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LARGE SUPERCONDUCTING COIL FABRICATION DEVELOPMENT*

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UNLIMITED

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Summary

Toroidal fields for some fusion devices will be produced by an array of large superconducting coils. Their size, space limitation, and field requirements dictate that they be high performance coils. Once installed, accessibility for maintenance and repairs is severely restricted; therefore, good reliability is an obvious necessity.

Sufficient coil fabrication will be undertaken to develop and test methods that are reliable, fast, and economical. Industrial participation will be encouraged from the outset to insure smooth transition from development phases to production phases. Initially, practice equipment for three meter bore circular coils will be developed. Oval shape coil forms will be included in the practice facility later. Equipment that is more automated will be developed with the expectation of winding faster and obtaining good coil quality. Alternate types of coil construction, methods of winding and insulating, will be investigated. Handling and assembly problems will be studied. All technology developed must be feasible for scaling up when much larger coils are needed. Experimental power reactors may need coils having six meter or larger bores. o o o o

Fabrication of superconducting magnet coils for fusion devices involve some unique responsibilities. The coils will be large, expensive, many in number and must have high magnetic performance. Once installed, they will be very inaccessible for maintenance and repair. It is apparent the cost will be prohibitive unless the maximum reliability is obtained with maximum fabrication efficiency.

It is the opinion at Oak Ridge that the state-of-the-art in coil fabrication can and should be expanded but any increment step forward must build on the solid foundation of years of established experience. However, most of this experience has been with room temperature coils. As this program progresses it will require an ever enlarging industrial participation. Continuing contacts and visits have been maintained with industrial and government agency fabricators during the last year. A review of these contacts reveal considerable expertise and interest in the fusion program. Some companies, generally the smaller ones, do not desire or in some cases even accept engineering and development work. They are only interested in working from the customer's complete specifications and drawings. This does not imply that that they cannot do excellent work and on occasion they can be very ingenious in developing solutions for unforseen problems that arise during fabrication. Other companies prefer to start with such basic parameters as bore size, available coil space, and magnet field requirements. With this information they would design, develop, and fabricate the coils completely. Although this is their preference, they will also fabricate to the customer's specifications as in the first instance.

The first coil to be fabricated in this program will be the background coil (~ 1 m bore) for the Eccentric Coil Test (ECT). This coil will magnetically simulate a full toroidal field for a single test coil placed inside its bore with the two coil center lines parallel but displaced. If new fabrication techniques can be proven in time to fabricate this coil, they will be used. Otherwise, in the interest of time, the coils will be fabricated using the best conventional techniques available.

The Compact Torus (CT) will consist of a toroidal array of background field coils with one space open to accept a test coil (all coil bores ≈ 3 m). Particular attention has been directed toward developing techniques for the CT test coil. Space has been set aside in the Y-12 electric shop for this winding development work (Fig. 1). Essential components for this facility are on order and the first practice winding is scheduled for early 1976. The facility is adaptable for round or oval-shaped coils. Actual windings will spiral radially outward forming pies. Alternate pies are connected at their inside diameters forming pancakes. The two pies of a pancake must be wound in opposite directions, and consequently, all winding equipment must be able to turn clockwise or counterclockwise. A pancake may be fabricated by placing the midpoint of a length of conductor at the inner radius and each half length spirals radially outward with opposite rotation so the ends are on the outer circumference. This means one half of the conductor will be carried on the winding table while the other half is being wound. Next the conductor in the winding table is placed on the payout spool and is ready for winding. On occasion it is desirable to back up the winding to correct or rework an unacceptable portion and this reversible feature is built into the equipment. Space for two payout spools has been allotted in case it is necessary to interleave stainless steel reinforcing with the superconductor. Ample space has been reserved between the payout spools to insert necessary work stations such as straightening, tension, insulating, etc. All stations consider the desirability of keeping the mechanical abuse at a minimum in the superconductor. At the present time, superconductor manufacturers can only promise conductors with small cross sections (~ 5 × 10 mm). This dictates coils wound with many turns having large circumferences and increases the need to automate as much equipment as possible to reduce winding time with assurance of no loss in coil quality. Initial conductor winding speed of 3-4 meters per minute is expected and later this will be increased to 6-10 meters per minute. Large coils imply that the conductor spools as received from the suppliers will be large and heavy. To avoid overstressing the conductor being pulled from the payoff spool the conductor tension is sensed and the spool's rotational inertia is removed by a hydraulic motor maintaining minimum tension from spool.[1] The spool will also reverse rotation if backup conditions are necessary. A conductor straightener is present, but to avoid unnecessary flexing it will automatically operate only when present tolerance settings are exceeded (Fig. 2).

