NAA-SR-3265
COPY

MASTER

A REMOTELY MAINTAINABLE RECTILINEAR MANIPULATOR FOR THE PROCESSING REFABRICATION EXPERIMENT (PRE)

AEC Research and Development Report

ATOMICS INTERNATIONAL
A DIVISION OF NORTH AMERICAN AVIATION, INC.

NAA-SR-3265
METALLURGY AND CERAMICS
PAGES

A REMOTELY MAINTAINABLE RECTILINEAR MANIPULATOR FOR THE PROCESSING REFABRICATION EXPERIMENT (PRE)

BY
G. P. STREECHON

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.
P.O. BOX 309 CANOGA PARK, CALIFORNIA

CONTRACT: AT-(11-1)-GEN-8
ISSUED: MAR 15 1959

DISTRIBUTION

This report has been distributed according to the category "Metallurgy and Ceramics" as given in "Standard Distribution Lists for Unclassified Scientific and Technical Reports" TID-4500 (14th Ed.), October 1, 1958. A total of 600 copies was printed.

CONTENTS

TABLES

FIGURES

FIGURES (Continued)

ABSTRACT

To aid in the handling and maintenance of in-cell process equipment, a remotely maintainable, general-purpose rectilinear manipulator is required in the PRE. A description is given of the modifications to a commercially available rectilinear manipulator which were required to facilitate the remote removal, replacement, and maintenance of the manipulator and its major components. The feasibility of the PRE modifications and operating and maintenance techniques were satisfactorily demonstrated on an in-cell mockup of this manipulator. An in-cell crane and/or a through-roof hoist can effect remote maintenance and removal of the carriage and bridge of the manipulator.

I. INTRODUCTION

The Processing Refabrication Experiment (PRE) program[1,2] encompasses the development and demonstration of low-decontamination processes, equipment, facilities, and techniques for reconstituting reactor fuel materials which have been irradiated in a power reactor.

In order to permit the handling, transfer, and maintenance of processed materials and equipment in the shielded facility proposed by Atomics International for the PRE, remotely operated manipulators must be developed. The basic PRE philosophy for developing remotely controlled equipment assumes that no in-cell contact maintenance will be permissible after hot operations begin and that every in-cell mechanism will fail during its useful in-cell lifetime. Only the in-cell crane and a unique through-roof hoist are capable of servicing the rectilinear manipulator in the proposed PRE facility; consequently, the abilities of these devices to perform tasks must be kept in sharp focus during the modification and development of the manipulators.

The operational functions and operating requirements of a rectilinear manipulator, suitable for use in the PRE facility, were specified. Manipulator installations in existing AEC facilities and commercially available manipulators were investigated to determine the performance reliability of the equipment under specific operating conditions. A heavy-duty, general-purpose rectilinear manipulator was procured, installed in the PRE cell mockup, and operated to familiarize PRE personnel with the characteristics of the unit.

Operational attachments were devised to improve the versatility and reliability of the manipulator. Equipment and techniques were developed for mechanically overriding an inoperable manipulator to position it for remote maintenance as well as to complete limited emergency operations after the unit fails. Techniques were devised and the manipulator was modified to facilitate the remote removal and replacement of the carriage and bridge from the wall-mounted rails. Mechanical components of the carriage and bridge were modified to permit the remote removal and replacement of inoperable components without removing the contaminated manipulator from the shielded cell complex.

II. FUNCTIONS

The prime function of the rectilinear manipulator in process cells is that of an auxiliary handling device to augment the in-cell crane in the handling, transfer, and servicing of process equipment. In a remote maintenance cell it will be utilized as one of the major tools for the repair and maintenance of processing, fabrication, and supporting equipment.[3]

III. REQUIREMENTS

Installation and operational requirements were specified for a general-purpose, heavy-duty manipulator for use in the PRE hot cells. The manipulator should be:

a) Rectilinear in operation

b) Remotely controlled

c) Electrically, pneumatically, or hydraulically powered

d) Capable of lifting 500 lb

e) Capable of performing in-cell operations from the floor level to a height of approximately 8 ft over the entire floor area

f) Provided with mechanical overrides for the longitudinal, transverse, and vertical motions

g) Assembled so as to facilitate the remote removal and replacement of all major components except the supporting rail installation for the bridge

h) Installed in such a manner as not to contribute to cell atmosphere leakage during remote operating and/or maintenance procedures.

Requirements (a) through (e) are typical specifications for a general-purpose, heavy-duty rectilinear manipulator. Requirements (f) through (h) describe the unique features of a rectilinear manipulator installation in the proposed PRE hot-cell complex. Requirements (f) and (g) are dictated by the fact that the in-cell handling equipment will be inaccessible to any contact maintenance once the plant is in operation. Therefore, it will be necessary to remove and replace the inoperable manipulator and/or its major components remotely at some time during the in-cell lifetime of the equipment. Manipulator maintenance will be performed utilizing an in-cell crane and/or a through-roof hoist as the principal pieces of handling equipment.[4,5]

Requirement (h) was prescribed to counteract any or all of the following undesirable environmental conditions. The process cell might have an anhydrous inert atmosphere and an appreciable out-leakage of this atmosphere from the cell would be expensive; a far greater expense would be incurred by the leakage of oxidants into the inert atmosphere of the cell and the subsequent loss, via corrosion, of extremely expensive fuel materials; and the presence of lethal quantities of radioactive gases in the cell atmosphere during the PRE processing operations precludes the possibility of operations of a process cell which is not gas-tight.

IV. EVALUATION OF EXISTING MANIPULATOR INSTALLATIONS

The investigation of existing hot-cell facilities which utilize rectilinear manipulators showed that the shielded cells were accessible to personnel for limited contact maintenance of equipment. Consequently, most of the maintenance techniques applicable to these existing cells are not applicable to PRE operations.

Detailed evaluations pertaining to availability, cost, capacity, and operating history were made of four models of rectilinear manipulators, products of different manufacturers. As no one model suited all of the PRE requirements, the unit that could best be modified to meet PRE operating requirements was purchased for installation and operation in the mockup cell.

V. DESCRIPTION OF ORIGINAL EQUIPMENT

The manipulator, as initially installed, was a commercially available general-purpose, heavy-duty, electro-mechanical manipulator. The major components include the track, the bridge assembly, the arm carriage, the telescoping hoist, the arm, the cable takeup, and the control console as shown in Figure 1.

The track is composed of two rails mounted on the front and rear walls of the cell. The bridge assembly serves as a mobile support for the arm carriage. Each rail of the bridge track and one rail of the carriage track are equipped with an integral gear rack which meshes with the spur gears of the bridge and carriage drive mechanism. The mobile arm carriage supports the manipulator on the bridge and contains the drive mechanisms for the arm and telescoping hoist. The coordinated movements of the bridge and arm carriage enable the arm unit to be positioned longitudinally and laterally, respectively, in the cell.

The telescoping hoist is a tubular column whose three tube sections telescope in and out of a housing on the arm carriage. The hoist lowers the shoulder housing by the effect of gravity on the combined weight of the arm and tube columns. The hoist raises the shoulder housing by a cable and drum arrangement on the hoist drive motor.

The arm assembly consists of the shoulder housing, shoulder joint, upper arm, elbow joint, forearm, wrist joint, hand or hook, and the corresponding drive mechanisms. The manipulator hand consists of two flat fingers which are actuated and kept parallel by a parellelogram linkage, has a maximum finger opening of 5 in., is capable of continuous rotation at the wrist joint in either direction, can exert a continuous gripping force of 150 lb, and is capable of performing in-cell operations from floor level to a height of approximately 10 ft. The grappling hook, which can be attached to the wrist in place of the hand, has a maximum lift capacity of 750 lb along the center line of the telescoping hoist. The cable takeup is a counter-weighted reel which can be located outside of the shielded cell structure but inside of the cell's atmosphere envelope. The power cable is supported between the takeup reel and the bridge by cable rollers attached to the inside edge of one of the wall-mounted rails. The main in-cell power cable feeds into the cell through a hole in the cell wall connecting the housing with the cell. The housing contains the cell atmosphere. Auxiliary shielding is necessary in the housing to prevent radiation shine through the cable-feed hole in the cell wall.

The control console contains the electrical components which make up the dc power supply for the manipulator drive motors, the control-handle switching assemblies, and the visual and audio grip-force monitors. The controls are oriented to facilitate the "natural movement" of the pistol-grip handles for complementing movements of the in-cell equipment.

The manipulator, as installed in the PRE mockup cell, is shown in Figure 2. It has a bridge span of 10 ft and a bridge travel of 30 ft. The rails are installed at an elevation of 12 ft above the cell floor level, thereby permitting the shoulder to be lowered to within 2 in. of the floor.

