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MECHANICAL FEATURES OF THE ELECTROSTATIC DEFLECTOR FOR THE BERKELEY 88-INCH CYCLOTRON

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ABSTRACT

The mechanical features of the electrostatic deflector are described. The deflector channel starts as close as possible to the dee. It must deflect the particles enough to clear the leg of the magnet. The channel width at entrance is 5/32 in. (0.4 cm) and at exit is 1/2 in. (1.3 cm). The nominal voltage is 63 kV. The deflector is 108 deg long. It is built of four segments, two in the outer high-voltage element and two in the inner ground element. The channel elements are water-cooled welded Inconel. Each of the two high-voltage elements is separately cantilevered from an insulating bushing.

The whole assembly is built like a drawer. The floor of the drawer is a 1/2-in. sheet of K-Monel. Bearings throughout are Teflon-impregnated sintered bronze. A moving 1/4-scale model of the deflector elements is installed in the control room. It reproduces automatically all motions of the deflector in the cyclotron. The initial deflector is equipped with a standard metal fixed septum. A sawmill septum is being developed to replace the standard septum when and if desired. This sawmill septum consists of two metal rotating disks.

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An electrostatic deflector is used for removal of accelerated particles from the field of the magnet. It was designed to deflect the particles electrostatically, without the aid of any modifications to the magnetic field. A single dee is used in the cyclotron. The entrance of the deflector was moved as close to the dee as possible in order to give the deflector the maximum path length for getting the deflected beam to clear the leg of the magnet; the deflector is 108 deg long (see fig. 1). The nominal deflector settings for 60-MeV deuterons are 63 kV, and a channel that tapers from 5/32 in. at the entrance, to 1/2 in. at the exit. Orientation of the cyclotron is such that the deflected beam points toward the experimental area.

The magnet gap of the cyclotron is horizontal. A vacuum-tank faceplate supports the entire deflector structure. Two methods of support for the high-voltage parts were considered: (a) some system of stand-off insulators, which would give support from below, or (b) they could be cantilevered out from the faceplate, on insulating bushings. The latter option was chosen. The cantilevered bushings are more or less away from the magnetic field and avoid most of the discharge probelms peculiar to crossed magnetic and electrostatic fields. Also there is more room to solve the support problem when away from the narrow confines of the magnet gap.

The magnetic field where the insulating bushings are placed is quite weak. One or two bushings could have been used. Two were chosen.

† Work done under the auspices of the U. S. Atomic Energy Commission.

It would have required a very large structure to support the deflector from one bushing; also, with two bushings different potentials can be put on the two parts. There are two separate high-voltage supplies, each capable of going to 125 kV for the two high-voltage elements. This allows the electric gradient to be tailored more carefully. Each end of both high-voltage elements can be more or less independently adjusted to the desired radius. These two elements do not touch each other.

The ground-potential part of the deflector structure is supported from a large flat metal sheet, 1/2-in.-thick, that covers almost half of the pole area. This ground plane is cantilevered out from the faceplate; it is the foundation to which linkages and water lines are fastened (fig. 2).

There are two ground-potential elements. These have a common center pin. Altogether there are seven points to adjust radially. Four of these points are at high voltage and three are at ground potential. The radial range of adjustment is approximately 3 in. Specifically, the entrance of the deflector can be moved from about 37 to 40 in. radius. The seven points of the deflector can all be adjusted remotely, from the control room. The rate of radial motion of the deflector is approximately 3/8 in./min.

The vertical height of a high-voltage element is 2 in. and for a ground element is 3 1/4 in. (fig. 3). All four elements are centered on the median plane. These heights were chosen as a compromise, so as to be compatible with the vertical opening in the dee (1 1/2 in.), as well as to provide electrical clearance above and below the high-voltage element.

There are no moving seals in the deflector mechanism. Vacuum seals are achieved by stainless steel bellows. All deflector motions are made with rods that translate by means of screw threads on the atmospheric side of the faceplate (fig. 1).

Materials used in the construction of the deflector assembly are nonmagnetic. The ground and high-voltage elements are made of 3/32-in.-thick Inconel, which was chosen because of its good voltage-holding characteristics. The septum, which separates the deflected beam from the circulating beam, is made of tantalum. It was machined to a curve matching the trajectory of the deflected beam. This tantalum septum is secured to a graphite part by four small screws. This graphite part was also machined to fit the curve of the trajectory and is inserted into the Inconel structure (fig. 4).

Parts that are in the shadow of the poles are generally made of K-Monel or copper, which are very nonmagnetic materials. The permeability of K-Monel is about 1.0015. Parts that are outside of the shadow of the magnet poles were made of stainless steel, which is nonmagnetic but does have a somewhat higher permeability than K-Monel. All the magnetic field data was obtained without any of the deflector structure in place. Therefore every effort was made to keep the deflector structure as nonmagnetic as possible, to keep from invalidating the precision of the magnetic field data. All bearings inside the vacuum system and many outside the vacuum system are made of sintered bronze impregnated with Teflon. These have a low coefficient of friction, are nonmagnetic, tolerate much heat, and are good in a vacuum. They were obtained from the Glacier Company in England.

The deflector is water-cooled. This cooling system includes the ground and high-voltage element, as well as other parts adjacent to the septum. The typical scheme for cooling the elements of the deflector is shown in fig. 3. The water passages were all formed from Inconel. Tubes were not used. One reason tubes were not used is that it is difficult to fasten tubes to an Inconel structure. Inconel does not tolerate soldering; it corrosion-cracks. Also, by having the water directly in contact with the

Inconel, there is less temperature drop through the metal. This welded construction was actually quite difficult to do. It was done by our Laboratory sheet metal shop.