A tension device is being constructed that will not bend or mar the conductor or its insulation (Fig. 2). The tension will be automatically controlled within

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prese[illegible] limits. [illegible]ations are effected by suitable electronics that also measure and record the tension versus the number of turns in a pie (Fig. 3). Interlocks that shut down the system are provided in case of conductor breakage, loss of power, or abnormal excursions of the tension.

Conceptual studies and drawings have been prepared for conductor splicers, cleaning, insulating, handling fixtures, coil leads, and winding table clamps. Several types of splices are under consideration and a program is being set up for mechanically and electrically testing and evaluating splices in liquid helium with a background magnet field.[2] Insulation used in the windings will be subject to a wide range of temperatures and pressures during fabrication and operation. A continuing literature search and testing at room temperature and liquid nitrogen temperature are aimed at selecting the best material to meet these requirements. Also some insulations must have unique shapes to permit helium circulation through the windings. Molded insulation sheets to be placed between pancakes and having built in cooling channels is being developed for this purpose. A photograph (Fig. 4) shows a 3M round practice bobbin mounted on the winding table. Additional guides and tampers are installed at the winding table that will reduce handwork. The winding table clamps will rotate with the table and will automatically release and withdraw on each revolution to avoid interference with new material being laid in place.

All windings will be clamped securely throughout the fabrication. At no time will all the clamps be removed and probably never more than one at a time. Errors in the roundness, radial height, and axial width will be compensated for by adding extra fillers and sheets of insulation after winding all pancakes. Axial clamps will be lifted one at a time and segments of the outer bobbin flange will be pressed down and welded in their place. Some work stations will be omitted at first, or temporary substitutes will be used, until concepts materialize into actual hardware.

An element of uncertainty exist with all newly developed equipment. For this reason backup methods are constantly being studied. Some methods anticipate only minor changes in existing design. Others are quite different and involve such concepts as winding with forced cooled conductors. The case for using forced cooled superconductors has become steadily stronger. Furthermore, the possible need for going to higher fields may mean that it will be desirable to use two types of superconductor (NbTi and Nb_3Sn) in the TF coils. These significant changes have prompted studies of special winding techniques to effectively produce such coils. A major task will be fabrication of pulsed coils that are located near the surface of the toroidal shell. Preliminary fabrication studies have begun in this area.

Development of toroidal field coils must eventually converge on coils having bores of 6–10 meters if they are to be useful in an Experimental Power Reactor (EPR). Since all coil development leads to a scale up to large coils, no development has been considered unless it is clear that it can be scaled up for future use. Although some preliminary studies have been made for fabricating, handling, and shipping of large coils, the greatest effort is currently being conducted in engineering and a comprehensive report will be submitted later this year. This report will supply the criteria for the conceptual design of the Superconducting Magnet Fabrication and Test Laboratory (SMFTL). Actual coil fabrication will be included in this report only insofar as they effect the building and building facilities.

It is considered prudent to maintain parallel efforts on the problems of fabricating large as well as small coils if large coils are to be fabricated in the time frames needed. Effort expended on large coil problems are also useful for keeping the ultimate goals in sharp focus.

