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Consolidated Fuel Reprocessing Program

ADVANCED REMOTE HANDLING FOR FUTURE APPLICATIONS: THE ADVANCED INTEGRATED MAINTENANCE SYSTEM

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ABSTRACT

The Consolidated Fuel Reprocessing Program at Oak Ridge National Laboratory has been developing advanced techniques for remote maintenance of future U.S. fuel reprocessing plants. The developed technology has a wide spectrum of application for other hazardous environments. These efforts are based on the application of teleoperated, force-reflecting servomanipulators for dexterous remote handling with television viewing for large-volume hazardous applications. These developments fully address the nonrepetitive nature of remote maintenance in the unstructured environments encountered in fuel reprocessing. This paper covers the primary emphasis in the present program; the design, fabrication, installation, and operation of a prototype remote handling system for reprocessing applications, the Advanced Integrated Maintenance System.

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INTRODUCTION

The Consolidated Fuel Reprocessing Program (CFRP) at Oak Ridge National Laboratory (ORNL) is developing advanced techniques for remote maintenance of future U.S. nuclear fuel reprocessing plants. These developments have been based on the application of teleoperated force-reflecting servomanipulators for dexterous remote handling with the operator removed from the hazardous environment. Closed-circuit television is used for viewing. These developments fully address the nonrepetitive nature of remote maintenance in the unstructured environments encountered in fuel reprocessing. Employing highly dexterous manipulation will allow the CFRP to meet a major goal of decreasing reprocessing plant mean-time-to-repair through increased maintenance system capabilities. Another major goal is to decrease plant personnel radiation exposure through the use of remote maintenance techniques for the maintenance equipment as well as the plant process equipment.

The application of maintenance systems with the level of dexterity of a force-reflecting servomanipulator-based system is a major step forward in reprocessing plant design.[1] The CFRP has been working in this development effort for over eight years. The effort involves all the major subsystems necessary to apply dexterous manipulators to large-volume reprocessing plant maintenance. Included are manipulators, transporters, sensors, tooling, signal and power transmission, and human-machine interfaces. Previous developments have included the design, fabrication, and operation of two major maintenance systems.

The first large-volume servomanipulator-based maintenance system was installed in the Remote Systems Development Facility (RSDF). The RSDF was equipped with a pair of Teleoperator Systems SM-229 servomanipulators mounted on an overhead, telescoping tube transporter. Efforts in the RSDF included studies of man-machine interface issues for both manipulation and viewing systems as well as manipulator joint duty cycles.[2,3]

The second large-volume system was installed in the Remote Operations and Maintenance Demonstration (ROMD) facility.[4] The maintenance system in ROMD is based on a pair of Central Research Laboratories Model M-2 servomanipulators mounted on an overhead, telescoping tube transporter with television cameras on positioning arms and an integral 230-kg hoist.[5] The M-2 system was the result of a cooperative development of Central Research Laboratories and ORNL. The M-2 control system was the first successful implementation of digital control techniques for a force-reflecting servomanipulator.[6] Efforts in the ROMD facility currently involve full remote maintenance checkout for prototype reprocessing equipment. Detailed testing of various issues in the application of remote manipulator systems is carried out in this facility. Investigations of performance of various manipulator systems, advanced viewing systems, and the issues related to force reflection are described in refs. 7-9. Remote handling demonstrations for the National Aeronautics and Space Administration, the U.S. Navy, and the U.S. Army have also been carried out with the ROMD/M-2 system. Development of each of the two maintenance systems described previously has served as the basis for current CFRP efforts.

ADVANCED INTEGRATED MAINTENANCE SYSTEM

The primary emphasis in the current program is the design, fabrication, installation, and operation of a prototype remote handling system for reprocessing applications, the Advanced Integrated Maintenance System (AIMS). This system is the culmination of the development program and represents CFRP's prototype for maintenance systems in future nuclear fuel reprocessing plants. As in past CFRP developments, the AIMS system, shown in Fig. 1, incorporates all the subsystems required for large-volume reprocessing applications. The key feature of the AIMS system is the use of the Advanced Servomanipulator (ASM), a force-reflecting servomanipulator system with slave arms designed for modular remote maintainability. The ASM system is the first force-reflecting servomanipulator incorporating this feature. These manipulators, combined with the other AIMS subsystems, are used to perform remote maintenance demonstrations on the simulated process equipment to verify the remote handling design. The subsystems of the AIMS are described in the following paragraphs.

Advanced Servomanipulator Slave Arms

The ASM slave arms were developed specifically for the extremes of a reprocessing environment. The two prototype ASM arms, installed in AIMS (Fig. 2), were designed and fabricated at ORNL. Radiation and surface contamination levels are very high in a reprocessing cell, and the atmosphere contains nitric acid vapors. The final version of the ASM slaves must function reliably in this environment. The slave arms were designed for 23-kg capacity in any orientation, end-effector