The deflector was built to fit, in an optimum manner, the trajectory of a 60-MeV deuteron entering the deflector at 39-in. radius. For construction, four separate metal templates were made—one for each of the deflector elements. These templates were made from 1/4-in. thick aluminum by the Bendix Corporation in Kansas City, using a tape-controlled milling machine. The templates appear to be a very accurate product, probably closer than 0.003 in. to a perfect curve. They were used by the sheet metal shop in the fabrication of the electrodes. The electrodes were not machined; they were made to fit the templates by hammering the sheet metal after each welding pass had been made during construction. This was a rather time-consuming and painstaking job, but the final fit between the templates and the electrodes was better than 0.10 in., and, typically, considerably better. The electrode surfaces have a good polish on them but they are not perfectly smooth. They have waves in them as a result of fabrication handling. These irregularities are of random wavelength, but typically might be 3 or 4 in. center-to-center. However, these waves are generally only a few thousandths of an inch high. The upstream electrode elements are approximately twice as long as the downstream elements. This was the optimum ratio to produce the best fit with trajectories slightly different from the design trajectory.

The ground electrodes are not insulated. It is not possible to read current to them. However, each of the electrode water circuits is monitored carefully for temperature rise. The temperature rise of the water in each of the electrode circuits is displayed in the control room; full scale corresponds to 5°C temperature rise of the water. It is expected that the water will rarely

rise more than 5°C. Since the water takes only on the order of 2 sec to run through the electrode, the temperature rise should provide fairly prompt and reliable indication of beam falling on an element. One other temperature-sensing device was installed on the deflector. It is a photoelectric tube which is mounted in the proximity of the septum, and looks directly at the septum. Its output is proportional both to light and heat emitted from the septum.

The whole deflector mechanism was designed to be very rigid. The reason for this was to get good control and stability of position of the electrodes. Linkages in general were made of a shape and size to contribute to this (fig. 5). A good bit of effort was put in at assembly to get close-fitting pins in all the moving joints. Fits were always snug. Clearances were typically on the order of 0.0001 to 0.0003 in. The motions of the elements have good reproducibility and are essentially free of backlash. Backlash is typically less than 0.001 in., and reproducibility, when moving over a course in the same direction, is on the order of 0.0001 in.

The high-voltage equipment is cantilevered out from a ceramic bushing. These bushings are 18 in. long, 9 in. diam, and 3/4 in. wall thickness. They were made massive to be sure that they did not accidentally break because of the weight of the cantilever load. This is a good place to mention the stabilizer, which is a temporary mechanical support brought up under the high-voltage sandwiches when the deflector is being removed or installed in the tank. The stabilizer reduces shock loading in the insulators due to handling of the deflector. The rod down the center of the bushing is a stainless steel tube 4 in. in diameter with a 1/2-in. wall thickness. On the end of the rod is the high-voltage sandwich assembly. This consists of two stainless steel plates , between which are linkages and water lines. These sandwich assemblies are adjustable at assembly, to position the high-voltage electrodes. The ceramic bushings have

flanged ends which are gripped by metal parts cushioned with Teflon washers (fig. 3). (The vacuum seal is independent of the gripping.) These flanges were loaded to 150 lb per linear inch, and none of them broke. The ceramic bushings are made of 97.6% alumina.

Figure 1 gives the general arrangement of the control of the deflector motion. One set of equipment is shown in fig. 1 but there are seven sets, all essentially indentical. The electrode moves when the control room supplies push-button power to the "workhorse" motor. The workhorse motor drives through a clutch that limits the torque that can be transmitted by the motor to the mechanism. The clutch is to prevent the accidental destruction of any of the mechanism.

In the control room is a quarter-scale model of the deflector, which reproduces the geometry and rate of motion of the deflector in the cyclotron. The model mechanism is driven by slave selsyns which are driven by sending-selsyns at the main deflector. The model correctly reproduces the radius and the gap of the deflector to 1/4 size, and provides the operator with knowledge of what he is doing inside the tank when the deflector is being adjusted. Also, the model provides a place to mount microswitches which prevent the accidental colliding of ground and high-voltage electrodes, or any other collisions. However, if a microswitch malfunctions, the clutch at the main deflector usually prevents damage. If the model microswitch protecting the septum fails, the septum is at the mercy of the operator because the septum is so fragile that it will break before the clutch slips.

There are counters both on the deflector and on the model, which give the radial position of the elements. The model and full-size counters have exactly the same number on them. The operator is provided with a table which gives the radial position of an electrode as a function of the counter

number. Figure 6 shows a photograph of the model of the deflector.

There was some concern that if the cyclotron worked well and put out a high current, the septum might become the part that limited the extracted beam current. The deflector was installed with a traditional stationary septum, but considerable time and thought has gone into the developement of what we have called a sawmill septum (see fig. 7). An attempt was made to design and build a stationary septum in such a way that in the future it will be easy to replace the stationary septum with a sawmill septum. The idea of the sawmill septum is that the two wheels rotating can dissipate considerably more heat without melting than a stationary septum can. The wheels would be heated only where they dip down into the beam, and could be radiating heat on the back part of their rotation. The sawmill septum is partially developed. The material is tungsten or possibly tantalum. The tantalum is easier to fabricate but does not have as high a melting point. The tantalum also has a more tolerable radioactivity.