References

1. Supplied by Acrometal Products, Inc., Michigan City, Indiana.

2. K. J. Froelich, "The Effects of Biaxial Loading on the Critical Current of NbTi." This publication.

WINDING EQUIPMENT

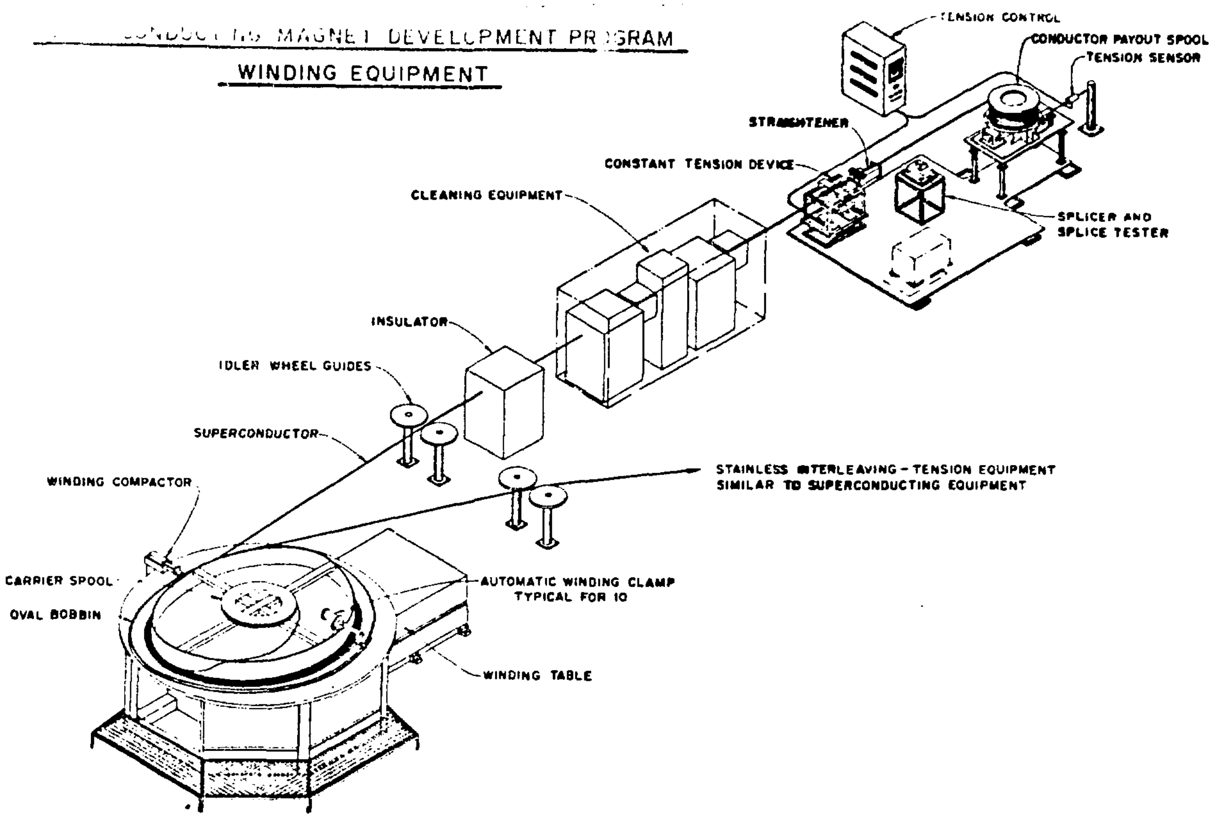


Fig. 1. Winding equipment planned for practice winding of round and oval bobbins with ~ 3M bores. Room is available for winding the superconductor and a stainless interleaved material either clockwise or counterclockwise.

