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DESIGNING FOR REMOTE HANDLING

MASTER

PROJECT NERVA

Contract SNP-1

August 1962

Prepared by
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R E O N

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ABSTRACT

This manual discusses problems of remote handling and suggests design details for components, assemblies and systems of NERVA engines which will greatly aid remote maintenance.

Approved:

W. D. Stinnett
NERVA Technical Systems Manager

FOREWORD

This manual discusses problems of remote handling and suggests design details for components, assemblies, and systems of NERVA engines which will greatly aid remote maintenance.

Torque values for bolts and nuts contained in this manual were obtained from the following sources: "Torque Manual," P. A. Sturtevant Company; "Selector," Holo-Krome Screw Corp.; "Bolt and Nut Torques," Klincher Locknut Corp.; and Report No. XDC 59-12-172, "Remote Handling Wrenches and Tool Clearance Requirements for Bolts and Nuts," General Electric Company.

The author is indebted to the following for supplying information on remote handling equipment included in this manual: Jack Minor, E. B. Wiggins Oil Tool Co., Inc.; Harvey Johnson, General Mills, Inc.; Don Milton, Programmed & Remote Systems, Inc.; Frank Chesley, Central Research Laboratories, Inc.; Neil Wilson, Lee Associates, Inc.; Joe Beno, Hughes Aircraft Co.; William Koelsch, Koelsch Corp.; and, Harry Sparks, Cole Electric Co.

Many of the illustrations in this manual were taken from the following General Electric Company documents, most of which were prepared under the author's supervision: Report No. XDC 60-7-87, "Power Plant Design for Remote Handling," J. E. Brown, July 1960;* Handbook No. DC 58-9-112, "Remote Handling Design and Data Book," W. C. Shissler, Jr., January 1959;* Report No. XDC 61-1-133, Remote Handling Equipment Catalogue, Chas. Ridgeway;* Report No. XDC 59-12-172, "Remote Handling Wrenches and Tool Clearance Requirements for Bolts and Nuts," C. R. Davis, December 1959;* Memorandum No. XDC 53-4-26, "Analysis of Circumferential Flanges, H. R. Meck and H. J. Macke, April 1953; and, Report No. APEX 911, "Remote Handling," R. F. Morand, December 1961.

* Documents prepared under the supervision of the author.

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I. SUMMARY

A. ESTABLISH PROCEDURES

Procedures for remote operations should be established at the beginning of the design. Make procedure as thorough as possible. Try to cover every move necessary for disassembly, inspection, replacement of damaged components and reassembly.

Determine component to be taken off first. What has to be done to remove it. Remove nuts, bolts, disconnect wires, pipes, ducts, etc. Is a fixture needed to handle the part. Is a stand required to store it. Does it have to be upended. If so, how.

B. ESTABLISH LIST OF EQUIPMENT

A list of equipment required for remote maintenance should be compiled at the beginning of the design. This equipment includes manipulators, viewing equipment, vehicles, cranes, turntables, slings, stands, alignment machinery, wrenches, power tools, power sources, etc.

C. PRODUCT DESIGN

The product should be designed so that general-purpose remote handling equipment can handle it, if possible. For example, design so that a manipulator can handle a part without additional tooling if this is feasible. The manipulator hand grasps the part, lifts the part, lays the part down, picks the part up, aligns and orients the part for assembly.

Joints and fastening means should be designed for remote handling (see Section III). For example, the following procedure should be used in designing a bolted, flange joint: (1) determine the size of the flange, material, finish, tolerance, seal (if any), heat treatment, etc.; (2) determine the number, size, and kind of bolts and nuts; (3) from Tables 1 through 5, determine torque requirements and select power wrench; (5) calculate tool

clearance and nut and bolt clearances; and (6) check with design for compatibility.

D. DESIGN ALIGNMENT AND ORIENTATION

Provide for alignment and orientation in the design. Determine whether or not dowels, pilot pins, rabbets, mechanical guides, fixtures, or a manipulator are required for the mating of parts; and, are they needed to maintain alignment during reactor operation.

