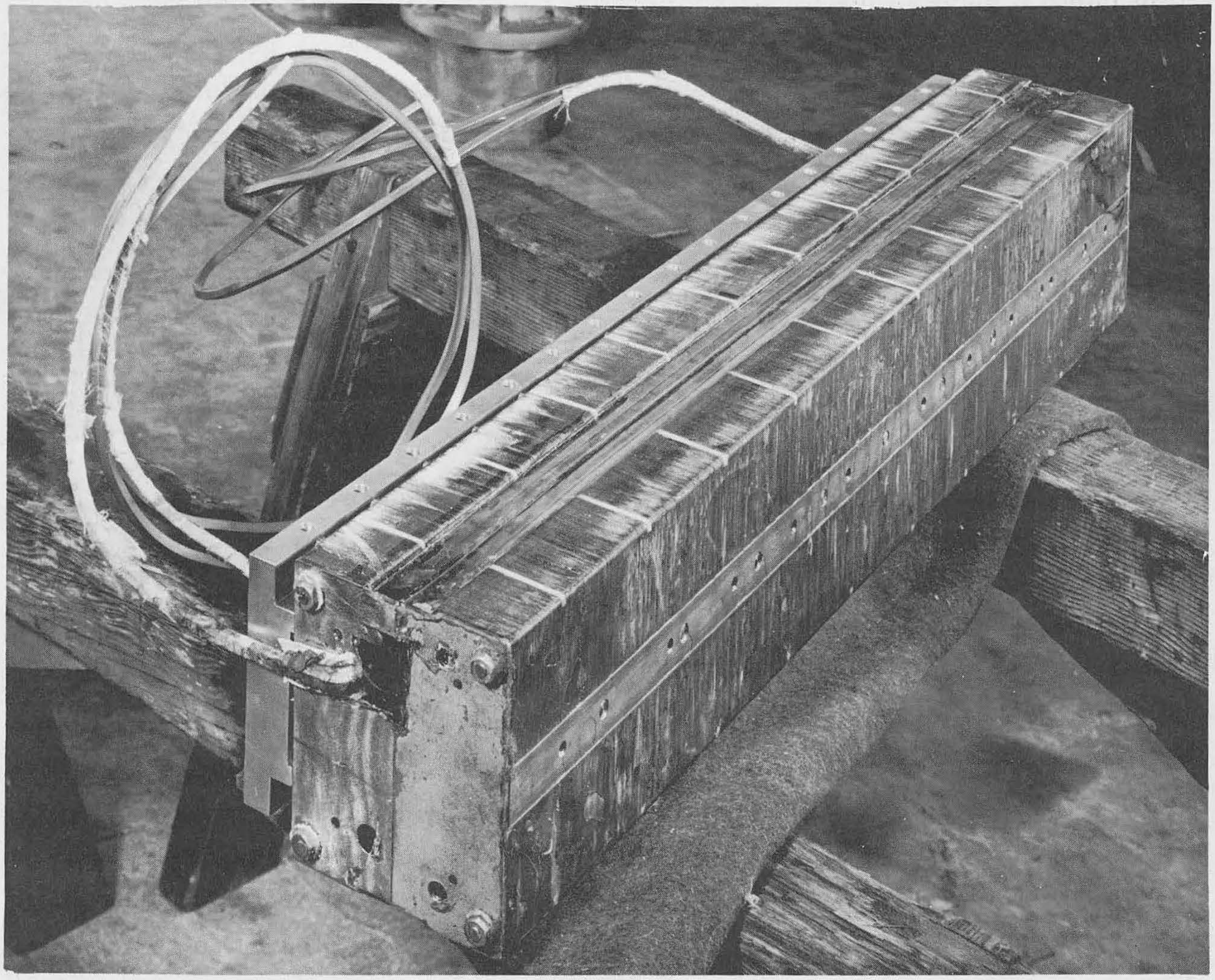

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Fig. 9. Completed motor for 184-inch cyclotron vibrating-blade condenser.

The coil was initially insulated with unsized glass tape, 0.007 by 1 inch. This material proved inadequate in preventing turn-to-turn shorts, which are intolerable in this application. Adequate insulation was finally obtained by first coating the conductor with "Formvar," next wrapping, 3/4 lap, with 0.001-by-1-inch "Mylar" tape, and then spacing the taped conductor with fish paper 2 inches long by 0.015 inch thick, alternately placed vertically and horizontally. This "egg crate" construction provides a positive clearance between turns and an open grid which the impregnating plastic easily penetrates.

The coil-core subassembly (Fig. 7) was potted in the fixture shown in Fig. 8. This fixture was lined with 1/32-inch teflon, both as a parting agent and as a cushion to prevent lamination damage under tight clamping. When loaded, the fixture was hung, with the long dimension vertical, in a vacuum tank which had internal heaters. The work was brought to the epoxy resin curing temperature under vacuum. The plastic syrup was separately heated under vacuum, to decrease viscosity and to deaerate, before it was introduced from the lowest part of the fixture. When the work was filled with liquid plastic, the vacuum was released and the curing proceeded.

The two motor halves were assembled into a unit (Fig. 9) and, to obtain good support and no clearance between the two motor halves, the parting line was taped, plastic was injected into the gap with a veterinarian's syringe, and the assembly baked again. This last step was found more satisfactory than bolting the halves together with a thin teflon spacer between. The teflon would tend to work and loosen under vibration.

Example 3 is shown in Figs. 10, 11, 12, 13, 14, 15, and 16, which depict the coil treatment employed on a high-intensity auxiliary magnet used with the UCRL Bevatron. This magnet provides a 22,000-gauss uniform field in a 4-inch gap over a 12-by-60-inch steel area, using 425 kw dc (1850 amp 230 volts) exciting power. To provide flexibility (wider fields at lower intensities) the coils were made in four units, so the inner two coils may be removed.

A unique method of impregnating, admirably suited to single-component fabrication, was developed for this job. The coils were wound with the same egg-crate insulation technique described for Example 2, except that no "Formvar" was used. The outer surfaces were then provided with 0.015-inch fish paper scuff strips and the assembly was packaged with an