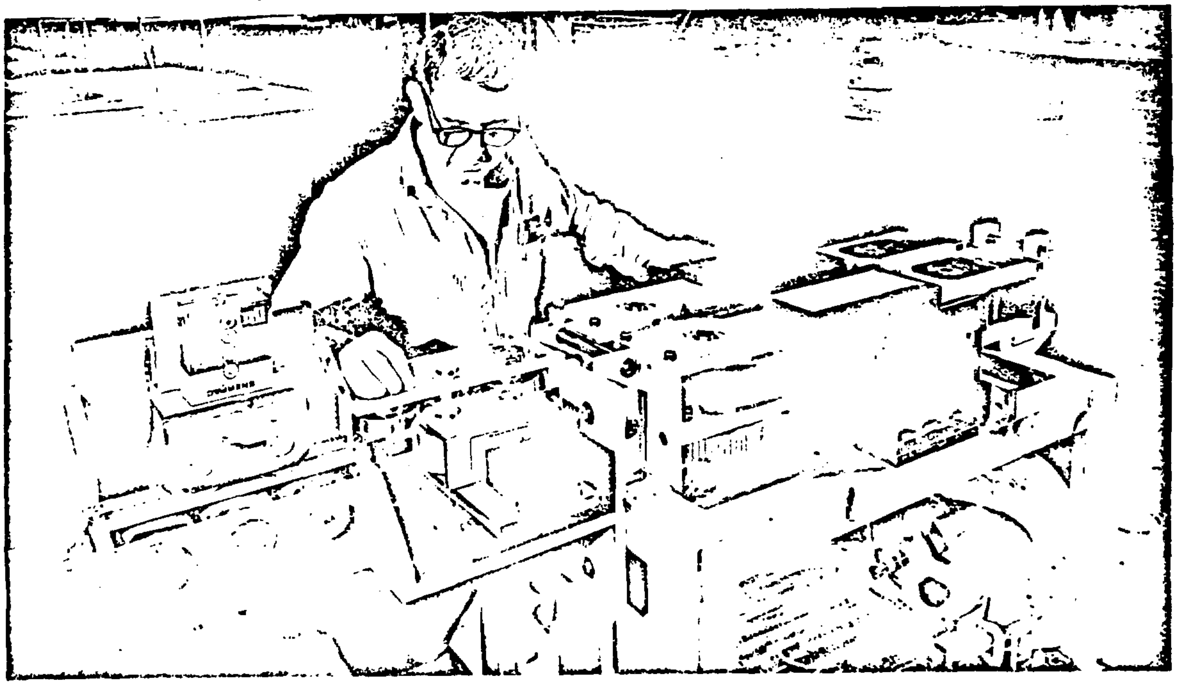
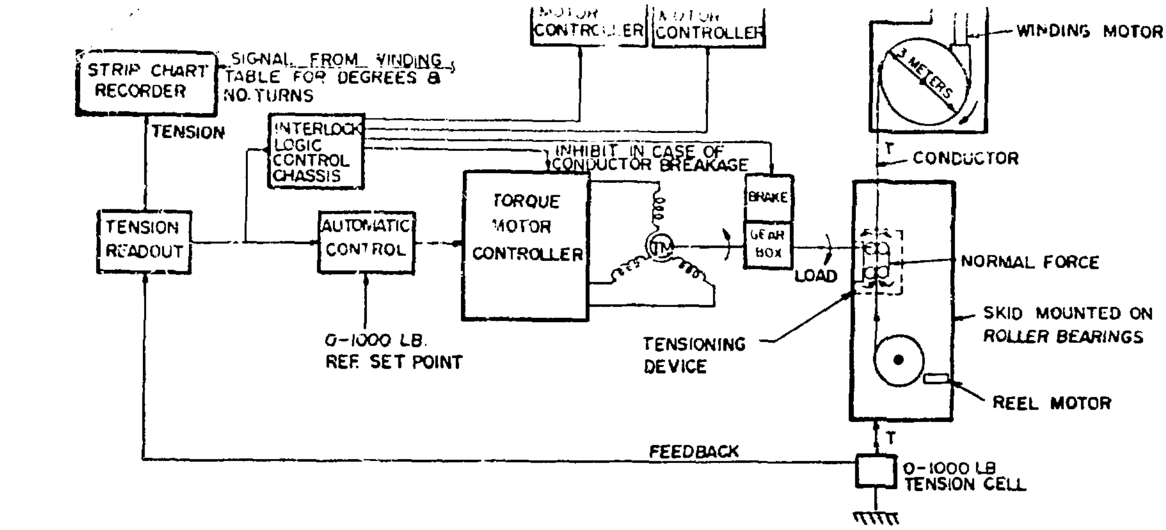
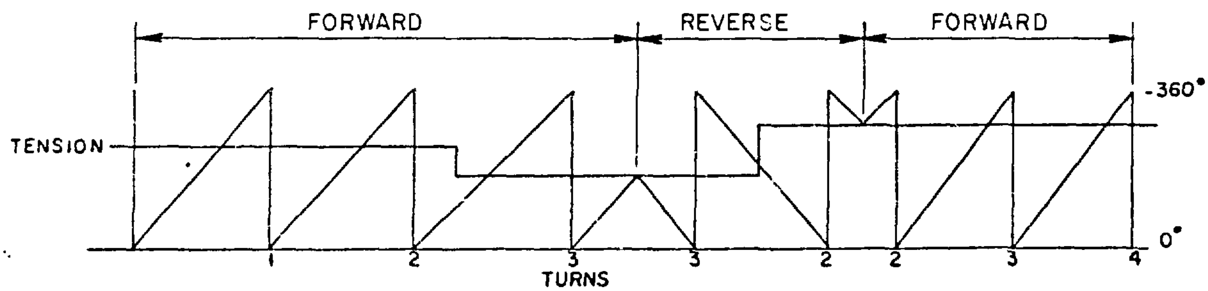