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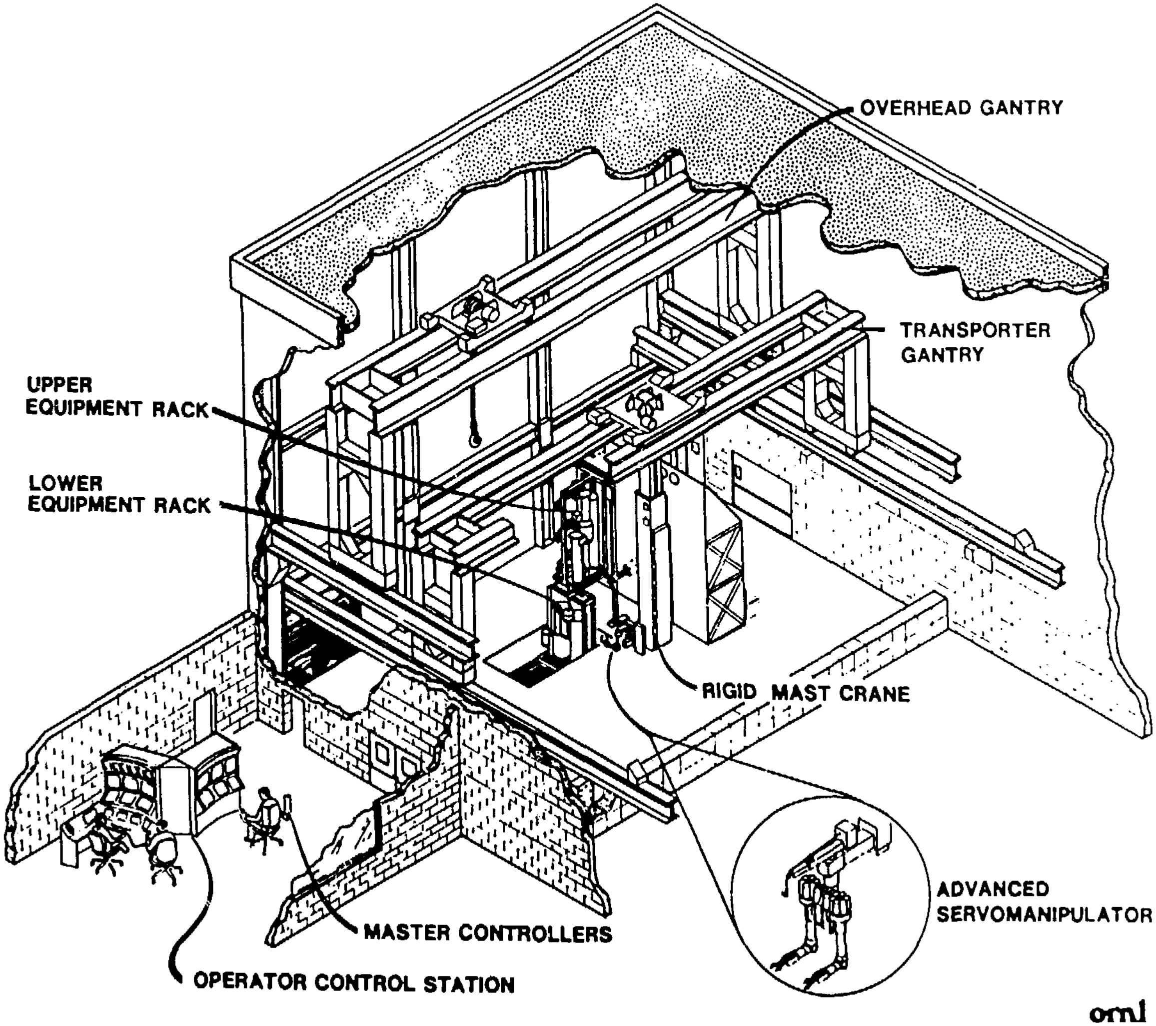
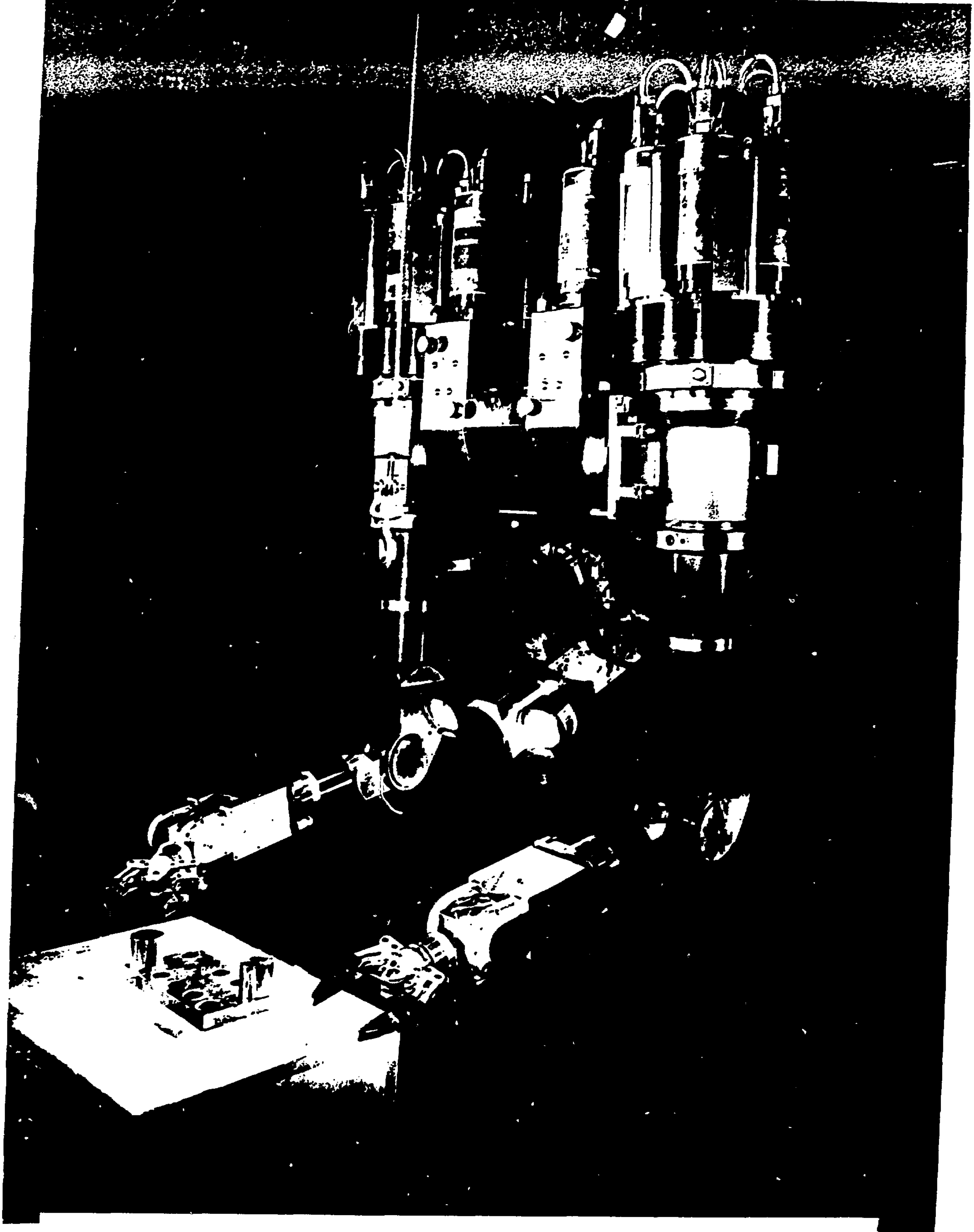


Fig. 1. Advanced Integrated Maintenance System.



maximum no-load velocities in excess of 1 m/s for all joints, and low backdriving torque requirements (approximately 2% of capacity) for force-reflecting operation with bilateral, position-position servo-control. A special brush-type dc servomotor with very low inertia was developed by Inertial Motors Corporation for this application. The arms have 6 degrees-of-freedom for generalized positioning in space with a grip as the seventh degree-of-freedom. An anthropomorphic (man-like) kinematic arrangement was employed to provide for horizontal reach capabilities into constrained areas. The range of motion of the arms is shown in Fig. 3. The unique four degree-of-freedom wrist utilized on the ASM has pitch, yaw, and output roll motions with axes intersecting at a single point and followed by the grip. The arm is composed of 15 individual modules which are each less than 23 kg in weight for handling by another manipulator. These modules are illustrated in Fig. 4. The modularized design is accomplished by the use of precision gear and shaft drives throughout. This is a significant departure from previous designs for bilateral force-reflecting servomanipulators which employ tendon drives for reduced friction and inertia. In addition, electronic counterbalancing is used to eliminate balance weights and thus reduce the cross-sectional size of the arm. A detailed description of the ASM slave arms can be found in ref. 10.