The speed of the sawmill is not very critical, but there is a relationship between speed of rotation and energy radiated. Wheels rotating at 1 000 rpm radiate about 85% as much heat as wheels rotating at infinite speed. The wheels get rid of all their heat by radiation; there is no water cooling. Water cooling at best could get rid of only 15% of the total energy to be eliminated, and so it did not seem worthwhile to provide the water cooling – especially since water seals at this speed would be very troublesome and difficult to make reliable.

There are a number of problems in such a device. One of the first is that eddy-current losses in an ordinary metal shaft are prohibitive. These are the eddy-current losses due to rotating a conductor in a D.C. magnetic field. These losses take too much power and make parts too hot. So we

chose a ceramic shaft, which does not have eddy current losses, and, in general, can stand much heat. Bearings likewise are troublesome. Ball bearings rotating in a magnetic field get very hot due to the eddy-current losses. Also, it is difficult to get a reliable bearing to operate in a vacuum at a high temperature for a long time. We have gone to the use of the Glacier sintered-bronze Teflon-impregnated sleeve for bushing-type bearings. The ceramic shaft has shrunk over it a very thin-wall stainless steel sleeve which is highly polished for low-friction and long-life operation with the Glacier bearing. Again, the wall is made thin to reduce eddy-current losses.

We expect to operate these wheels at 800 or 900 rpm. They will be driven by three-phase 60-cycle motors; each wheel has its own motor. The space available for a motor is approximately 3 in. in diameter by 6 in. long. There are some eddy-current losses in the wheels themselves; there are bearing losses, both friction and eddy current; and there are eddy-current losses in the rotating element of the motor due to the presence of the D. C. magnetic field. The magnetic field at the radius of the motor, approximately 55 in., is 1 or 2 kG. This is too high a field for a motor to operate in satisfactorily. Therefore, a small D.C. coil is to be placed near both motors, and enough current run through this coil to neutralize or "buck" the D.C. magnet field in the area of the motors. It is expected that the motor and coil disturbance of the orbit of the circulating beam will be negligible. It is expected that a small brush will be required to drain the current off of the rotating wheels.

A number of tests have been made rotating a wheel in a vacuum, and loading the wheel with an electron beam. Electrons were emitted from a hot filament mounted close to the edge of the wheel. Typical values were 2000 V and 3 A of emission. In the most successful test to date the wheel

ran for 1/2 hr at a 6-kW load. The problems are not all solved but there is hope.

The deflector is installed and removed by the use of a four-wheel truck, which rides on a pair of steel rails (fig. 8). These rails come from outside the shielding, through a tunnel, through the concrete shielding, and then go up to the side of the cyclotron. It is expected that eventually a cave will be built at the outside terminus of this track, so that a deflector which is very active could be run back into this cave with its truck, and the cave door closed. The truck would be power-operated.

When installed, the outside parts of the deflector are enclosed in a large aluminum-screen cage. All the walls of this cage are hinged doors which can be swung out or removed by lifting up on them. The doors of the cage are interlocked so that it is impossible to have high voltage on the deflector if any door of the cage is open.

Several water and power lines need to be disconnected to remove the deflector from the tank. These connections were made easy to break. After rehearsal two people should be able to remove and store a deflector in 15 min.

