

## KREVITT: REMOTE MAINTENANCE TECHNIQUES FOR 200 BEV ACCELERATOR

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### REMOTE MAINTENANCE TECHNIQUES PROPOSED FOR THE 200-GEV ACCELERATOR\*

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#### Summary

Remote maintenance is one of the prime considerations in determining the size of the main-ring enclosure for the 200-GeV accelerator. The maximum residual radiation level 7 h after beam turn-off is expected to be ~50 mR/h in the so-called "quiet" areas of the main ring and approximately 200 R/h at the most intense point in the enclosure.

We have assumed a maximum permissible radiation dose per man of one-half the permissible dose allowed by AEC regulations. Therefore, an unshielded man can work for a few hours per week in the quiet areas, but only a few seconds per week in the "red" radiation areas. He must work rather quickly.

For these red radiation areas, we propose using a self-propelled, manned, shielded vehicle on which are mounted two master-slave manipulators to be used as a backup for extension tools penetrating the vehicle walls.

#### Introduction

Accelerators built to date were designed for beams of energies and intensities that would not create much of a problem with residual radiation. However, as various improvement programs were undertaken at these facilities to increase beam intensities, residual radiation increased considerably, and the problem could no longer be ignored. Beam extraction areas were now almost impossible to work in for any length of time without endangering personnel or without "using up" all available personnel at the facility. Components had to be redesigned completely for remote or more rapid setup changes and maintenance. Rarely was there enough room for the new design. It became very clear that entirely new approaches to accelerator design must be used in the construction of future accelerators.<sup>1</sup>

#### Main-Ring Enclosure

The main magnet-ring enclosure of the 200-GeV accelerator is a tunnel approximately 14.5 ft high by approximately 19 ft wide and shaped like a donut with an approximately 1-mile-diam hole. A

perspective section of the tunnel is shown in Fig. 1. We propose a vehicular right of way approximately 6 ft wide on both the inside and outside radii of the machine. This is necessary for servicing if a "C" magnet configuration is used. If the various ring components are designed for servicing from only one side, then one vehicular right of way can be eliminated.

The equipment that will be installed in the tunnel includes 480 normal 30-ton gradient magnets, 24 Collins quadrupoles, and 24 short-gradient magnets. In addition to these 528 primary magnets, there will be 456 correcting elements, which are sextupole magnets, trimming quads, closed-orbit deflectors (radial and vertical deflecting magnets), skew quads, and steering magnets. There will also be 288 beam-position monitors.

#### The Problem

The residual radiation problem has received considerable attention in our design study.<sup>2</sup> It is expected that about 95% of the circumference of the 200-GeV accelerator can be serviced by unshielded personnel. These areas are the so-called quiet areas. Although the level is relatively low, stay times will still have to be carefully monitored and controlled to ensure that an allowable dosage of 100 mR/week average is not exceeded.

At the extraction points for the external beams, shown in Fig. 2, which comprise the remaining 5% of the circumference, the expected levels are such that in complying with AEC regulations, an unshielded man would be able to work only a few seconds. Obviously this is impractical. Then, too, there will be areas that in the future will become red areas as new extraction points, collimators, perturbation magnets, etc., are added.

The hottest part of the machine is predicted to be approximately 4000 times as hot (200 R/h) as the quiet areas. Obviously personnel shielding is required for maintenance. Even if an area is temporarily activated by an accidental or short-term beam loss and the residual radiation level is only 20 times as hot (1 R/h), shielding should still be used.

It is generally agreed that it is highly desirable, if not necessary, to have a man right at the work site as opposed to performing a task by purely remote control with TV surveillance. William Salsig, of the Mechanical Systems Group

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for the 200-GeV study, has said, "No other system of intelligence acquisition, discrimination, and universal motion capability comes with such compactness, economy, and reliability as a human being. It's a shame he isn't a little more radiation-resistant." We therefore have to provide shielding for these non-radiation-resistant mortals. Once it is decided that personnel shielding is required, it becomes an entirely different ball game; however, the designs are still fairly straightforward.