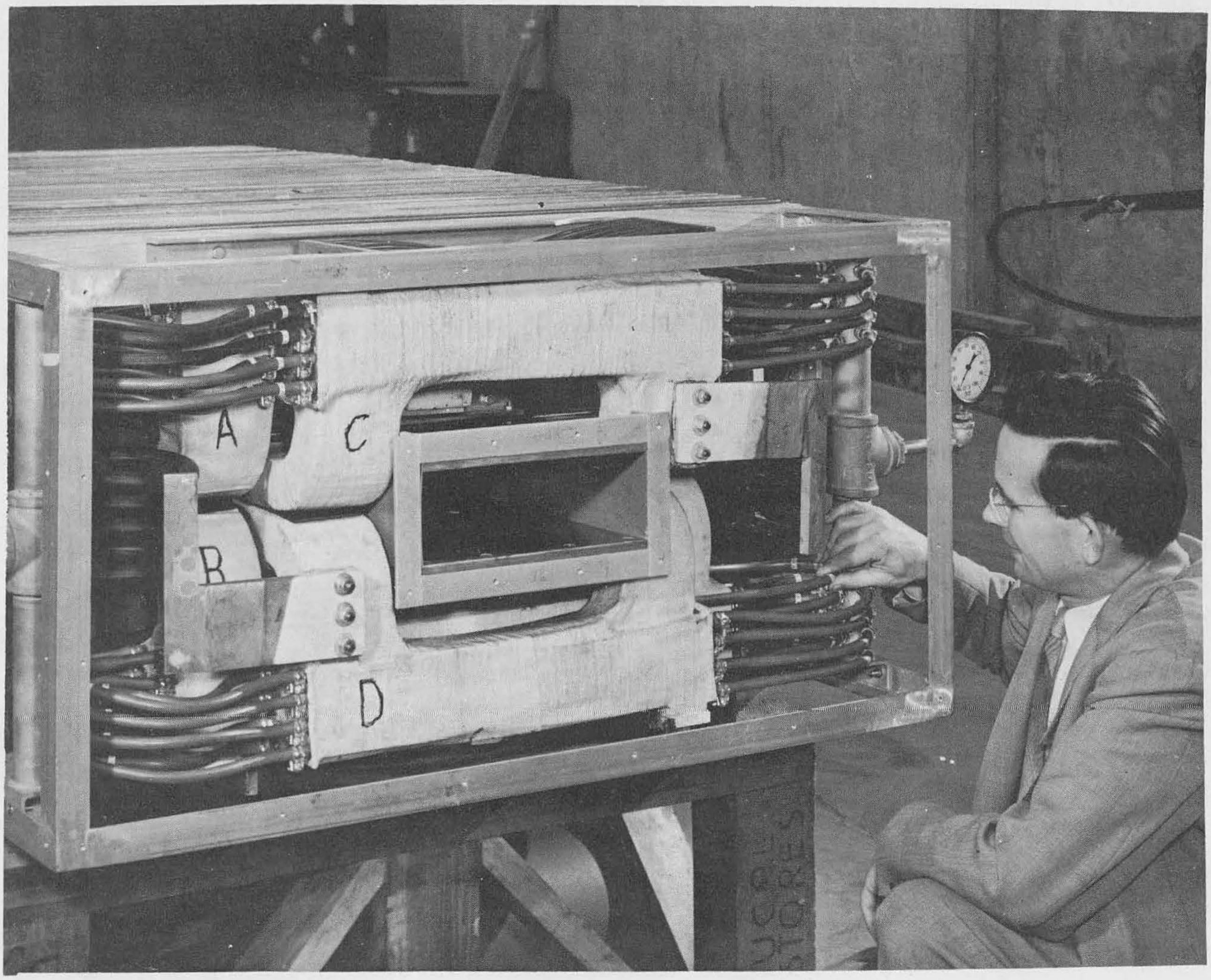

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Fig. 10. Terminal end of the 12-by-60-inch analyzer magnet used with the UCRL Bevatron.

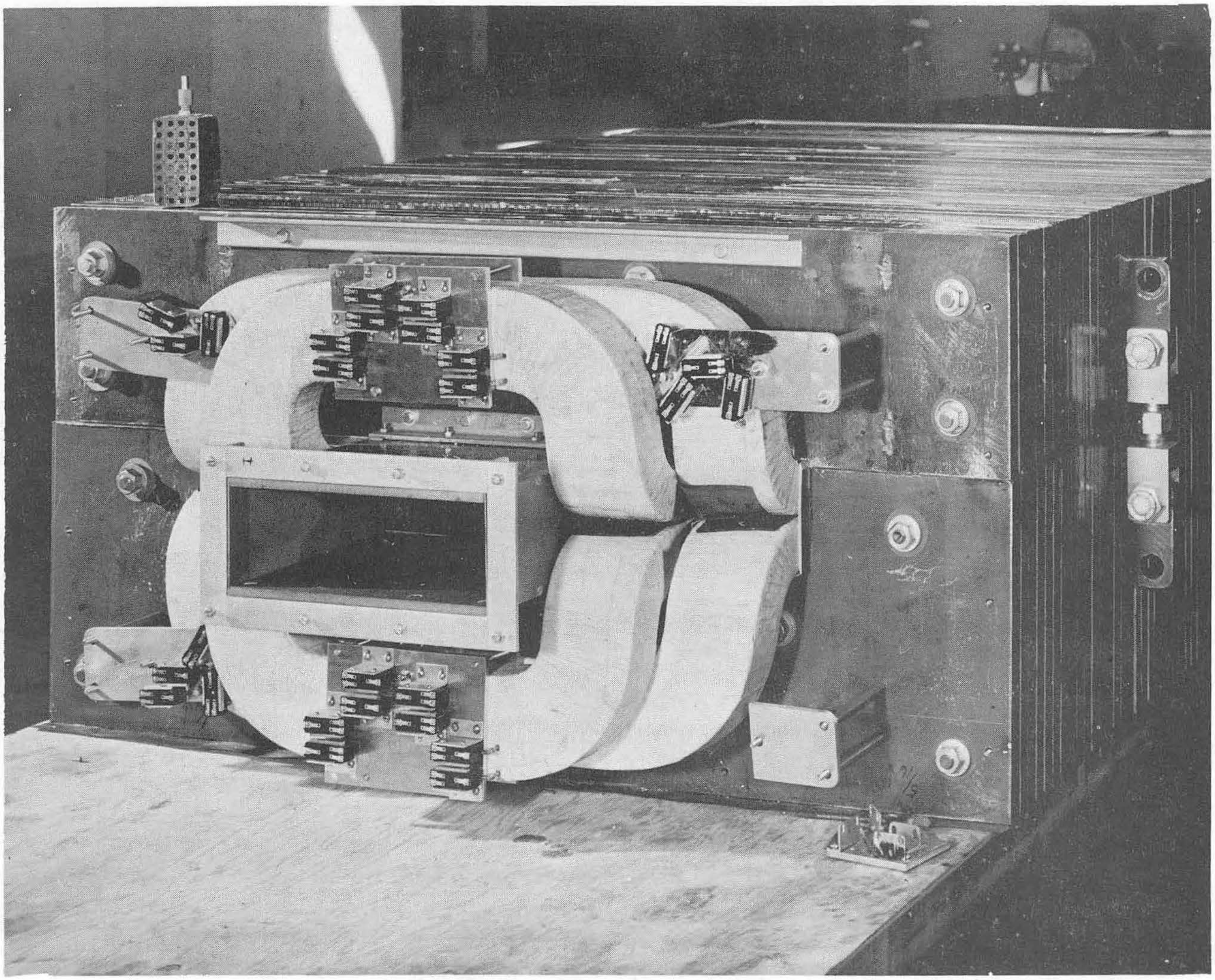

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Fig. 11. Over-temperature interlock end of 12-by-60-inch analyzer magnet used with UCRL Bevatron.