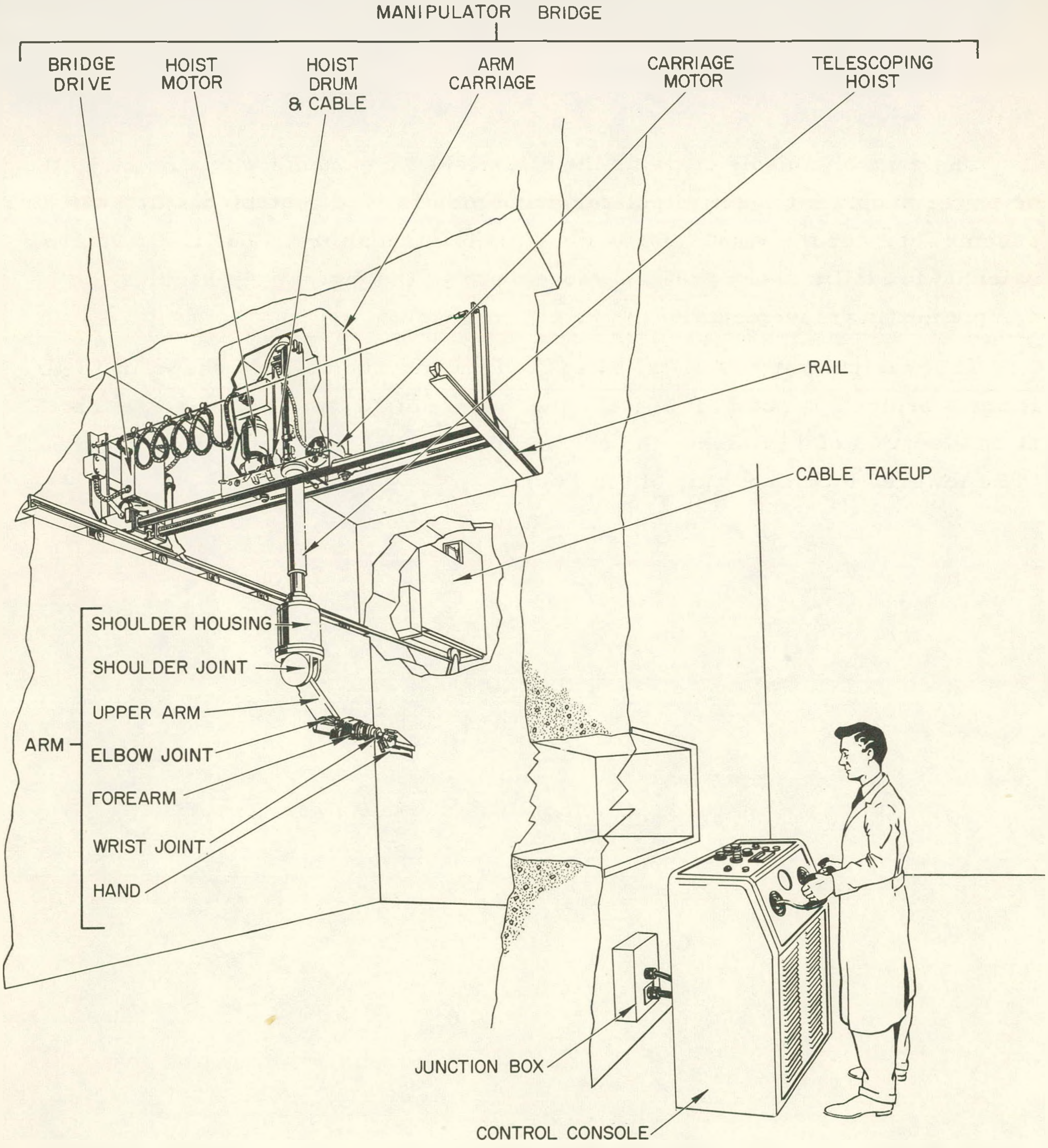


Figure 1. Typical Rectilinear Manipulator (Arm carriage cover in phantom)

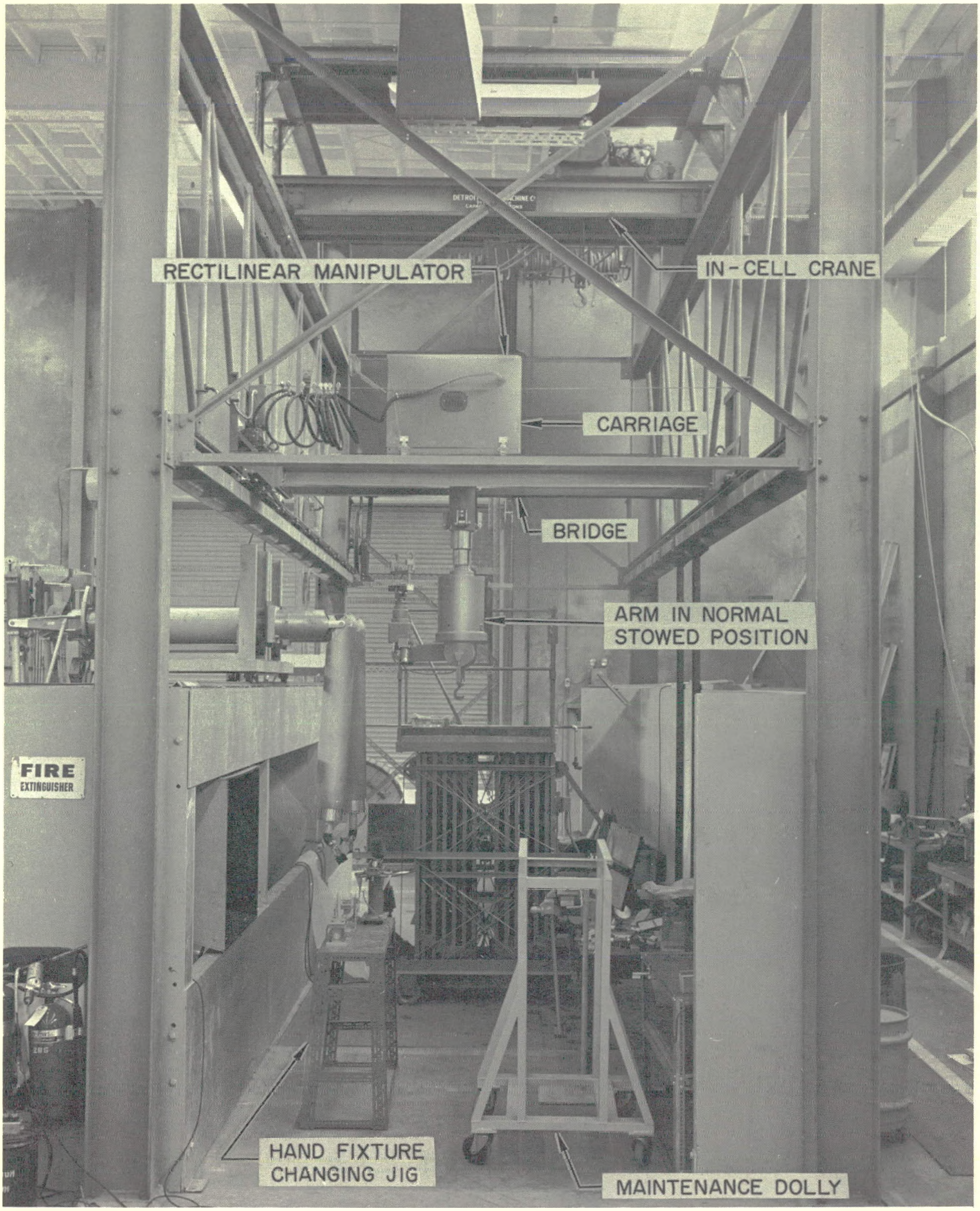


Figure 2. PRE Cell Mockup, (Rectilinear manipulator installation)

VI. INITIAL OPERATION

Initial operation of the installed manipulator indicated that several items could be added to the equipment to increase its versatility and reliability for PRE application. The structural design and mechanical assembly of the major components were analyzed for modification to facilitate in-cell disassembly and replacement of the least fail-proof subassemblies by remote techniques.

A shoulder hook, as shown in Figure 3, was installed on the manipulator to permit it to lift its maximum load of 750 lb without removing the hand fixture attached to the wrist unit. An adjustable double-hand hook, shown in Figure 4, was fabricated for attachment to the wrist joint. This double-hand hook enabled the manipulator to lift and maneuver an object with a long moment arm, such as a vacuum-cleaner wand, and increased the stability of the forearm when operating impact tools.

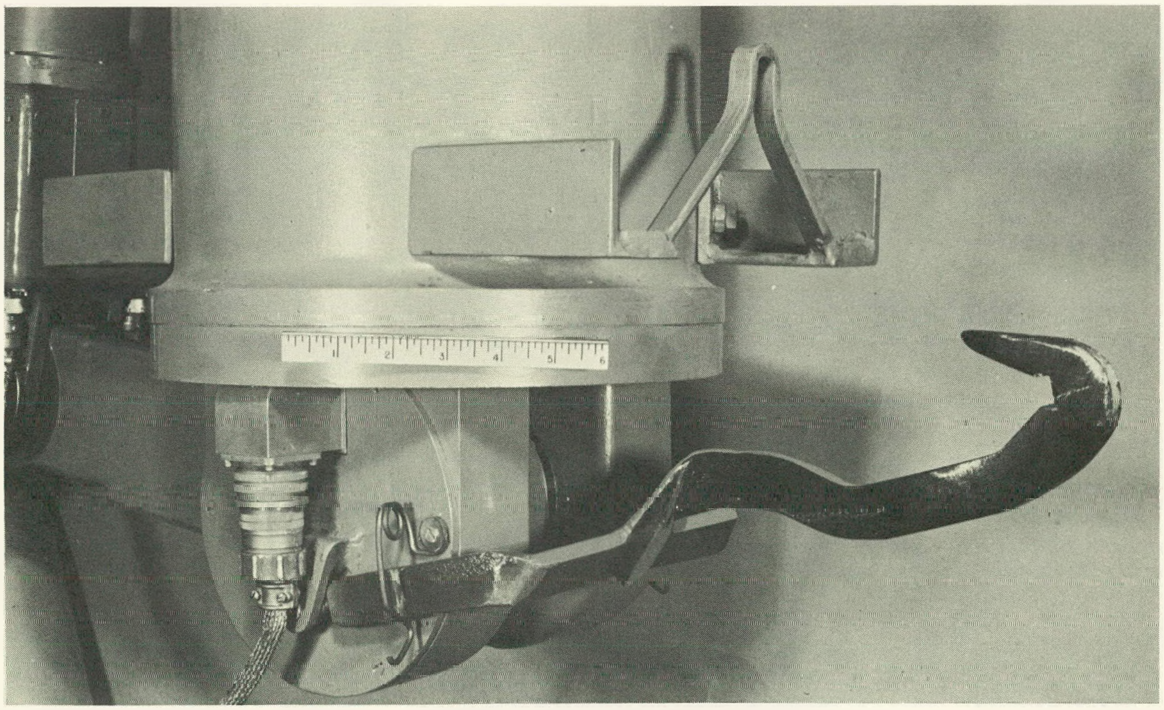


Figure 3. Shoulder Hook (Normal stowed position)