Since there is an element of uncertainty about knowing exactly where temporary beam spills will be or where future extraction points will be, the more prudent approach is to design the machine as though the entire circumference were a red area. In this way you avoid the very frustrating situation where you can't service a particular component because of lack of forethought.

There are several jobs that we know will have to be done reasonably often and they are pretty well defined. There are approximately 1000 relatively major components in the enclosure. In other words, there will be 1000 to 2000 power connections, 1000 to 2000 vacuum connections, 1000 umbilical-cord terminations (cooling-water flow and temperature interlocks), 1000 to 2000 water joints, and approximately 2000 position adjustments; only a few of these require remote operation during a shutdown.

It is our firm belief that as many of these operations as possible should be made from the back side of the magnets. The magnet yoke thus provides some natural shielding for personnel. The open side of the magnet gap and the coil ends will be the hottest part of the magnets. In the quiet areas, 7 h after beam turn-off, the radiation level at the back side of the magnet is predicted to be 6 mR/h, while the level at the gap side and end is estimated to be 50 mR/h. In the red radiation areas (the beam-extraction points) 7 h after turn-off the levels at the back side and the ends of the magnets are expected to be 5 R/h and 190 R/h respectively at the first magnet downstream from the septum. The level drops off by a factor of three at each successive magnet downstream. At the ninth magnet we are at a quiet area again. These estimates are at a distance of 1 ft from the magnet and by the nature of the calculations are accurate within a factor of two.

The operational philosophy is unchanged whether the actual radiation fields are a factor of 2 higher or a factor of 2 lower. The design that we propose will not be sensitive to perturbations of this magnitude.

Dr. William Gilbert of LRL completed a shielding experiment at CERN at the end of 1966,<sup>3</sup> and as a result of the very preliminary analysis of some raw data, he concludes that his original residual radiation levels mentioned above are still valid.

#### The Solution -- Shielded Manipulator Vehicle

The Shielded Manipulator Vehicle (or SMV) shown in Fig. 3, we feel, is the solution to the problem of placing a man at the work site. It is essentially a manned, self-propelled, shielded turret with 4-inch thick lead walls and a total weight of 30 to 40 tons. The main turret has continuous rotation and will have viewing windows of 6.2 specific-density lead glass approximately 8 in. thick which will be distributed around the turret circumference for maximum visibility. The main turret walls will be penetrated in two or three places by extension tools operating in lead swivel joints similar to those found in "hot boxes."

The upper turret also has continuous rotation and serves as a mount for two master-slave manipulators which are intended to be used as an aid, supplement, and backup to the extension tools. The main and upper turrets can be rotated independently. The manipulators will be used for positioning tools, for holding parts that are disconnected or for picking up dropped parts and tools.

What we actually have is a hot cell 19 ft wide, 14.5 ft high, and 3 miles long. Since it is impractical to mount manipulators every few feet along the wall, we need a portable set of manipulators that can be easily transported to the work site and positioned precisely.

The main and upper turrets will be supported by a track-mounted chassis running on rails that extend around the entire circumference of the main enclosure. Propulsive power will be obtained by extending a telescoping trolley to contact the overhead bridge-crane power-supply bus. An auxiliary battery will be on board for travel through the entrances and for emergency power.

The design of the inside of the vehicle will be a human engineering nightmare. We need various controls for the drives, braking system, telescoping trolley, tools that may be held by the manipulators, vehicle ventilation and lighting, radio control for the overhead crane, and emergency power. Also needed are monitors for the condition of the various systems such as the battery, air supply for the emergency brake, and constant monitoring of the radiation level inside the vehicle. There must be indicators for the various protective interlocks and there must be a reliable communication system with an emergency back-up system. Above all, there must be room for an operator; room for him to perform the necessary tasks efficiently.

