ENGINEERING FEATURES OF ISX†

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Summary

ISX, an Impurity Study Experiment, is presently being designed at Oak Ridge National Laboratory as a joint scientific effort between ORNL and General Atomic Company. ISX is a moderate size tokamak dedicated to the study of impurity production, diffusion, and control. The significant engineering features of this device will be discussed.

The design of ISX will emphasize the production of a predictable test plasma, experimental flexibility, ease of assembly and disassembly, and good diagnostic access. It will employ water-cooled copper coils, driven by the ORMAK power supplies to produce a toroidal magnet field of 18 kG at the major radius of 90 cm. The rectangular coils feature a removable top section to allow easy replacement of the vacuum chamber. The plasma minor radius will be about 25 cm and the maximum plasma current will be 150 kA, induced by an iron core transformer. Vertical field and transformer primary coils are placed to allow good diagnostic access to the plasma.

Scheduled for operation in December 1976, ISX, with its built-in flexibilities, will provide a valuable facility for the systematic study of wall materials and geometry, cleaning methods, and diagnostic development.

Design Description

The problems associated with the study of impurities are broad enough to require that a mchine to study them must be flexible and easily modified. These requirements dictate that the machine should use proven technologies whenever possible and provide for rapid access to the plasma and all vital machine parts. The configuration chosen, shown in Fig. 2, not only provides this flexibility of operation but also provides a maximum amount of space for future changes in wall and limiter configurations, and rapid, easy assembly and disassembly operations.

Because the impurity studies will require frequent changes of wall materials, impurity sources, diagnostics, pumping and gas inlet configurations, the device has been designed for rapid changing of the entire vacuum tank-limiter assembly. The demountable toroidal field coils scheme shown is the result of this requirement. The design features of large aspect ratio (R/a = 3.6), moderate toroidal field, and no conducting shell provide additional space to be used for additional pumping, experimental related equipment, diagnostic developments and new configurations as the needs arise.

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Assembly and disassembly are facilitated by making the plasma/vacuum tank systems independent of the structural and magnetic field systems. For disassembly, the upper part of the oil transformer lifts off. The center leg is then removed. The upper sections of the picture frame toroidal field coils are removed after unbolting the top finger and lap joints. The entire vacuum tank can then be lifted clear. The two concentric cylinders, supporting the ohmic heating and vertical field coils can also be removed intact maintenance or modification to the system. The procedure is reversed for reassembl_.

The grouping of the toroidal field coils affords a circumferential clearnace of approximately 16 inches. The locating of the ohmic heating and vertical field coils not only provides a clear access of 18 inches at the plasma equator, but also allows for full radial access spanning the top and bottom of the vacuum tank.

Toroidal Field System

The toroidal field system consists of a set of copper coils driven by the 74 MW solid state ORMAK power supply. The 72 turns are arranged into 18 sets of 4 turns each. The number of turns was chosen to produce a magnetic field of 18 kG at the plasma centerline, 90 cm, for a driving current of 120 kA.

The coil pieces are formed from 1-inch thick alloy copper plate. CDA alloy 182, containing 1 percent chrome was chosen as the material for coil construction. The excess power available in the power supply allowed for the use of an alloy that has greatly enhanced strength with slight degration of electrical conductivity. The rectangular "picture frame" geometry (shown in Fig. 3) was chosen to afford a maximum volume within the coil apperature for future experimental needs and for ease in assembly and disassembly. The assembled turns are each 53 inches x 66 inches with a cross section varying from 1 x 3 inches to 1 x 7 inches.

A key feature of the design is the removable top leg of each turn. Extensive finite element stress analyses have been performed to insure the structural integrity of the coils and identify allowable locations for the inclusion of the joints. Two programs were used extensively in the design of the coil system. FEATS was utilized to analyze in-plane stresses and deflections, and to obtain the material distributions required to "maneuver" the low stress zones into positions of required joint location. NASTRAN was used to generate a three-dimensional model used to study the effects of the elastic support system. In-plane and out-of-plane effects we studied using NASTRAN. A separate paper[1] will be presented at this conference discussing this effort in greater detail.