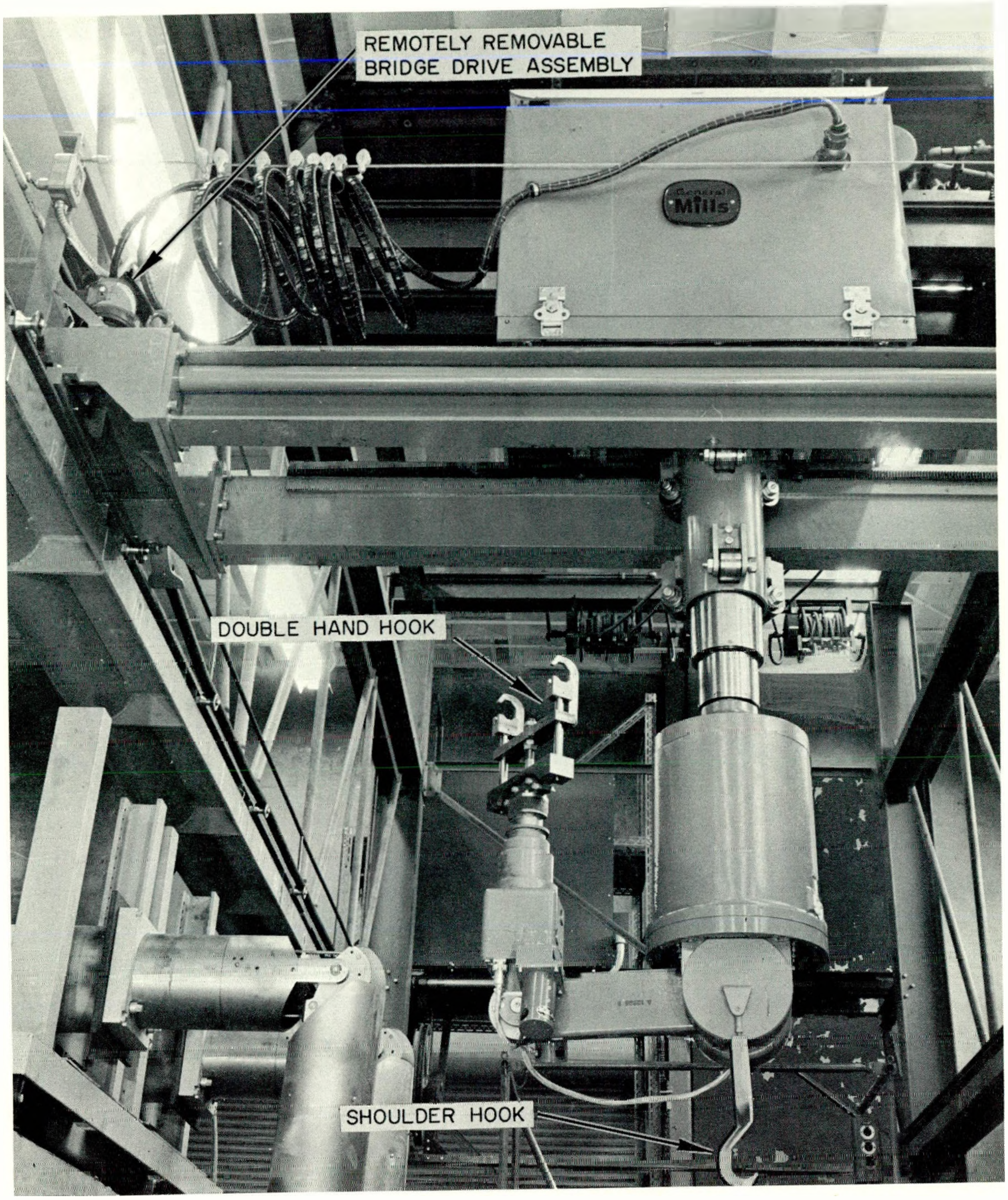


Figure 4. Double Hand Hook

A commercial load simulator unit was installed on the control console. This simulator was used to locate electrical malfunctions in the control console. A commercial audio grip-force indicator also was added to the control console to supplement the visual system and thereby allow the operator to devote all of his visual attention to the in-cell manipulator operations.

Any impact or resistance to the downward travel of the gravity-powered telescoping tubes, during lowering of the manipulator hoist, will cause a slackening of the tension in the hoist cable, and can permit the unrestrained cable to slip from the hoist drum. Consequently, a hoist-cable retainer was devised and installed over the hoist drum to prevent any possibility of the hoist cable slipping from the hoist drum during grapple-changing operations.

VII. DEVELOPMENT OF OVERRIDES

The PRE philosophy of operations assumes that the manipulator will fail during its useful lifetime. Only the mobile in-cell crane and the fixed-position, through-roof hoist are capable of servicing this rectilinear manipulator. Consequently, provisions must be made to override the manipulator mechanically when it fails.

The hoist override must be able to lower and release a load on the manipulator and to retract the unloaded arm prior to remote removal of the manipulator carriage from its bridge. The overrides for the carriage and bridge drives must be capable of completing limited emergency operations in the event of bridge, carriage, or hoist-drive failure. In addition to their functions as emergency operating devices, these overrides will enable the operator to position the carriage and bridge accurately if the through-roof hoist is to be used for the remote removal and replacement of one of one or the other of these component assemblies.

Conceptual designs were made of several techniques for overriding each of the three operational components of the manipulator. Two separate and independent methods for overriding each of the components were fabricated, installed in the cell mockup, and satisfactorily operated.

A. BRIDGE OVERRIDE

In one system for overriding the bridge assembly, "dogs" are attached to a continuous double cable to disengage the clutch assembly for the bridge drive and pull the bridge to any desired location along its track (Figure 5). The cables and "dogs" remain stationary during normal manipulator operations.

The other bridge override method requires the extension of the bridge-clutch actuating shaft and the bridge-drive motor shaft so that each shaft extension can be actuated by an impact wrench suspended from the in-cell crane (Figure 6).

B. CARRIAGE OVERRIDE

In one override system for the carriage drive system, an impact wrench actuates the carriage drive through an extension shaft and a clutching mechanism which was modified so that it can be engaged and disengaged by the in-cell crane (Figure 7). The other carriage override system consists of a through-wall,

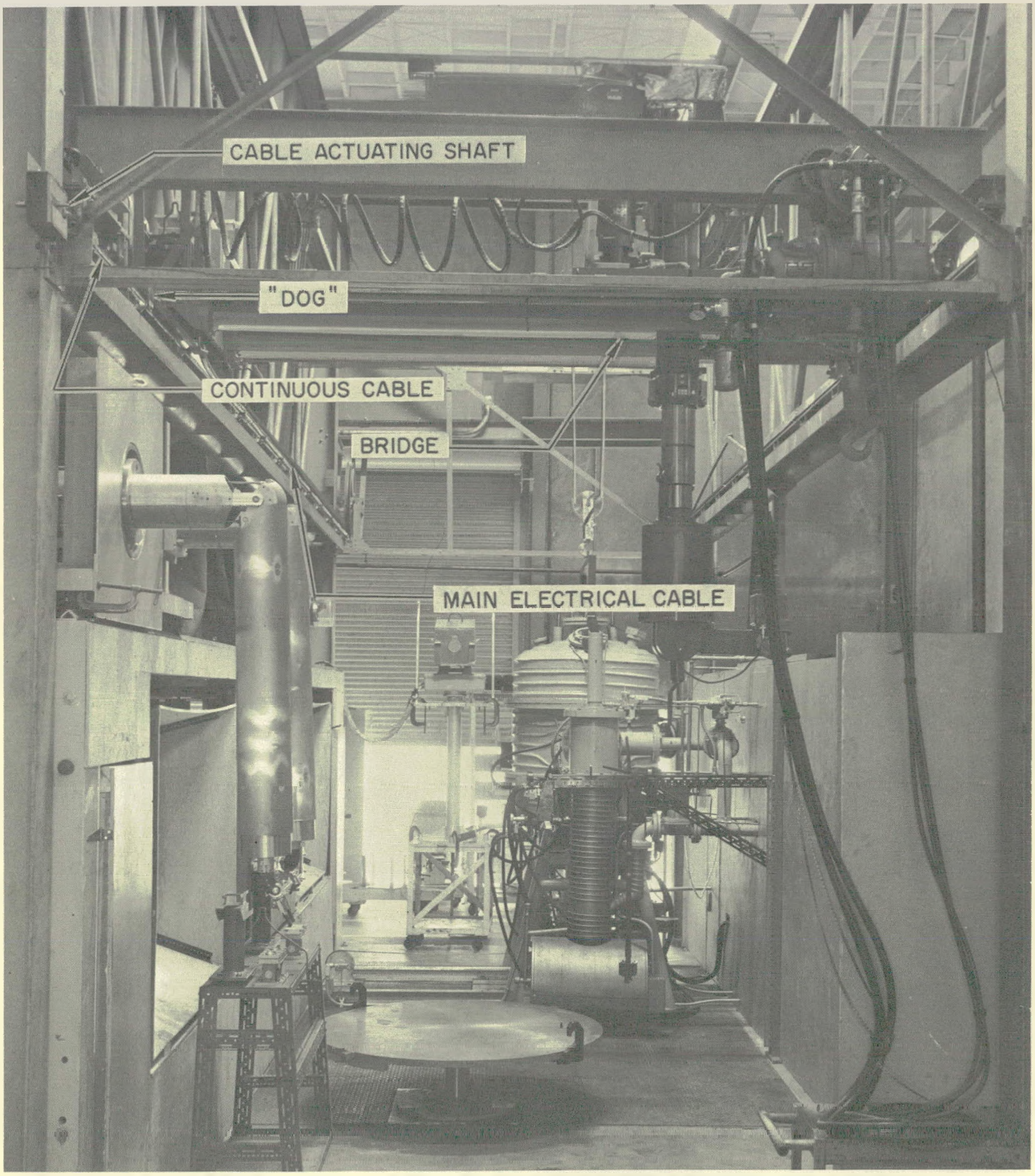


Figure 5. Bridge Override (Actuated out-of-cell)