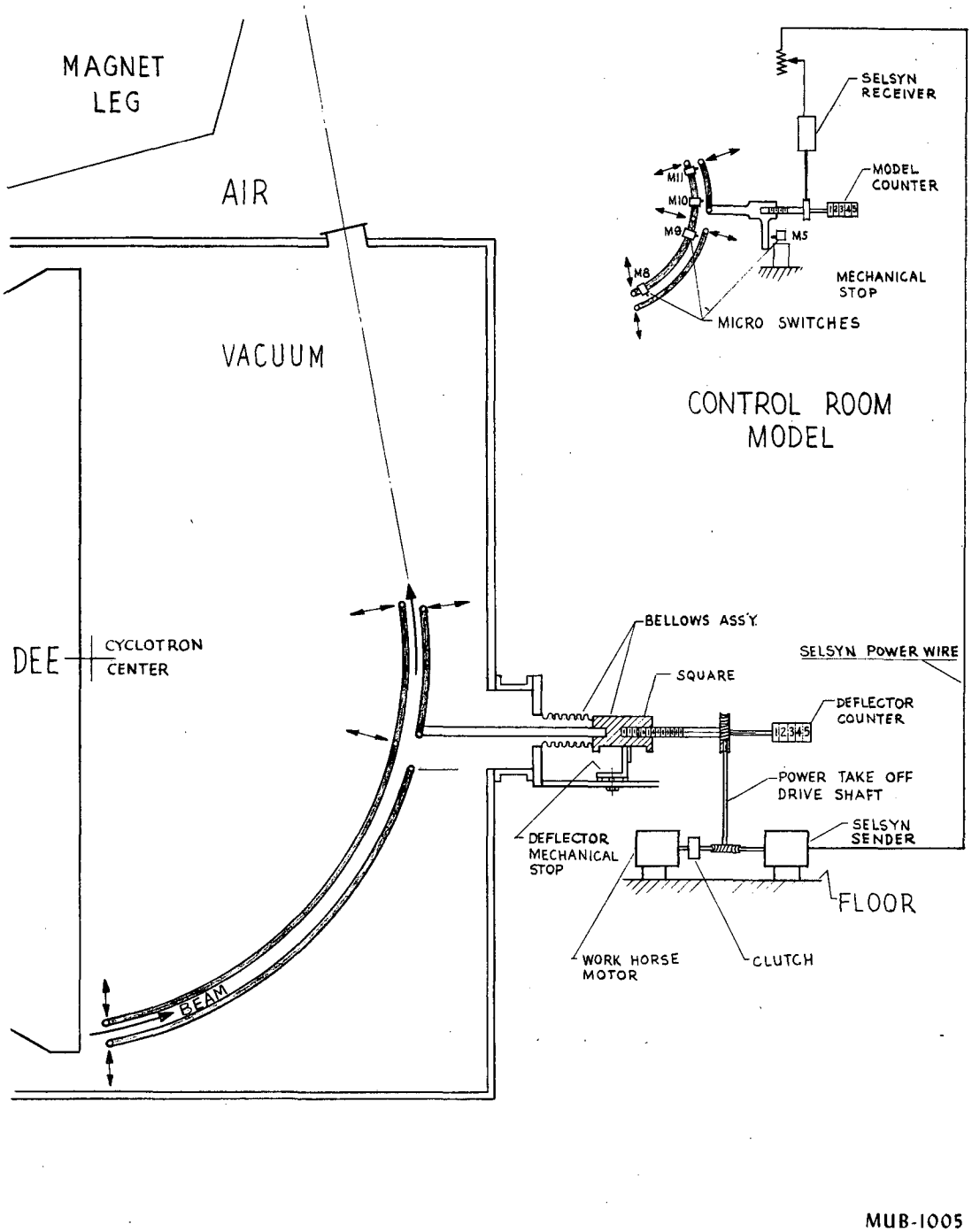

Fig. 1. Schematic of deflector and control-room model.

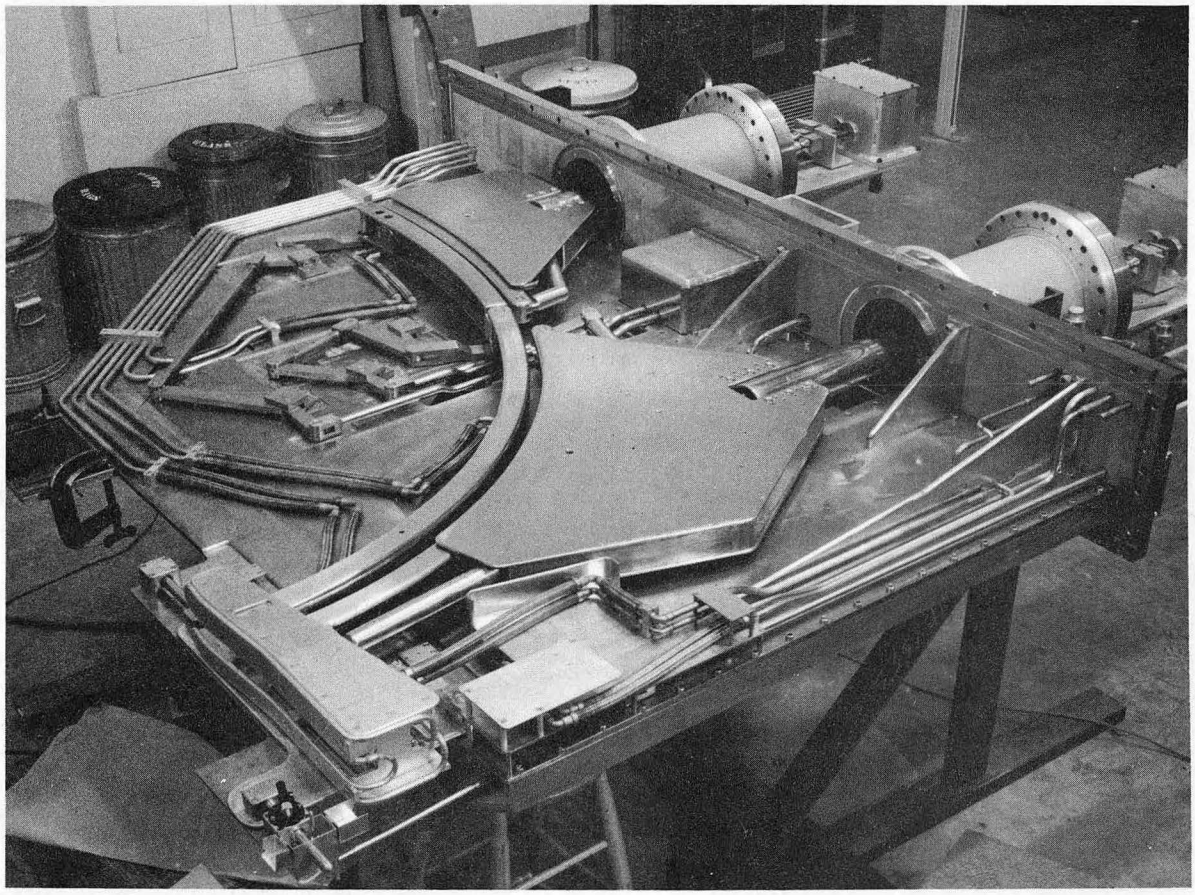

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Fig. 2. General view of deflector.