Finger joints are used on the inner legs where space is limited. Two throughbolts each torques to 30 ft lbs affect the required contact pressure of 1200 psi on each of the contacting surfaces. Half lap joints are used on the outer legs where more space is available. The joint designs are based on experience gained at General Atomic Co. (Doublet IIA and III), Princeton Plasma Physics Lab (PDX), and at Oak Ridge. Test performed at MIT in July verified the ability of the joints to carry the full 120 kiloamp design load. Mechanical testing, both static and fatigue, of the joints are presently underway. Figures 4 and 5 show two of the joints tested.

A bucking ring, to be constructed of filament wound fiberglass, is used to react the centering forces of the coils. The cylinders used to sup-ort the ohmic heating and vertical field coils are used to react the relatively light circumferential loading resulting from the fringing poloidal magnetic fields.

The current density is such that heating is not a major problem. Cooling is provided by water circulating in tubing soldered to the coil on an edge. A maximum temperature of 180°F is reached in the joint region at a pulse repetition rate of 1 second every minute.

OH and VF Coils

The primary and vertical field windings are located on and supported from two concentric insulating cylinders located between the vacuum vessel and the toroidal field coils. Each turn is a continuous bar of copper conductor. The proper sequencing of current paths is obtained through the crossovers located on the inner surface of the cylinders. This arrangement allows for the complete construction of the system before installation into the machine and can be modified by repositioning of the coils on the cylinders with required changes to only the crossover links. The placement allows full radial access to the top and bottom of the vacuum tank. A typical arrangement is shown in Fig. 6.

A total of 8 vertical field windings are required. To assure radial plasma stability for long pulses, the vertical field system will be connected in a feedback control loop consisting of position sensors, amplifiers, and the power supply. The OH and VF systems will both utilize the respective ORMAK power supplies on a time-share basis.

The 150 kA of ohmic heating is supplied to the plasma by the 8 turns acting through the transformer core shown in Fig. 7. It will be constructed from .014 in. thick grain oriented silicon steel plates bonded together to achieve the final dimensions required. The core will have a single return leg and overall dimensions required. The core will have a single return leg and overall dimensions of 148 in. in height by 122 inches in span. The center section will have a 23-in. diameter cross section, and the return legs will be 23 in. square. Back bias windings are included on the center leg only. The core will have a total weight of approximately 60,000 pounds.

Plasma-Vacuum Tank

A single region vacuum plasma chamber is being designed for ISX. The vessel will be composed of alternating bellowed and fixed sections. The basic geometry of this component is shown in Fig. 8. The initial liner will be constructed from austentic stainless steel. The thin wall bellows (.018 in. thick) eliminate the need for an insulating break; while the fixed sections are structurally rigid enough to allow diagnostic access limited only by the coil geometry.

The liner will be an all welded vessel, completely assembled before installation into ISX. Penetrations will utilize high temperature metallic seals. Once installed, the liner will be baked to 400°C by induced currents. The design vacuum of 3×10^{-9} torr will be achieved by use of turbomolecular pumps.

The system shown fulfills the requirement of a 25 cm radius plasma ta a 90 cm major radius, while allowing for a possible expansion to a 28 cm radius plasma at at 93 cm radius.

Conclusions

Detail design of the various ISX components are in varying degrees of completion. However, overall efforts to date have uncovered no obstructions to achieving the originally proposed highly flexible facility for the study of impurity effects on plasma. The overall plan calls for this facility to be used to study wall and limiter materials and geometries, wall cleaning methods, and for test and development on new diagnostics.

References

1. R. O. Hussung, D. C. Lousteau, N. Johnson, ISX Toroidal Field Coil Design and Analysis, Sixth Symposium on Engineering Problems of Fusion Research, November 1975.