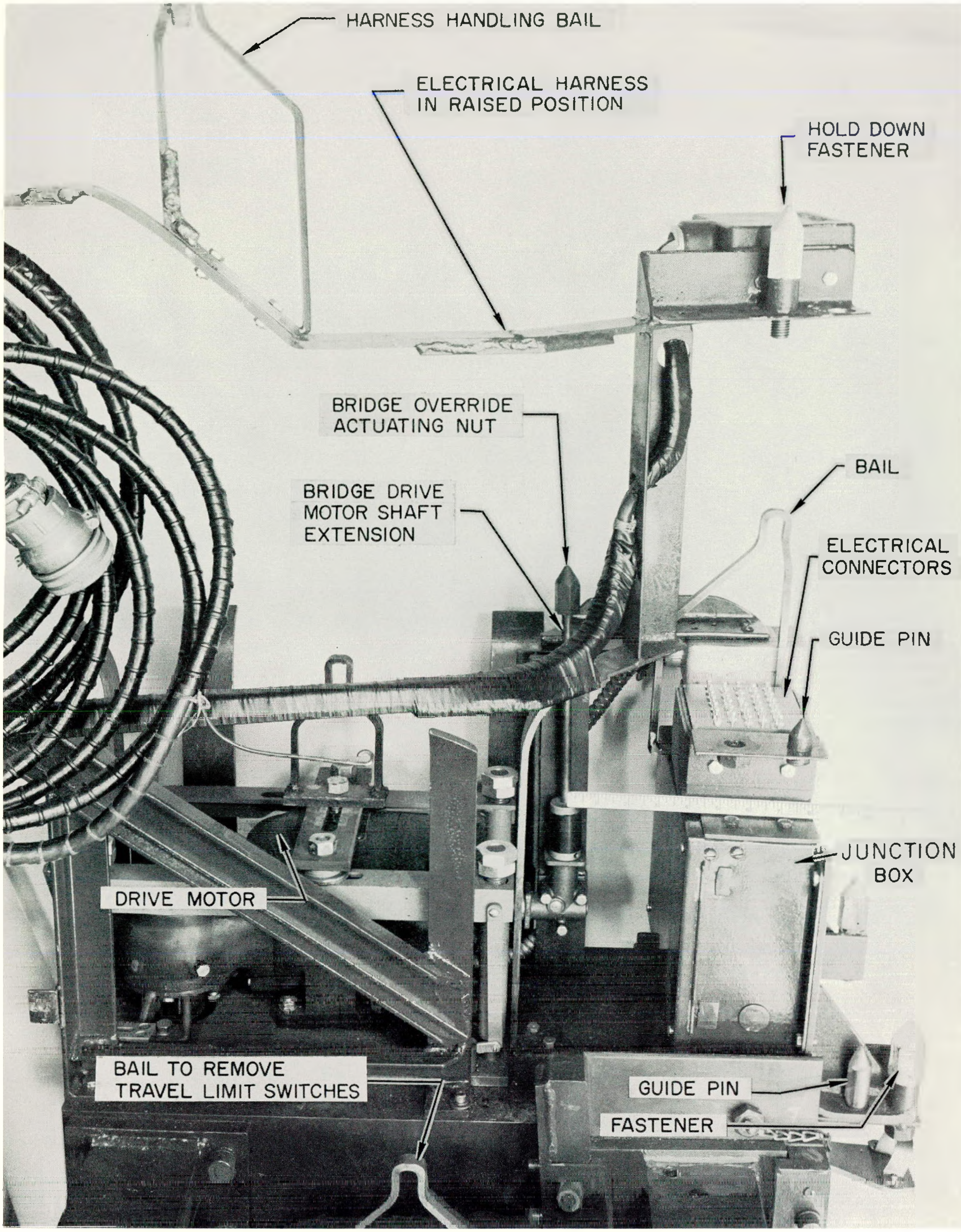


Figure 6. Bridge Override and Electrical Harness

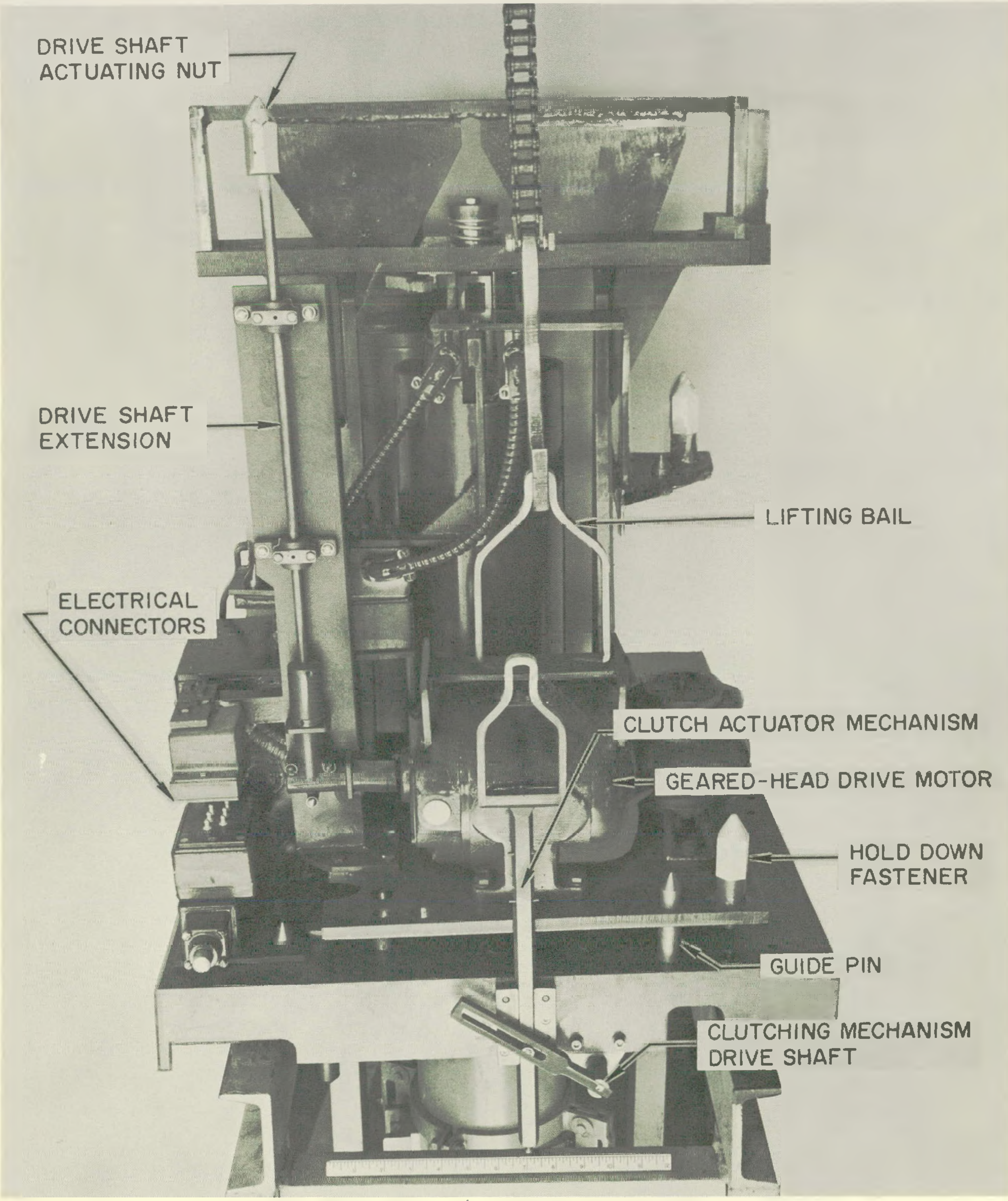


Figure 7. Carriage Override (Impact wrench actuated)

push-pull rod located immediately above the bridge rail and directly in line with the through-roof hoist. This rod actuates the carriage clutch and pushes or pulls the carriage into position under the through-roof hoist.

C. HOIST OVERRIDE

One method for overriding the hoist system requires the extension of the hoist motor shaft to permit the telescoping tubes to be raised or lowered by rotating the hoist-motor-shaft extension with an impact wrench suspended from the in-cell crane (Figure 8). This override method is effective except in the event of a cable failure or locking of the telescoping tubes in an extended position. The other hoist override system would be utilized in the event of a hoist cable failure. This system consists of lifting lugs attached to the shoulder housing, a crane-hook-supported offset bail with a latch pawl actuator, and a two-part latching device attached to the shoulder housing and the carriage. In the event of a hoist-cable failure, the latch pawl is moved from the non-latching position by the latch-pawl actuator as shown in sequence 1 of Figure 9. The offset bail is then engaged in the lifting lug on the shoulder housing and raised until the latching mechanism is engaged, as shown in sequence 2 of Figure 9. Lifting lugs and latching mechanisms are installed on each side of the shoulder housing to facilitate servicing of the manipulator when it fails adjacent to either end wall.

In the event that the telescoping tubes lock in an extended position, no attempt would be made to override the hoist. Removal of the manipulator in this condition is discussed in the next section.