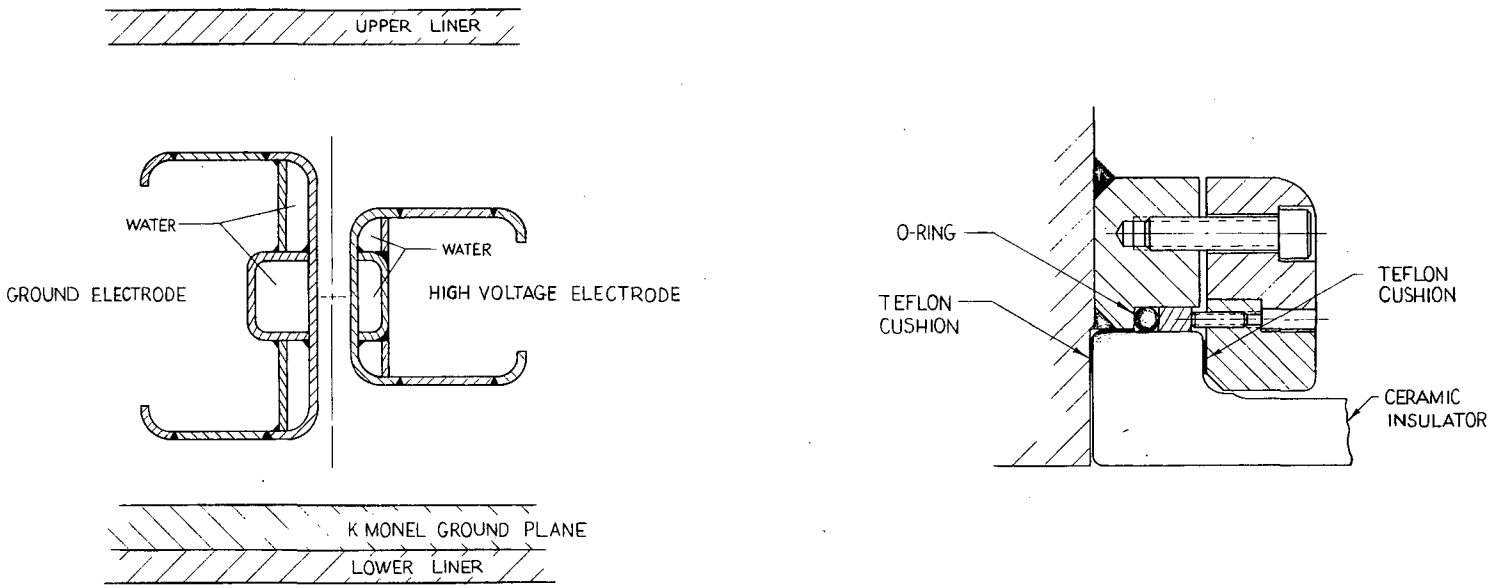

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Fig. 3. Electrode cross sections and insulator grip.

