LINAC TANK INSTALLATION AND TUNE-UP FOR 200 MEV LINAC*

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ABSTRACT

The installation and set-up procedures for each tank are detailed as well as test results to date. Included are "Q" measurements with and without stems, tuner bar calculation techniques, the bead perturbation system and results, projected power requirements for each tank and probe pick-up calibration. Tank fabrication and inspection procedures are outlined. The installation and alignment of tanks and drift tubes in the linac tunnel is described.

Part I - Mechanical

The 200 MeV Linac for the AGS Conversion, consists of nine (9) rf cavities. The following tabulation lists some parameters of general interest.

Tank	Number of Sections	Overall Length in.	Inside dia. in.	No.of cells	No. of stems per drift tube	Energy out MeV
1	2	293	37.378	56	1	10.4
2	3	748.73	36.346	60	3	37.5
3	3	650.65	35.291	35	4	66.2
4	3	656.85	35.291	29	4	92.6
5	3	613.53	34.110	24	4	116.5
6	3	611.99	34.476	22	4	139.0
7	3	623.19	34.476	21	4	160.5
8	3	625.08	34.476	20	4	181.0
9	3	619.43	34.476	19	4	200.3

The copper clad steel was purchased from Lukens Steel Company. It consisted of O.F.H.C. Copper to ASTM B-152-68 · 160" thick clad on to a carbon steel backing ASTM A285 grade B · 750" thick.

Lukens clad steel is a composite plate consisting of copper and steel which have been mill rolled under heat and pressure until they are integrally bonded over their entire interface.

In the manufacture of copper clad steel plates, a sandwich of: steel to copper, to copper, to steel is made with a silicone parting compound painted on the copper to copper interface. The assembly is then seal welded around its entire periphery and the

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sealed assembly is then heated and rolled to obtain the required plate dimensions. This method ensures a reliable metallurgical bond over the entire mating surfaces. During the fabrication of the tanks, at no time was there any evidence of a poor copper to steel bond.

Fabrication

The fabrication of the tanks was carried out by the Youngstown Welding and Engineering Co., Ltd., Ohio.

Manufacturing sequence:

1. The plates were inspected for defects, marked out and trimmed to required lengths. The outer edges were then radiused in a hydraulic brake, an essential step prior to rolling.
2. The plate was formed into a cylinder in a rolling mill (See Fig. 1).
3. The cylinder was tack-welded along the seam, internally braced with screw jacks and externally braced longitudinally with two 'I' beams. (See Figs. 2 and 3.)
4. The "J" groove weld preparation was then cut in a planing machine. (See Fig. 4.)
5. The external bracing was removed and the seam tack-welded, frequent dimensional checks on the circumference being made throughout this operation.
6. The steel weld was now completed. (See Fig. 5.) Details as follows.

   Arcosarc 70 - Flux core wire was used in a semi-automatic wire feed process during which time several passes were required.

   Composition - Of welding wire Arcosarc 70. AWS ASTM A-559-65T.

   Carbon - .05 min., 0.09 max.

   Manganese - .075 min., 1.10 max.

   Silicon - .30 min., 0.45 max.

   Sulphur - min., 0.03 max.
7. The copper was then ground away, beneath the steel weld about 3/16" wide and the copper weld completed in one pass-details as follows.

   Composition of welding wire Cupronar 900. ASTM B225-57T.

   Copper - 98.0 min.

   Tin - 1.0

   Silicon - 0.5

   Phosphorous - 0.15

   Manganese - 0.5

   Preheating at the weld of from 500 to 600°F was found to be essential. This was accomplished by placing a number of gas torches below the weld area. The iron migration to the copper was kept below .1%. A macrograph of a weld sample is shown in Fig. 6.

   The welded cylinder was then returned to the rolling mill for accurate rounding, the following tolerances being specified:

Inside circumference: - Nom. i.d. x π $^{+\,0.125''}_{-\,0.000''}$

Roundness: - Inside diameter ± 1/4" to within 24" of ends.
± 1/16" final 6" of tank ends.

The combined roundness and straightness tolerance was defined as follows: No point on the inner tank walls, as measured from the theoretical center line, shall deviate more than 1/4" from the nominal inner tank radius.

8. End flanges, cooling channels, tuner, vacuum and rf ports were welded in place at this point. (See Fig. 7.)
9. Machining was then carried out on all ports and end flanges to allow positioning of copper inserts.
10. All copper inserts and foot brackets were next welded in position .
11. The outside surfaces of the tanks were then sand blasted.
12. All ports were closed and an initial vacuum check completed.
13. A stress relieving operation was then carried out in a gas fired oven, a temperature of 1150°F being maintained for a period of two hours. During the stress relieving cycle, the inside of the tanks were purged with an Argon gas flow of approximately 1 cubic ft./min. (See Fig. 8.)
14. Following sand blasting, all finish machining operations were completed. (See Fig. 9.)
15. The tanks were then inspected on a large portage layout table, (See Fig. 10.). The tolerances requested were as follows:
    Overall length ± .005". Parallelism of end flanges within .005".
    Drift tube hole positions ± .005".
16. Abrasive flap wheels were used to remove any surface irregularities on the inside copper surfaces.
17. The copper surfaces were then liquid honed, (See Fig. 11) using water pressure at 100 psi combined with a sand mixture having the following composition.
    Grit sizes - 40 - 50 - 70 - 100 - 14 - 20
    Proportion - 8 - 4.0 - 15 - 33 - 25 - 12
18. A final vacuum check was carried out prior to painting and shipping.

Tank Polishing and Preliminary Assembly

On arrival at BNL the tank sections were polished as follows: Abrasive flap wheels were used; two passes of 80 grit, one vertical and one horizontal, followed by two passes at 120, one at 180 and 240; finally two passes were made, using 320 grit wheels. (See Fig. 12 - Note: Tank rotating fixture.)

Approximate μ inch values as measured:

After liquid honing	100 - 200
After polishing	40 - 60.

After polishing, the unloaded "Q" measurements were made giving an average value of 84,000, in the operating TM010 mode.

The tuner bar was then attached to the tank. The tuner bars consisted of square sections of solid copper bar, 3" x 3" square, maximum and 2" x 2" square, minimum size being utilized. Spring ring grooves were cut into the base of the bar to give rf contact with the tank walls.

Strongbacks and drift tubes were installed and roughly aligned, (See Fig. 13) dummy stems installed, end covers attached and "Q" and resonance checks completed, details of which are given in another part of this paper. The tuner bars were then removed and cut to the desired thickness, replaced in the tanks and final resonance checks completed.

Installation and Alignment

A beam line was brought out from the A.G.S. and three spherical targets were set up for use as a reference center line. The tank sections were placed on their footings, bolted together and aligned, jig plates being mounted at both ends with wire targets. To align the tanks at the joints, a drift tube was aligned relative to the tank centerline and a wire target positioned inside the bore tube.

Figure 14 shows a Farran telescope set up on the LEBT line with a 45° eyepiece for aligning Tanks 1 and 2. The tanks were aligned to ± .010" by means of vertical and lateral adjusting jacks and screws.

The next step was the alignment of the strongbacks, which was achieved by placing a scale above each supporting post and measuring the relative heights, using a precision Wild level. The holding down screws were torqued to 50 lbs./ft. prior to taking any readings. The shims between the posts and strongbacks (as shown in Fig. 17) were then ground to the required thickness, replaced, the bolts torqued and a second check for level completed. (See Fig. 15.)

To align the drift tubes two methods were employed. The Tank 1 drift tubes varied in length from 2 to 6 inches, making targeting at both ends impractical, so two location holes were drilled in the face of the drift tube, accurately located on the magnetic centerline of the quadrupole. These two holes were then used to locate a target jig which consisted of a wire target plus a reflecting optical flat. (See Fig. 16.) A telescope was used in conjunction with an Auto-collimator to view this target. The remainder of the drift tubes in Tanks 2 to 9 were of sufficient length to enable targets to be placed at both ends of the drift tube bores, which were machined locally to be concentric with the magnetic centerline.

To align a drift tube the following procedure was adopted:

The heights of the front and rear target were levelled by placing a brass tilt shim between the strongback and the stem supporting bracket so that the targets were now on a level with each other, but not necessarily at the correct beam height. A "C" shim between the stem bracket and the top side of a brazed collar on the stem (as shown in Fig. 17) was then ground to bring the drift tube to the correct beam height within ± .002". When the two preceding steps had been completed on all drift tubes, a K & E optical tooling tape was positioned in the tank ready for final alignment.

On final alignment both targets were placed on line and at the same time the axial position of the drift tube was established to within ± .005", using an alignment jig attached to a viewing microscope to read the tape. (See Fig. 18.)

The rigid dummy stems were then installed, a careful check being kept on the drift tube alignment. Finally the flexible dummy stems which had no effect on the positional accuracy of the drift tubes were installed. (See Fig. 19.)

The half drift tubes were then assembled to the end covers (See Fig.s 20 & 21). The covers were bolted to the tanks, targets were placed inside the half drift tube bore holes and the half drift tubes were aligned by moving the whole end plate. The end plates were then secured with bolts and taper pins were fitted to ensure accurate subsequent relocation. The tank was ready at this point for bead pulling.

The end covers were of three types:

Between Tanks 1 and 2 the space available was only 8-5/8". Therefore a rigid transition section was designed, which consisted of the last half cell of Tank 1B, the drift space and the first half cell of Tank 2, having an overall length of 17.320". Between Tanks 2 to 3 and Tanks 3 to 4 end caps were designed consisting of the end half cells of the adjacent tanks. This approach practically doubled the effective space between tanks during installation and alignment which proved extremely valuable. The remaining drift spaces were 100 cm (39.370") long and as this was considered to be adequate working space, the end covers consisted of flat plates. The rf surfaces on all end plates were copper plated, the copper deposit being a minimum of .004" thick before polishing and polished using abrasive flap wheels.

The copper plugs on the end plates as shown in Fig. 21 were to compensate for the absence of dummy stems on the half drift tubes. These plugs were only found essential for Tanks 6, 7, 8 and 9.

Figure 22 shows the tunnel as it appeared on August 20, 1970 with Tanks 1 through 7 set up and aligned.

Part II - Electrical

Preliminary "Q" Measurements

The sequence of electrical checkout is shown in Fig. 23. The initial problem encountered was low "Q" values for the unloaded tank sections. After extensive measurements it was concluded that the degradation of "Q" was due to surface roughness. The causes being twofold, namely (a) large pits in the copper clad plates which occurred during the rolling process; (b) liquid honing.

To increase the "Q" values it became necessary to polish each tank section and remeasure "Q". A typical run on a tank section is as follows:

"Q" before liquid honing	80.2^K
after liquid honing	75.2^K
rough polish (120 grit)	81.8^K

polish with 180 grit	82.0^K
polish with 240 grit	84.2^K
polish with 320 grit	85.2^K
polish with 400 grit	85.3^K

Each pass in the tank takes eight man-hours and on the average, a total of five passes are required. It was found that at a surface roughness better than 30 micro-inches no further improvement in "Q" was apparent.

After the drift tubes are installed, the "Q" of each section is checked. A repeat measurement is made after the dummy stems are inserted. The results to date are as follows.

"Q" X 1000

Tank Section	Empty Tank	Drift Tube	Tuner Bar Drift Tube And Dummy Stem	Final Tank
2A	84.2	--	47.75	
2B	84.5	--	50.2	
2C	82.0	--	41.1	
3A	82.0	57.9	50.6	50
3B	83.5^K	56.8	49.2	50
3C	80	58.8	49.6	50
4A	86.6	68.2	48.3	50
4B	85.1	58.1	49.2	50
4C	83.7	54.8	44.9	50
5A	87.5	49.1	41.3	43
5B	81.2	52.0	42.0	43
5C	82.7	46.7	41.0	43
6A	84.4	47.6	40.0	43
6B	84.7	50.1	41.8	
6C	85.0	46.5	39.9	
7A	86.9	46.0	40.0	
7B	84.7	47.5	40.5	
7C	81.6	45.4	39.7	
8A	86.8	--	38.3	
8B	81.9	--	41.3	
8C	81.7	--	40.2	
9A	87.1	--	41.1	
9B	82.6	--	--	

Tuner Bar

Initially the "Q" values are measured and the frequency is set for each tank section separately. A tank section is one-third of a cavity. Rectangular copper bars running the length of the tank are used to set frequency of each section. These bars are mounted on the cavity walls. The middle tank section is terminated with two copper plates. The end cover, containing a half drift tube and a copper plate are used to terminate the two end tank sections. Frequency is measured with the uncut bar in and then repeated with the bar out. The bar size is determined as follows:

$$A_{EFF(X)} = (A_{EFF(K)}) \frac{\Delta fD}{\Delta fK}$$

where

A_{EFF} = effective cross sectional area of a bar on frequency perturbation.