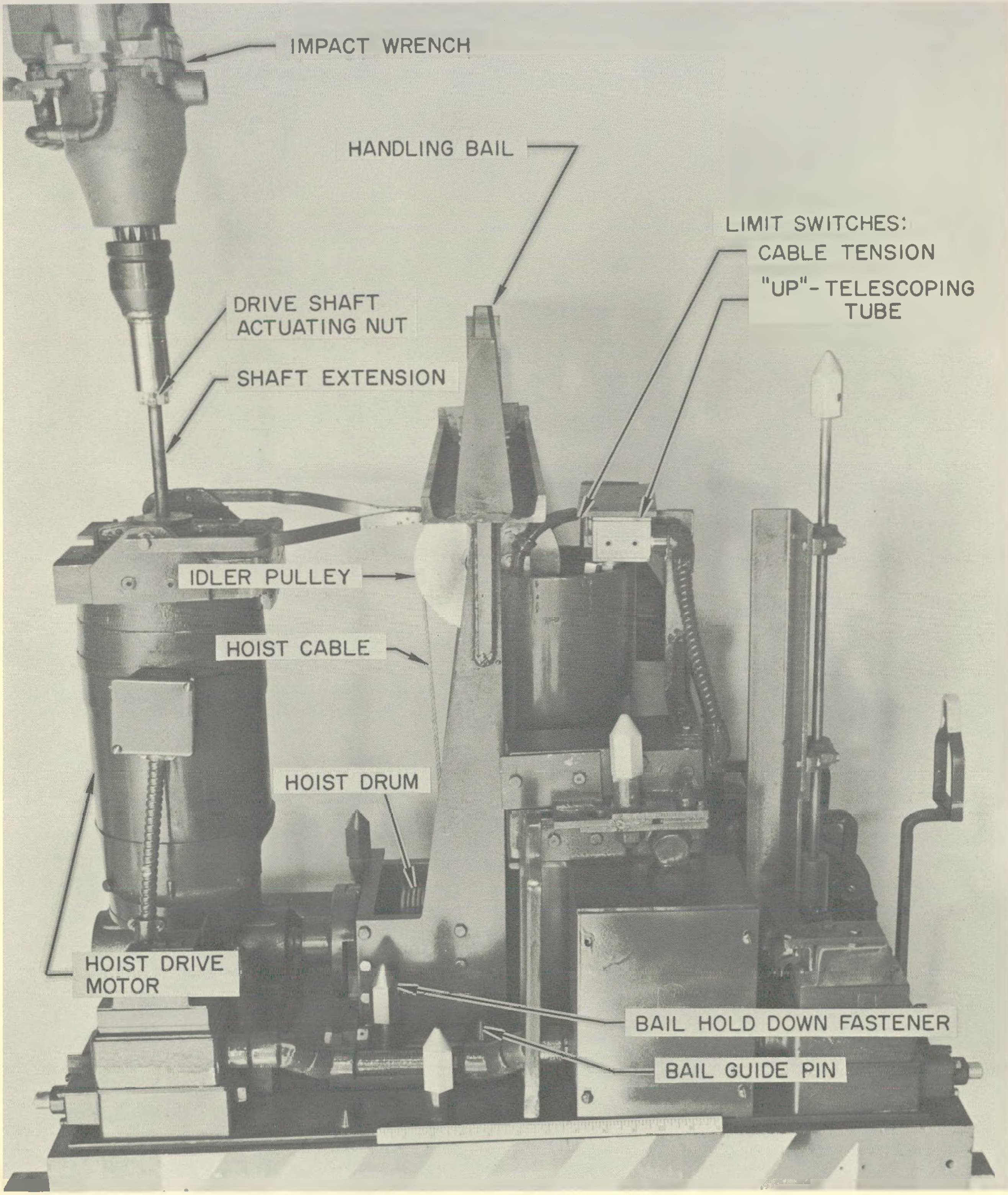
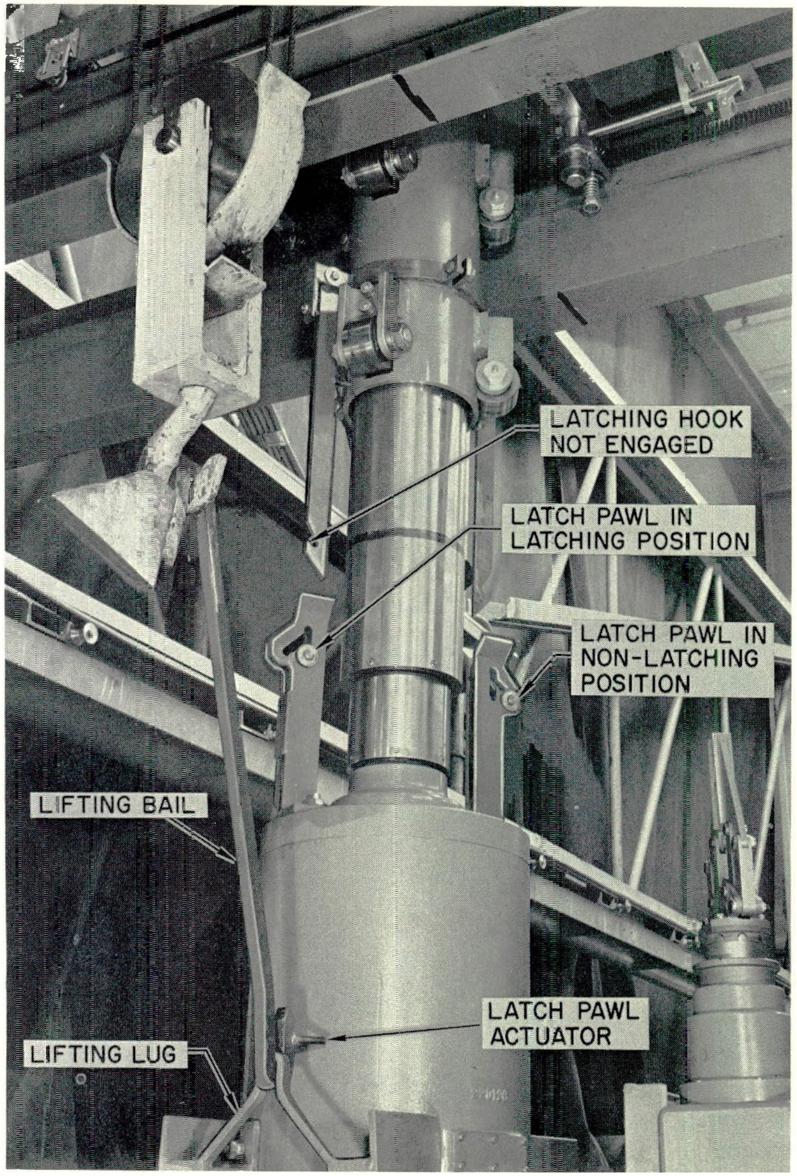
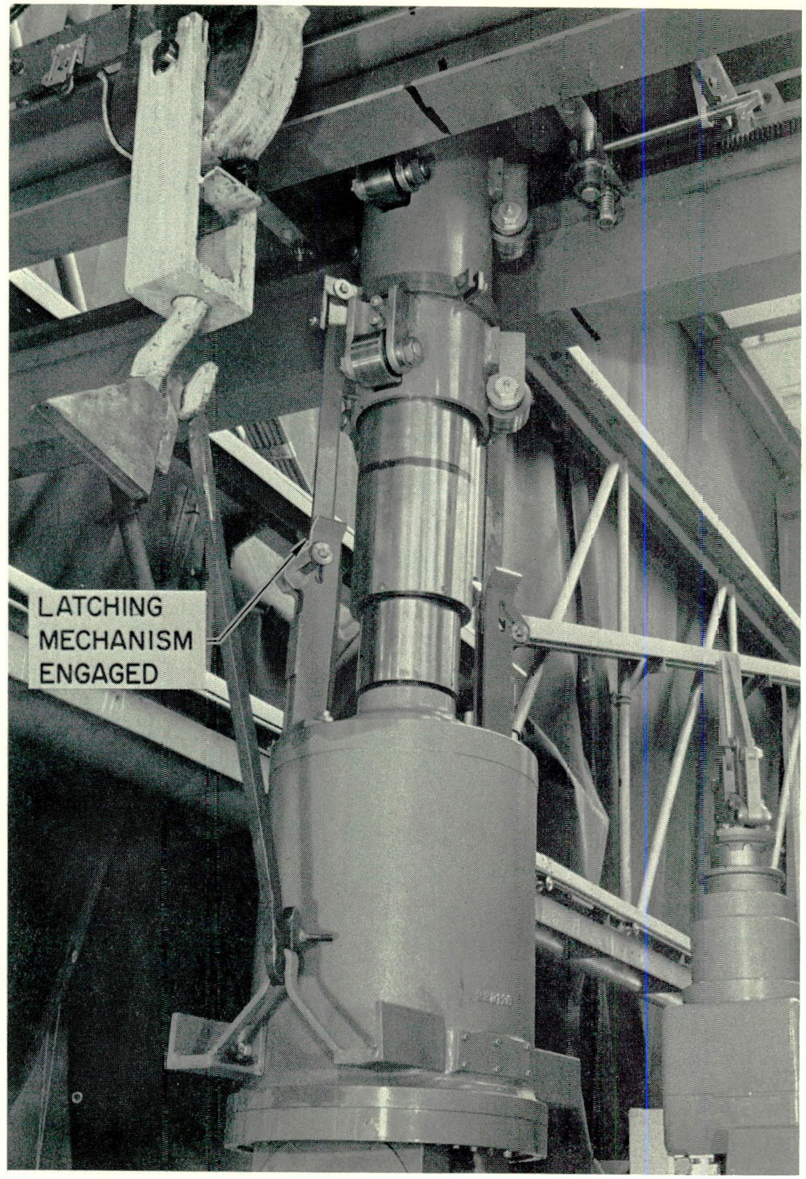


Figure 8. Hoist Override and Carriage Handling Bail



(a) Sequence 1



(b) Sequence 2

Figure 9. Shoulder Latch

VIII. TECHNIQUES FOR REMOTE REMOVAL AND REPLACEMENT

The basic criterion established to govern the design and development of in-cell equipment is the assumption that all equipment will fail eventually and will have to be replaced remotely. Due to the elevation of the manipulator, its removal and replacement can utilize only the in-cell crane and/or the through-roof hoist in the proposed PRE facility.

A technique was devised to demonstrate the remote removal of the carriage and arm assembly from the manipulator bridge when the arm was not locked in its extended position. The sequence of operations is:

a) Release any load on the manipulator's hooks or grapple.

b) Retract the hoist to its full-up position.

c) Fold the upper arm and forearm into their normal stowed position as shown in Figure 3.

d) Disconnect the electrical leads to the carriage using the crane hook.

e) Engage the crane hook with the lifting bail on the manipulator and lift it free of the bridge until the folded arm and shoulder housing are clear of the bridge.

f) Move the crane until the manipulator carriage assembly is over its maintenance dolly and lower the carriage onto the dolly.

g) Transfer the carriage and dolly to the maintenance area for replacement of components which have failed.

The manipulator, with the telescoping tubes locked in an extended position, has an overall length of approximately 16 ft. Removal of the inoperable unit in this attitude from its bridge, utilizing the in-cell crane, would require a minimum cell height of approximately 30 ft. A maximum cell height of 20 to 25 ft was envisioned for the PRE. A method requiring a cell height of 22 ft was devised and demonstrated to remove the manipulator from its bridge while in the extreme down position. This method entails the development of a bridge span member which can be remotely removed and replaced utilizing the in-cell crane while the manipulator carriage is supported by the through-roof hoist. The bridge was modified so that one span member fits into tapered ways and is held in position by two spring-loaded pins which can be released by the in-cell crane during the span removal operations.