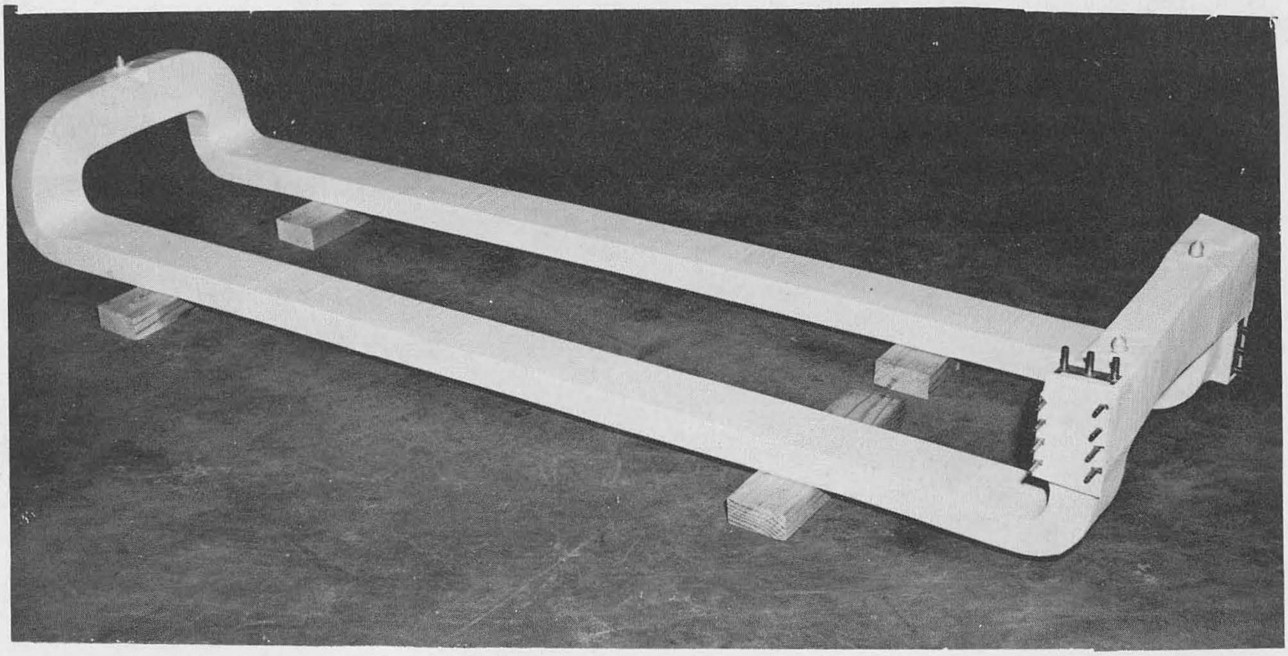

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Fig. 12. Completed coil ready for installation in 12-by-60-inch analyzer magnet.

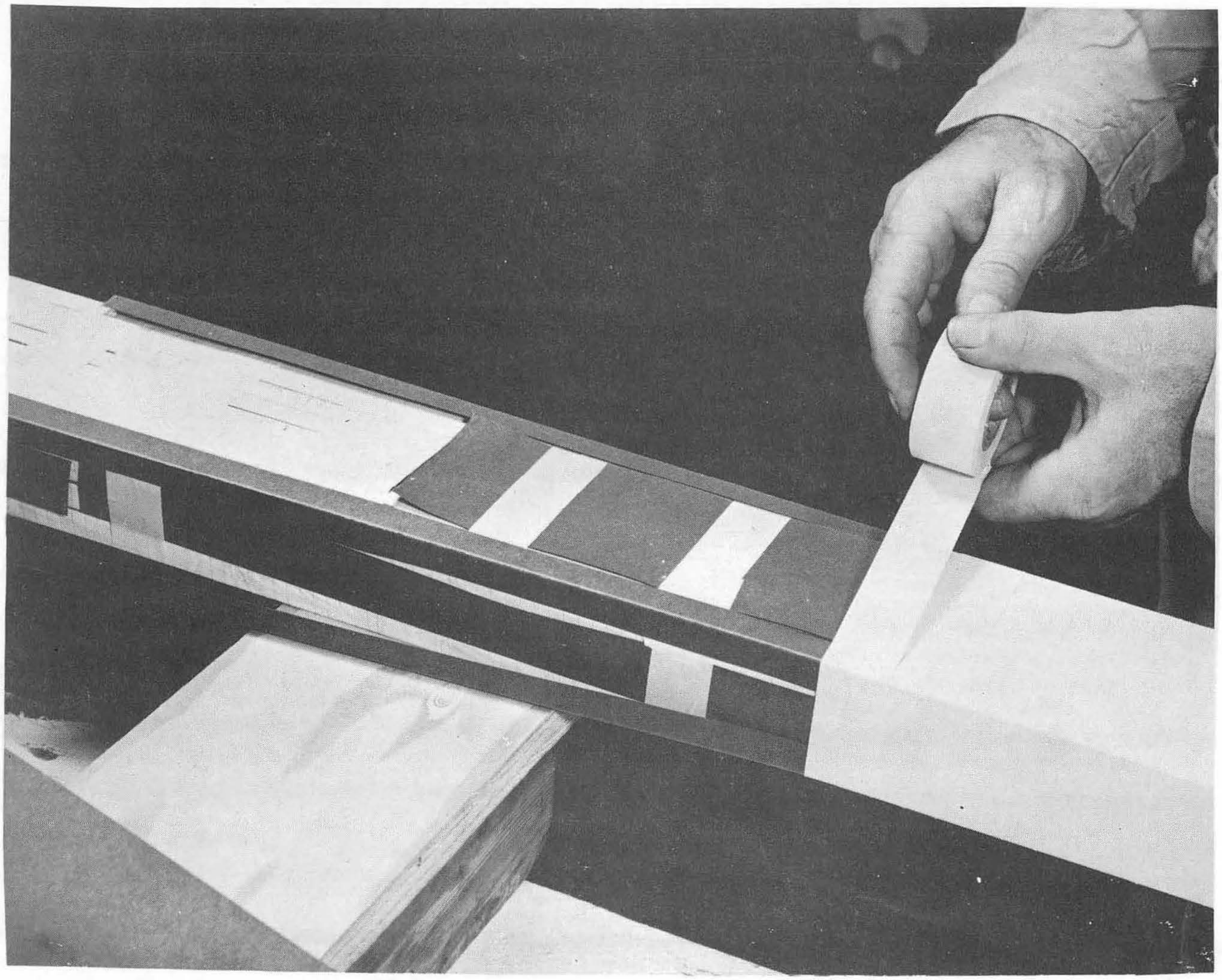

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Fig. 13. Taping fish paper insulation to coil of 12-by-60-inch analyzer magnet.