Master Controllers

The master controller arms for the ASM were designed for operation in the human-occupied control room and did not require the

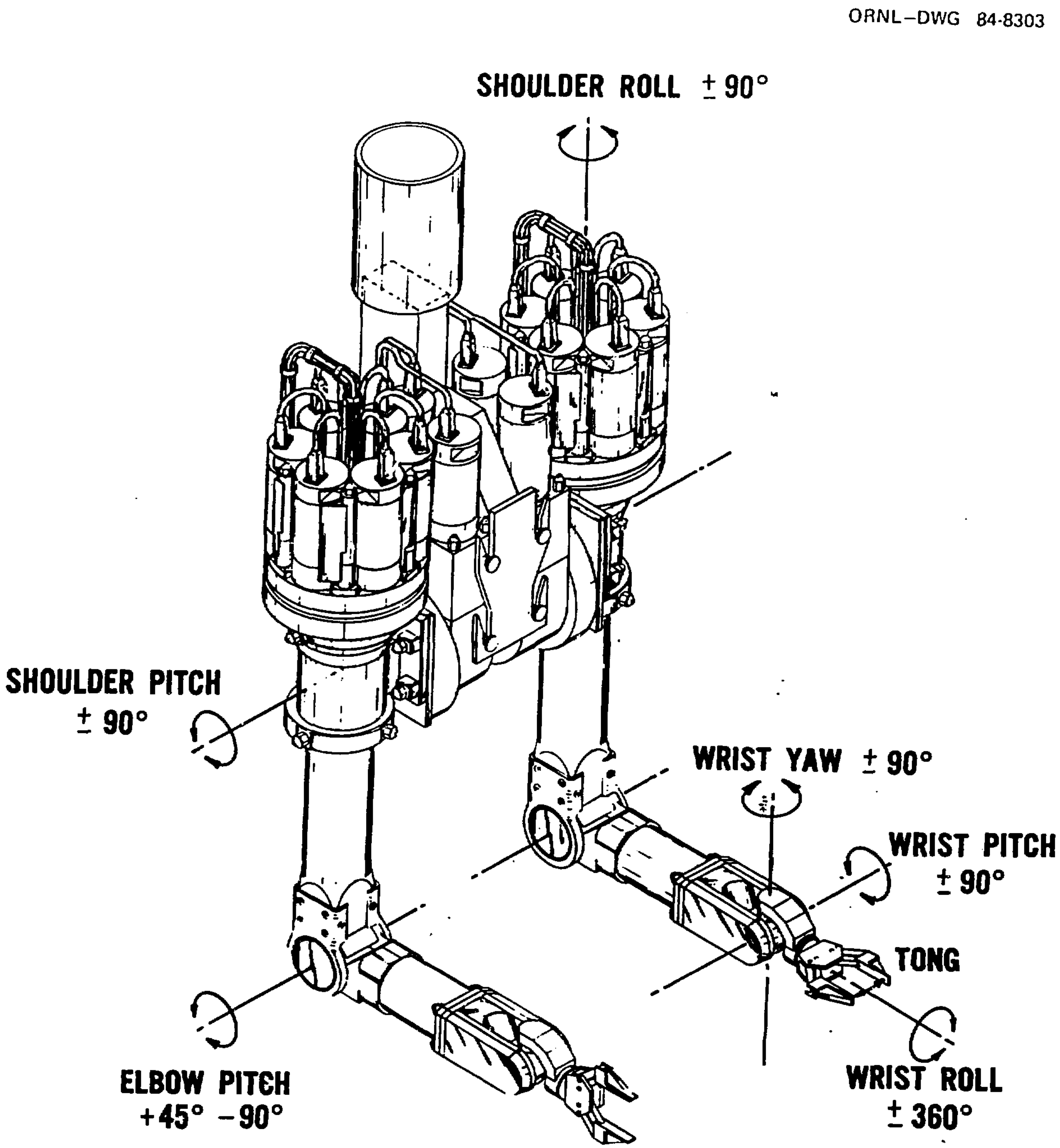


Fig. 3. ASM slave arm range of motions.

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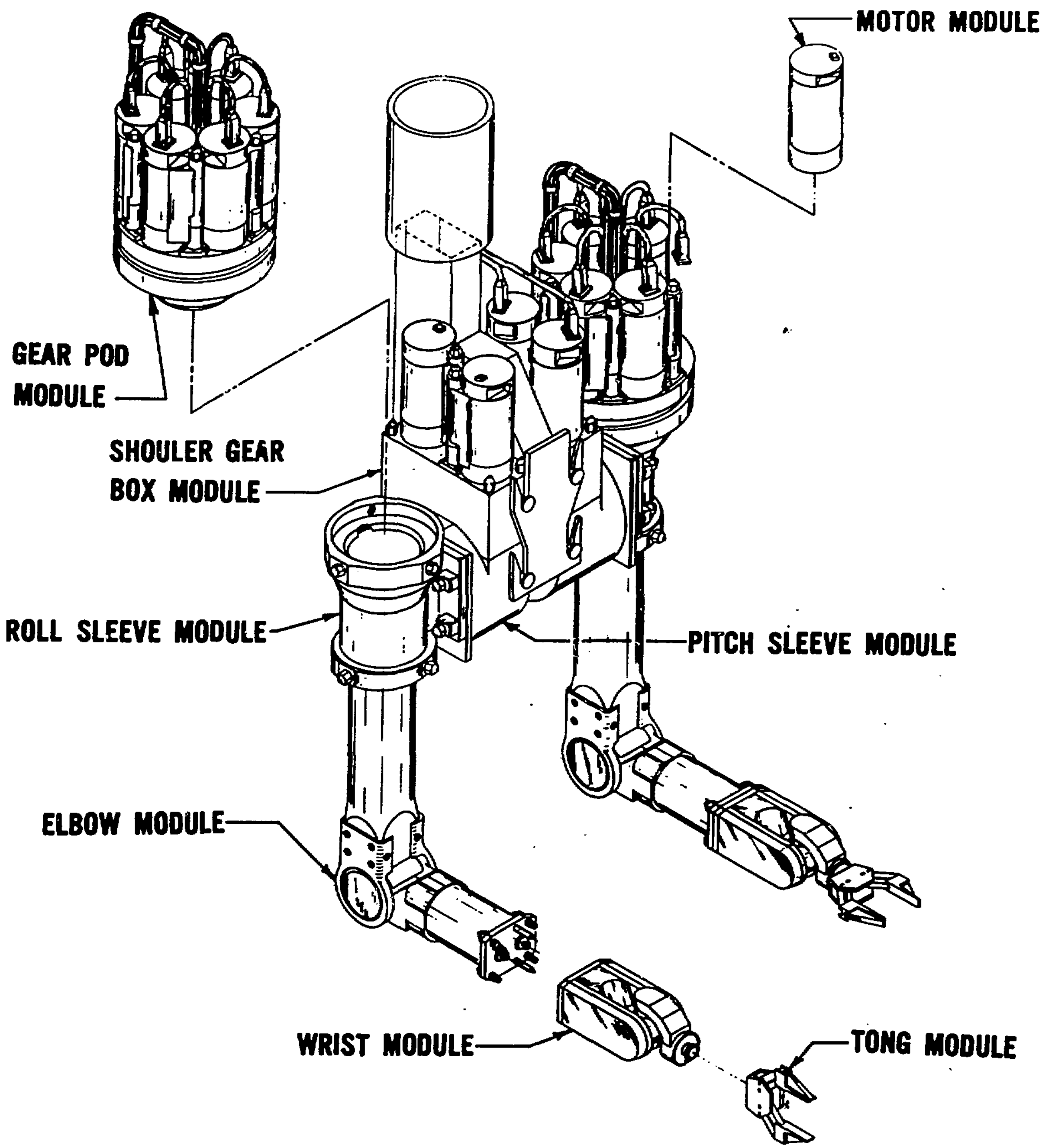

Fig. 4. ASM slave arm modules.

modularity provided in the slave arms. Stainless-steel cable drives were employed for all joints below the shoulder to minimize friction and inertia. The two prototype arms installed in AIMS (Fig. 5) were designed and fabricated at ORNL. The master controllers were designed for 6-kg capacity in any orientation; end-effector maximum no-load velocities in excess of 1 m/s for all joints; and low no-load back-driving torque (approximately 4% of capacity) for force-reflecting operation with bilateral, position-position servocontrol. The arms are one-to-one kinematic replicas of the slave arms so that real-time transformations for 30 joints at 100 Hz are not required. The slave arm torque cross-coupling is mimicked for simplification of control. The arm range of motion is shown in Fig. 6. Mechanical counter-balancing is used on the master for reduced drive friction compared to the electronic counterbalancing of the slave arms. A detailed description of the master controller arms can also be found in ref. 10.