The sequence of operations for removal of the manipulator, when the telescoping tubes are seized in the extreme down position, is as follows. The arm assembly is removed at the junction of the shoulder housing and hoist tube, using an offset impact wrench on the crane hook. The mechanical overrides are actuated to position the manipulator carriage under the through-roof hoist. The electrical leads to the carriage junction box are disconnected utilizing the in-cell crane or the through-roof hoist. The manipulator is raised approximately one foot utilizing the through-roof hoist and the modified span member is removed by the in-cell crane, as shown in Figure 10. After the span member has been removed, the bridge is moved out from under the carriage which is hanging from the through-roof hoist. The carriage is lowered until it is supported by the maintenance dolly with the extended telescoping tubes resting on the floor. The manipulator arm is disassembled and the resulting components transferred to the maintenance cell for further servicing.

A method for remotely removing the manipulator bridge from its tracks was devised and demonstrated. The in-cell crane disconnects the electrical leads to the bridge junction box. The hook of the in-cell crane or the through-roof hoist is then lowered between the bridge spanning members to the bridge handling bail on the maintenance dolly. The lifting bail, shown in sequence 1 of Figure 11, is raised to engage the bridge assembly. The bridge is raised and rotated to clear the rails on the cell walls. Rotation of the bridge has been accomplished both by out-of-cell rotation of the rigid-armed, through-roof hoist, and by imposing an eccentric side load on the bridge with the through-wall, carriage override rod (see sequence 2 of Figure 11). The bridge is lowered to its maintenance dolly for component disassembly and/or removal to the maintenance cell.

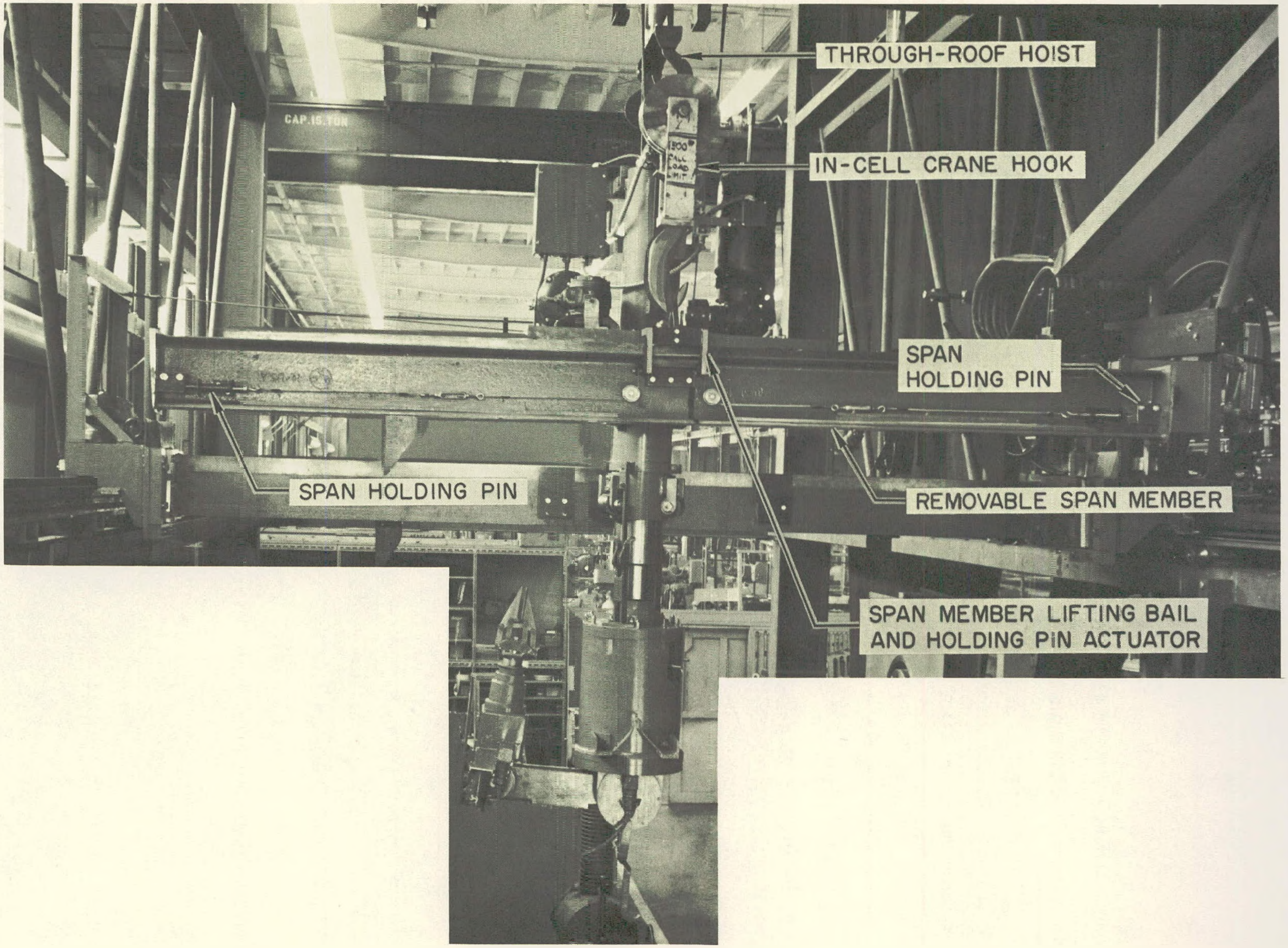
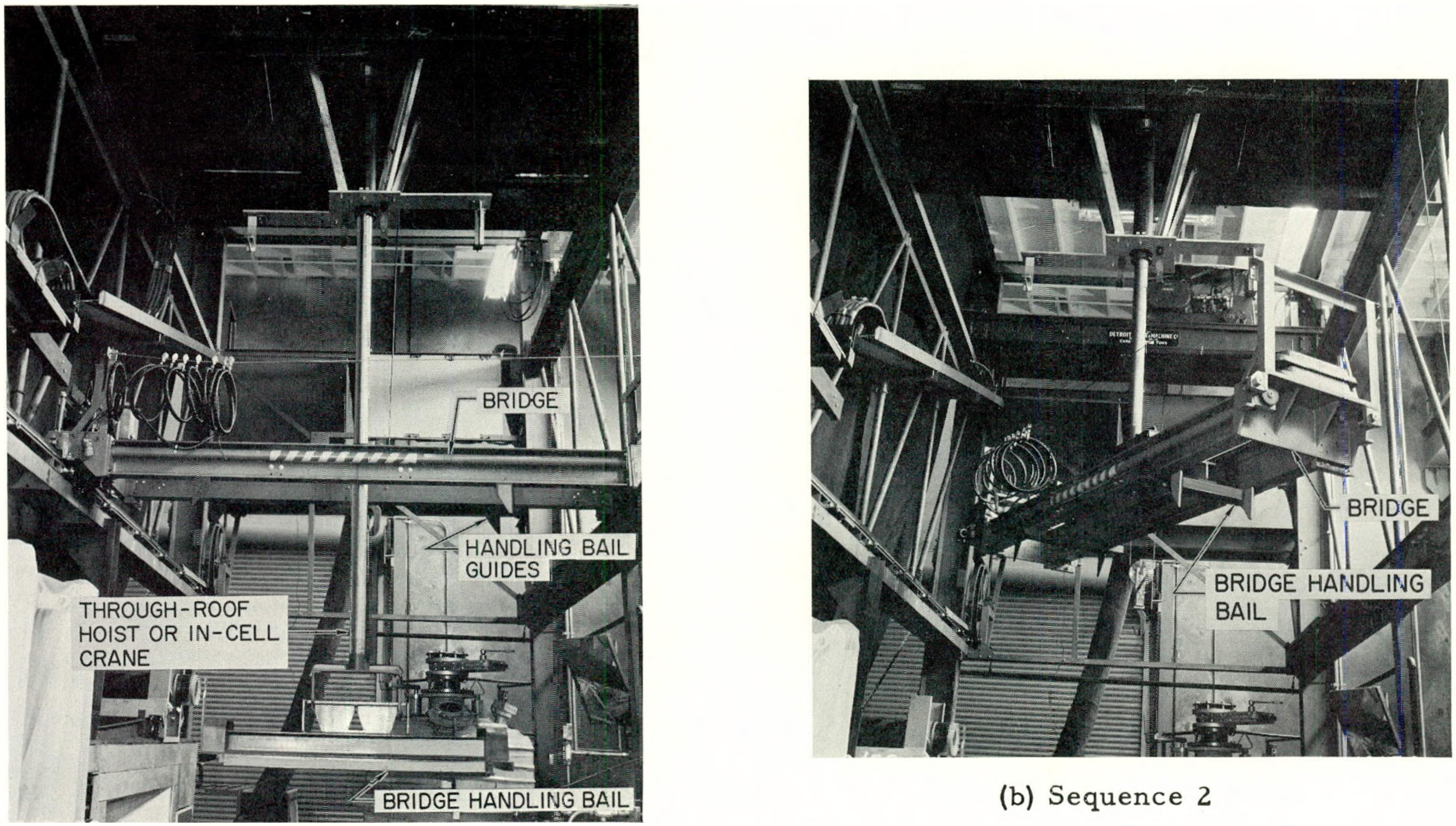


Figure 10. Removable Bridge Span Member



(a) Sequence 1

(b) Sequence 2

Figure 11. Bridge Removal

IX. REMOTE MAINTENANCE OF COMPONENTS

In order to make the rectilinear manipulator available in the PRE cell mockup for the remote operation of process equipment, a scale model (1 in. = 1 ft) of the proposed process cell was constructed and models of the handling and transfer equipment items were installed in the model cell. Techniques of remote removal and replacement of the equipment and major components thereof were developed in the scale model (Figure 12).

Manipulator failures can occur in one of three locations, namely, the control console, main power cable, and the in-cell unit (carriage and bridge assemblies). The load simulator can locate electrical malfunctions in the control console. Failures in the main power cable can be determined by connecting the in-cell units to an auxiliary power system. Malfunctions that occur in the arm, arm carriage, and bridge components can be corrected by remotely replacing the suspected assembly with a component known to be in good working condition.