#### Tasks for the Shielded Manipulator Vehicle<sup>2,4</sup>

The basic and best-known tasks to be accomplished by the SMV in the red radiation areas are (1) Adjusting the magnet position vertically, azimuthally, and radially, as shown in Fig. 4; (2) Assembly and disassembly of the vacuum and cooling-water systems for each magnet as shown in Fig. 5; (3) Assembly and disassembly of the magnet-power connection; (4) Assembly and disassembly

of the interlock umbilical connection for the various components; (5) Complete replacement, installation and (or) removal of components as operations dictate; (6) Vacuum-leak hunting; (7) Radiation monitoring; and (8) Unforeseen jobs that may come up from time to time. The SMV will be equipped to tow flat cars so that any component -- be it a beam monitor weighing 100 lb or an alternating-gradient magnet weighing 30 tons -- can be remotely disconnected, attached to and lifted by the crane, placed on a flat car and removed from the enclosure.

The booster synchrotron ring and main ring are similar as far as cross section size and arrangement of the components are concerned. Therefore, we feel that similar connections need to be of the same design, and the component design of the two rings must be well-coordinated.

#### Design Philosophy<sup>5,6</sup>

We very strongly believe in the modular-design -- quick-disconnect philosophy and believe that it must be executed to the maximum. Starting from scratch, so to speak, we have the opportunity to design the machine for maximum efficiency during servicing and (or) repair, barring any false economies that are imposed by budget limitations. Components must be designed from the beginning for efficient remote handling. Connections must be designed so that their remote operation can be accomplished with simple, rapid motions. The facility for quick removal of components minimizes personnel exposure to radiation; helps minimize downtime costs, and helps maintain a higher accelerator duty factor.

In designing quick disconnects it is also essential that the necessary tools are designed along with the connections so that the proper mating of the tool to the component is insured. Even if actual remote handling is not necessary for the first few months or years, if components are designed for rapid removal by hand, this design probably would be used for remote handling when needed later.

In cave work, the component to be worked on is brought to a well-designed facility where the operations have been done before and have been carefully analyzed. These jobs take two to four times as long to perform remotely as they would take to do by hand. In remote accelerator work, the facility has to be taken to the component that needs the attention. The facility must be portable, very versatile with general-purpose equipment, and still provide adequate shielding for the operator. On new operations where there is no prior experience and the part to be operated on has not been designed for remote operation, and assuming you have good access to it (both visual and physical), past experience has shown that the job will take eight to ten times as long to perform remotely as it would take to perform by hand. If the proper time and effort is spent on the proper design of quick disconnects with modular design, then the job might take only two to four times as long as it would by hand.

Although time, and therefore money, is spent on component design only once, hopefully, expenditures for maintenance are highly repetitive. Therefore, it makes good sense to expend more effort on the initial design, to reduce the time required to perform the operational and repair tasks. This point cannot be overemphasized. At an estimated \$10,000 per hour for unscheduled downtime cost for the 200-GeV accelerator, a few hours per week over the life of the machine can add up to an appreciable expense.

#### Present Studies

In the summer of 1966 we constructed a wooden mockup of the main tunnel, two alternating-gradient magnets, and the SMV to study the latter's operations.

We obtained two master-slave manipulators to study the feasibility of their use. We will install them in the vehicle mock-up along with various extension tools and actually remotely perform magnet position adjustments, interlock cable connections, vacuum-flange assembly and disassembly, and water connect and disconnect operations. Only by actually trying various operations with the mock-up can we gain an appreciable insight into these operational procedures. We plan to analyze the feasibility of using TV as an aid for blind operations.

We have built a special fixture for the assembly and disassembly of our specially designed "bolt-less" vacuum flanges, as seen in Fig. 6. This is a hydraulically operated device for making and breaking the hundreds of vacuum joints distributed around the magnet ring. This fixture has performed very well in preliminary tests and is an example of the advantage of designing the component and the fixture simultaneously.

These mock-up studies will continue for several more months, as they have proven invaluable in our concept analysis.