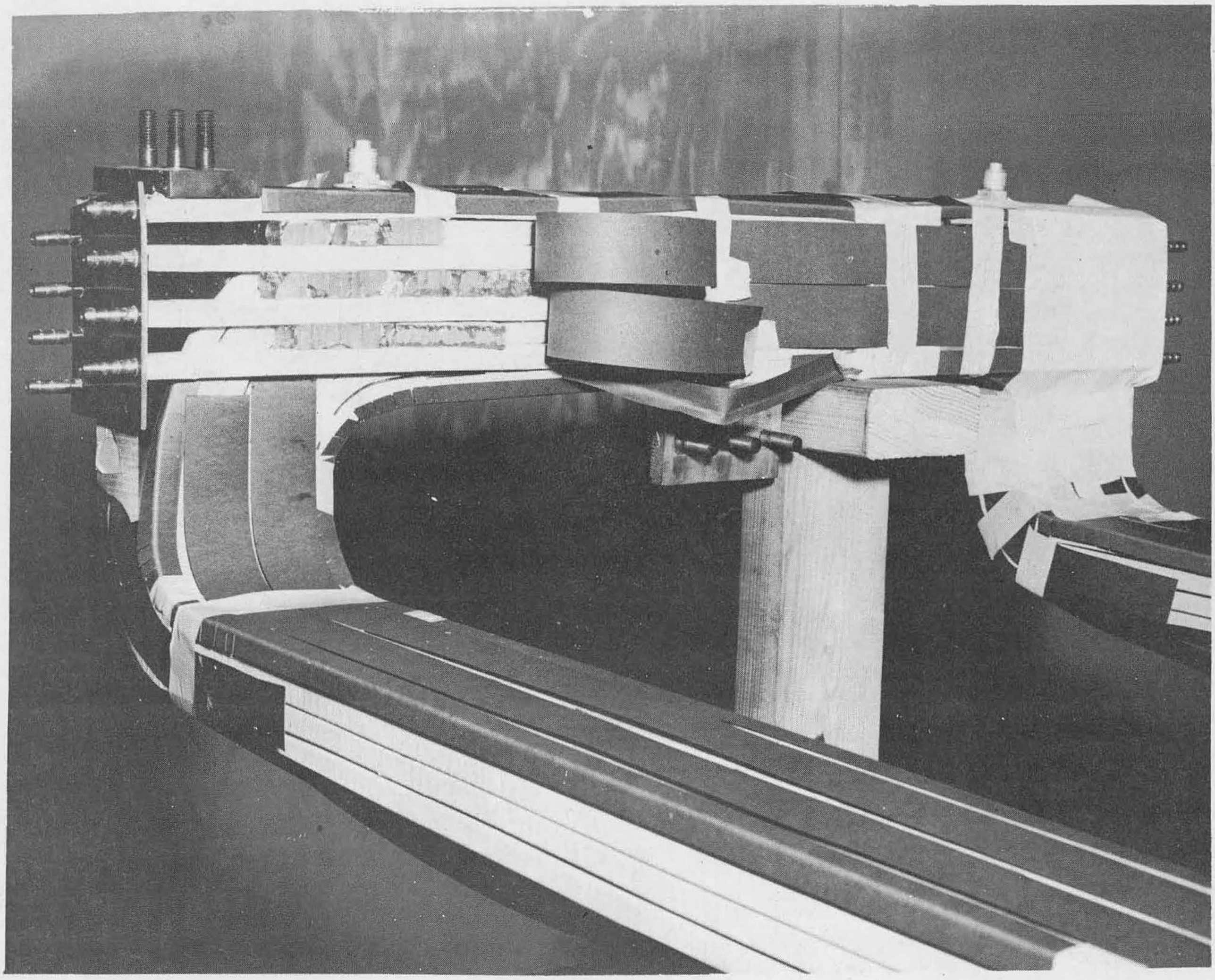

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Fig. 14. Preparation of 12-by-60-inch analyzer magnet coil; detail of terminal end.

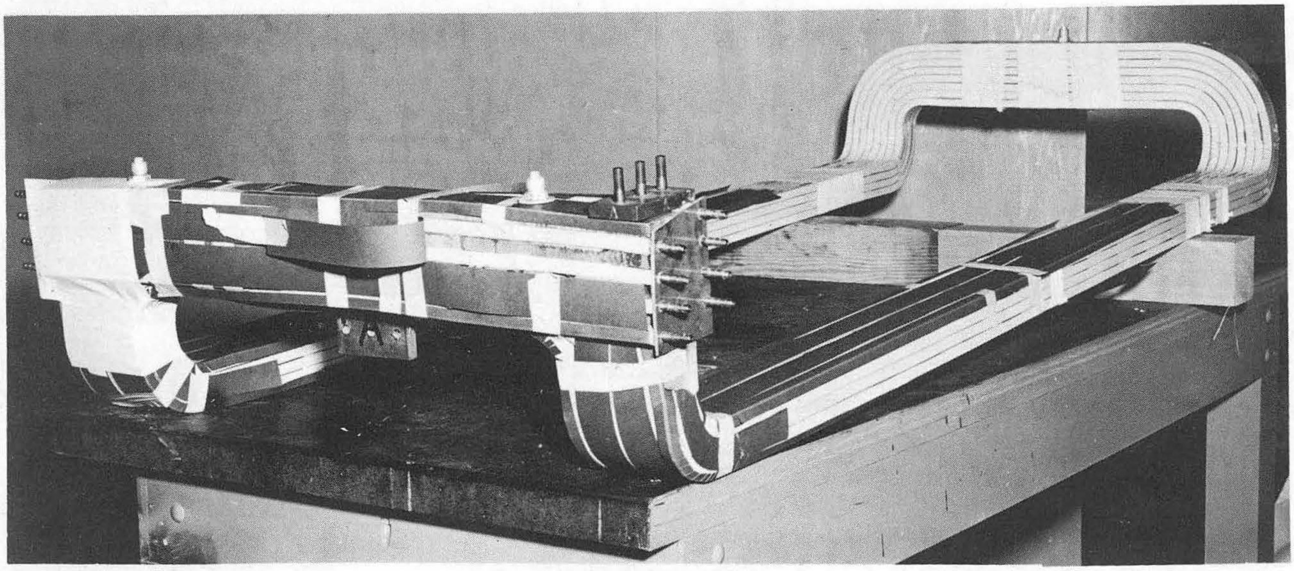

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Fig. 15. Preparation of 12-by-60-inch analyzer magnet coil for plastic impregnation.