$A_{EFF(X)}$ = effective area of bar required.

$A_{EFF(K)}$ = effective area of uncut bar.

ΔfD = desired frequency perturbation.

ΔfK = measured frequency perturbation of uncut bar.

Once, $A_{EFF(X)}$, has been determined the bar is cut to the required height. The relationship between the "effective area" and bar height is determined as follows. (See Fig. 24.)

Since the bar is placed in a section of the cavity where only 'H' (magnetic field) exists and this field is perpendicular to the longitudinal plane of the bar, the change in frequency is proportional to the "effective volume", V_{EFF}, removed from the cavity or $\Delta f \alpha (V_{EFF}) = (\text{length})(A_{EFF})$.

The "effective area" of an infinitesimally thin plate (See Fig. 24C) is equal to the area of a semi-circle inscribed by its height or

$$A_{EFF} = \pi \frac{h^2}{4} \quad \text{for a thin plate.}$$

From this it can be concluded that the effective area of a bar is given by:

$$A_{EFF} = \frac{\pi h^2}{2} + (h)\ (W)$$

where h = height of bar

W = width of bar.

Since a thin plate of 2.55 inches height produces the same frequency change as a 2" x 2" bar, it can be concluded that a thin plate is more efficient than a fat bar. Since these bars are 10 feet in length, they are awkward to handle and much more difficult to mount on the tank walls.

End Plate Correction

After each tank section has been fitted with tuning bars, it is moved to the Linac Building where all three sections are joined forming a full tank. Once the final drift tube alignment is completed, initial bead perturbation measurements are performed to check tank flatness (uniform E_{AVE}/CELL).

Tests on Tank 5 indicated that the half drift tubes on the end covers wanted to be moved out from their theoretical values (increase gap). The field distribution took the shape of Fig. 25. It was concluded that this was due to the absence of half drift tube stems and dummy stems on the end plates, causing the first and last cells in each tank to be low in frequency. This effect is increasingly pronounced in higher energy tanks, since the number of cells are decreasing and stem sizes are increasing. In Tanks 6 through 9, four cylindrical copper perturbers are installed on the end covers (See Fig. 21). Since these perturbers have to be in place before the tuning bar is cut they are installed before the tank section is sent to the Linac Building. These perturbers are sized so that a flat field pattern is observed by 'H' field pick-up probes on the tank walls. When the cut tuning bar is in place, slight adjustments are made in the half cell gap to re-adjust for a flat field.

Bead Pulling Measurements

The bead pulling equipment is shown in Figure 26. The pulley moving the bead along the tank length is sized such that the shaft encoder position readout is in inches. By use of the push button keyboard the operator punches in a preset value where the bead is to stop. When the bi-directional counter value agrees with the preset value the digital comparator provides a motor stop output. Two six-digit nixie readouts indicate the preset position and the actual position of the bead. A two-decade counter running in parallel with the main bi-directional counter provides gate signals to the HP frequency indicator at a rate determined by the thumbwheel selector box. By use of this system, the operator can run the bead in either direction from one cell to another stopping each time in the middle of the drift tube. The operator starts at the first cell and proceeds through to the last cell.

As the bead is run through the cell, the frequency counter is gated and provides a readout of instantaneous frequency of the oscillating tank, which is recorded on a tape. When the bead run has been completed, the tape is taken to the computer center where the mid-gap electric field, EMG, of each cell is determined by the change in frequency when the bead is in the middle of the gap. In Tanks 1 and 2, the computer picks out the minimum frequency in a cell and determines the mid-gap Δ frequency. (See Fig. 27.) In the higher energy tanks, the value of the maximum frequency between the two minimums is determined. The frequencies recorded entering and leaving a cell are averaged to compensate for frequency drift due to temperature variations.

$$E_{M.G.} = k \sqrt{\Delta fMG}$$

$$E_0 = K\, E_{MG}$$

where E_{MG} = Mid-Gap Electric Field

E_0 = Average Electric Field Through Cell.

K = Pre-calculated constant for each cell which is determined by drift tube and cell dimensions.

The computer converts the E_{MG} values to E_0 values for each cell. These E_0 values are then plotted to determine the field flatness.

After all necessary adjustments to achieve a flat electric field have been made, the slug tuners, which mount on the linac tank walls, are cut to the necessary size. The shims which determine the end cell gap lengths are also cut. A final bead run is performed after the tuning slugs and shims are returned. In addition to the fixed length slug tuners, each tank has seven variable slug tuners. One of these variable tuners is motor driven for small frequency corrections during operations.

Pickup Probe Calibration

The pickup probes on the tank walls are adjusted for 20 watts pickup when the linac tank is at operating gradient. These probes are calibrated with the use of a HP network analyzer. The pickup loop itself is housed on the air side of a ceramic cup. The printed circuit board loop is housed in a slitted copper cup that provides 'E' field shielding.

Fig 1. Tank cylinder in rolling mill.

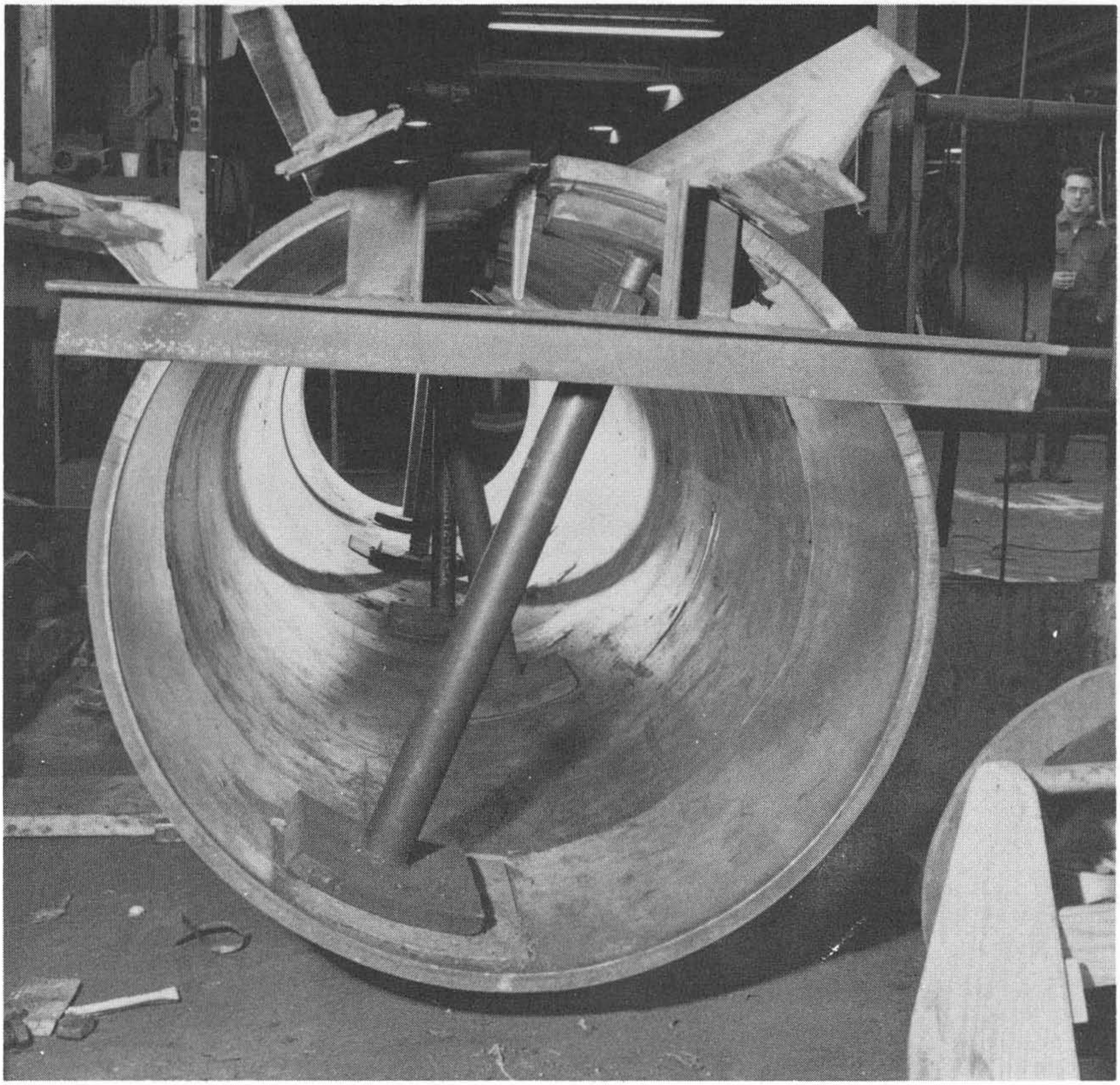


Fig. 2. Tank cylinder braced ready for cutting "J" groove.

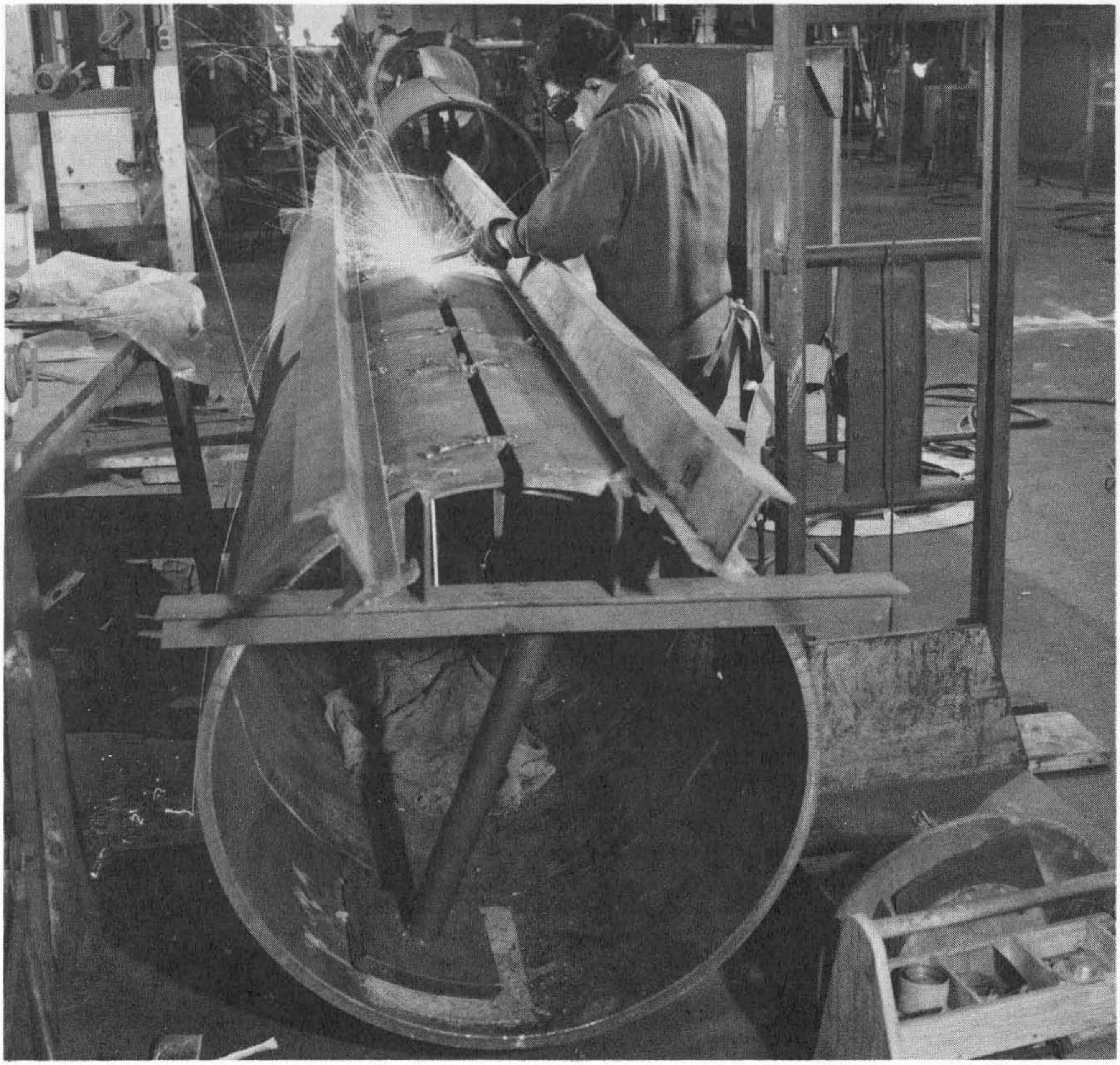


Fig. 3. Tack welding seam prior to cutting "J" groove.