Transporter and Interface Package

An adaption of an industrial rigid mast crane has been used for the AIMS transporter system. Rigid mast cranes have been used extensively in industry for many years for material handling and automated warehouse storage/retrieval systems. Harnischfeger Corporation performed the detail design and fabrication of a remotely maintainable stacker crane system for ORNL. The prototype for AIMS is a gantry bridge version and can be seen in Fig. 7. The transporter has a three-section, externally telescoping mast with an inner rigid section, a moving secondary mast, and an outer moving carriage which is used to

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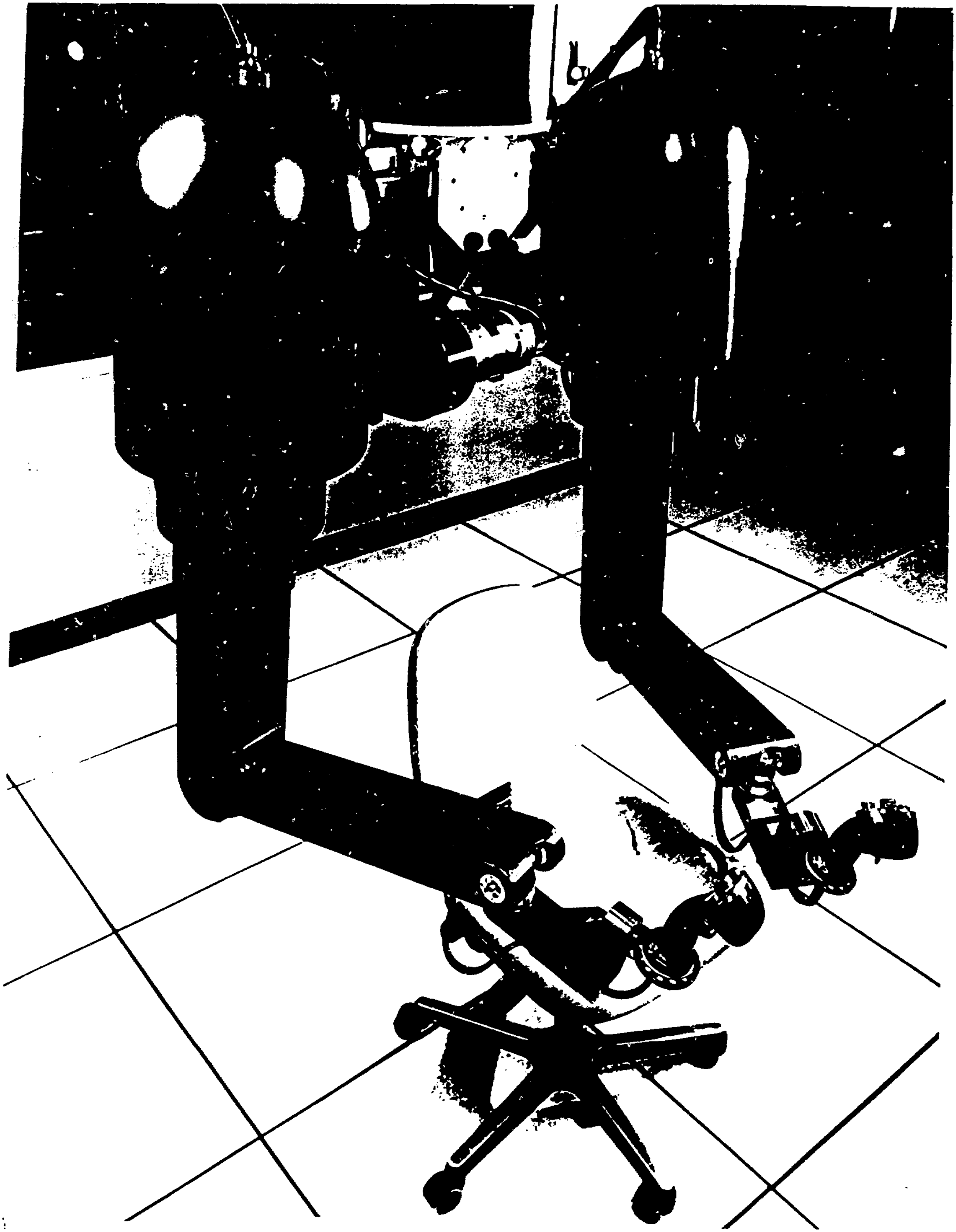