MAJOR RADIUS	90 CM
MINOR RADIUS	25 CM
CENTERLINE FIELD	18 kG
PLASMA CURRENT	150 kA
CROSS SECTION	CIRCULAR

Fig. 1 Basic Plasma Parameters

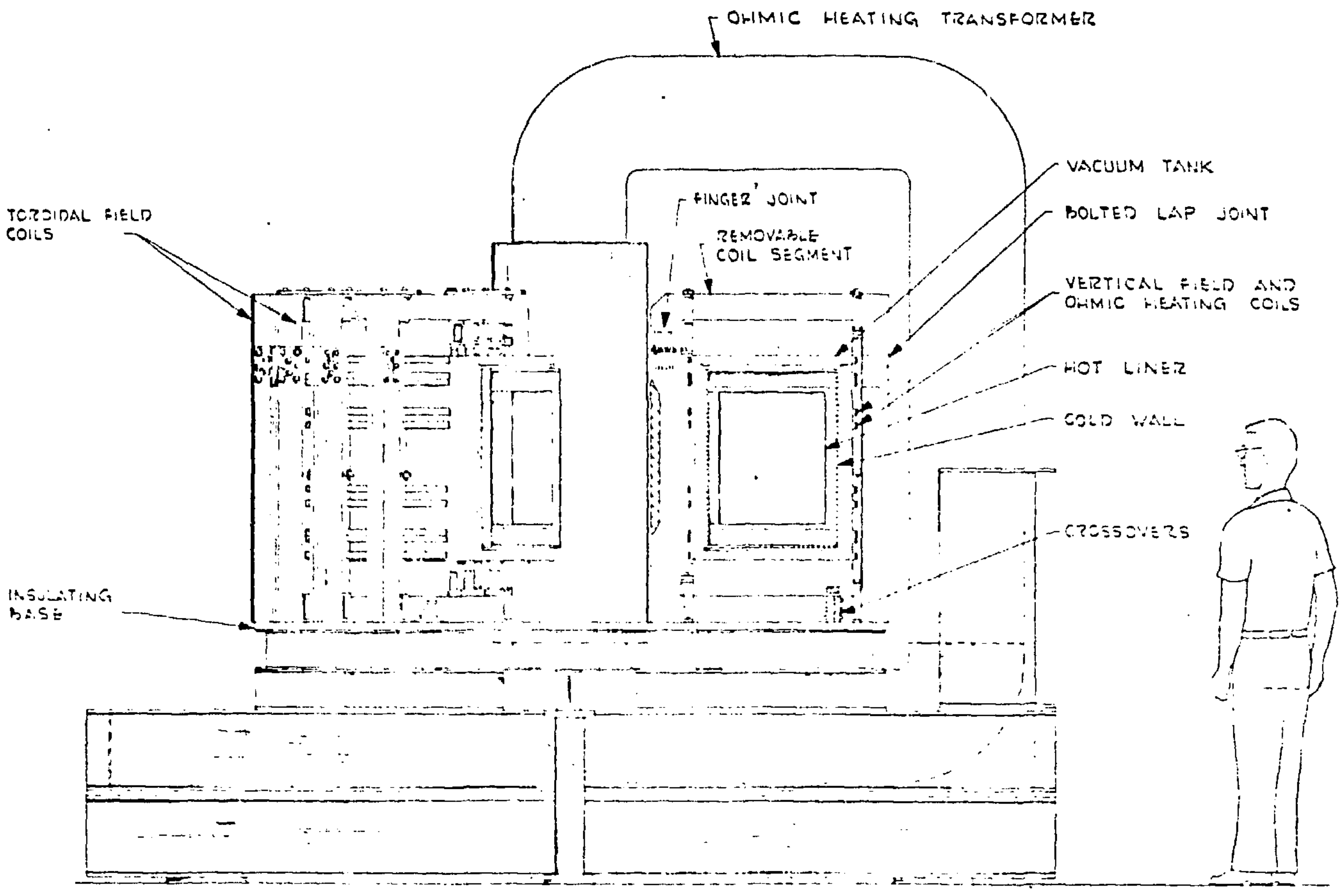


Fig. 2 ISX – Profile View

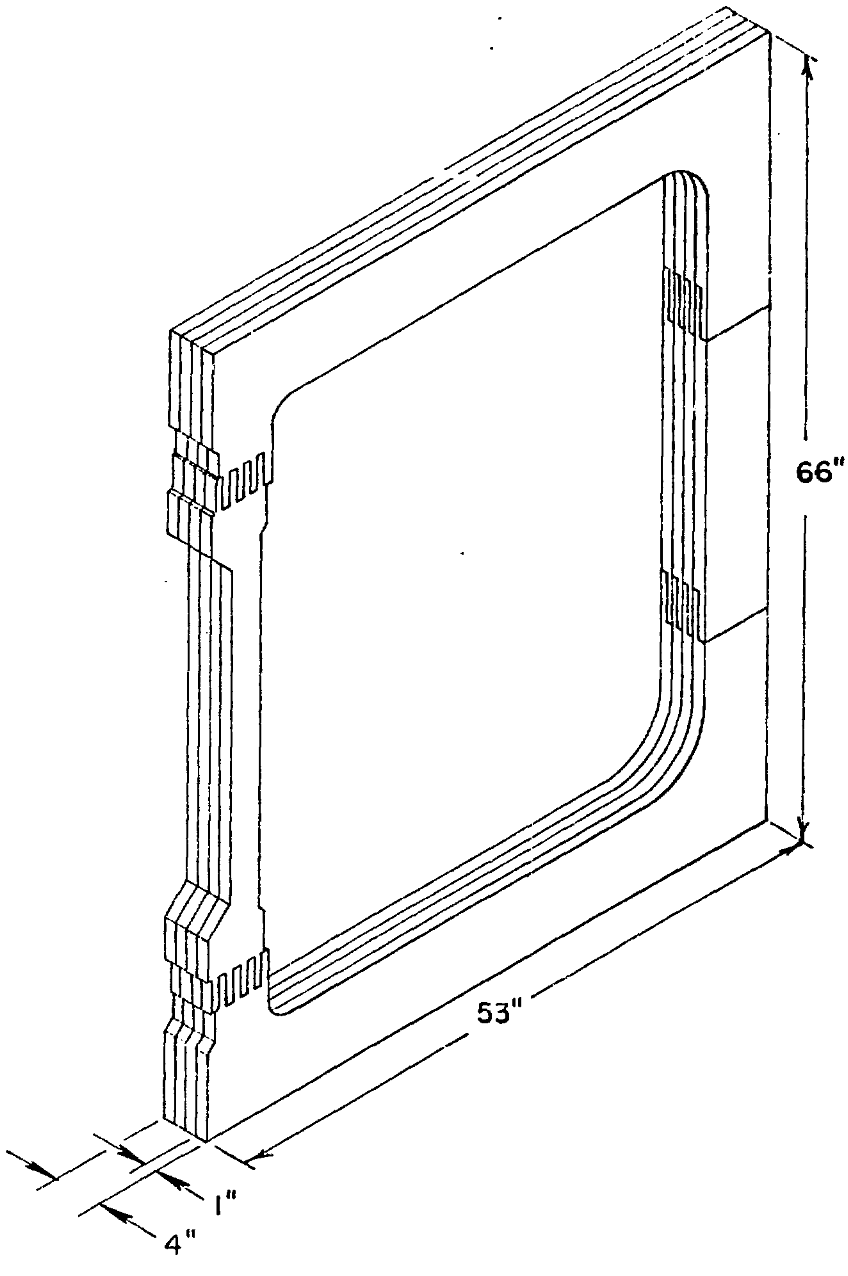


Fig. 3 TF COIL ASSEMBLY.