#### Conclusion

These concepts of remote maintenance that I have outlined are not the ultimate nor the final answer. They do represent the present extent of the state of the art in reliable, versatile, all-purpose manipulators with an operator on the scene. Obviously, from a safety standpoint it is best not to have to send a man into a "hot" area. However, considering the present state of the art in electronic and servo-manipulator fields and the inadequacies of present TV systems for the complete surveillance of intricate operations, we feel that our approach is best. This does not mean that we would not change our approach if a better manipulator and (or) TV system were to be developed. The totally remote servo-manipulator<sup>7</sup> shows great promise. With a device such as this some maintenance tasks could be carried out in nontarget or inactive target areas while the machine is running. The saving in maintenance costs is obvious.

The ultimate goal is obtaining an efficient and reliable machine. Only through detailed mock-up studies and careful analysis of the design and operation of the accelerator, with maintenance and reliability being carefully considered during the initial design, can this goal be achieved.

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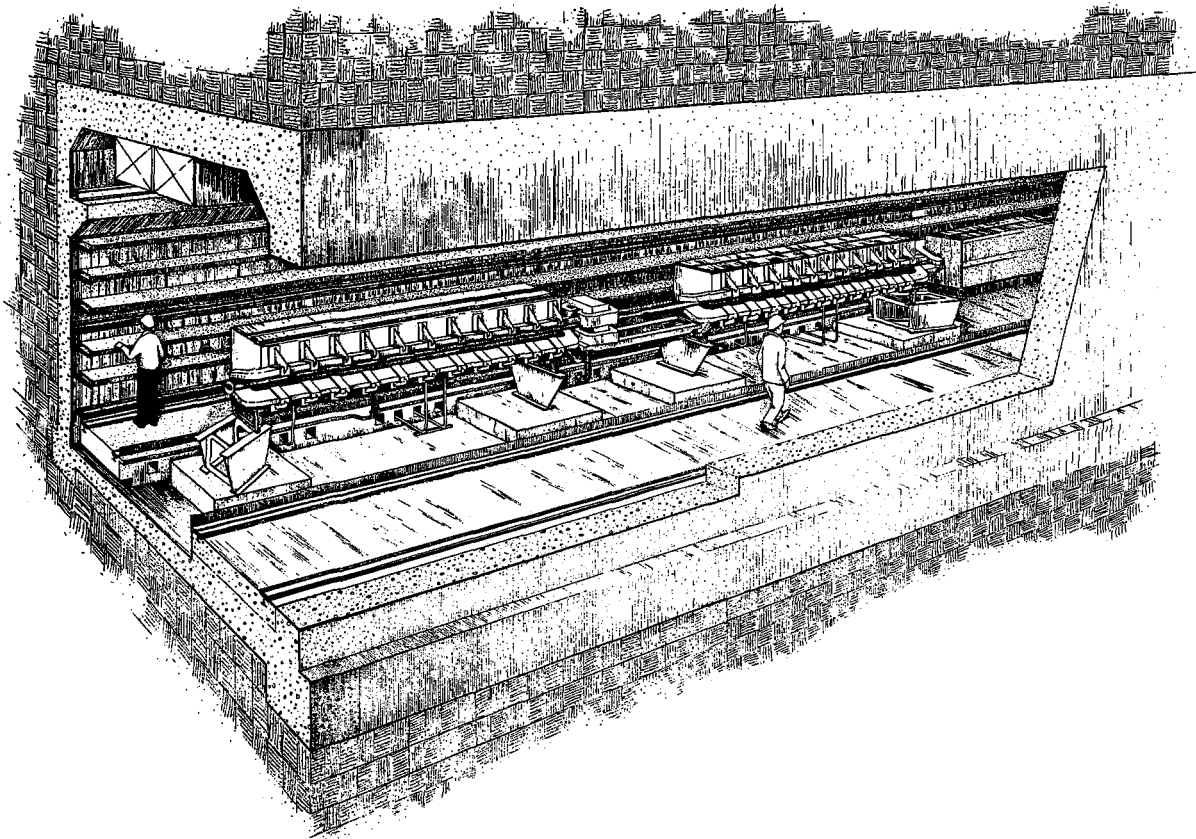


Fig. 1. Main synchrotron magnet enclosure.