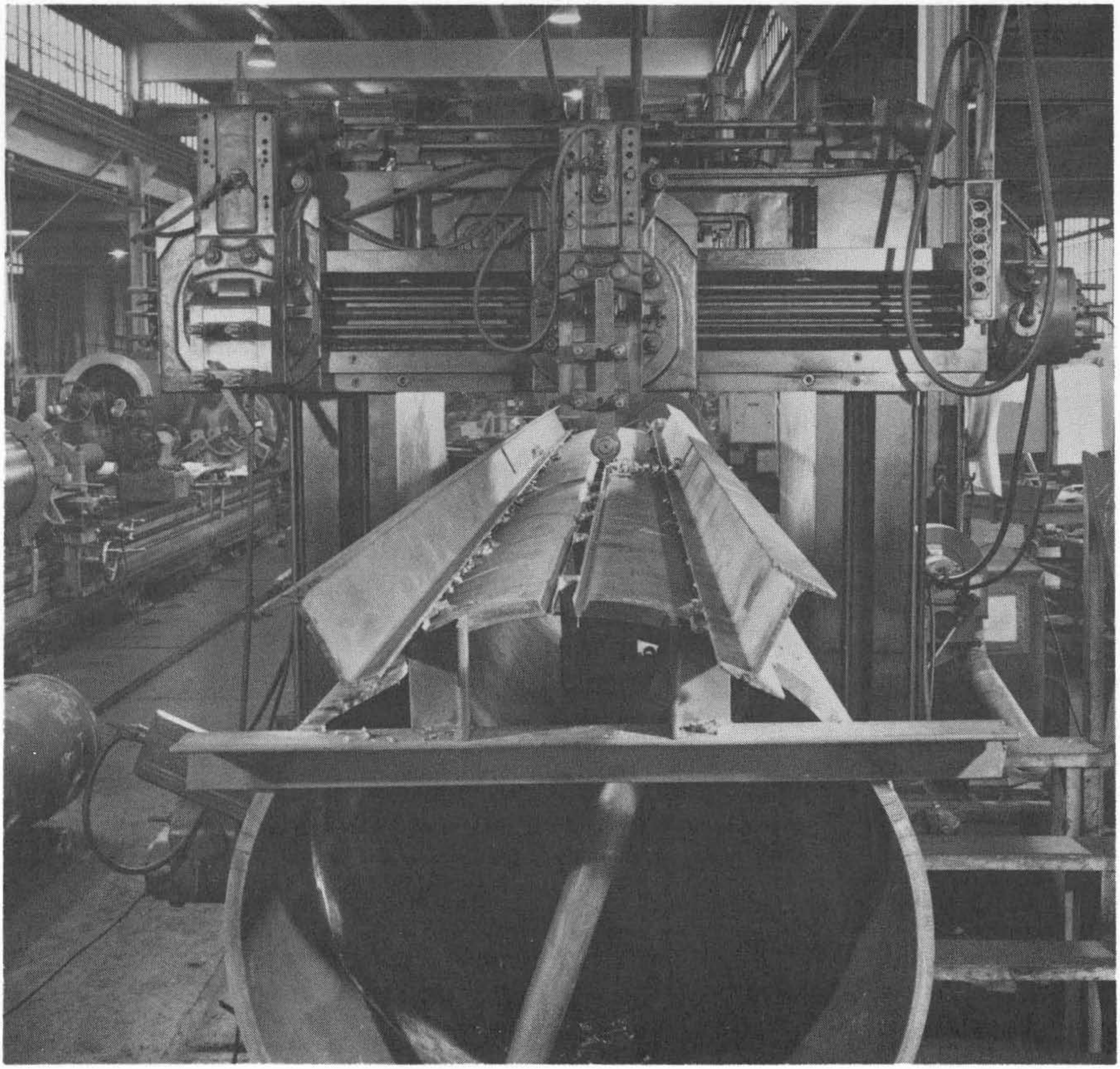


Fig. 4. Cutting "J" groove.

Fig. 5. Steel seam being welded.

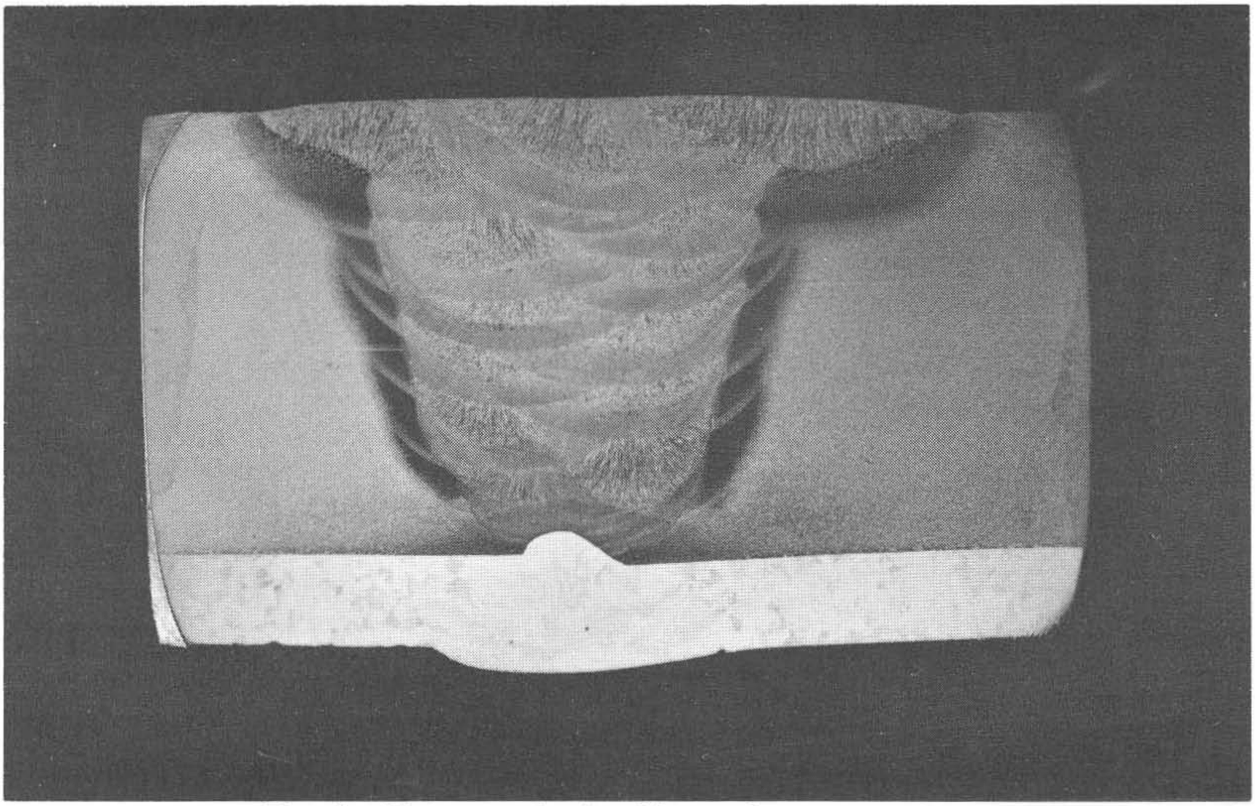


Fig. 6. Macrograph of weld sample cross section.

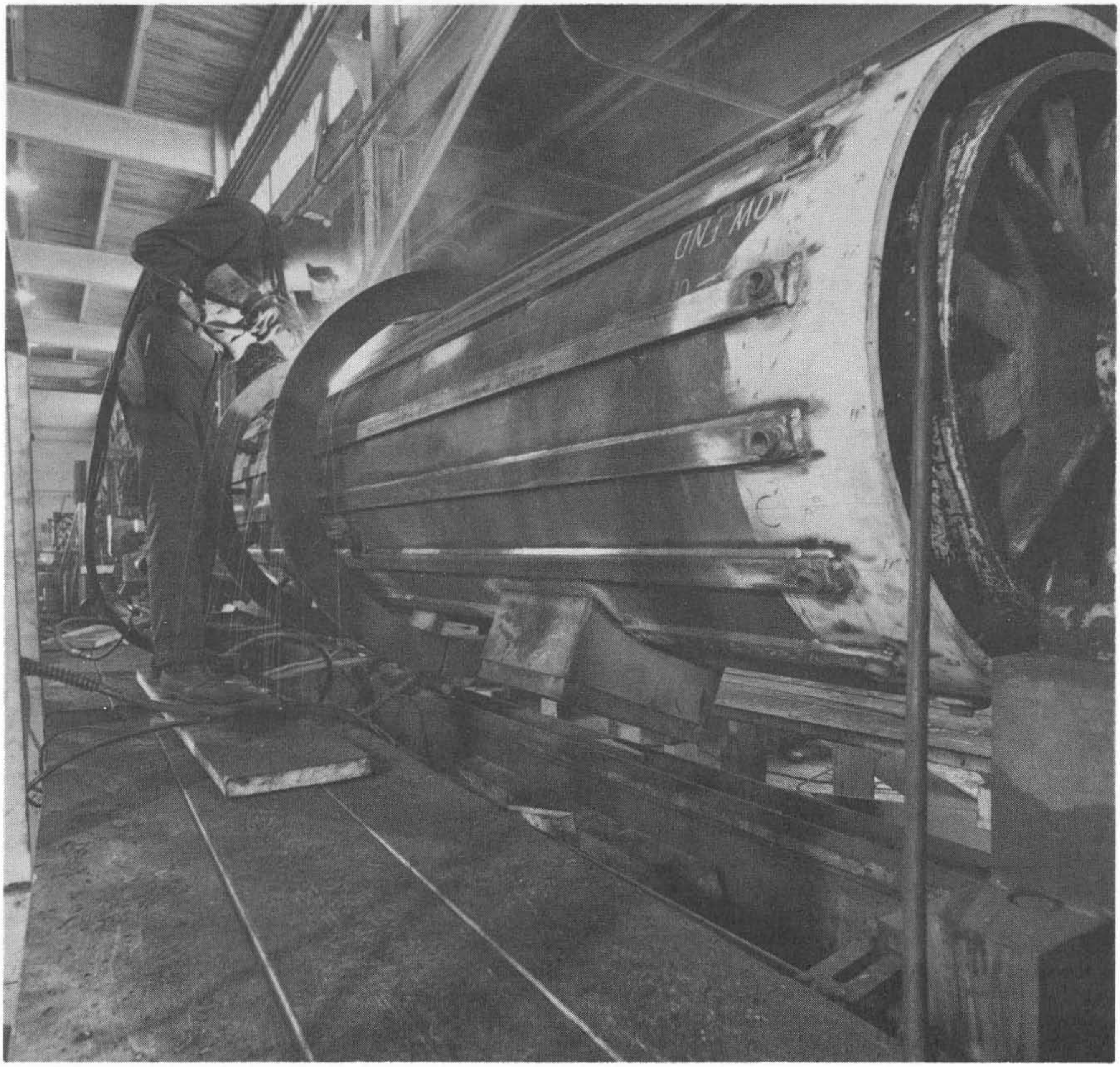


Fig. 7. Welding cooling channels in position.