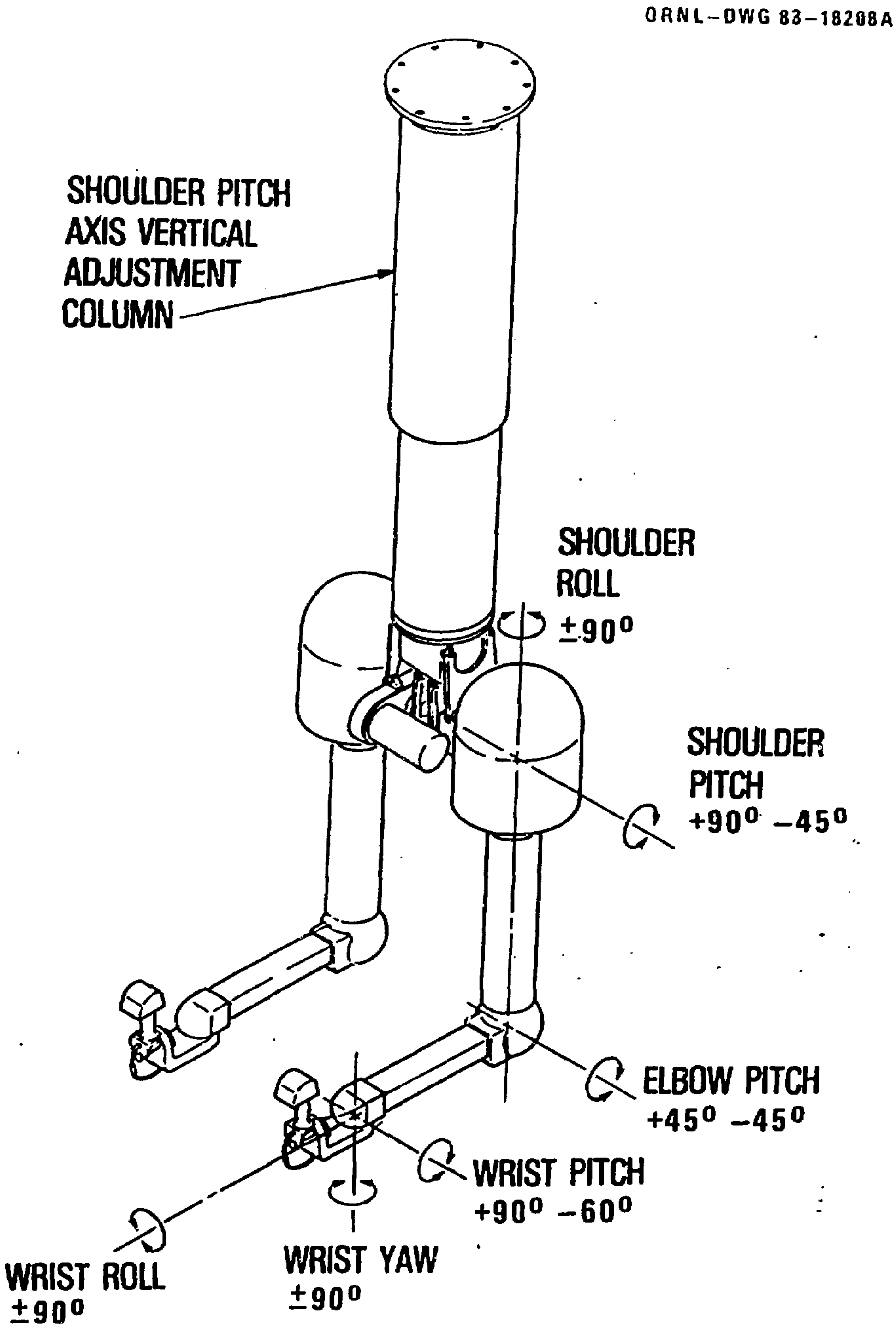


Fig. 6. ASM master controller range of motions.

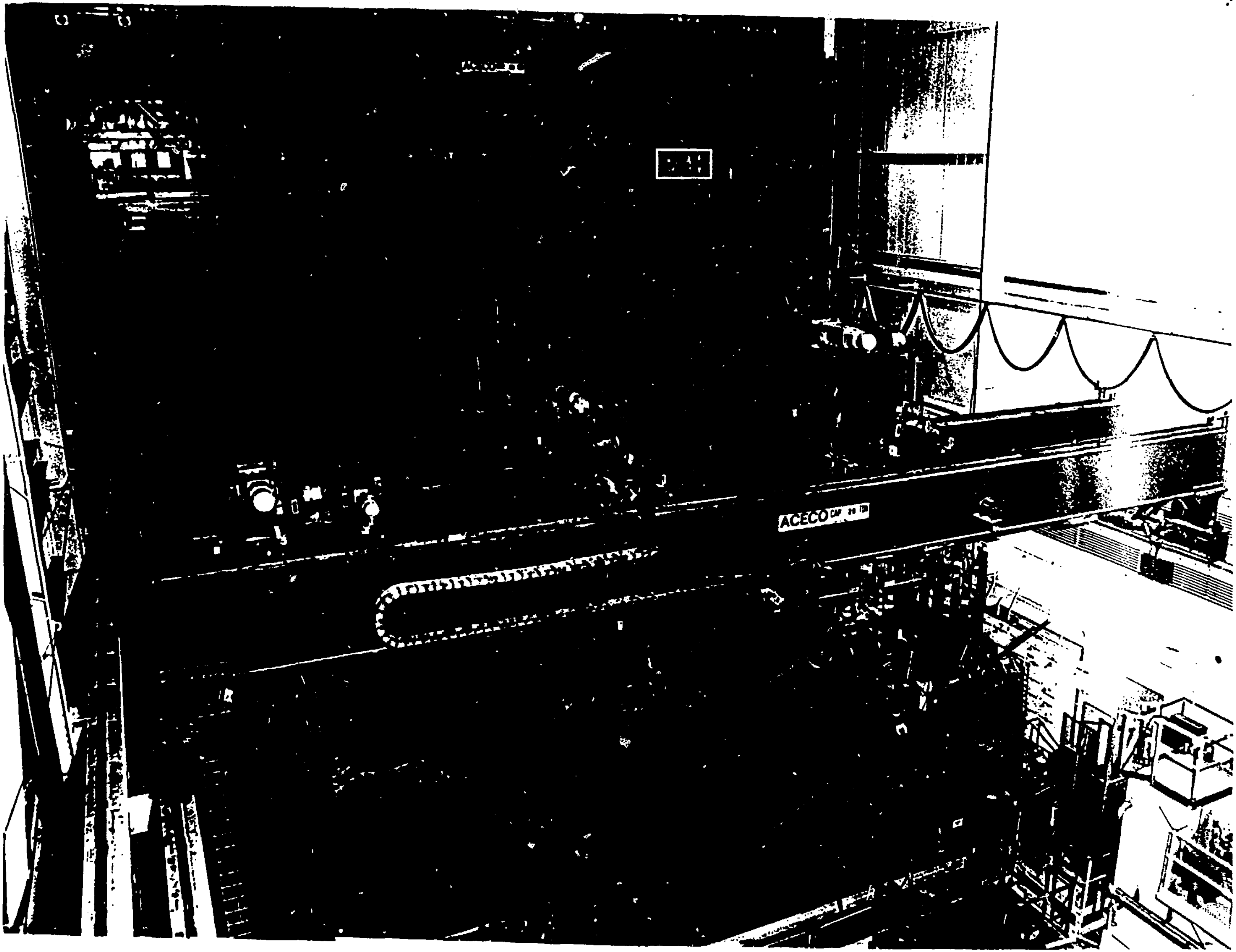


Fig. 7. AIMS prototype transporter.

support and move the servomanipulators. Hoists are used to provide independent vertical motions to the secondary mast and the carriage. The rigid mast section is mounted on a rotating turntable supported by a large-diameter bearing and an external gear to provide 370-degree rotation of the mast. The interface package, shown in Fig. 8, is remotely detachable from the transporter and provides the balance of the in-cell remote maintenance system. The AIMS interface package, designed and fabricated at ORNL, supports two overhead television cameras with lights on four degree-of-freedom positioners, a center camera with lights on a two degree-of-freedom positioner, mounts for the ASM slave arms, and a 460-kg-capacity auxiliary hoist with extend/retract motion. A rotation drive about the interface package centerline is also provided for ease of in-cell positioning in flexible orientations.

AIMS Operator Control Station

The operator control station design for AIMS benefited extensively from the RSDF and ROMD control station operation and from the extensive program of human factors research in teleoperation, which has been active within Remote Control Engineering (RCE) for over eight years. The AIMS operator station,[11] shown in Fig. 9, is based on a two-operator team approach to control of maintenance operations and the use of flexible graphic-display-based controls. Good interoperator communication, both visually and verbally, is essential. The manipulator operator, shown on the right of Fig. 9, is responsible for performing the dexterous maintenance operations using the master controllers with television viewing. This operator is also provided with three color