A full-scale mockup of the manipulator arm carriage was constructed utilizing spare components. The initial modifications and rework of the original design, required to adapt the arm carriage for remote removal and replacement of its components, were performed on this carriage mockup. When the compatibility and performance of the reworked components were satisfactorily demonstrated on the carriage mockup, the actual manipulator carriage was modified in accord with the carriage mockup.

The arm carriage assembly, as initially installed, consisted of more than a dozen subassemblies individually mounted to the carriage bed plate with conventional fasteners. Replacement of these subassemblies required close contact maintenance which is common with most complex electromechanical equipment.

The arm carriage, as modified to facilitate completely remote removal and replacement of components, consists of five major assemblies: the cover, carriage-lifting bail assembly, electrical harness, hoist drive and override, and the carriage drive and override.

The cover is provided with a lifting bail. The carriage handling bail assembly (Figure 8) includes the hoist-drum assembly, hoist cable, the cable-tension limit switch, the "up" limit switch for the telescoping tubes, and the hoist-cable idler pulley.

The carriage electrical harness comprises the main junction box, travel limit switches, and the electrical plugs for the electrically powered components of the arm carriage as seen in Figure 13. Fasteners and guide pins on the harness are standard PRE types,[5] as are all guide pins and fasteners on the arm carriage. The electrical plugs are self-aligning units.[5]

To couple the hoist drum and the hoist drive shaft, a vertically actuated coupling, shown in Figure 14, was installed. Attached to the hoist drum shaft is the male portion of the coupling which consists of a straight bar slotted on each end. The female portion of the coupling is a slotted flange connected to the hoist motor drive shaft. The slots of the female portion must be within 15 degrees of the attitude of the male portion to effect a coupling. The female portion can be aligned by actuating the hoist motor override. The hoist drive and override includes a geared-head drive motor with the drive shaft extended, for overriding with an impact wrench and the female portion of the drum coupling.

The carriage drive and override, shown in Figure 7, includes a geared-head drive motor and a bevelled pinion gear on the drive shaft. The bevelled drive pinion fits into a bevelled gear rack on the bridge, and the electrical connection is remotely made as the motor is lowered onto the carriage and precisely located by guide pins. Impact-wrench-operated fasteners secure the unit in place.

The shoulder housing was modified to incorporate impact-wrench operated fasteners, guide pins and a self-aligning electrical plug into the assembly. As a result of these modifications, the arm assembly can be separated from the telescoping hoist, as seen in Figure 15, utilizing the in-cell crane and attachments.

The bridge drive and override assembly was modified to facilitate remote removal and replacement. It consists of two major assemblies, a geared-head drive motor with the drive shaft extended for overriding with an impact wrench and the electrical harness with the necessary junction box and travel limit switches (Figures 6 and 13).

Techniques were conceived for removing and replacing the main in-cell power cable and servicing the cable takeup assembly which is located in a housing outside the cell. The remote removal and replacement would be accomplished utilizing the in-cell crane to guide the in-cell cable end through the cell wall into the shielded cable takeup assembly. A new cable and takeup assembly would be

(a) manipulator carriage cover

(b) carriage assembly

Figure 12. Scale Model of Proposed Cell (Remote removal of: (a) manipulator carriage cover; (b) carriage assembly)