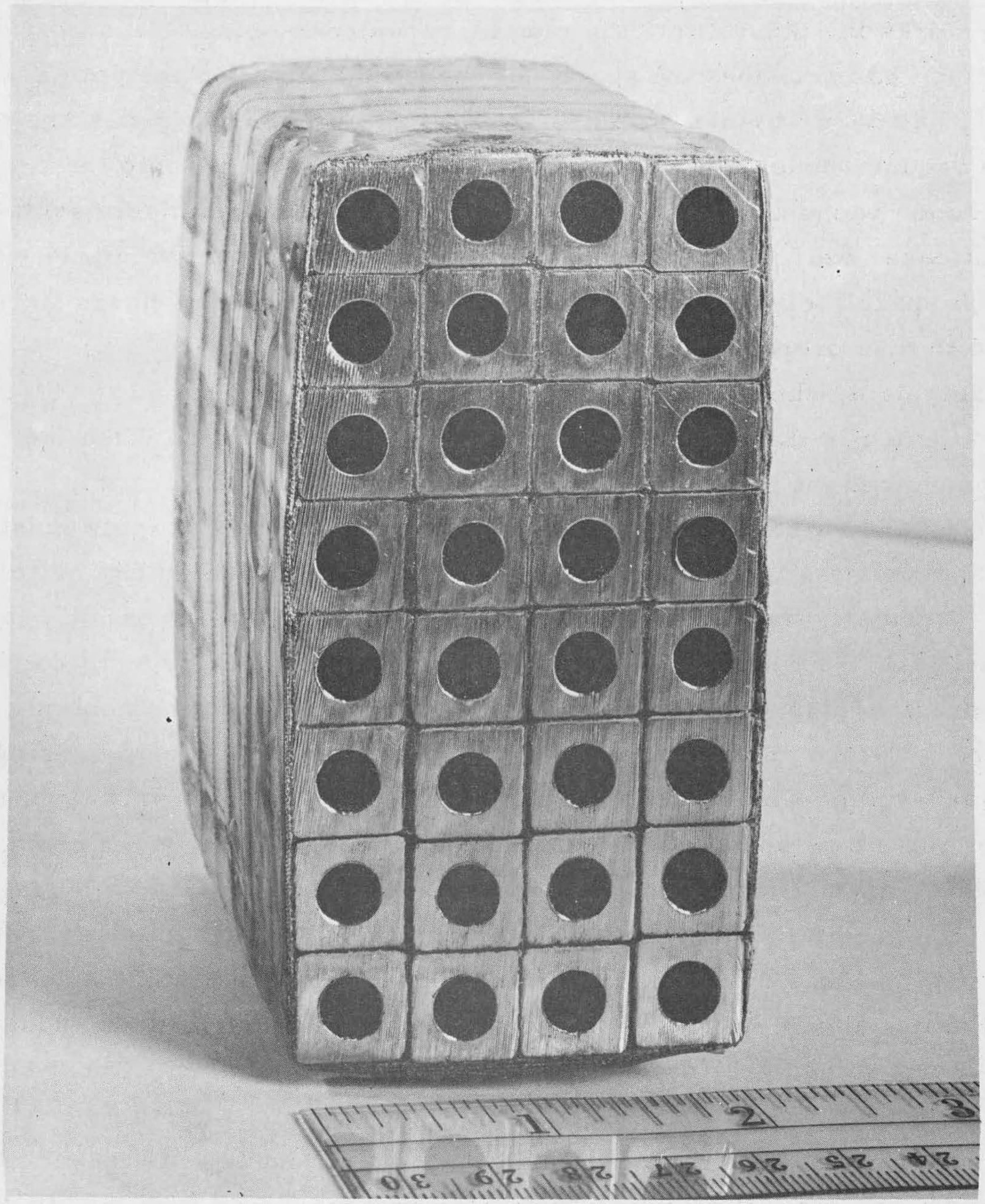

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Fig. 16. Cross-section sample of 12-by-60-inch analyzer magnet coil, showing excellent space factor obtainable from technique described.

adhesive glass tape (Figs. 12, 13, and 14). The outside taped surface is coated with cold-curing epoxy resin to form an actual vacuumtight cocoon.

This coating is best applied by hand - the operator, with rubber gloves, actually works the plastic into the tape by repeated rubbing. When the outside surface has set, the coil space is evacuated and, after the entire assembly has been warmed with heat lamps, resin is introduced. The syrup is again vacuum-deaerated and warmed before being sucked into the cocoon by the cocoon vacuum. The completed coil emerges with a highly scuff-resistant case, well packaged mechanically and, as Fig. 16 verifies, a very good space factor is achieved. Approximately 200 man-hours were required to thus prepare four coils.

Example 4, shown in Figs. 17 and 18 is a small coil used to raise targets situated in the vacuum tank of the UCRL Bevatron. When the coil is energized, it interacts with the magnetic field of the particle accelerator and raises a target through a 90° arc. These targets must rise in approximately 1/4 second, so the shock load on the coil is quite severe. Normally the targets are operated 3,000 to 6,000 times a day and they must last 6 to 8 weeks between maintenance periods. In addition, the coils operate in high vacuum (10^{-6} mm Hg) with only radiation cooling.

The 220-turn coil is wound on a methyl methacrylate frame, using "Formvar"-coated No. 23 solid copper wire. The assembly is wrapped with adhesive glass tape and the outside sealed with cold-curing epoxy resin. The inside is then loaded from one end by use of a veterinarian's syringe. The syringe needle makes a small but open hole. The part is baked with the end with the hole up. Baking drives trapped air to the top, therefore during the initial curing period more plastic has to be periodically added. A quite thorough penetration by the plastic was here obtained without using vacuum, but I believe this is possible only on quite small parts.

The last example, shown in Figs. 19, 20, 21, and 22, is a quadrupole or focusing lens magnet of 4-inch-diameter aperture used with the UCRL Bevatron. Epoxy resins neatly solved three design requirements here: (a) assuring adequate electrical insulation, (b) mechanically holding the coil to the pole tip, and (c) providing an exterior surface that will shed dirt, metallic chips, and other foreign material that could possibly cause

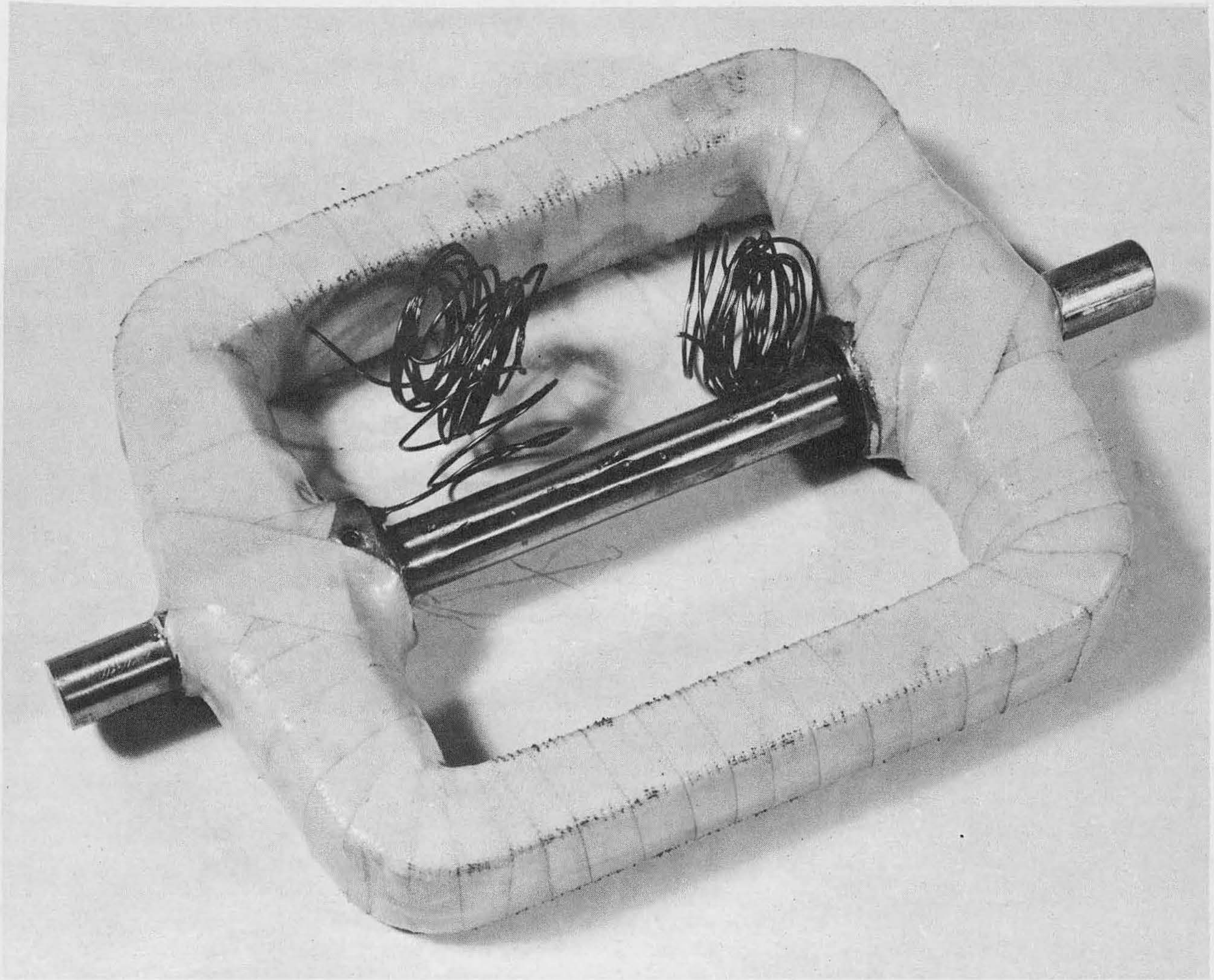

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Fig. 17. Actuating coil for MK III flip-up target. Outside dimensions are approximately 5 by 4 inches.