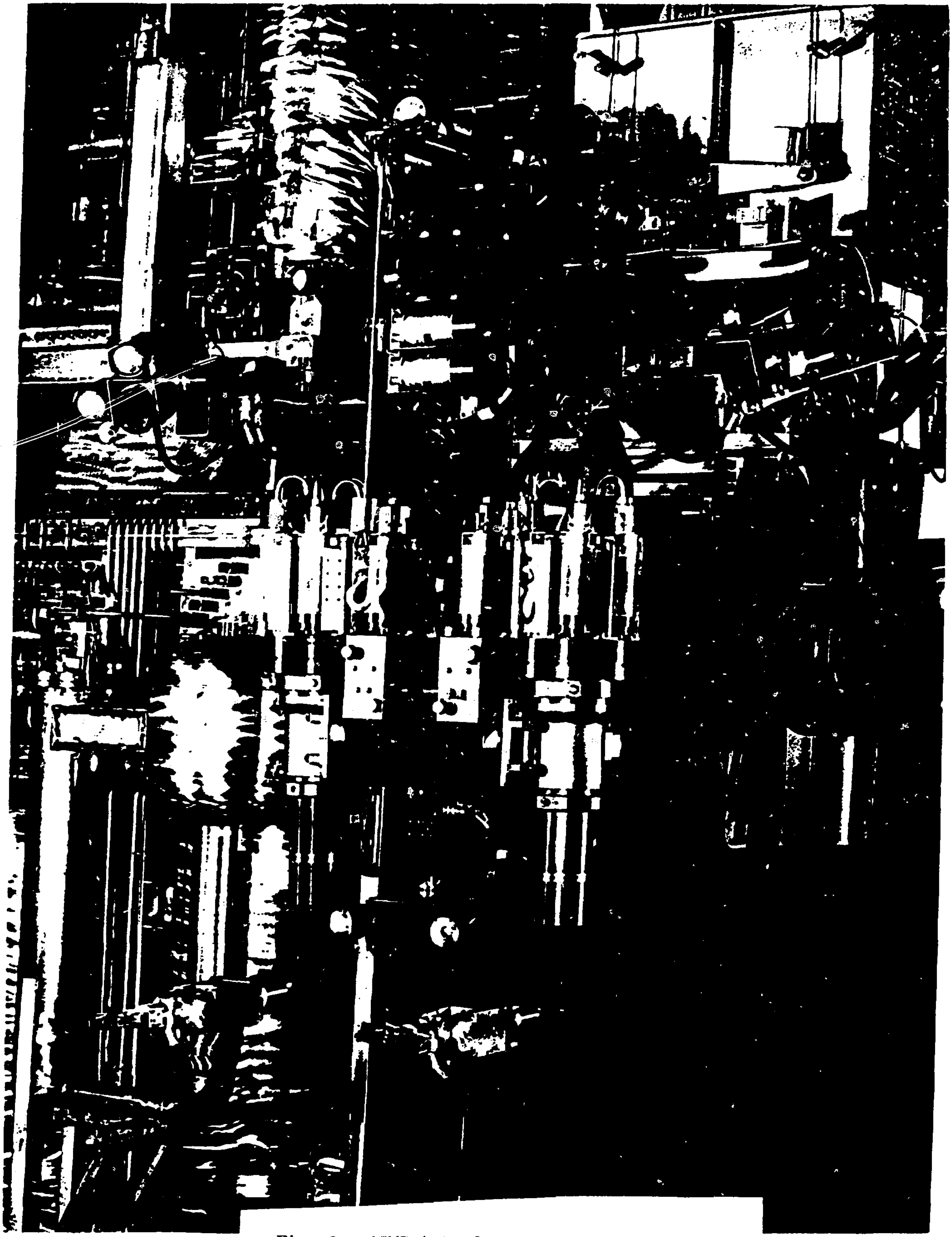


Fig. 8. AIMS interface package.

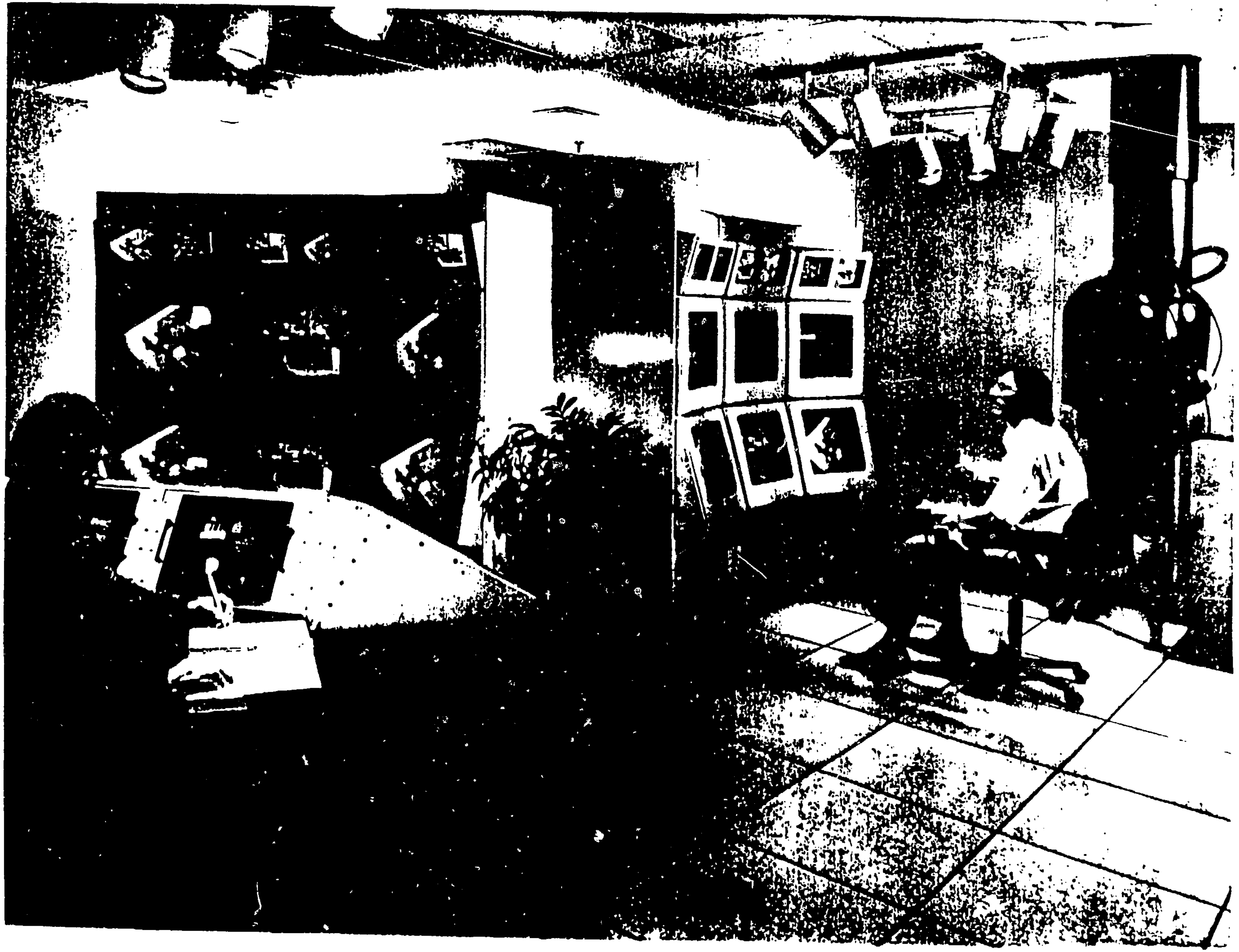


Fig. 9. AIMS operator control station.

graphic displays for status and menu selection using a master controller grip-mounted cursor control. The secondary operator, shown on the left side of Fig. 9, is responsible for control of the transporter, a large overhead 20-ton crane, television camera positioning, control station displays, and overall maintenance supervision. Prior to fabrication, this control room arrangement was completely designed based on ergonomic principles, mocked up, and thoroughly tested for ease of use by the required operator population.