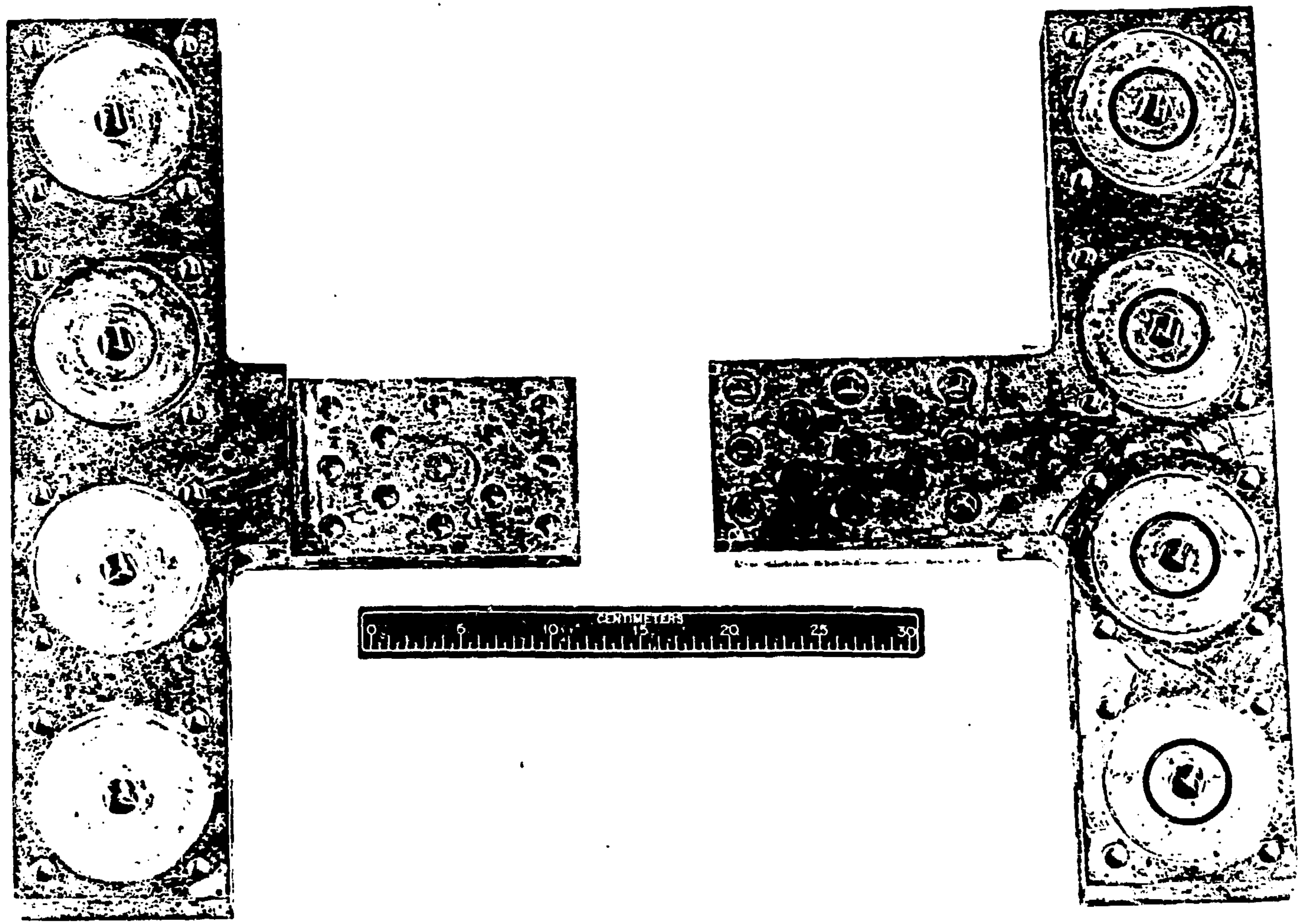


FIG. 4
LAP JOINT TEST SAMPLE