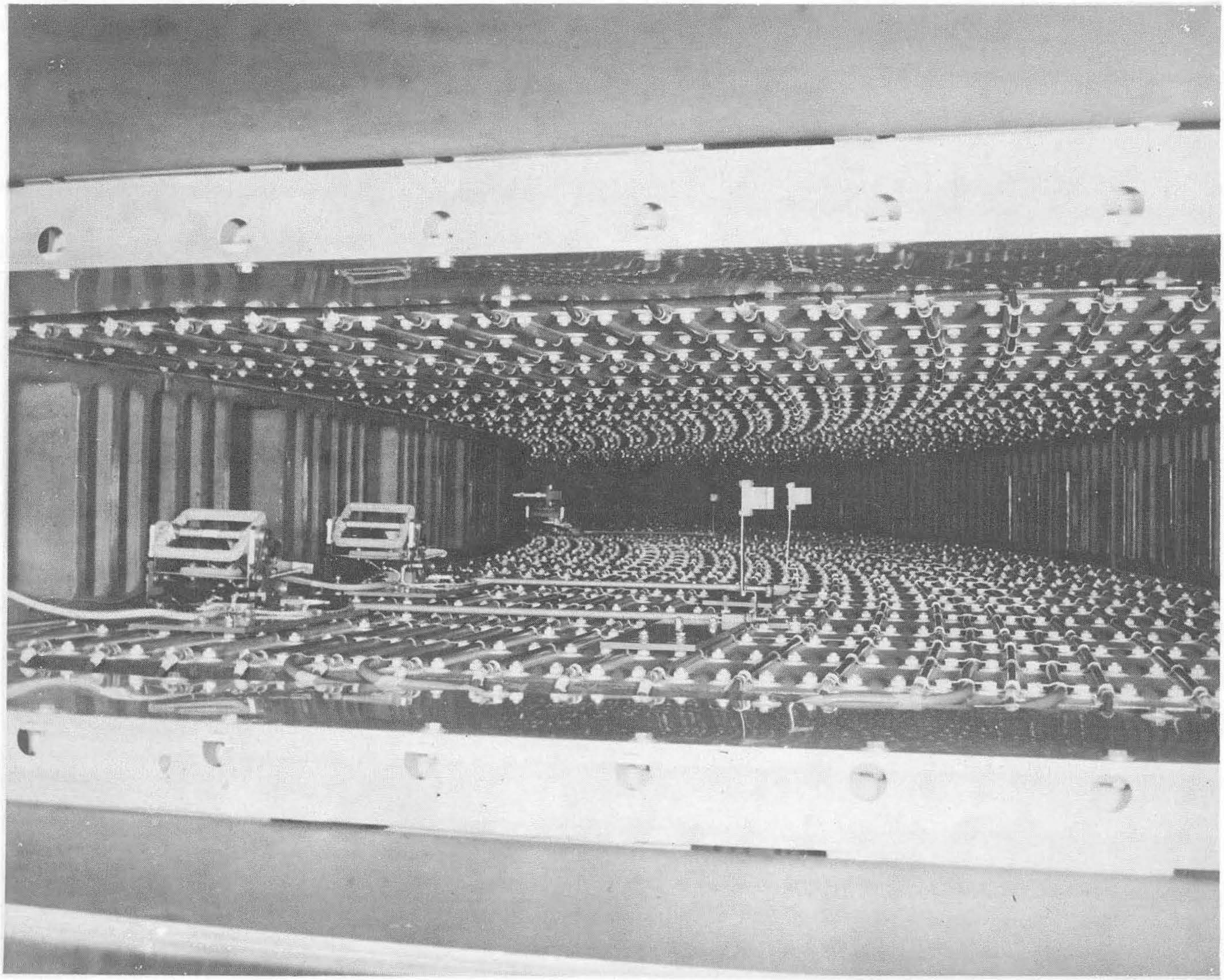

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Fig. 18. Installation of three MK I flip-up targets in gap of UCRL Bevatron.