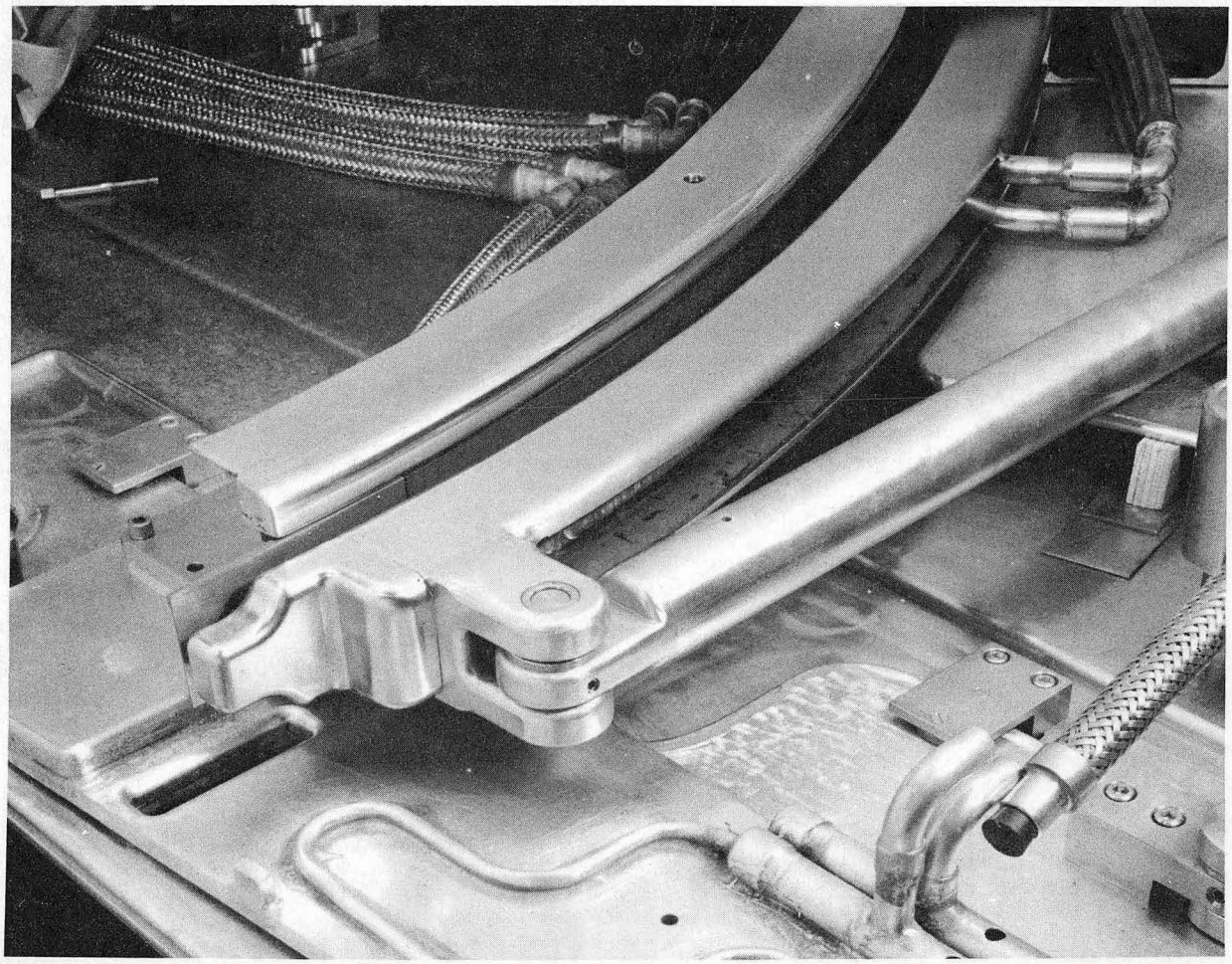

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Fig. 4. Deflector entrance.

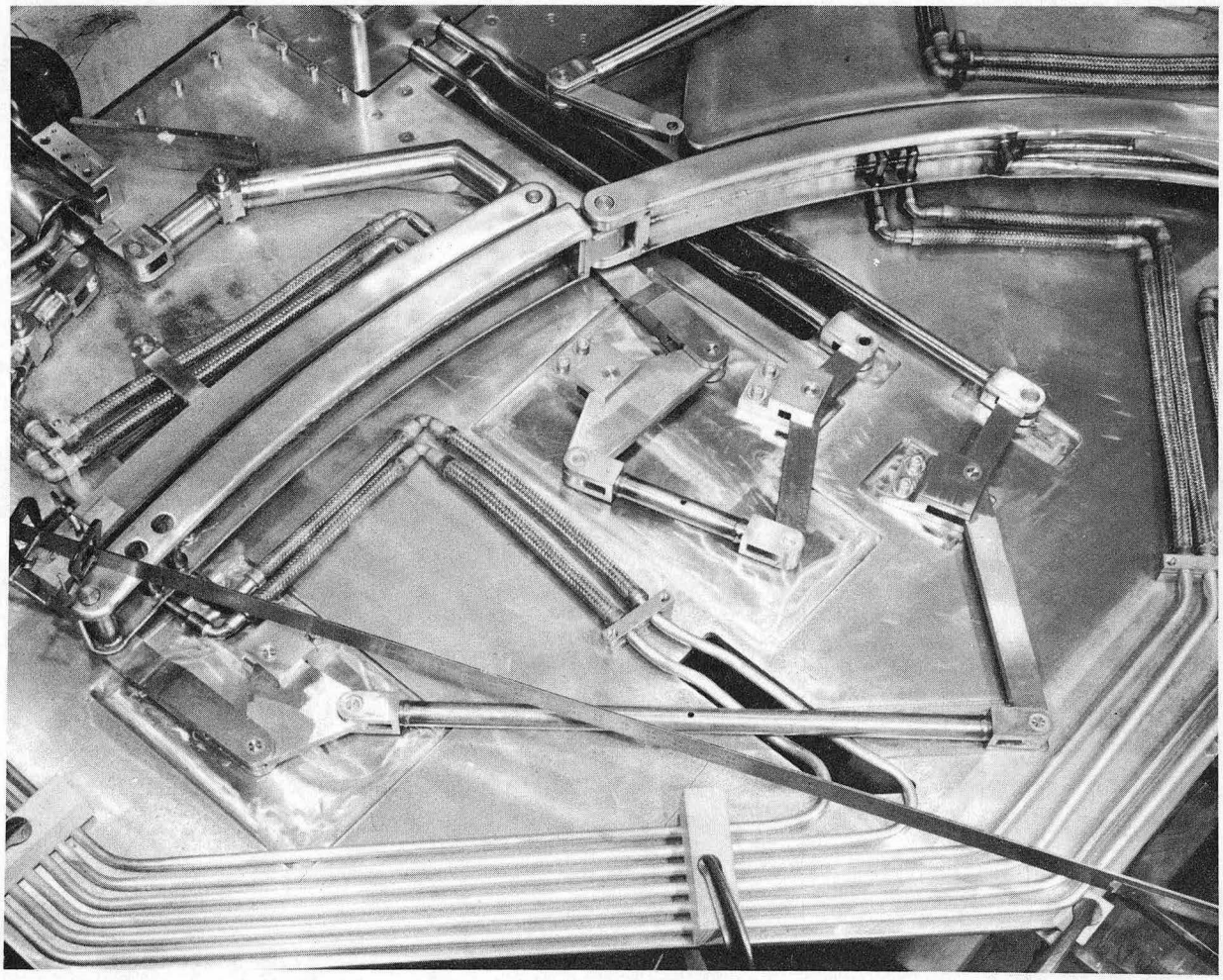

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Fig. 5. Deflector linkages.