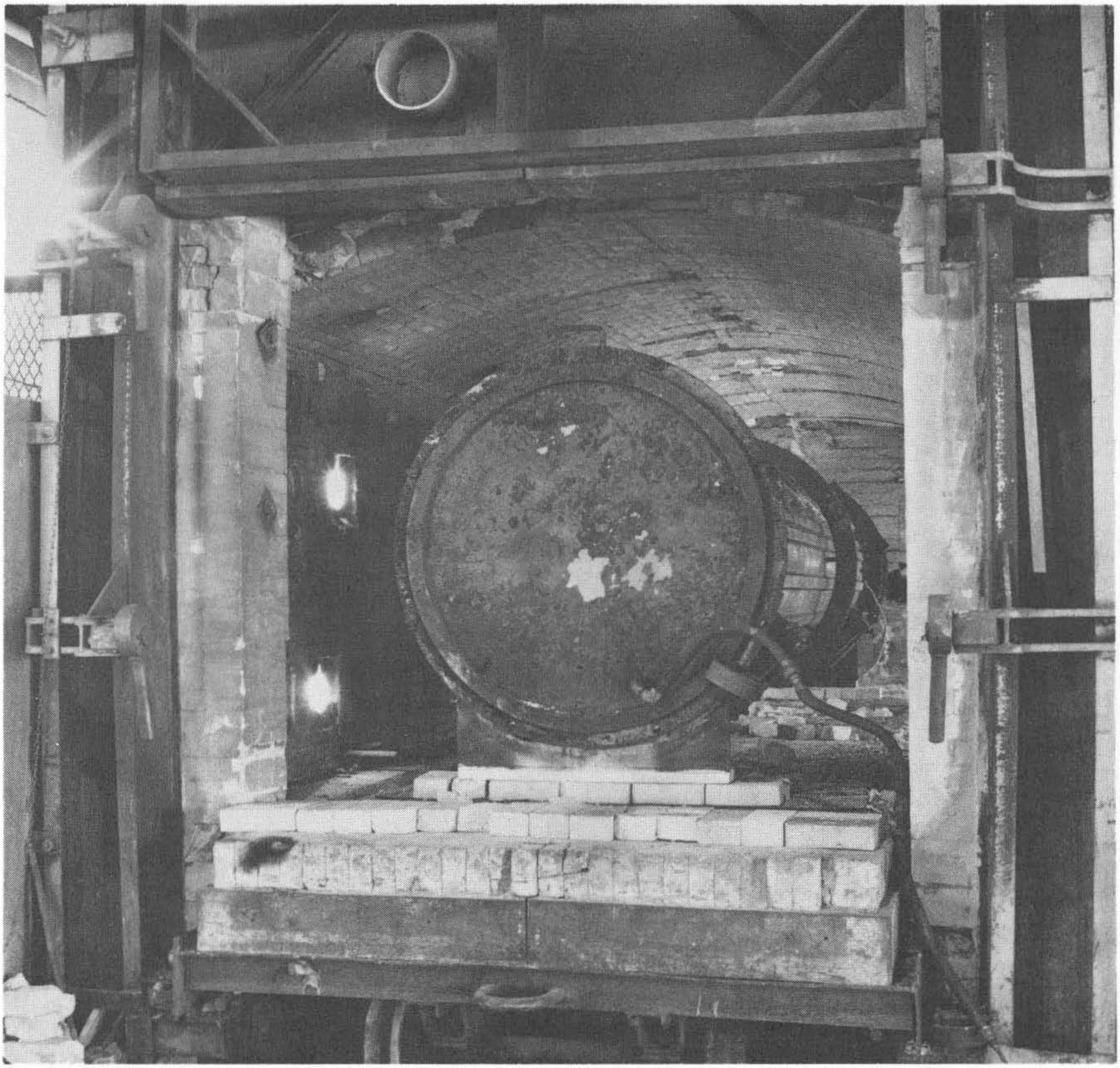


Fig. 8. Stress relieving in gas-fired furnace.

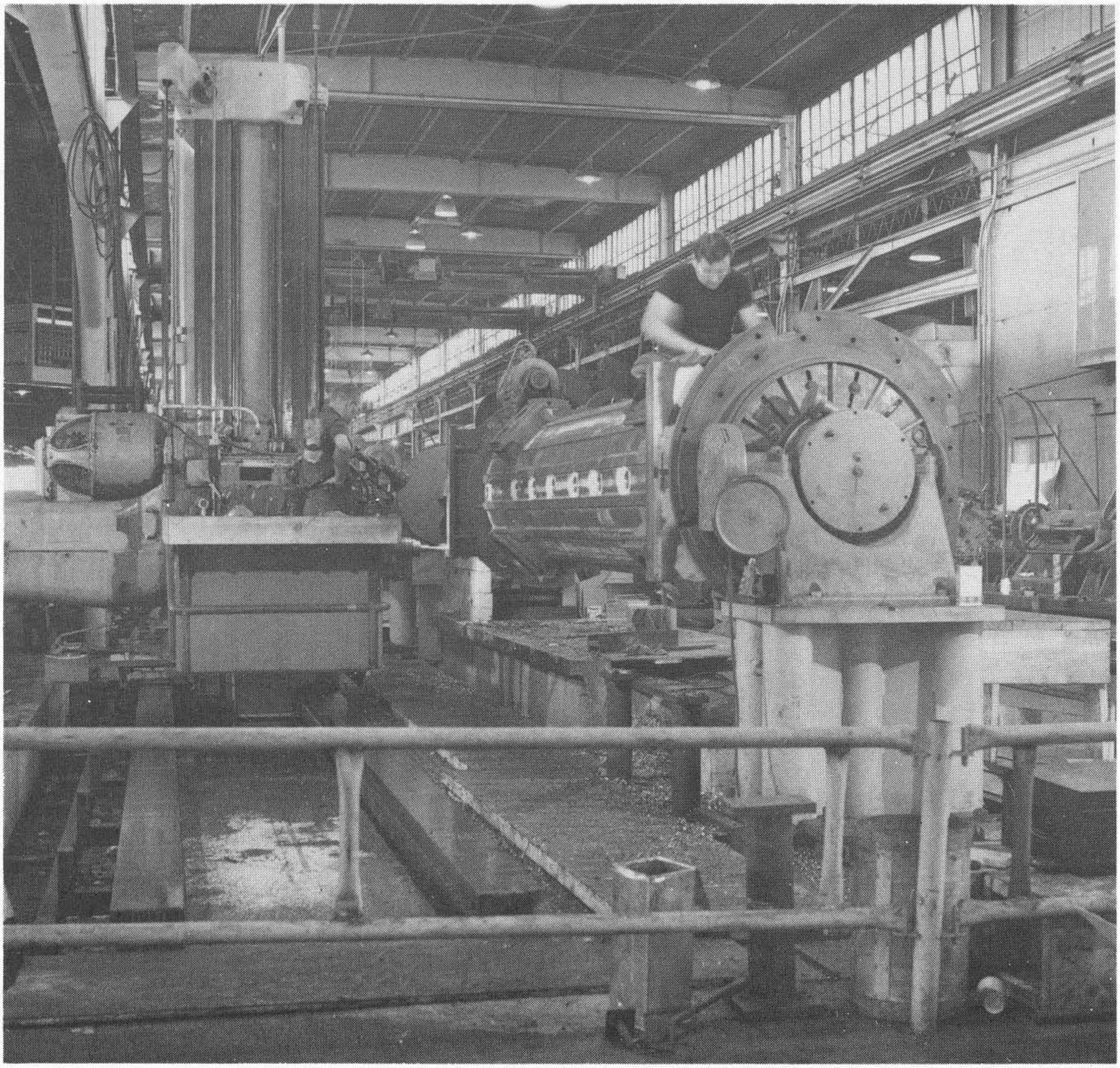


Fig. 9. Finish machining in 6-in. horizontal milling machine.

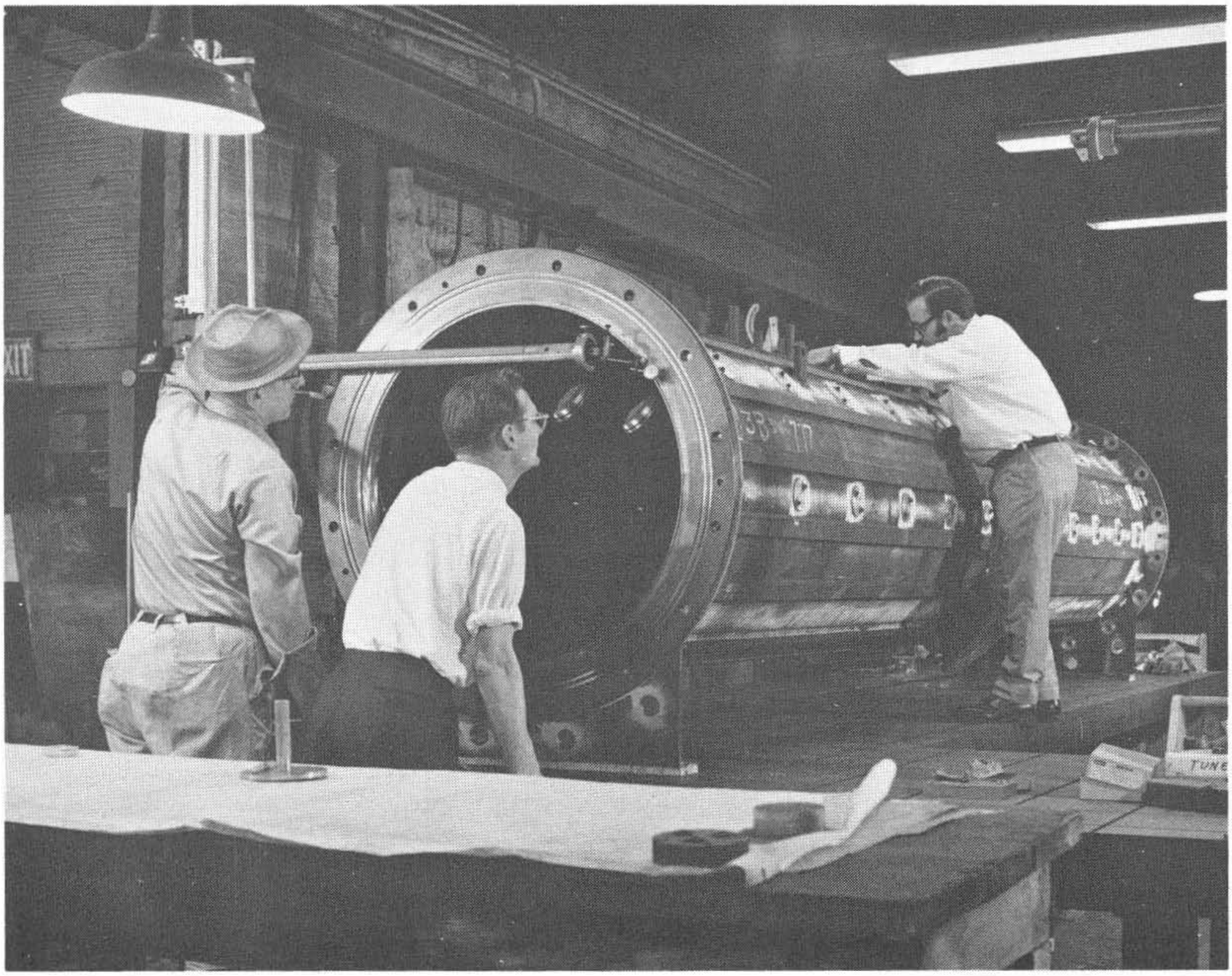


Fig. 10. Inspection of tank section on portage machine.

Fig. 11. Liquid honing.

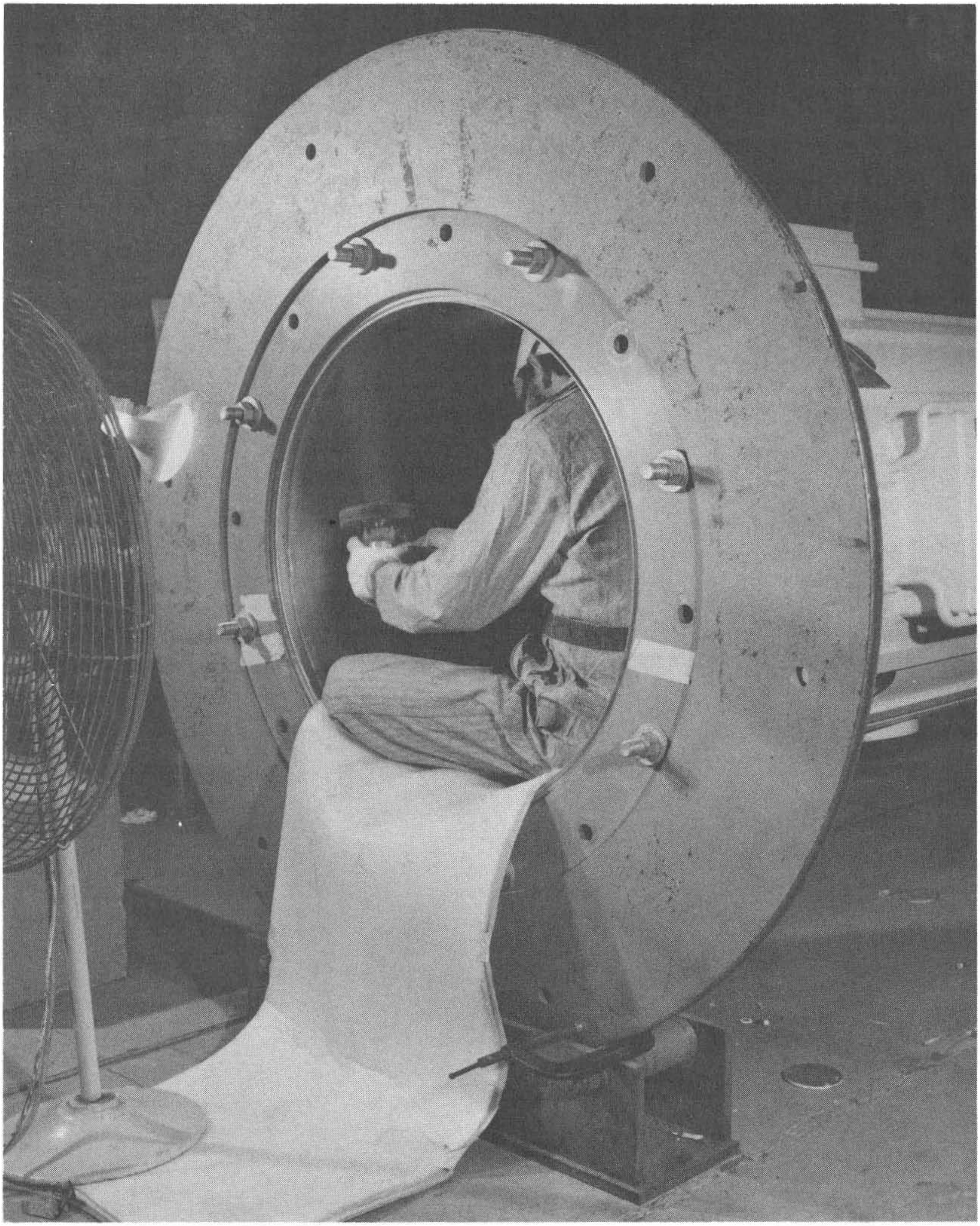


Fig. 12. Tank polishing.