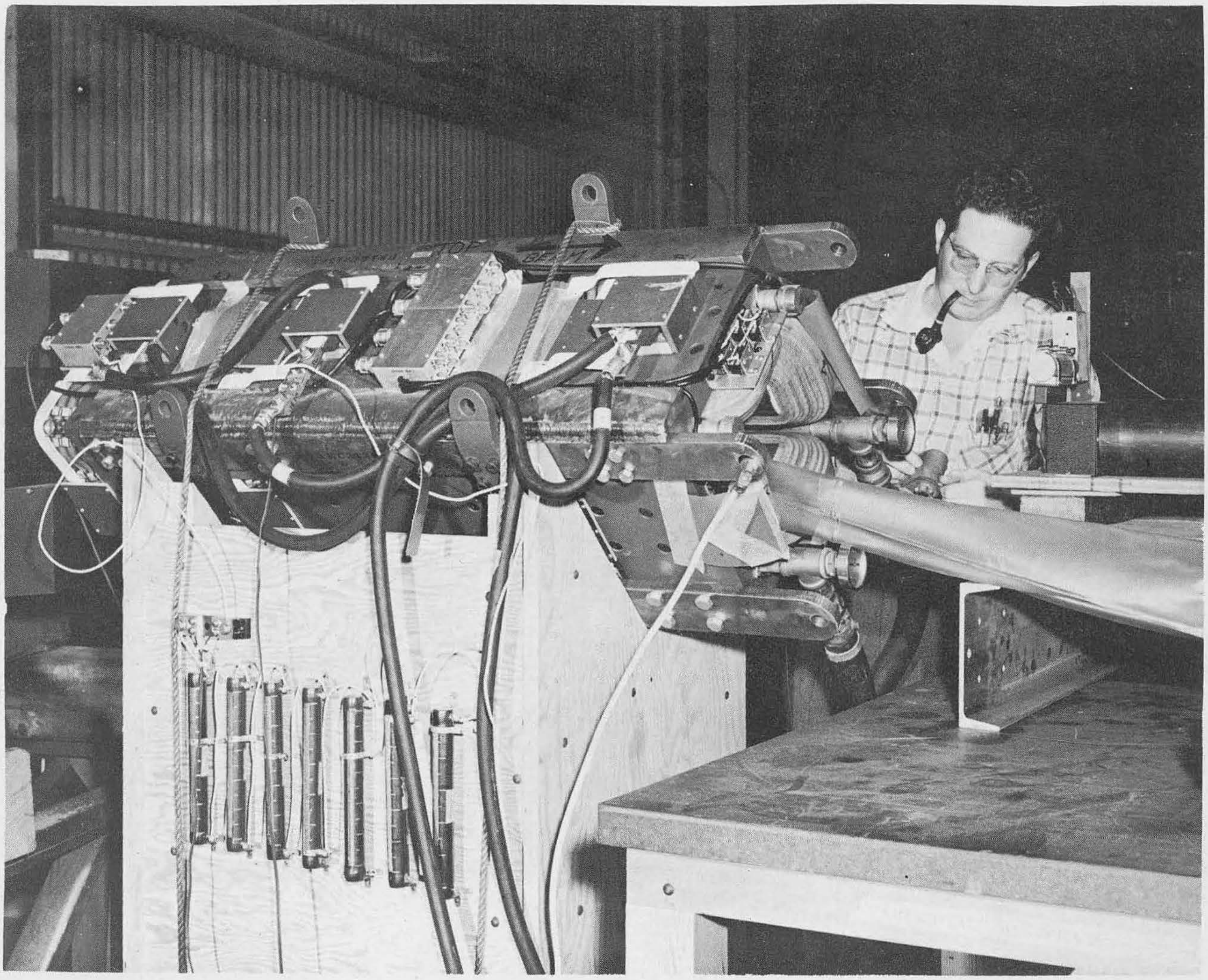

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Fig. 19. Four-inch-diameter focusing magnet used in antiproton experiments with UCRL Bevatron. Coil disposition is visible at open end.

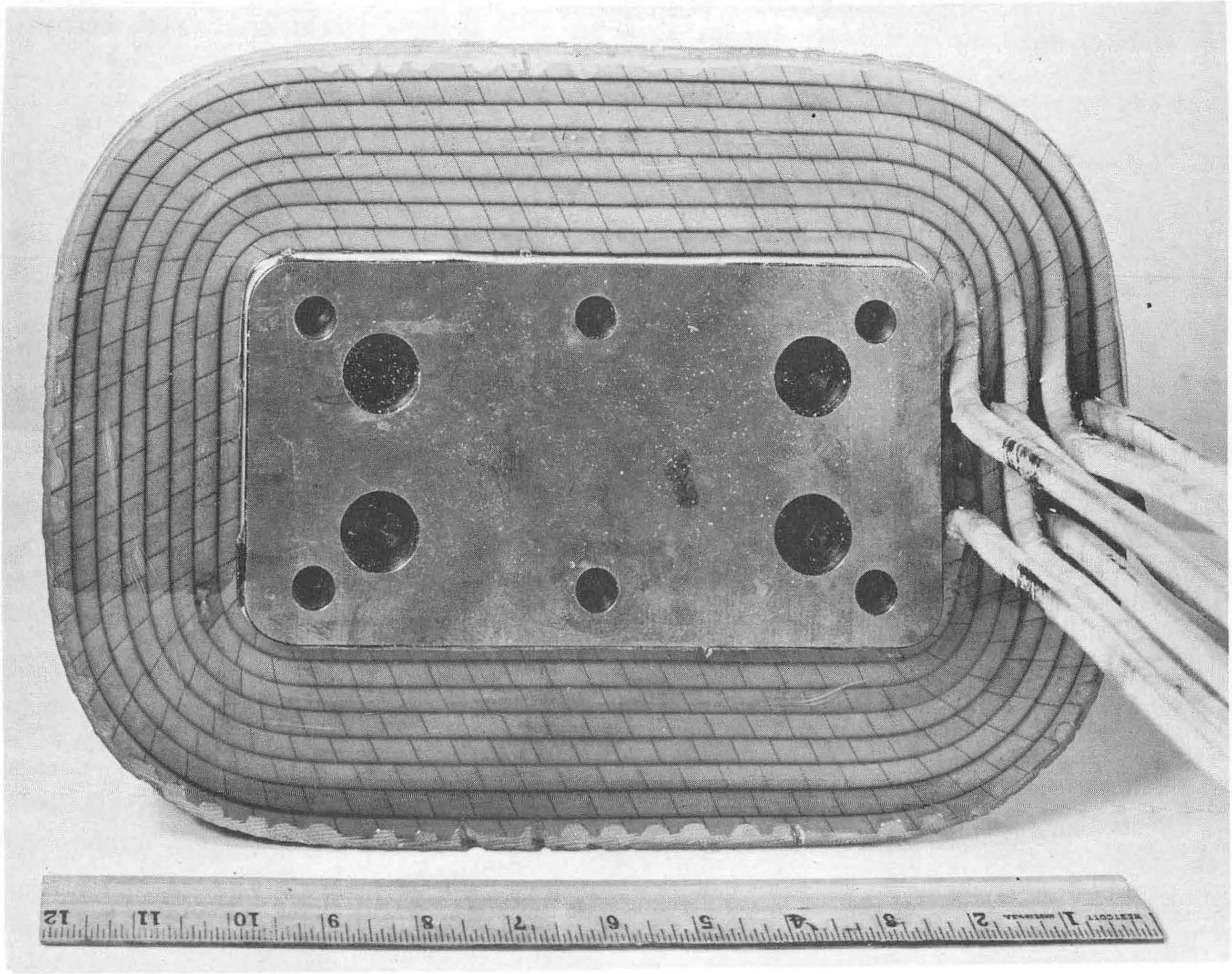

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Fig. 20. Flat face of 8-inch-long pole and coil subassembly for 4-inch-diameter quadrupole focusing magnet.