Fig. 2. The conductor straightener (left end) consists of two sets of rollers for straightening in two planes. The constant tension device (right end) is for superconductor or interleaving material. The current in a DC torque motor is controlled to maintain constant tension on two spring loaded belts sandwiching the conductor. The conductor is protected from damage since the belts move with the conductor. Backup operation is possible if needed.



BLOCK DIAGRAM FOR
AUTOMATIC TENSION MACHINE



RECORDER CHART

Fig. 3. Controls for the constant tension device. A load cell measures actual tension and DC torque motor controller maintains constant tension on the conductor by varying the current. Interlocks shut down entire system if tension deviates from preset range. A recorder maintains a record of tension vs. turns. Forward and reverse directions are determined by slope of recorded trace.

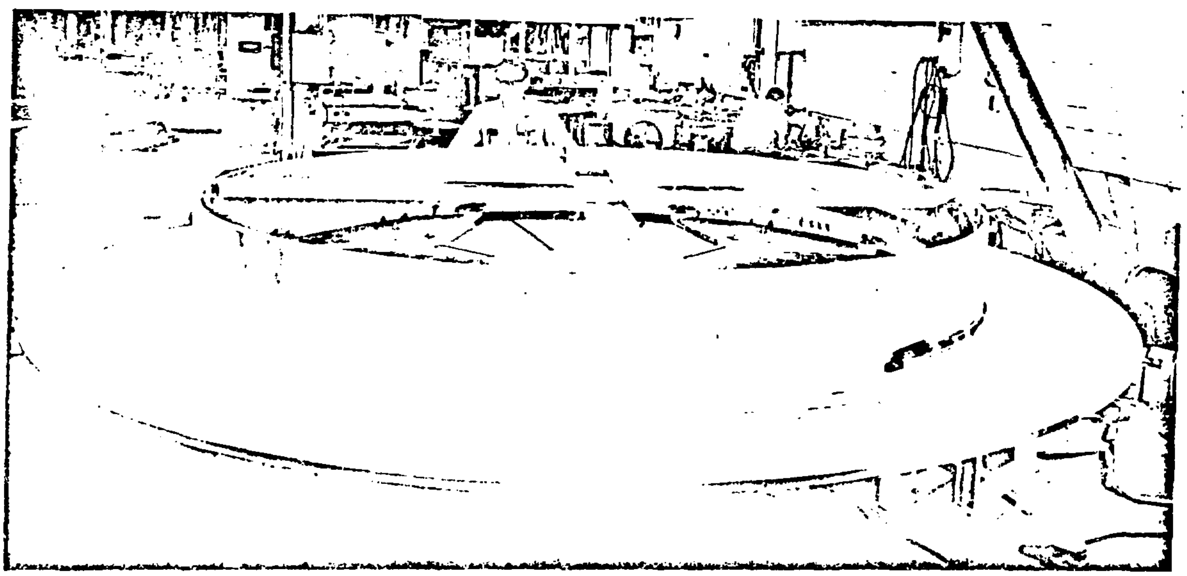


Fig. 4. Round aluminum practice bobbin (3M bore) shown mounted on winding table.