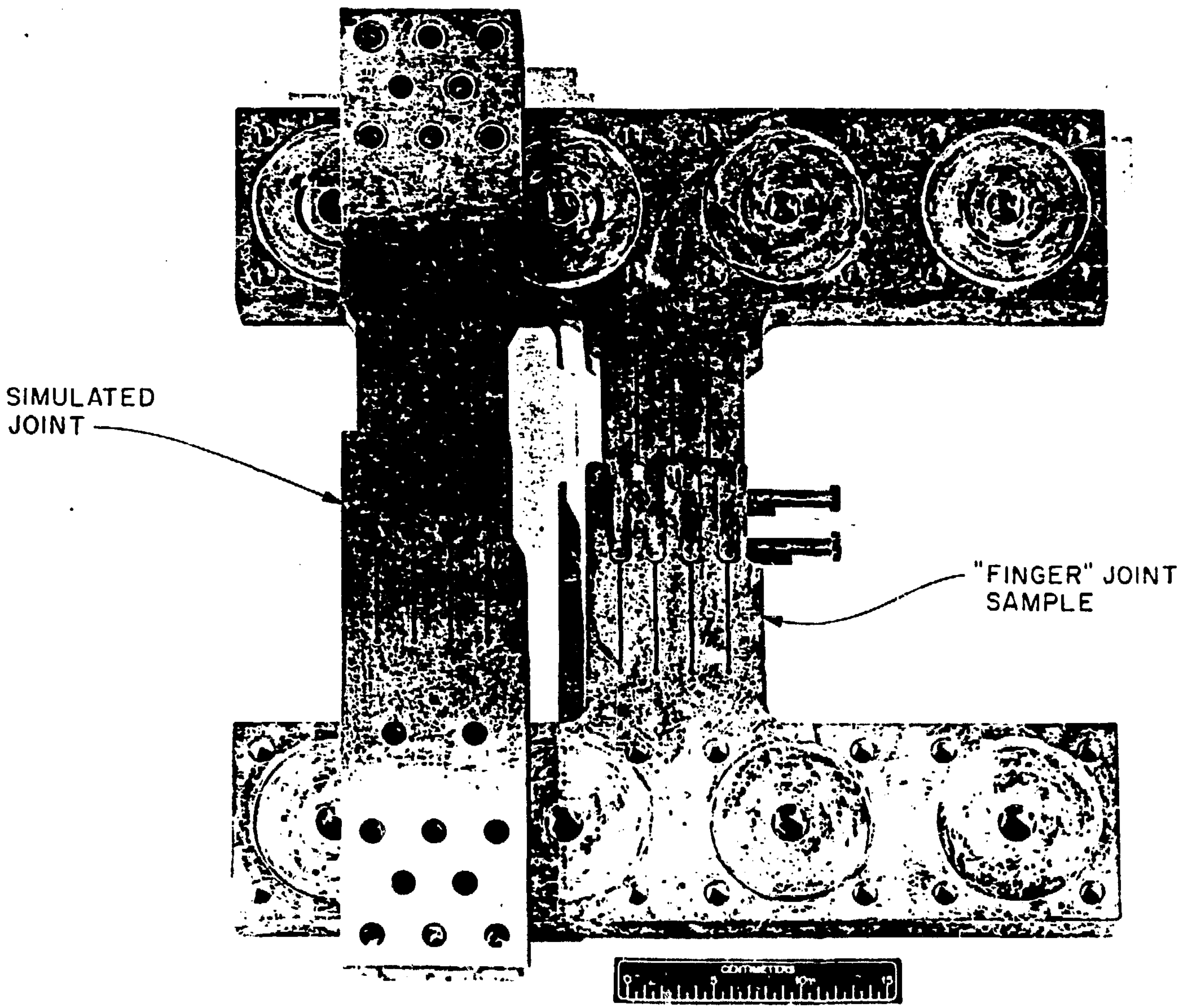
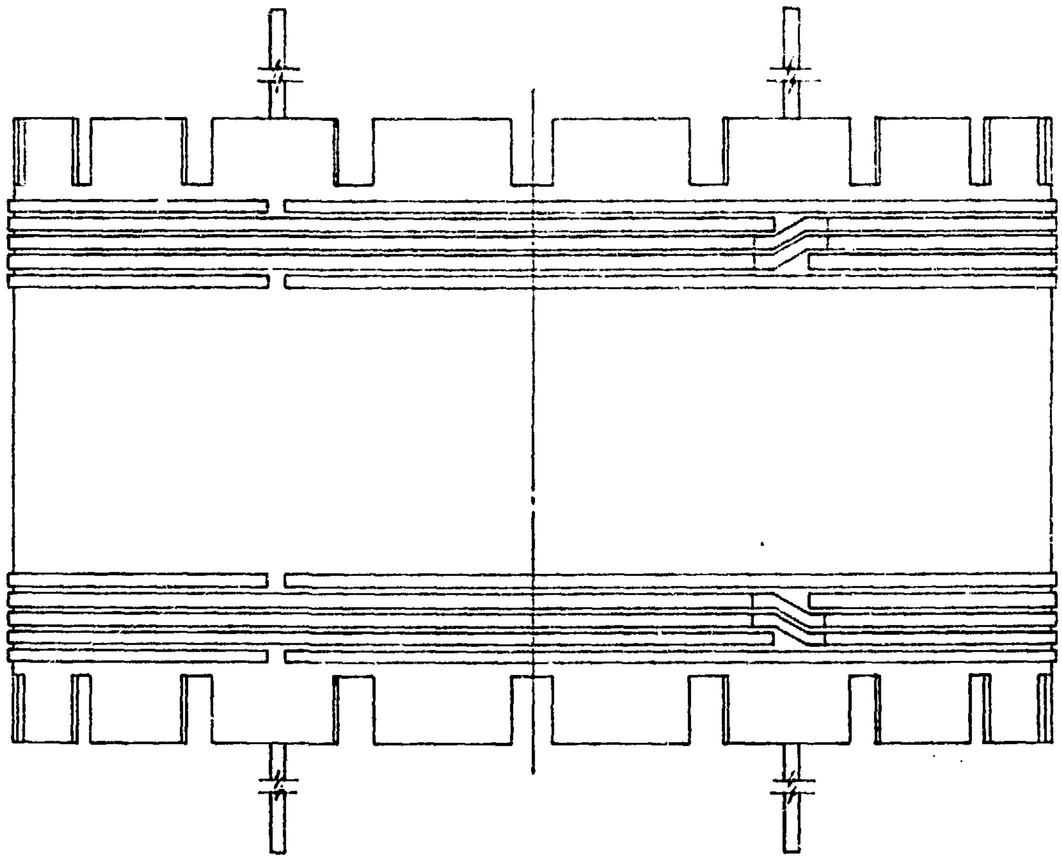