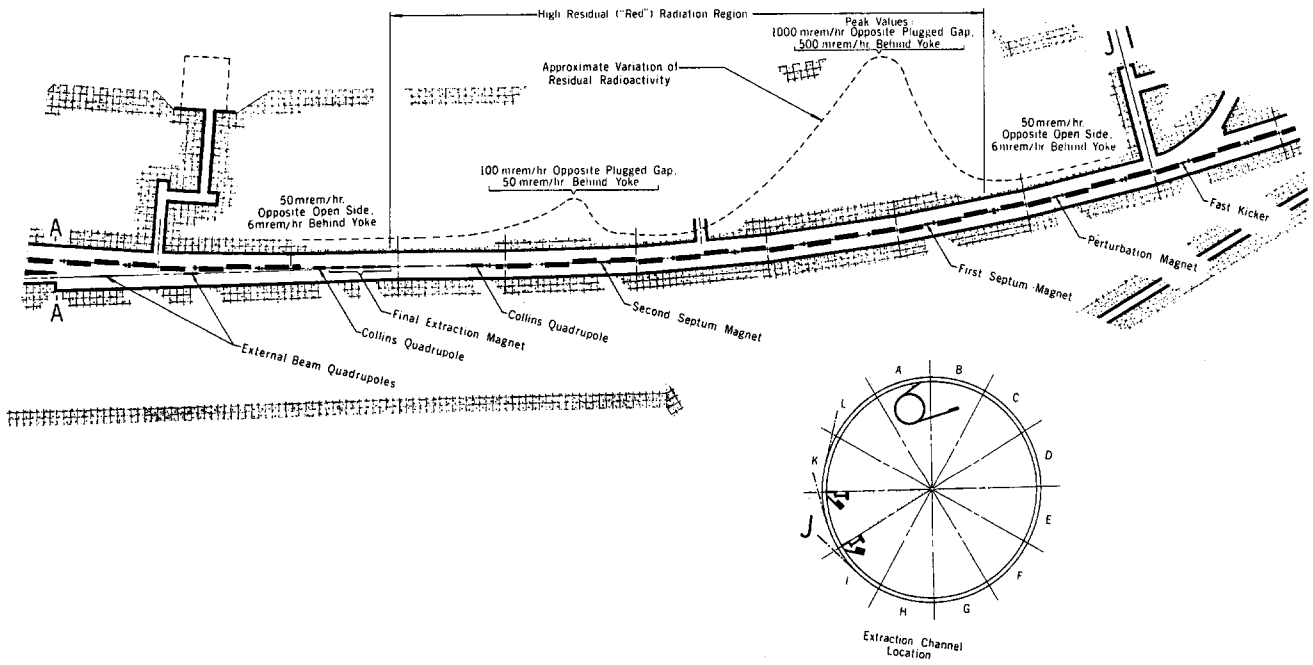


Fig. 2. Beam-extraction layout.

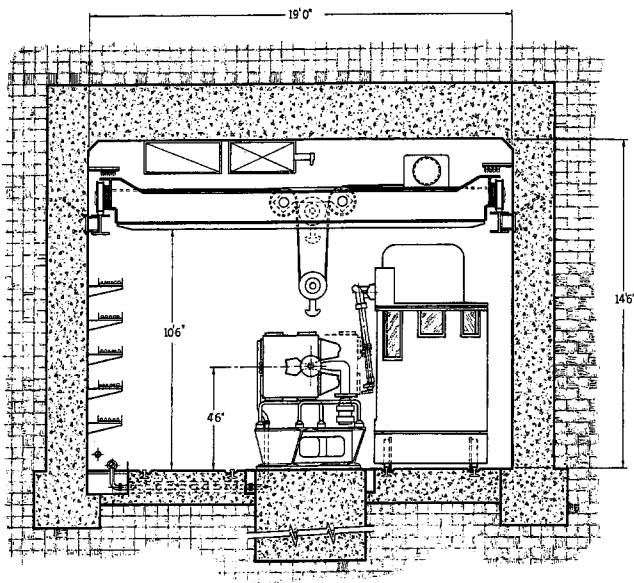


Fig. 3. Main-ring enclosure with shielded manipulator vehicle.