Fig. 13. Drift-tube installation.

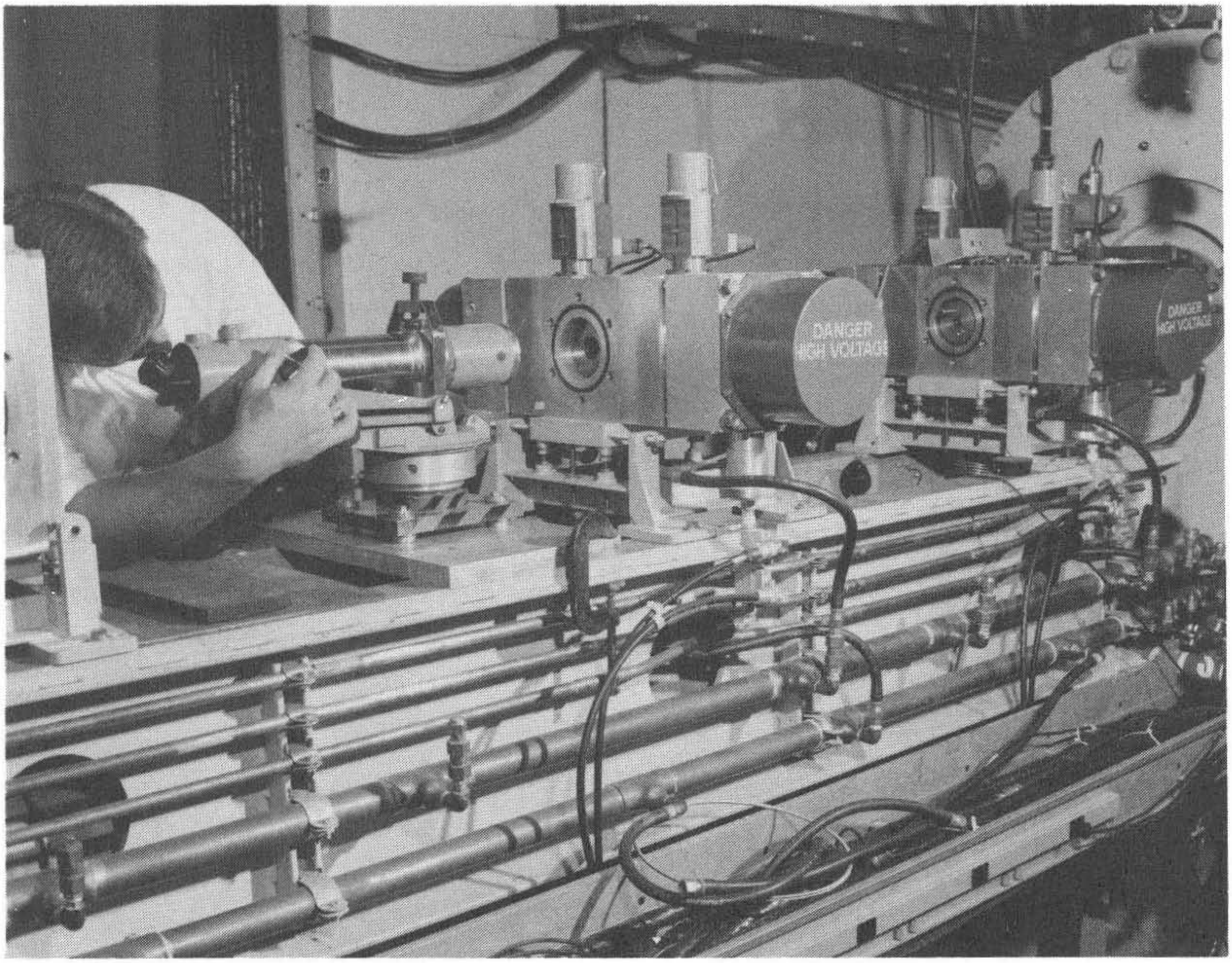


Fig. 14. Farran telescope mounted on L. E. B. T.

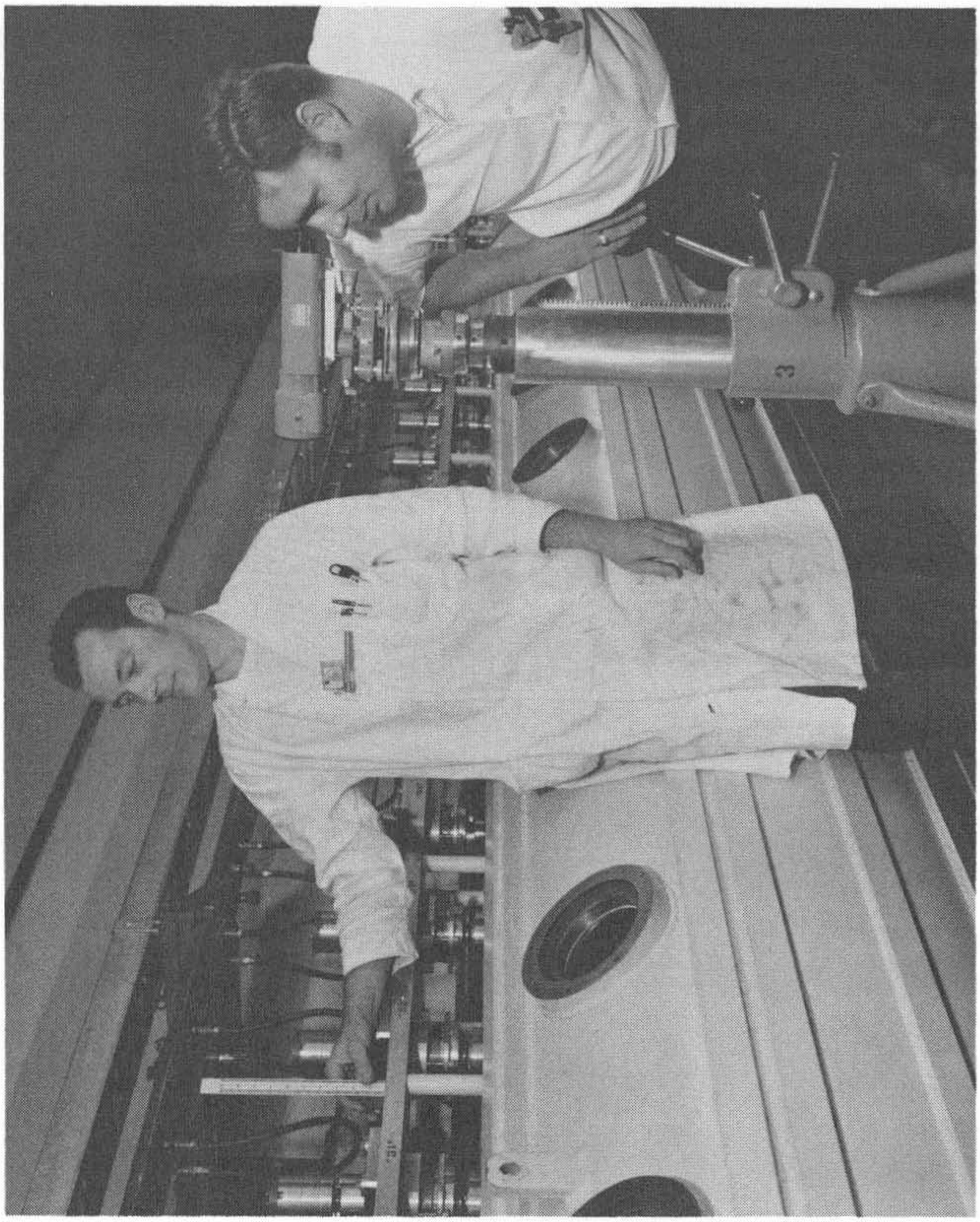


Fig. 15. Strongback alignment.

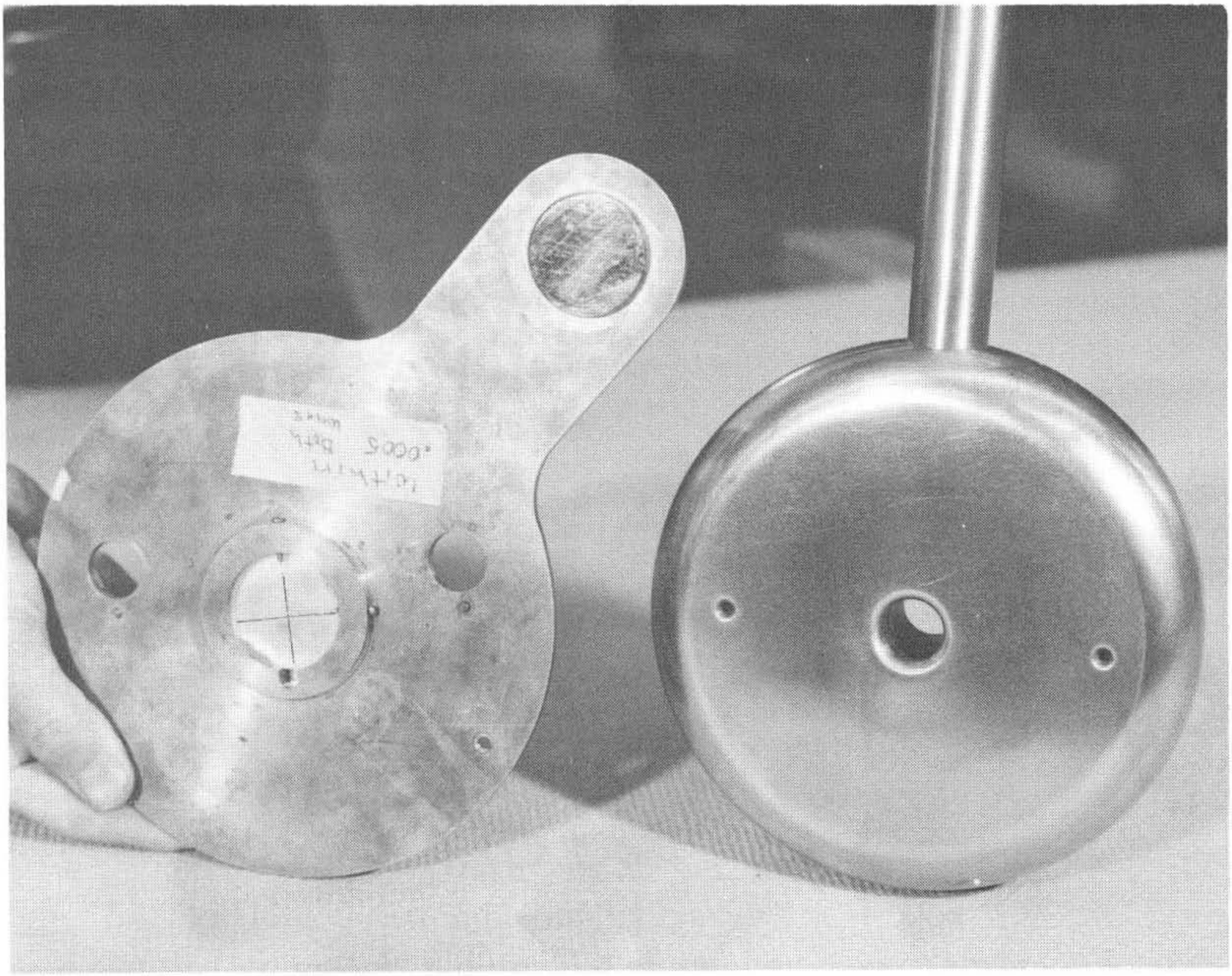


Fig. 16. Tank I target jig.