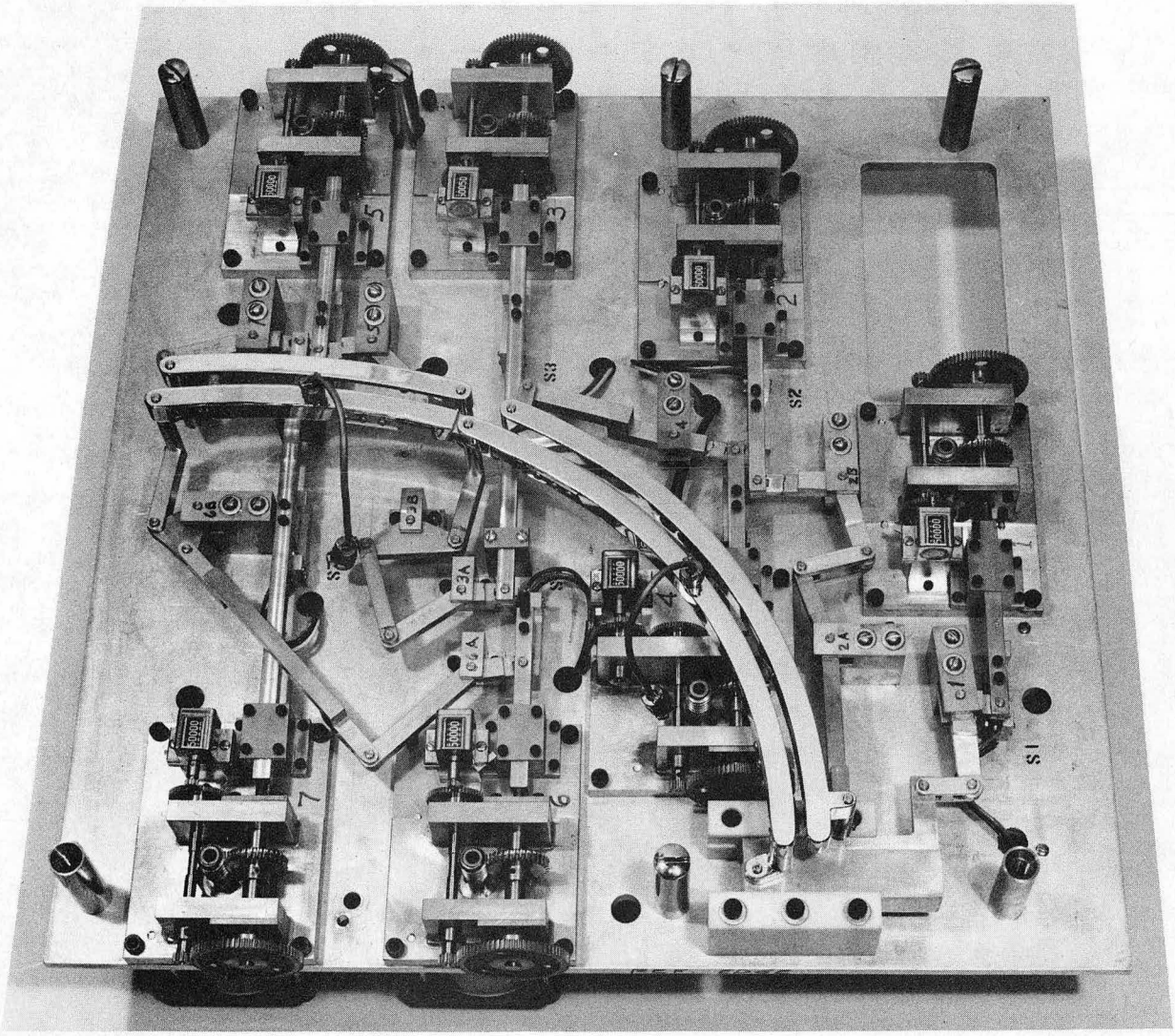

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Fig. 6. Overall view of the deflector model.