AIMS Control System

Control of the AIMS system is a sizable challenge because of the breadth of the requirements. The control system must provide for 26 bilateral, force-reflecting joints which require updating at 100 Hz; 58 non-force-reflecting drives; over 100 discrete outputs; 6 graphics displays; 21 television displays; and 2 separate operator control stations. This problem has been solved by a hierarchical, building block approach (see Fig. 10) utilizing an industry-standard Multibus backplane (IEEE 796) for expandability and flexibility. Single-board Motorola 68000-based computers for control calculations and Megalink communications devices are used throughout the system with input/output and special devices chosen to meet individual subsystem requirements. All software modules in the system are being programmed in FORTH for speed of execution in a high-level language environment.

ORNL has led the world in the development of digital-based control systems for bilateral force-reflecting servomanipulators. The controls for the ASM,[12] based on the hardware described above, are the most advanced of any existing force-reflecting servomanipulators. Through

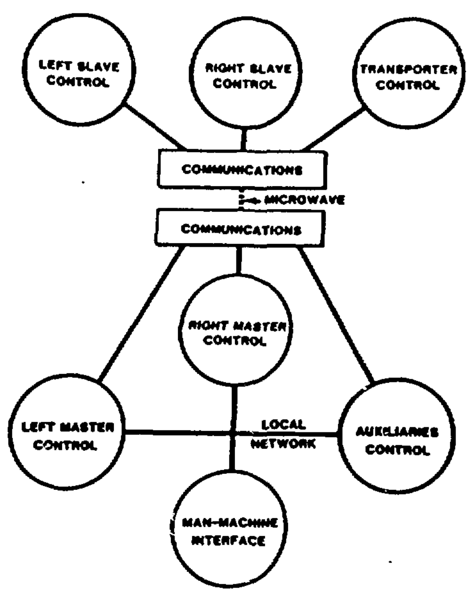


Fig. 10. AIMS control system block diagram.

special software compensation methods, the adverse effects of much higher levels of friction, inertia, and cross-coupling of torques on the ASM slaves have been minimized. In addition, electronic counter-balancing of the slave arms has been achieved without significant adverse effects on the force-reflection sensitivity.

Other AIMS Subsystems

The CFRP is developing two other major items for the AIMS system: wireless signal transmission and radiation-hard television cameras. Wireless signal transmission methods are very important for the implementation of a remotely-maintained transporter in a very large cell. The AIMS system, with five television cameras mounted on the mobile system and three 1-megabaud-rate data channels, is a very demanding application. A prototype microwave-based signal transmission system for this application is currently in fabrication. To provide reliable remote cell television cameras, the CFRP has developed a radiation hardened version of the commercially available MTI/Dage camera shown in Fig. 11. The illustrated camera head and Fujinon lens have been successfully radiation tested to 10^8 rad absorbed dose in their commercially delivered form. The CFRP has modified the camera control unit through selective component and circuit replacement for improved radiation hardness. These modifications have been verified in irradiation testing to give control box radiation hardness in excess of $6\text{-x-}10^6$ rad absorbed dose.

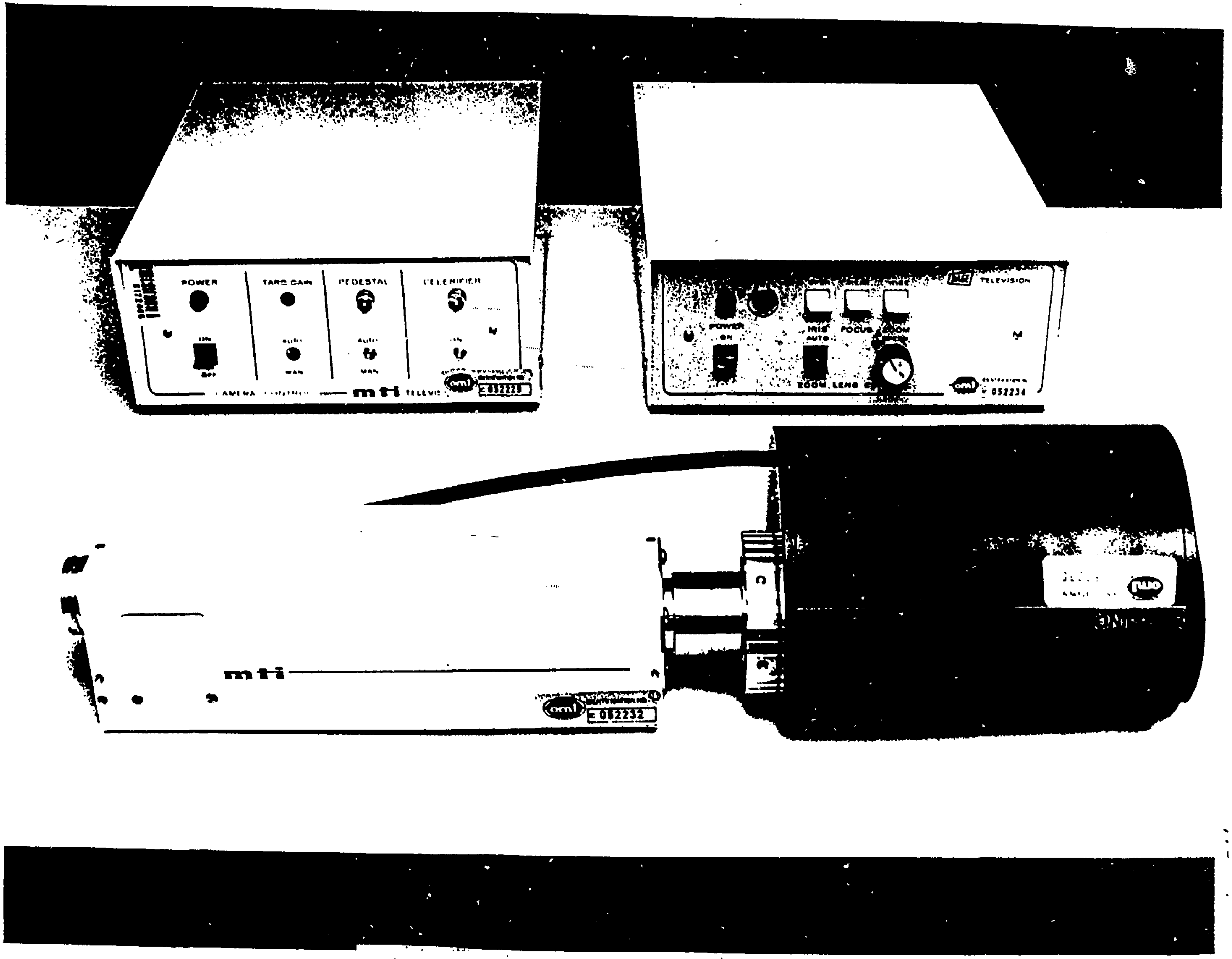
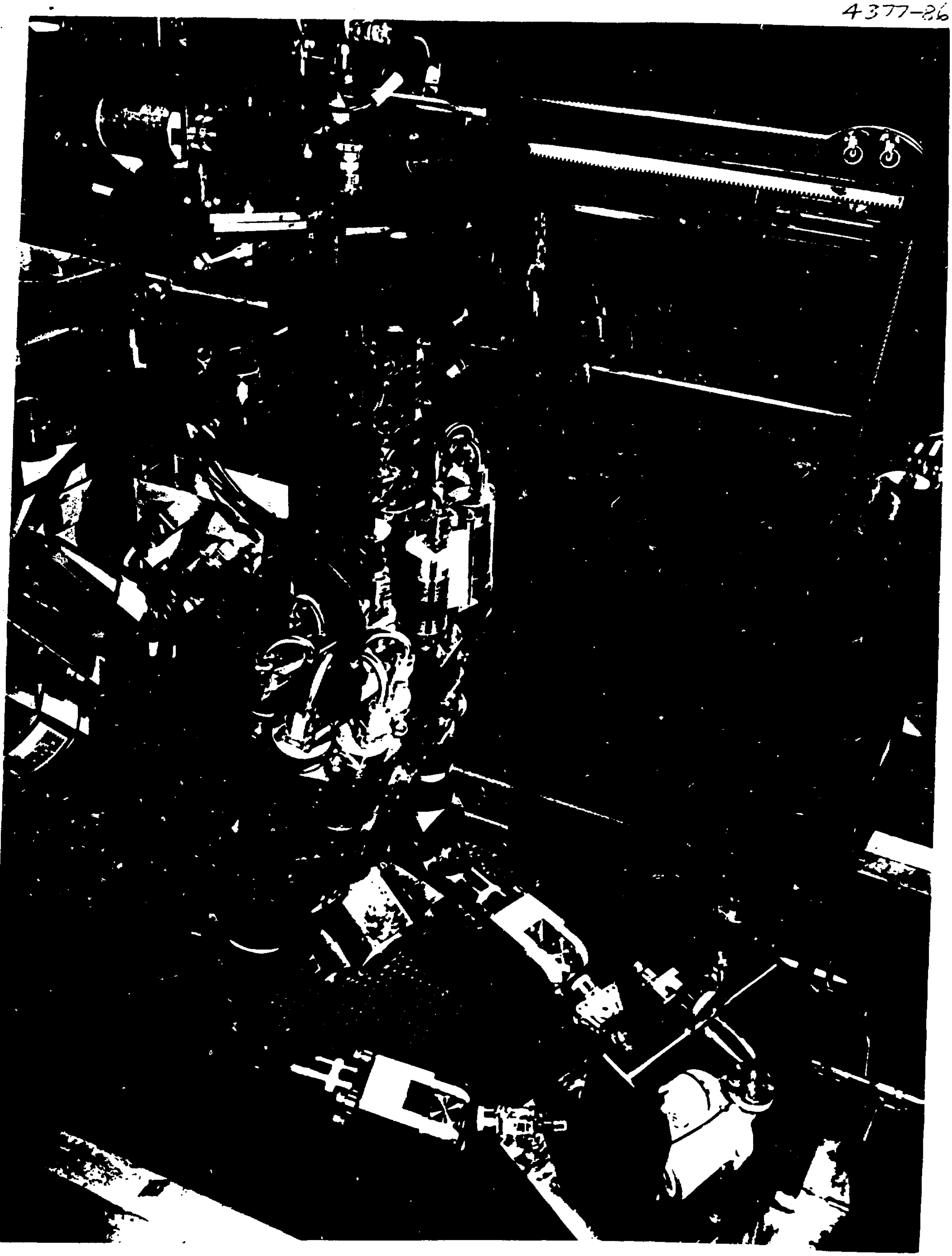