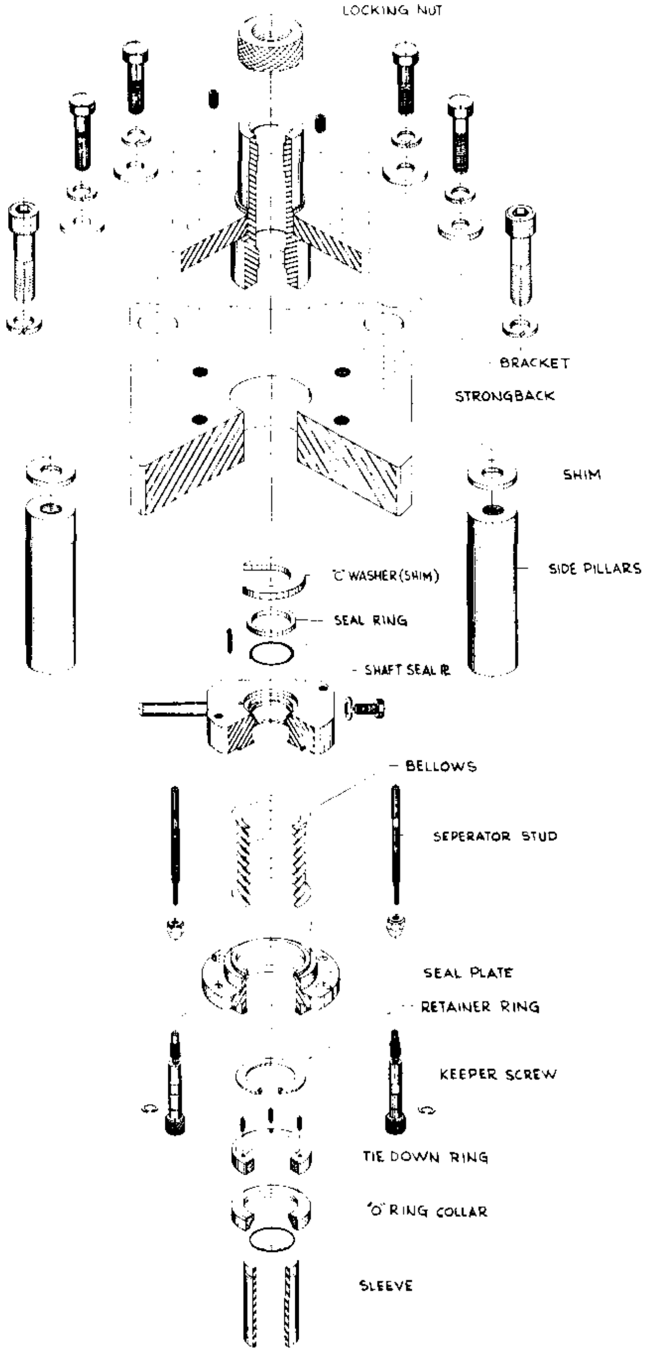


Fig. 17. Stem support and seal assembly.

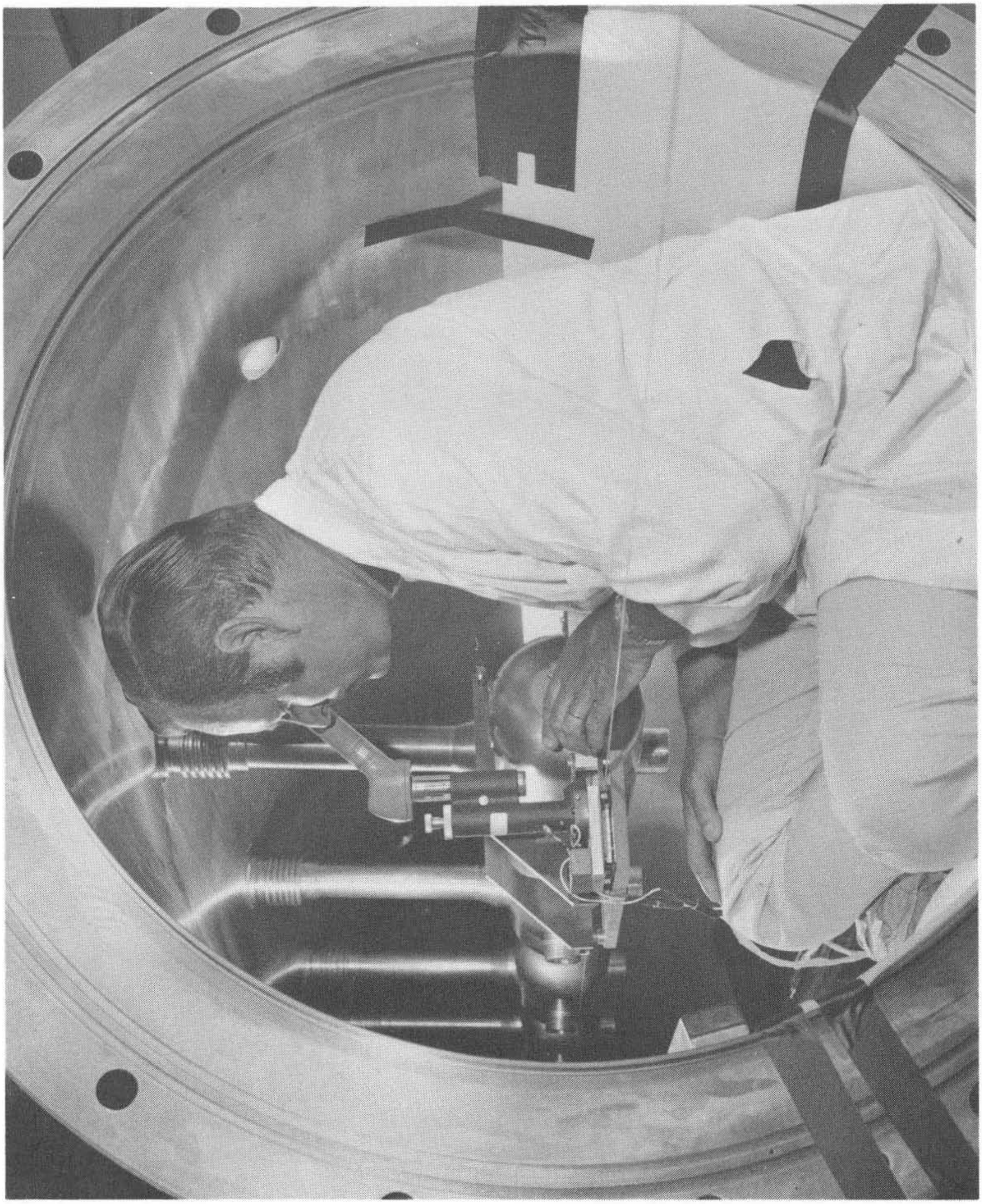


Fig. 18. Drift-tube alignment.

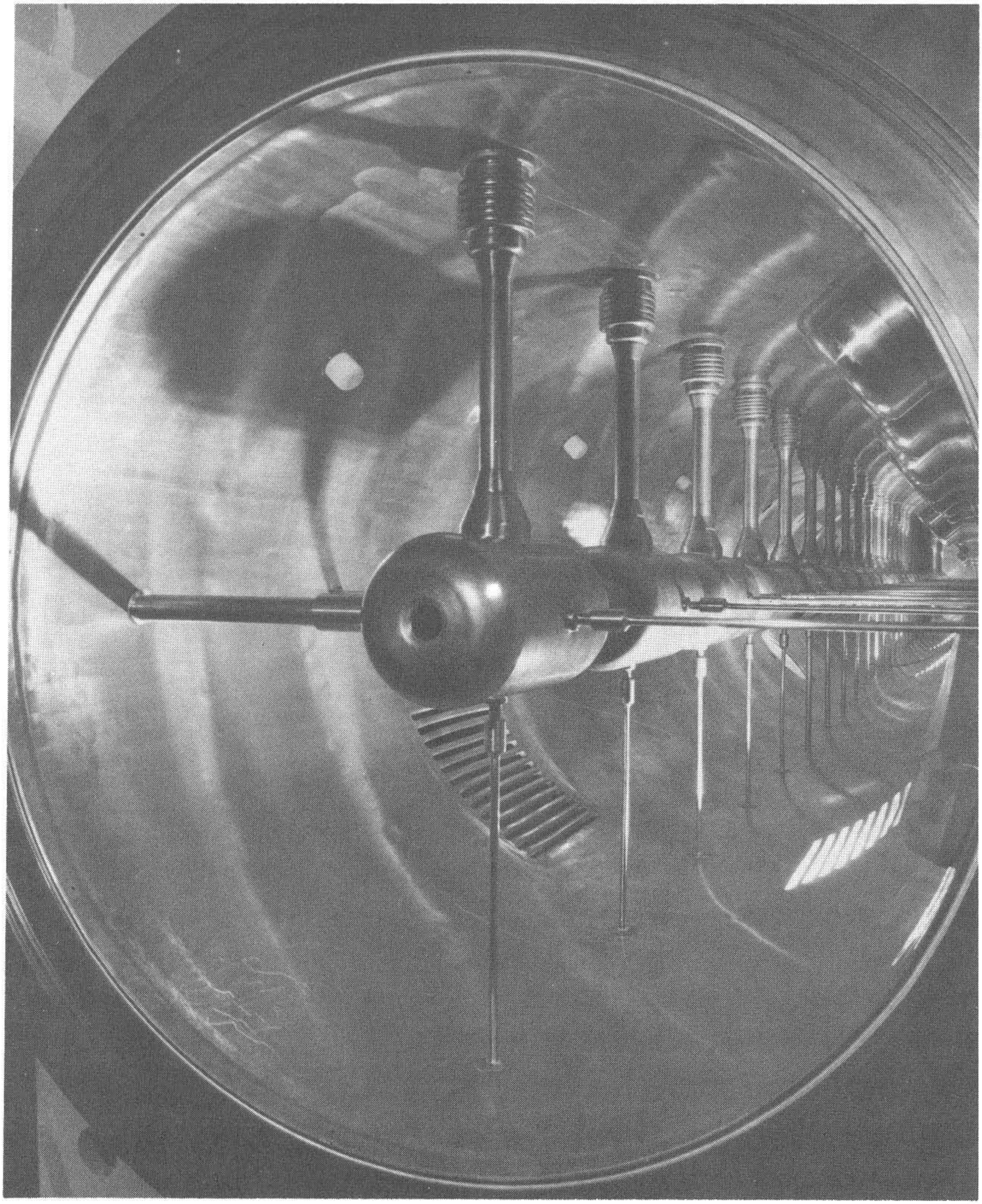


Fig. 19. Tank III drift tubes and dummy stems.