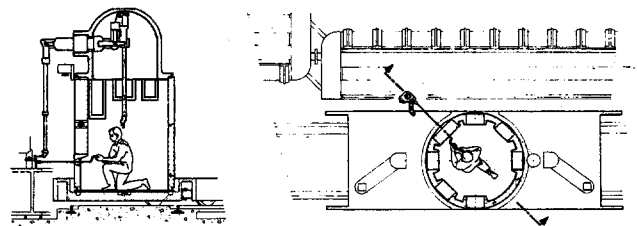


Fig. 4. Magnet position adjustment from shielded manipulator vehicle.

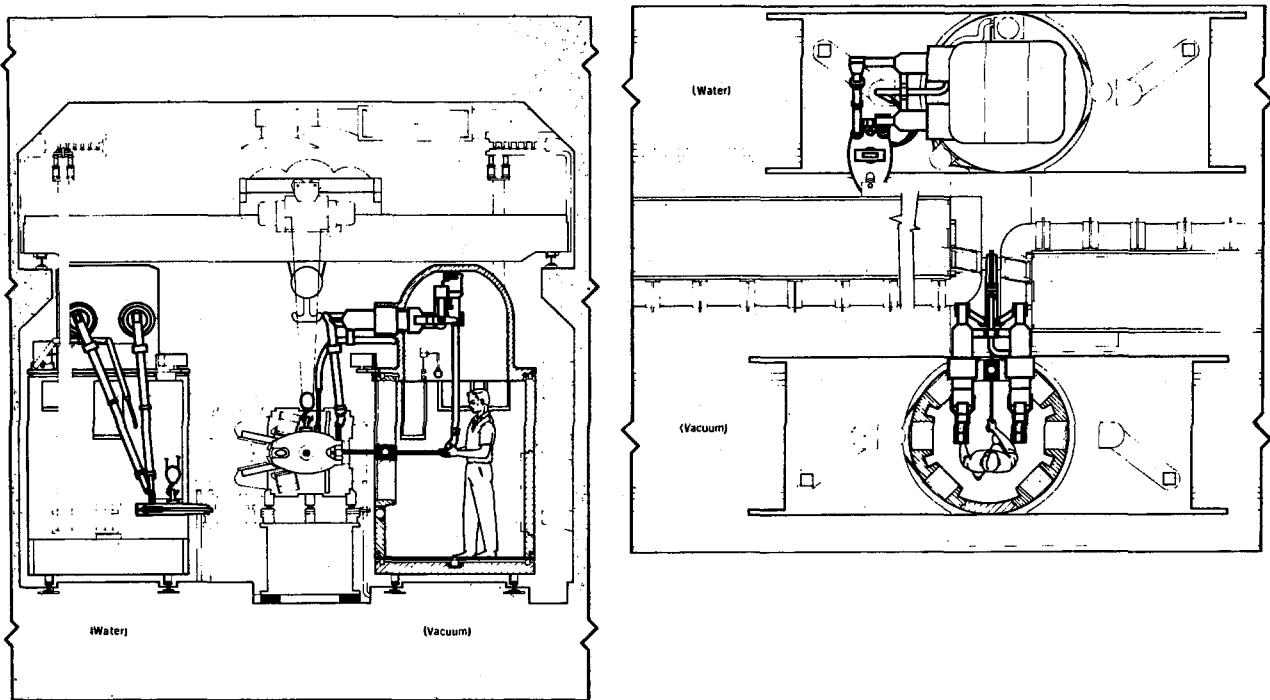


Fig. 5. Vacuum and water quick-disconnect operations from shielded manipulator vehicle.