Fig. 11. Dage/MTI television camera system.

Current AIMS Status

The ASM slave arms were operational for two years in the laboratory environment, and the full master-slave system and operator control station have been operational for one year. All AIMS systems, other than the microwave system, are now operational and are in initial application testing. Typical operations are shown in Figs. 12 and 13. The microwave signal transmission system will be installed in May 1987 to complete the overall AIMS prototype system.



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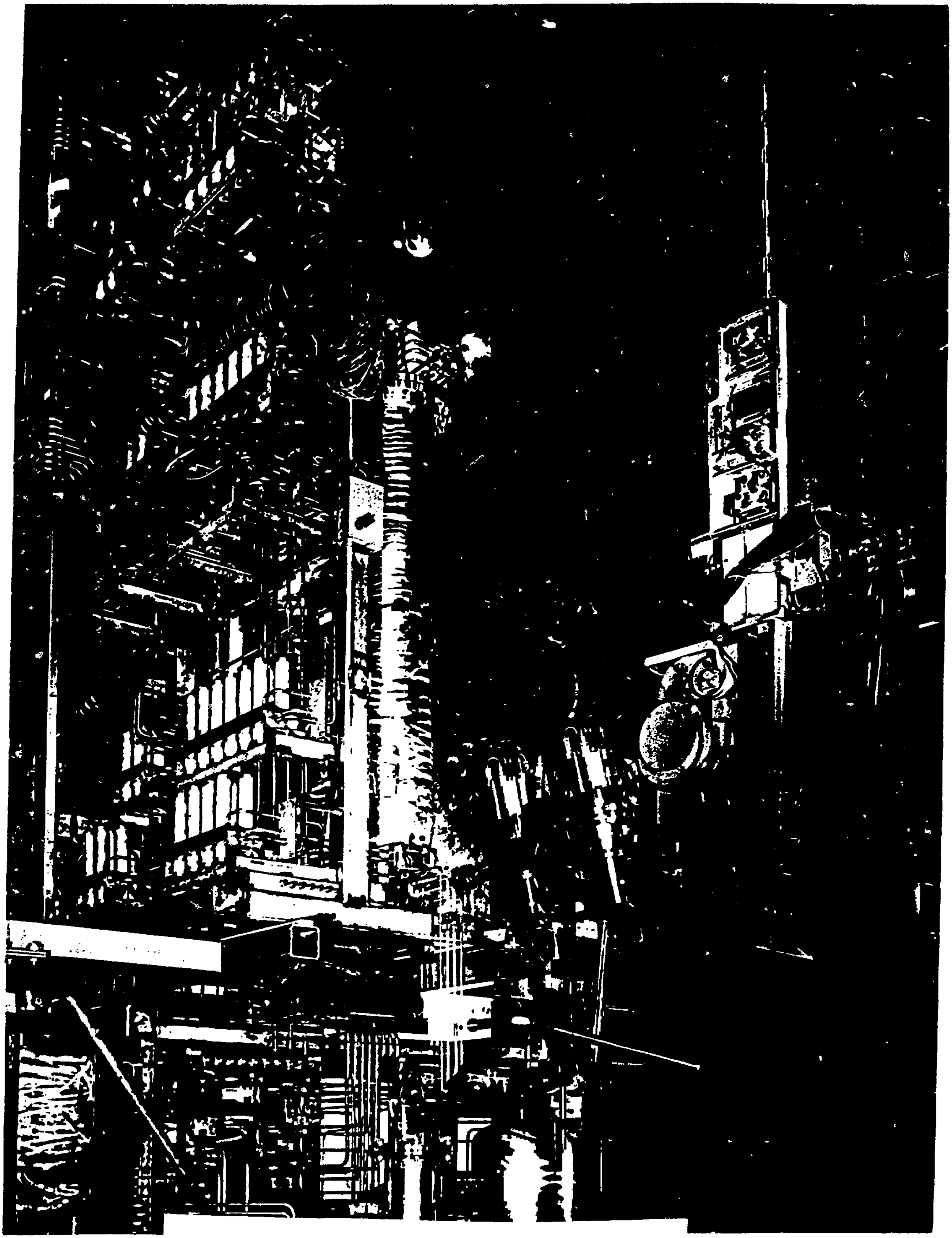

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