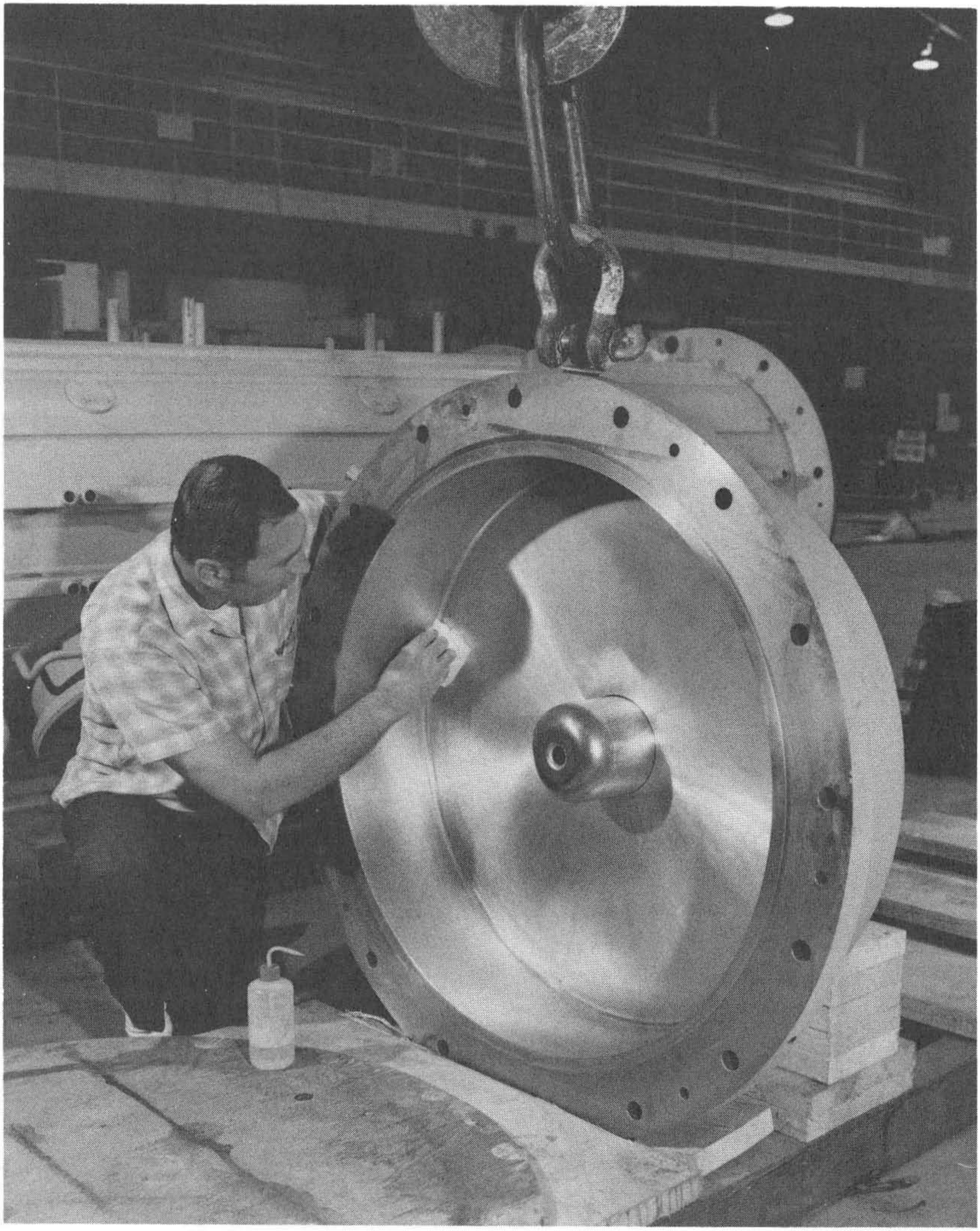


Fig. 20. Tank II end cover.

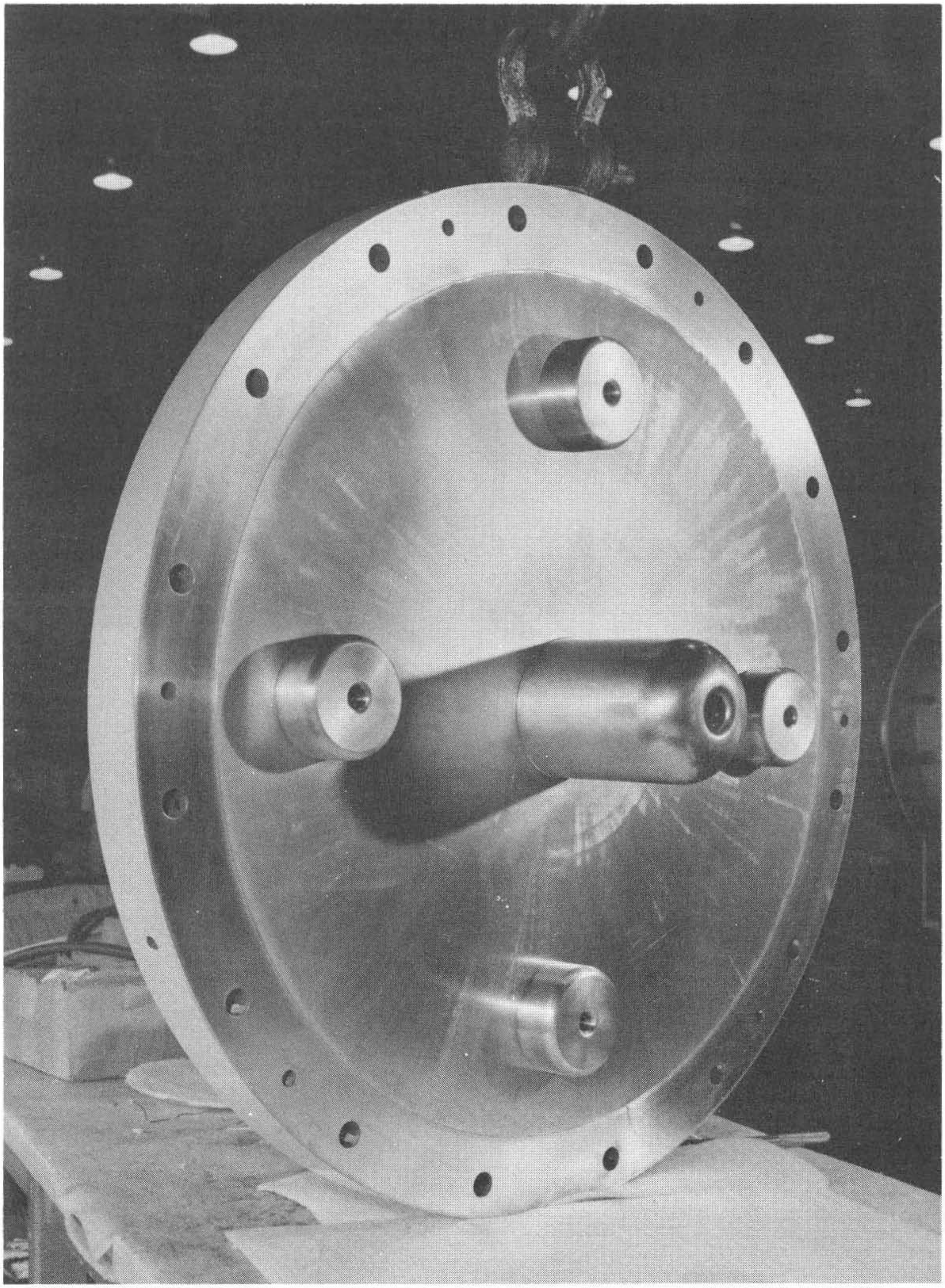


Fig. 21. Tank VIII end cover.

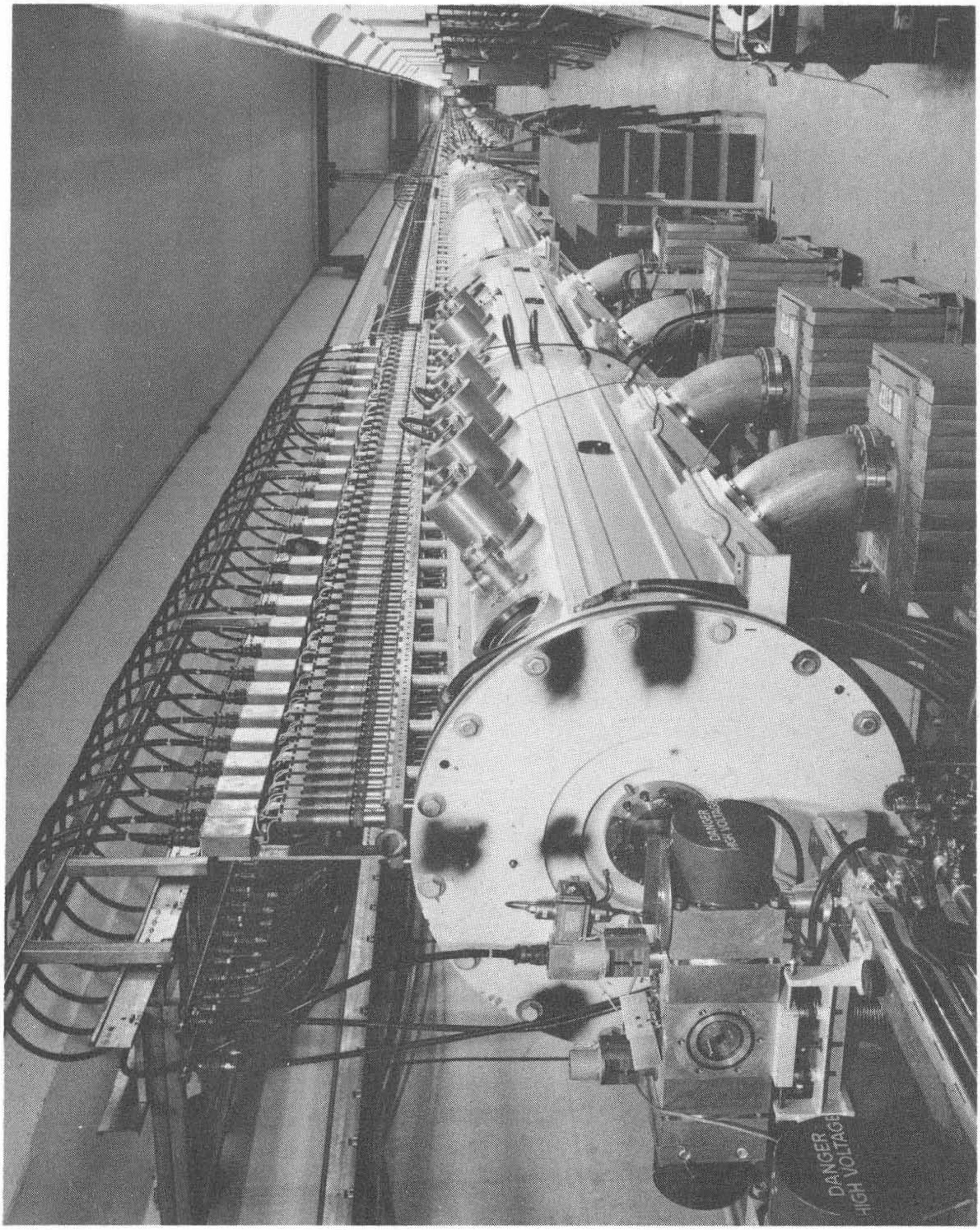
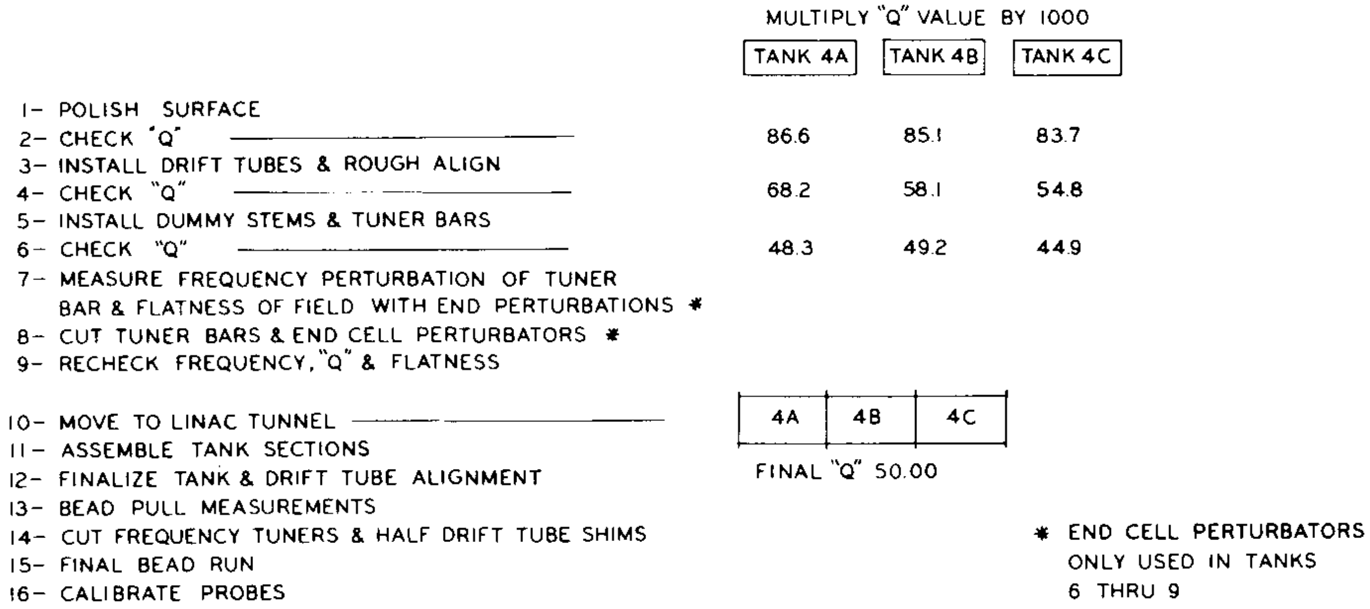


Fig. 22. Linac tunnel 8/20/70.