FIG. 5
FINGER JOINT TEST SAMPLE



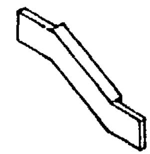
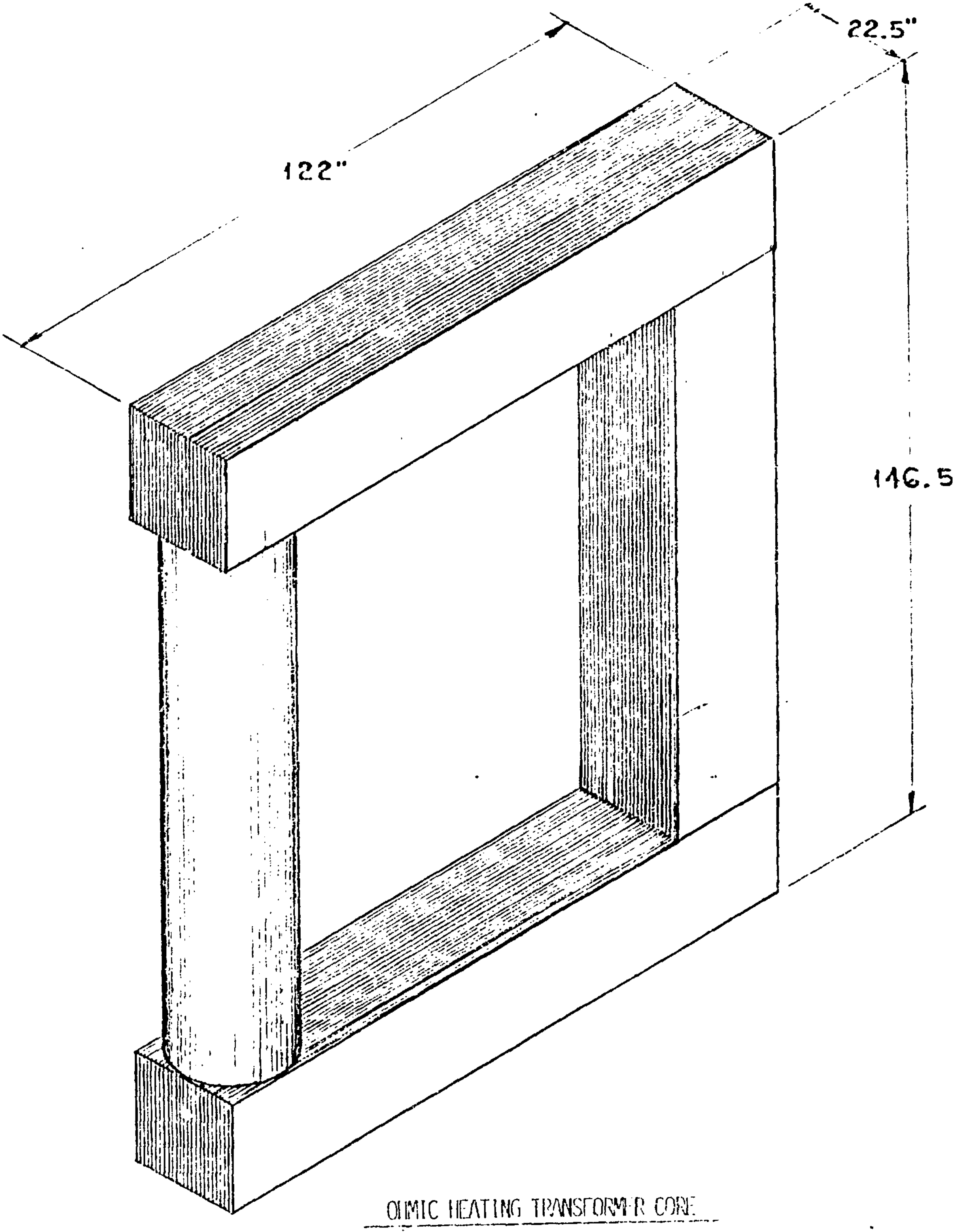