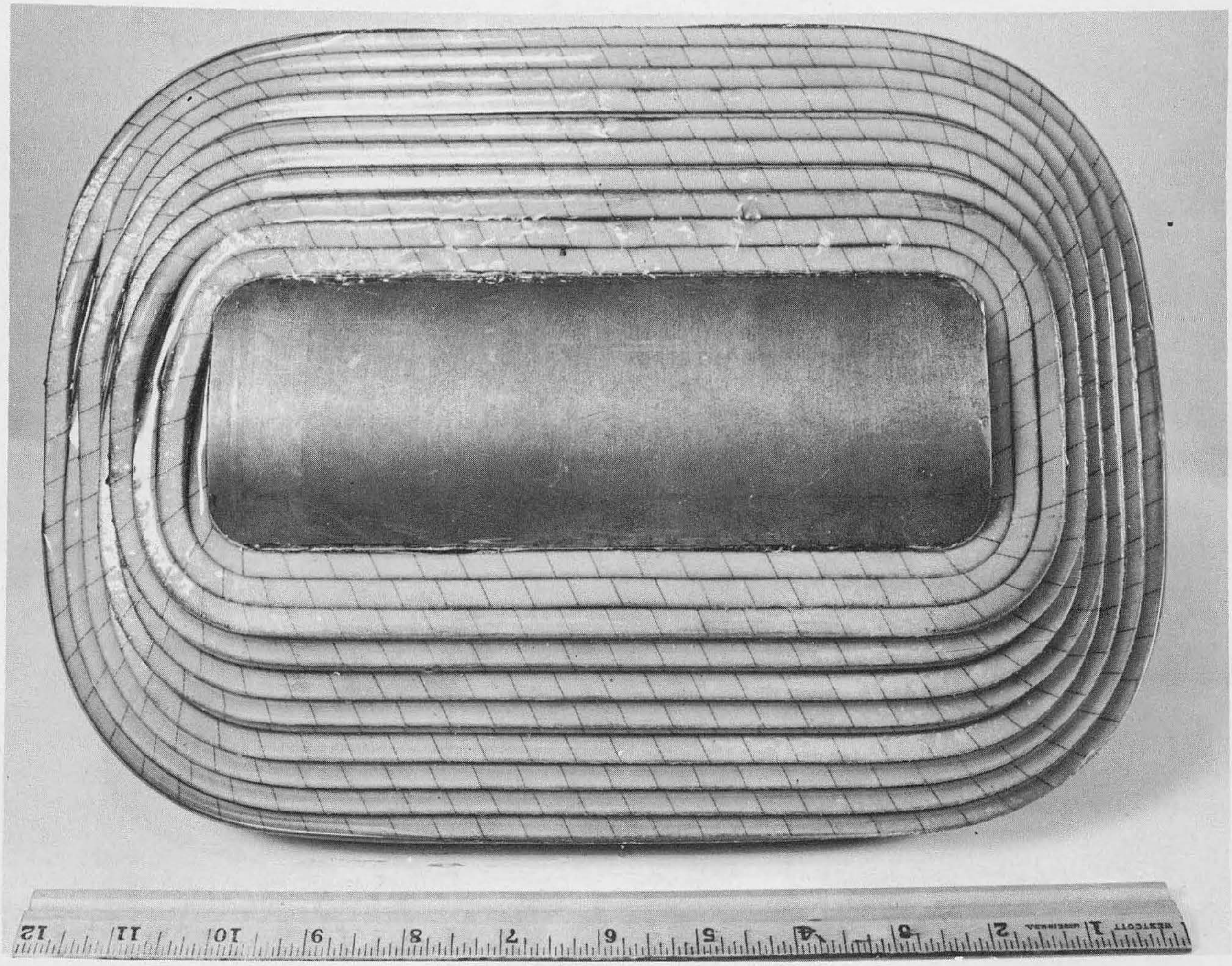

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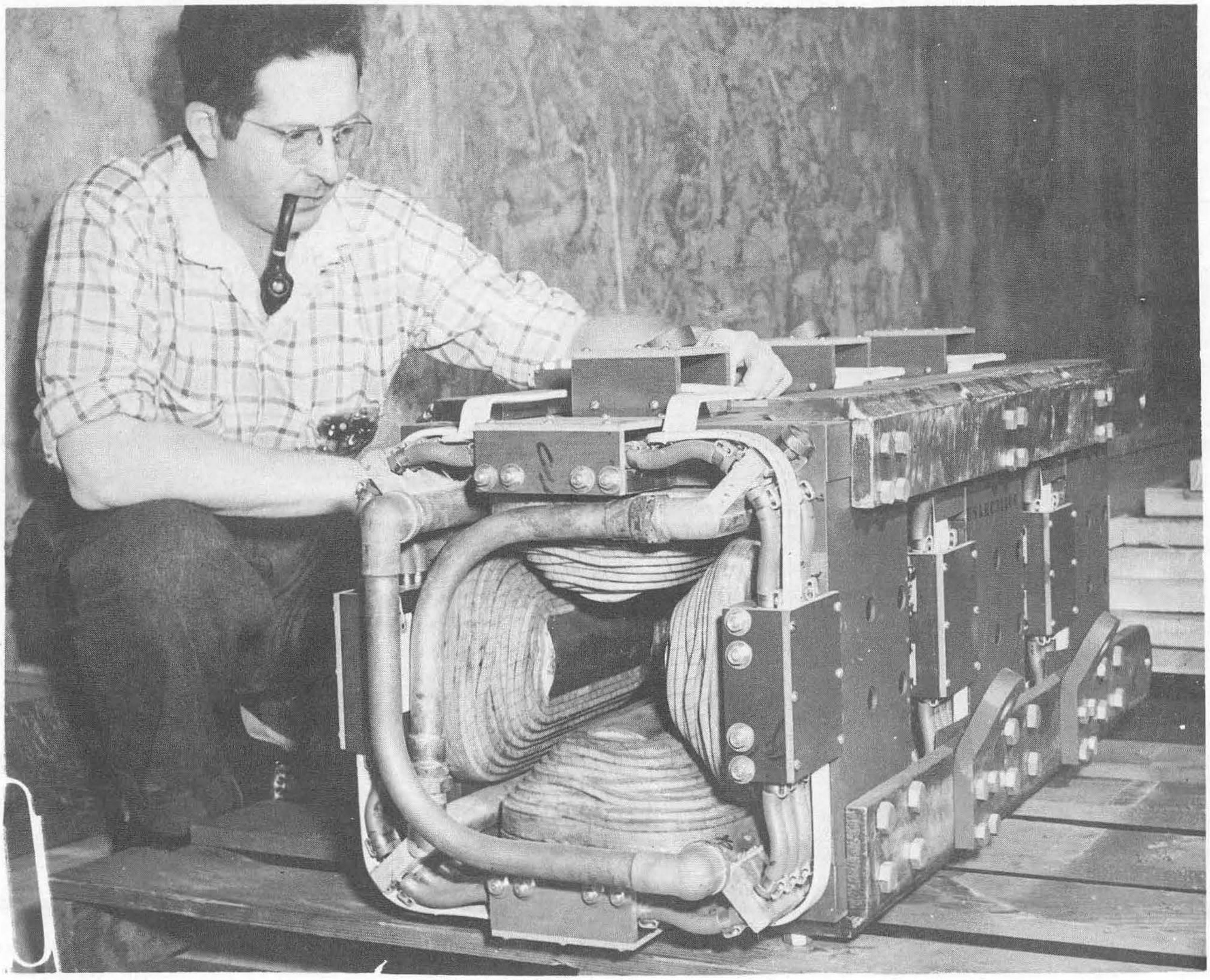
Fig. 21. Pyramidal face of 8-inch-long pole and coil subassembly for 4-inch-diameter quardrupole focusing magnet.



ZN-1417

Fig. 22 Four-inch quadrupole lens set.

future electrical trouble.

The ends of the pole pieces were covered with 0.005-inch fish paper secured with "Mylar" tape, and the coil was wound directly on the pole. Coil insulation was half-lap-wrapped unsized cotton tape, 0.014 by 1 inch.

After preheating to resin-curing temperature, the coil assemblies were bolted flat side up to a movable bar in a vacuum tank. Under the coil, but not in contact with it, was placed a sheet metal boat full of epoxy resin, also preheated. The system was pumped down and the plastic deaerated before the coil was lowered into the plastic. It was found that approximately 30 minutes' immersion was required to obtain full penetration of the plastic throughout the coil. Considerable capillary creeping through the cotton tape was required, since these coils were wound without the egg-crate spacing strips. It was found helpful to thin the plastic with 15% by weight of glycidyl phenol ether.

The coil is baked with the flat side up. After the initial impregnation has jelled, a rubber ring is snapped over the coil periphery and sufficient additional plastic is poured into the cavity thus formed to cover the flat face of the coil to a depth of 1/32- to 1/16 inch. This flat surface then emerges from the oven with a solid glossy case, while the pyramidal side is relatively rough. When the assembly has cooled, a generous coating of cold-curing resin is applied to the pyramidal side, and it also develops a glossy, continuous, foreign-body-excluding case.

Much credit is due the personnel of the Mechanical Assembly Shop and the Accelerator Technicians group at UCRL for overcoming many difficulties and successfully executing these projects.

This work was done under the auspices of the U.S. Atomic Energy Commission.