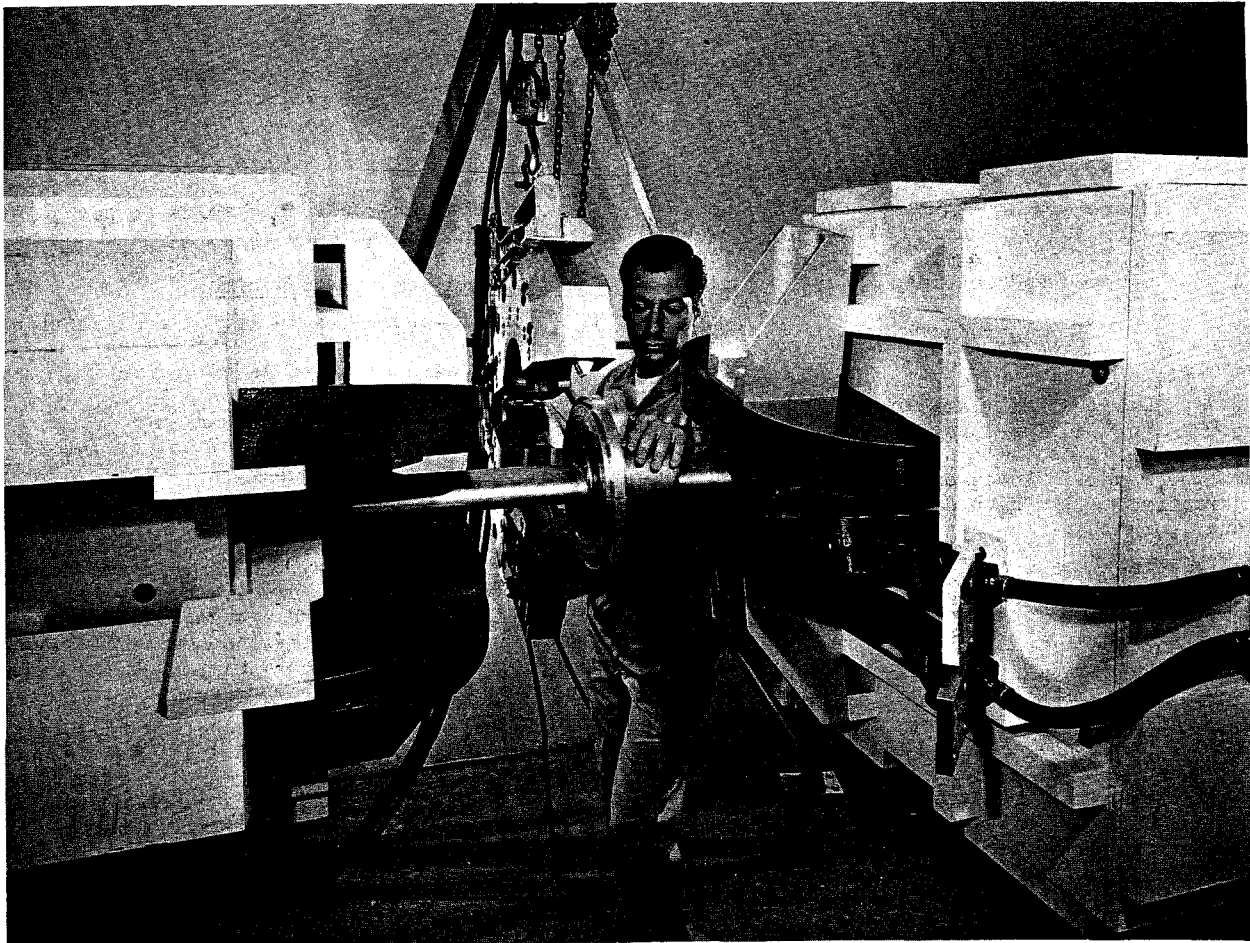


Fig. 6. Gradient magnet mock-up with operation of vacuum-flange assembly and disassembly fixture.