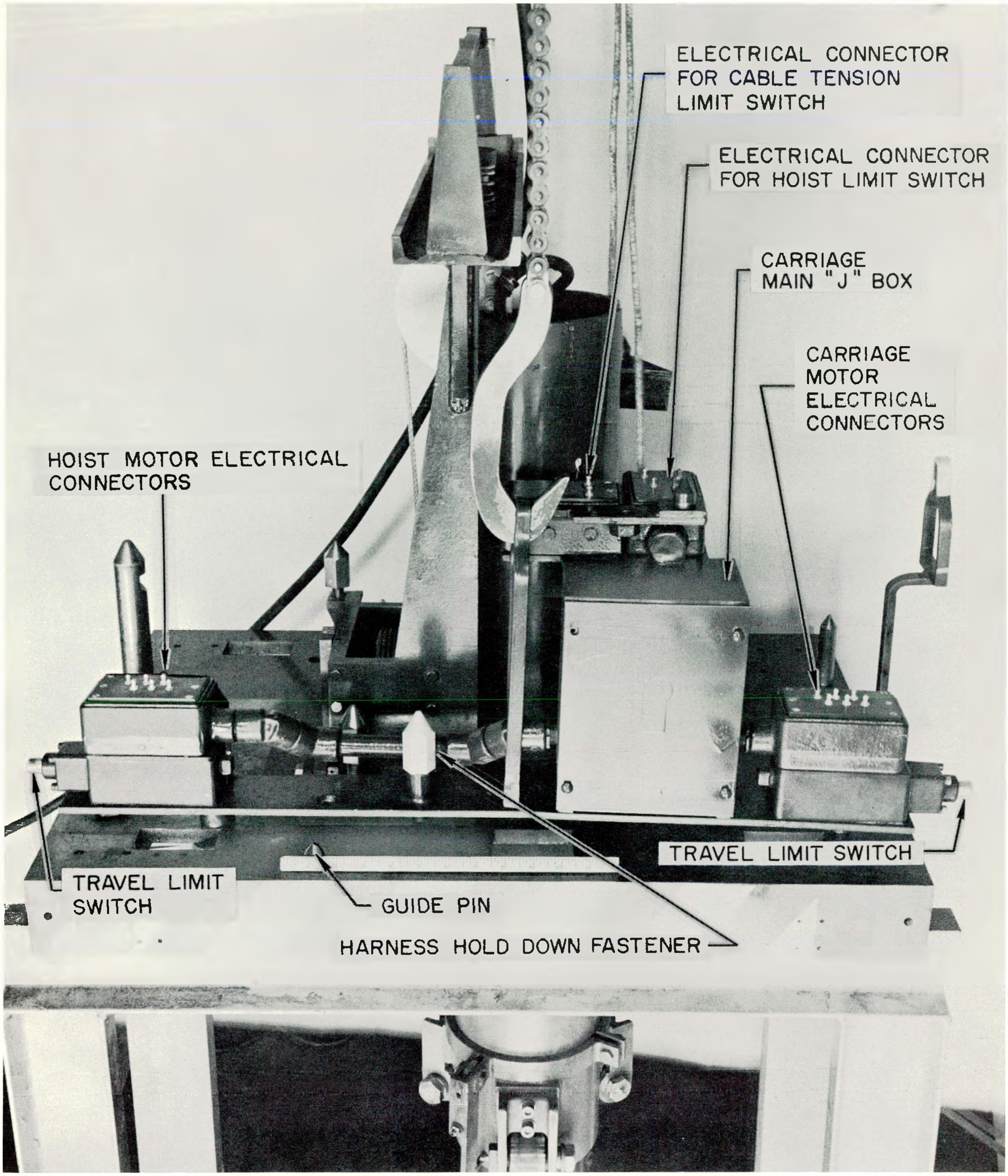


Figure 13. Carriage Electrical System

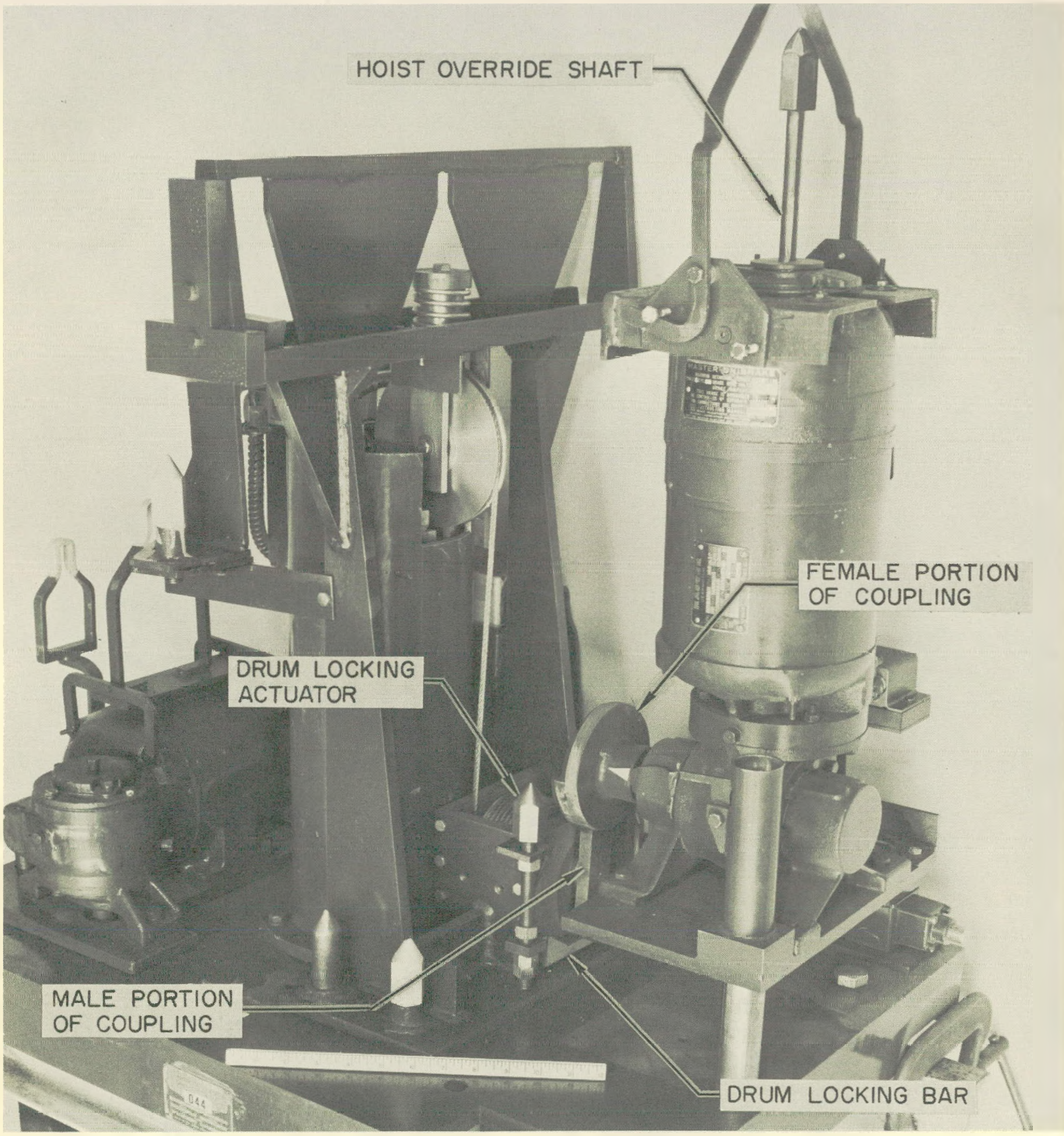


Figure 14. Hoist Drum Coupling

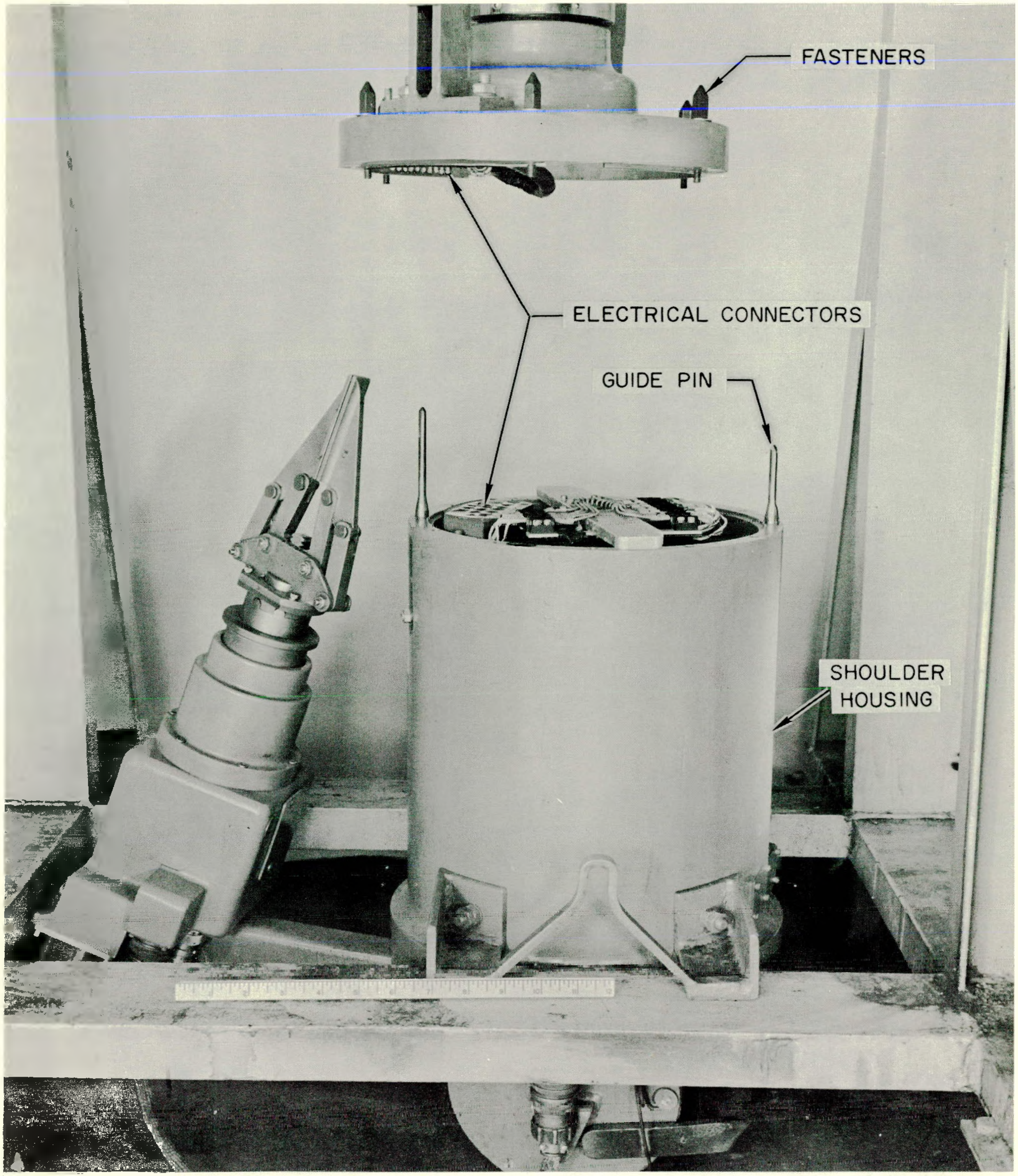


Figure 15. Shoulder Housing Separation

installed, using glove-box techniques, and the cable end would be attached to the bridge junction box utilizing a push-pull tool in the glove box, the in-cell crane and self-aligning electrical plugs.

X. EVALUATION AND COST OF MODIFICATIONS

Table I outlines the average in-cell time required to remove and replace manipulator components before and after the modifications described in this report.

TABLE I

TIME REQUIREMENTS FOR MAINTENANCE OPERATIONS

Maintenance Operation (utilizing in-cell crane)	Maintenance (man-min)	
	Contact Operation (premodification)	Remote Operation (postmodification)
Crane Installed in Cell Mockup		
Removal and replacement of the carriage assembly, in normal stowed position, from the manipulator bridge.	40	15
Removal and replacement of the bridge assembly, in normal stowed position, from the wall-mounted tracks.	40	15
Carriage Unit Supported on In-Cell Maintenance Jig with Cover Removed. Removal and Replacement of Components Listed, from the Carriage Unit:		
Bridge drive motor	35	5
Bridge electrical system	120	15
Carriage drive motor	35	5
Hoist drive motor	50	5
Arm assembly	45	30
Arm carriage electrical system	500*	30

*Estimated

The saving in remote maintenance manhours, achieved as a result of PRE modification of the as-purchased manipulator, are self-evident. If failure occurs while the cell is hot, extensive decontamination manhours would be required before the unmodified manipulator could be removed from the cell to permit maintenance by personnel contact. The modified manipulator can be made operable while the PRE cell is still hot. Even in conventional cells, great saving of time is possible with the modified manipulator since inoperable components can be replaced rapidly without extensive preliminary decontamination.

Outlined in Table II is an estimate of the labor and material cost involved in the modification of another manipulator, in accord with the PRE design criteria.

TABLE II

COST AND TIME ESTIMATES FOR MODIFICATIONS

	Labor (man-wk)			Material Cost
	PRE Engineer	PRE Technician	Shop	($)
Remote Removal				
Carriage	1/2	3	3	500
Bridge	1/2	3	3	500
Remote Maintenance				
Carriage	1/2	4	4	1000
Bridge	1/2	2	2	500
TOTALS	2	12	12	$2500

26 man-wk (40 hr/wk) = 1040 hr + $2500 material cost

XI. FUTURE DEVELOPMENT

Further mechanical development of the existing PRE manipulator should include modifications to: (a) facilitate remote maintenance of the arm assembly; (b) facilitate remote removal and replacement of the main electrical cable servicing the manipulator and supported along the bridge rail installation; (c) permit booting of the manipulator's arm assembly in order to reduce decontamination required for contact maintenance of small components.

An investigation should be made of the operational and mechanical problems associated with mounting the carriage on the bridge at right angles to its present position. In its present attitude, the short side of the carriage spans the rails on the bridge. In the proposed attitude the long side of the carriage would span the rails on the bridge. Remote removal of the carriage from the bridge with the revised carriage could be accomplished readily by lifting the carriage with the through-roof hoist, rotating it 90 degrees and lowering it between the bridge span members. This method of carriage removal could be performed in a cell whose height is 4 ft less than that required for the carriage removal using the present method. This proposed manipulator geometry should be investigated carefully prior to the procurement of additional manipulators.

To facilitate the remote maintenance of the arm assembly, a remotely removable two-section shoulder housing should be installed. This would permit access to the drive motor located in the shoulder housing for remotely replacing the brushes. Modification to the elbow joint should be made so that the forearm and wrist joint could be remotely removed and replaced. It is believed that the brushes in the drive motors located on the forearm could be replaced remotely. In addition, a special maintenance jig should be developed to facilitate the remote maintenance of the arm carriage and arm assembly.

The existing step-speed control system should be replaced with a variable speed control unit, thus eliminating the irregular motions of the bridge and carriage during startup. Elimination of the need for the travel limit switches on the bridge and carriage, and the associated wiring, should be attempted by incorporating a slip-clutch assembly in each drive unit.

XII. CONCLUSIONS

Using the methods developed in the PRE program, it is possible, with only an in-cell crane and its attachments, to remove and replace an entire rectilinear manipulator from an operating cell without entering the cell. It is also possible, utilizing an in-cell crane with its attachments and maintenance jigs, to remove and replace all manipulator components except the fixed bridge rail. The arm, the hoist and carriage drive systems, the carriage electrical system, the bridge drive system and the bridge electrical system have all been removed and replaced remotely without removing the manipulator from the cell.

Utilizing the product of the basic engineering and development work carried out in the PRE program, the entire cost of modifying another similar manipulator to meet the PRE in-cell requirements would be offset, solely by the saving which could be realized in reduced maintenance down-time in a contaminated operating cell.

The manipulator manufacturer has incorporated in his replacement parts a version of the hoist cable retainer and the self-aligning electrical connector in the shoulder housing which are similar to the respective items developed by PRE.

REFERENCES

1. Atomics International Staff, "The Pyroprocessing Refabrication Experiment (PRE)," NAA-SR-1670 (June 6, 1956).
2. D. I. Sinizer, et al., "The Processing Refabrication Experiment (PRE) for Irradiated UO_2, "NAA-SR-2778 (July 15, 1958).
3. G. Gustovich, "Through-Roof Hoist for Remote Maintenance of In-Cell Lights in the Processing Refabrication Experiment (PRE)," NAA-SR-2983.
4. D. I. Sinizer et al., "Terminal Status Report for the Processing Refabrication Experiment, (PRE)," NAA-SR-3269.
5. D. J. Stoker, "Remote Maintenance Techniques for the Processing Refabrication Experiment (PRE)," NAA-SR-2981.