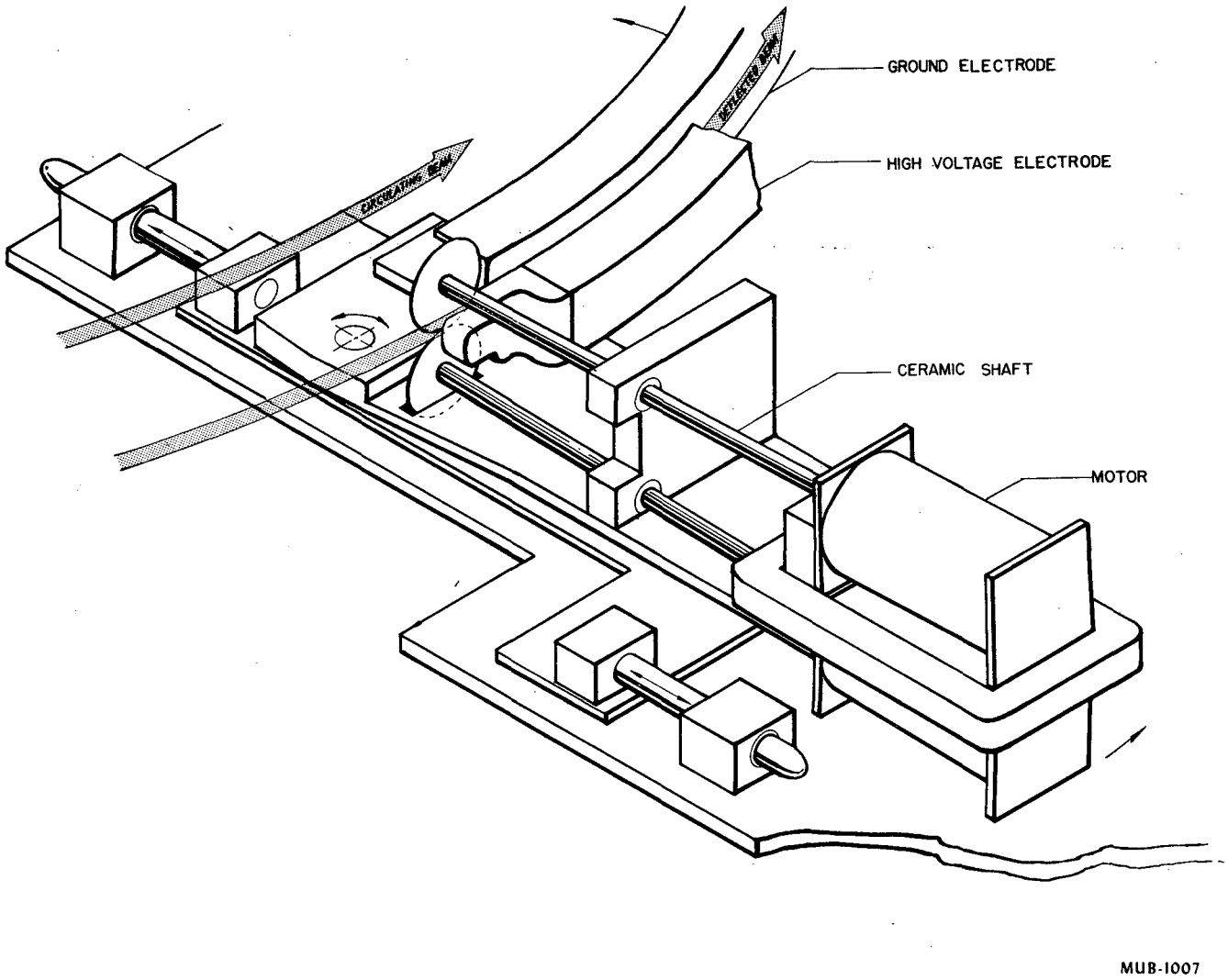
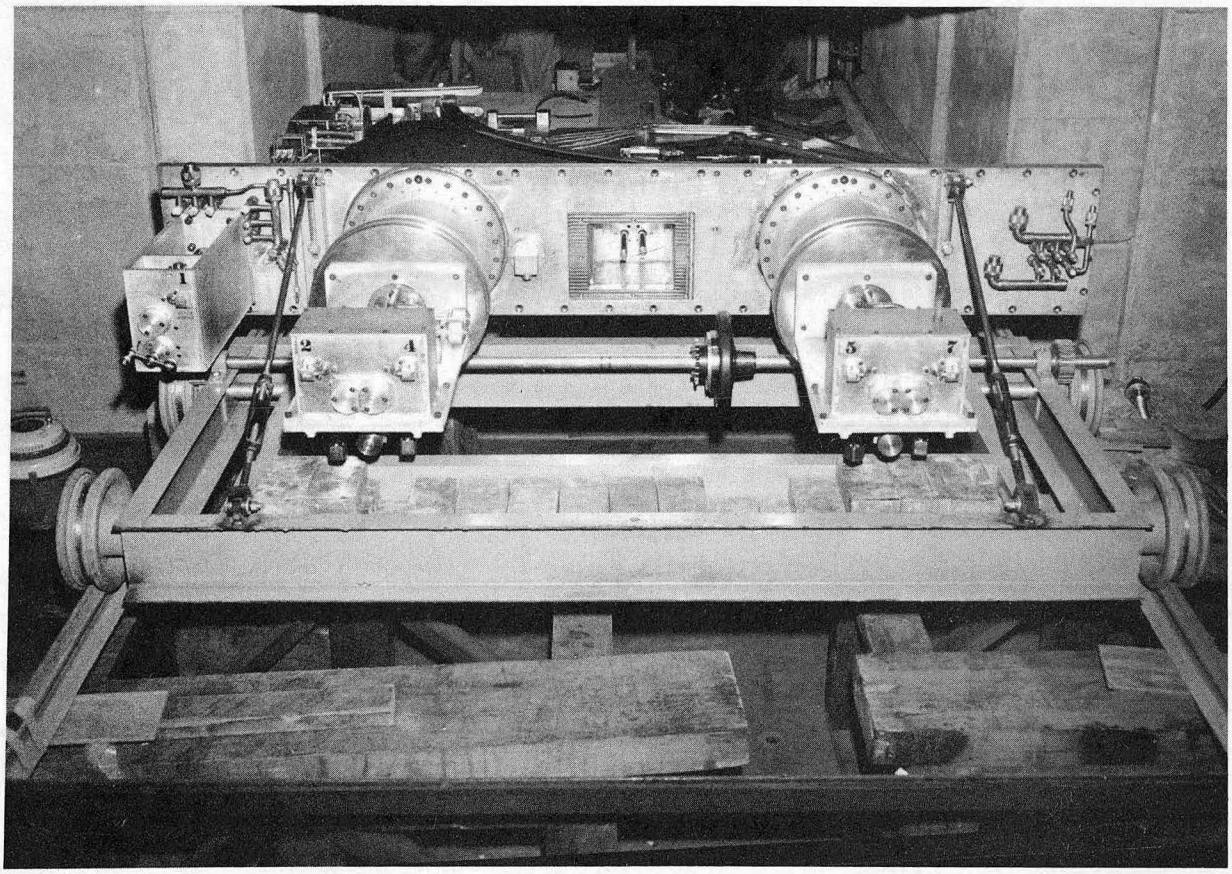


Fig. 7. Sawmill septum.



ZN-3056

Fig. 8. Deflector truck.

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