FIG. 6
TYPICAL OH & VF ASSEMBLY



OHMIC HEATING TRANSFORMER CORE

FIG. 7

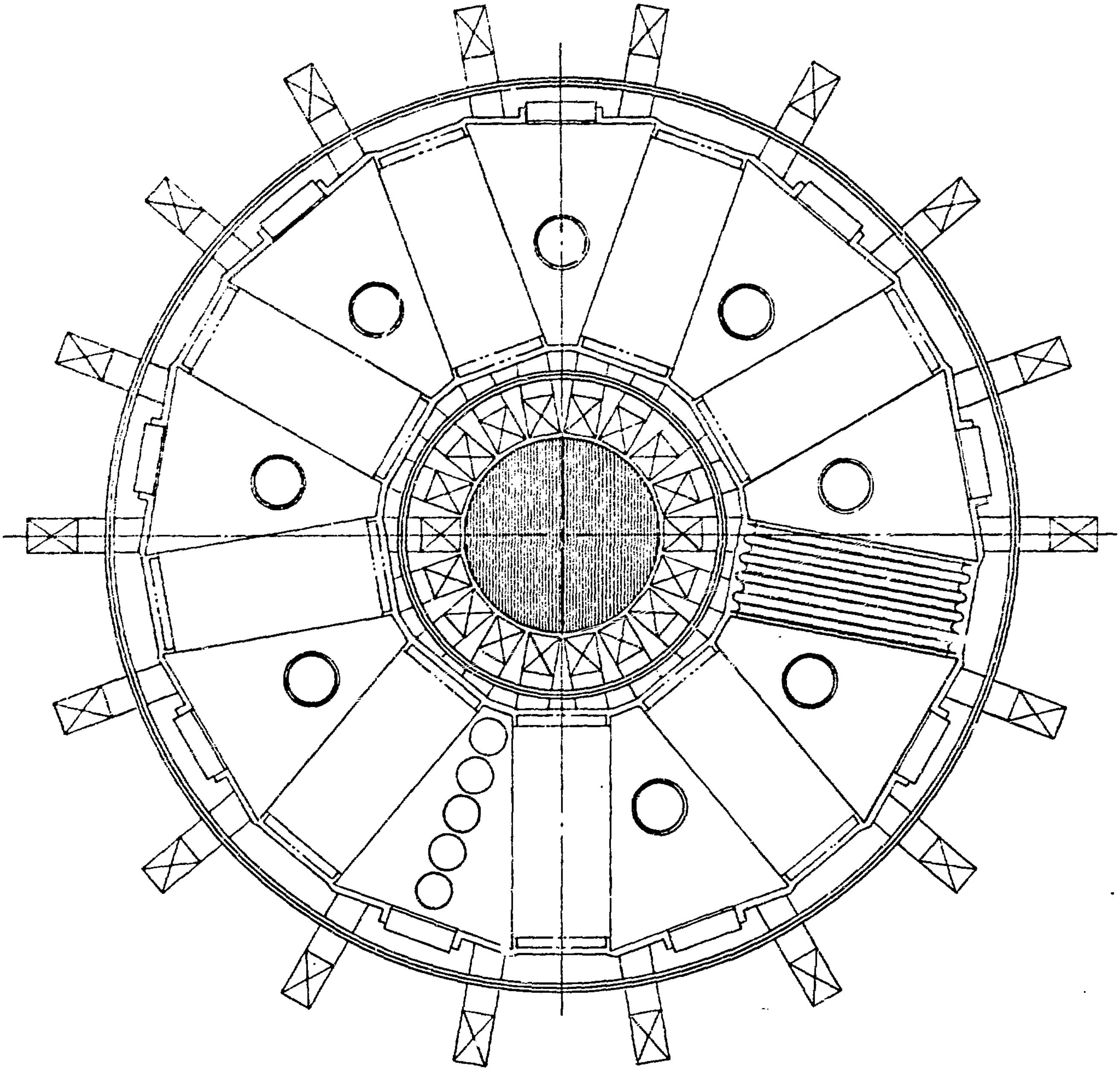


FIG. 8
LINER ASSEMBLY