MULTIPLY "Q" VALUE BY 1000

	TANK 4A	TANK 4B	TANK 4C
2- CHECK "Q"	86.6	85.1	83.7
4- CHECK "Q"	68.2	58.1	54.8
6- CHECK "Q"	48.3	49.2	44.9

1- POLISH SURFACE
2- CHECK "Q"
3- INSTALL DRIFT TUBES & ROUGH ALIGN
4- CHECK "Q"
5- INSTALL DUMMY STEMS & TUNER BARS
6- CHECK "Q"
7- MEASURE FREQUENCY PERTURBATION OF TUNER BAR & FLATNESS OF FIELD WITH END PERTURBATIONS *
8- CUT TUNER BARS & END CELL PERTURBATORS *
9- RECHECK FREQUENCY, "Q" & FLATNESS

10- MOVE TO LINAC TUNNEL
11- ASSEMBLE TANK SECTIONS
12- FINALIZE TANK & DRIFT TUBE ALIGNMENT
13- BEAD PULL MEASUREMENTS
14- CUT FREQUENCY TUNERS & HALF DRIFT TUBE SHIMS
15- FINAL BEAD RUN
16- CALIBRATE PROBES

FINAL "Q" 50.00

* END CELL PERTURBATORS ONLY USED IN TANKS 6 THRU 9

Fig. 23. Flow diagram of typical electrical check-out.

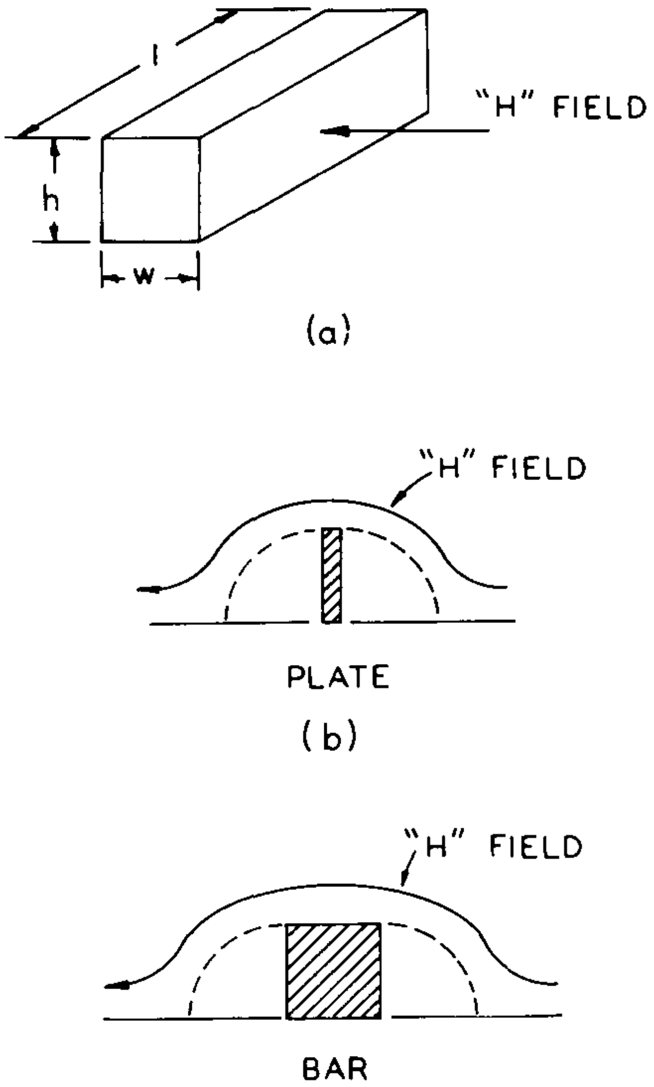


Fig. 24. Effective cross-sectional area of frequency perturbation.

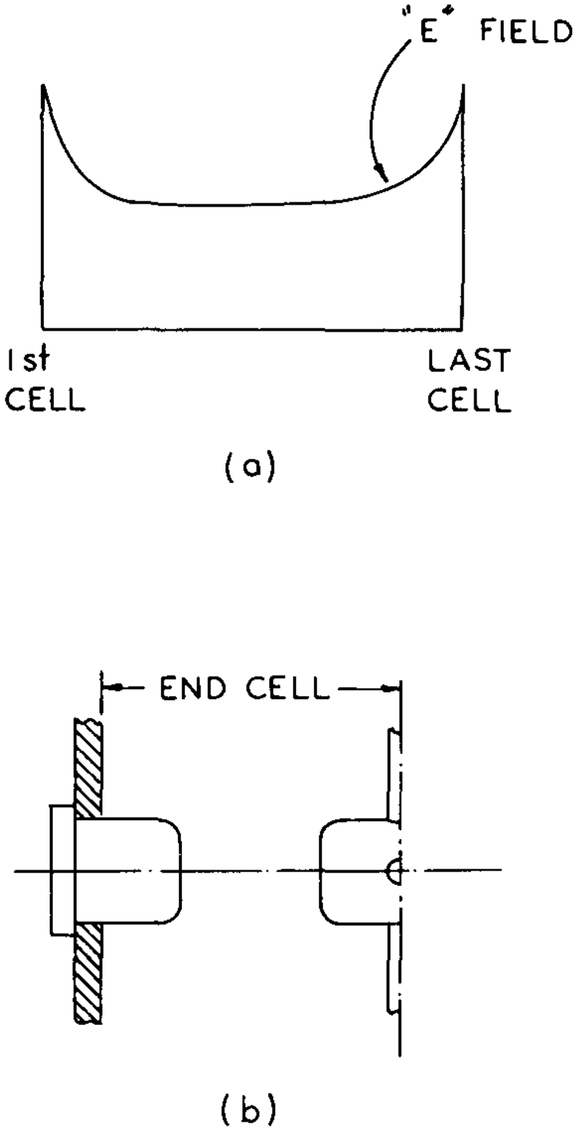


Fig. 25. End plate detuning.

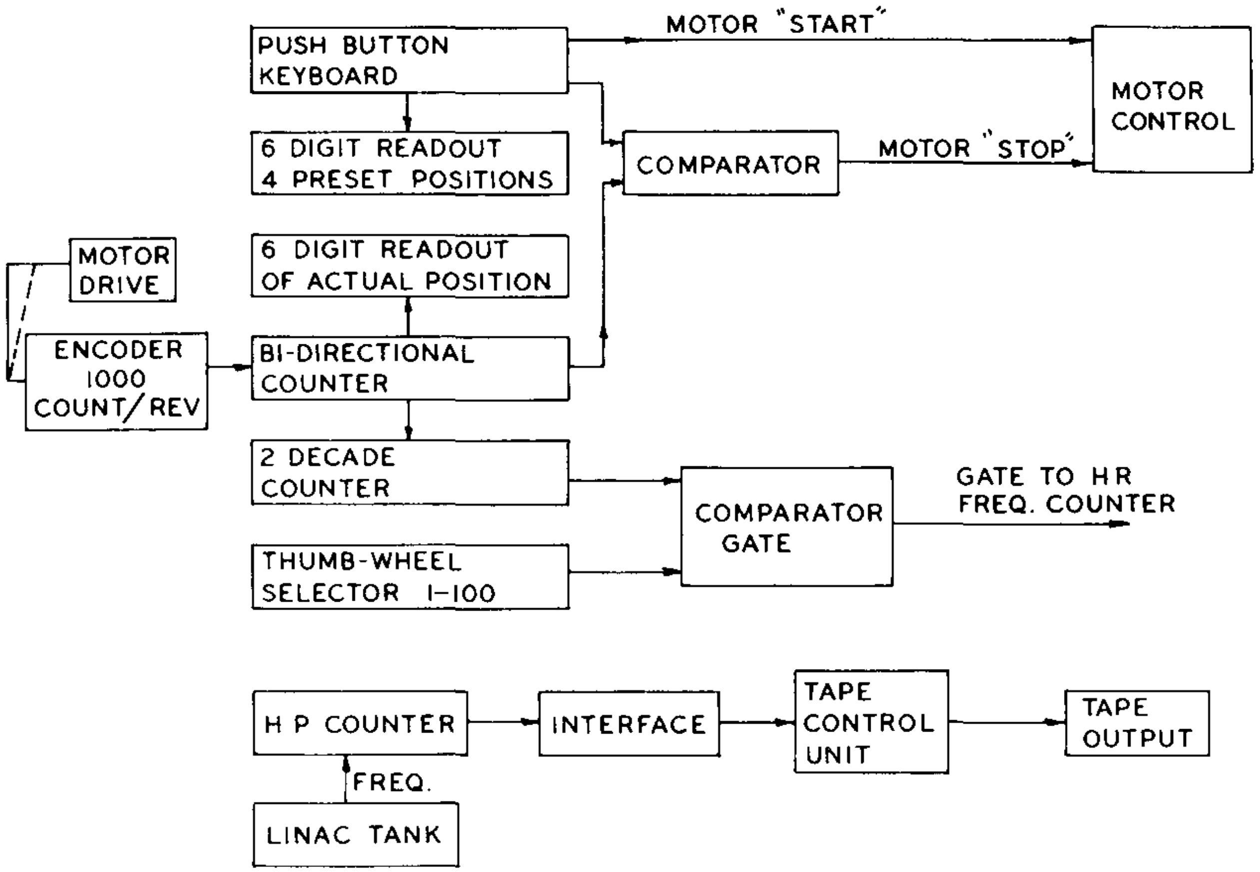
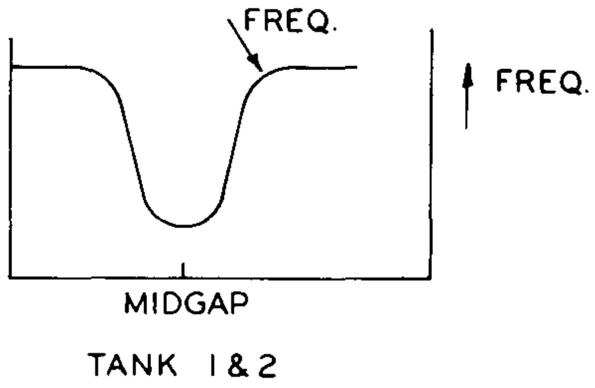


Fig. 26. Bead pulling equipment.



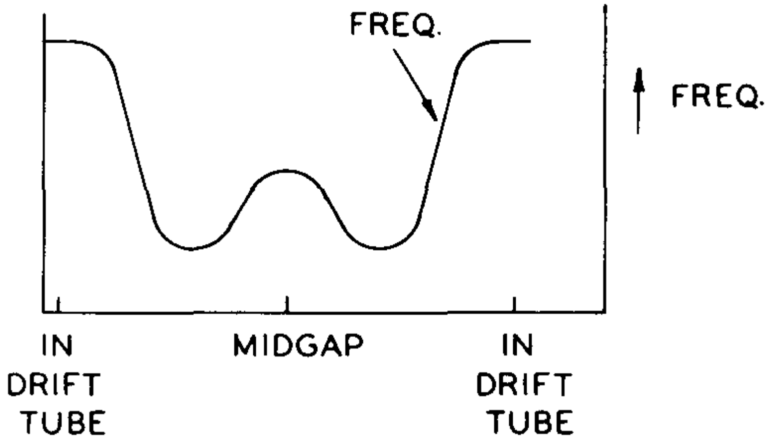


Fig. 27. Tank 3-9 "E" field patterns.

DISCUSSION

M. Palmer (NAL): How do you determine the perpendicularity on your K and E scale? You are off center and need to determine the perpendicular to the beam line to get over to the scale.

J. R. Aggus (BNL): We have a brass plate which actually touches the face of the drift tube. We look at the position of this edge as it lies on top of the K and E scale.

M. Palmer: Another thing, is the viewing instrument supported by the drift tube?

J. R. Aggus: In the case of the heavy stems which are 2-3/8 in. diameter stainless steel, we support the viewing instrument on the stem and the drift tube.

D. Swenson (LASL): Do you know the Q of Tank 9 in its completed state?

J. T. Keane (BNL): 40,000.