E. HANDLING POINTS

Provide lifting or grasp points for each part or assembly. Lifting or grasp points may be eyes, bails, trunnions, tapped holes, the under side of a flange, or a manipulator-hand contact point. Provide rest points for each part or assembly where required. Provide for visibility of all remote handling operations where possible.

F. CONTACT MAINTENANCE

Do not handle remotely if contact maintenance is possible, remove the part from the assembly and use normal maintenance procedures.

II. INTRODUCTION

The radiation levels of a NERVA nuclear power plant and its components after operation are many magnitudes above AEC laboratory tolerance for manual operation. The radiation levels may be a combination of induced activity and contamination. It therefore becomes mandatory to remotely disassemble and assemble the power plant to maintain and inspect it and its components. This manual is an attempt to acquaint the designers of NERVA components, assemblies, and systems with some of the shortcomings of remote handling and to offer a few suggestions which, when incorporated in the NERVA design, will greatly facilitate remote handling.

Nuclear components should never be handled remotely when manual handling is possible. In general, work cannot be accomplished manually when the surface of the part or assembly has a radiation level greater than 5 R.

BLANK

III. REQUIREMENTS FOR REMOTE HANDLING

The remote handling of various parts and assemblies requires consideration in the areas of lifting or grasping points, rest points for support, alignment and orientation, joining and fastening, sealing, tool clearances, accessibility, and visibility. These areas are discussed below.

A. GENERAL

Radiation levels of NERVA nuclear power plants require that remote disassembly, remote inspection, and remote assembly be accomplished in a shop having thick concrete walls. Radiation levels under these conditions are lethal. Operating personnel are, therefore, required to remain outside the area during these operations. The machinery for handling the power plant and its components during the disassembly, inspection, and assembly operations must be controlled by operators outside the shop. This machinery consists of overhead cranes, manipulators, turntables, disassembly equipment, stands, slings, dollies, etc.

The handling equipment above has no "feel" such as an operator has when performing contact maintenance. Visibility of the operation is poor because the operator may be at a distance of 20 to 30 ft. Depth perception is poor for the same reason. As an example, imagine an open-end wrench on the end of a 20-ft-long pole. By holding the opposite end of the pole, attempt to engage a 1/4-in. bolt 20 ft away. Or, imagine grinding the valves of your automobile engine (disassembling the engine and everything that goes with it) or cleaning the carburetor without having direct contact with the parts. These examples are analogous to the problems encountered in remote handling operations.

B. JOINTS

Joints may be defined as the joining of any two parts such as pipes, wires, ducts, structural parts, pressure-vessel components, etc. Methods of joining are soldering, brazing, welding, bolting, riveting, V-type clamps, quick-disconnect couplings, toggle mechanisms, and others. Configuration of joints may be almost anything; however, this discussion will be limited to structures in general and pressure-vessel flanges, pipes, ducts, and wires.

1. Flanges

Flanges are used to join pressure-vessel components, ducts, pipes, structures, and accessories. The use of flanges permits two members to be parted. Flanges may be designed to maintain high pressures as well as static and dynamic loads under various temperature conditions including very high temperatures.

Flange mating surfaces may be designed to be flat, they may be rabbeted, they may contain one or more guide pins and guide-pin holes, they may contain one or more mechanical seals, or they may contain almost any combination of these.

Flat-mating flange surfaces containing two guide pins and corresponding guide-pin holes have been successfully parted and mated remotely many times. Approximate dimensions were: flange I.D., approximately 6 ft; flange thickness, approximately 1 in.; vessel wall, approximately 1/2 to 3/4 in. thick; dowel pin diameters, approximately 1-1/2 in.

Guide pins are used to properly orient mating flanges and they may assist in the final alignment of mating parts. Figures 1 and 2 show recommended design.

A rabbet designed into a flanged joint provides shear strength into the joint and maintains alignment of the mated flanges under all load and temperature conditions as well as maintaining alignment of bolt holes. Rabbets should have a tapered lead to assist in engagement during assembly (Figure 3).

A plain flange without either rabbet or dowels may require mechanical means for aligning the flanges during assembly by applying force to their outside diameter.

Flanges may be any shape. They do not have to be round. They may be designed to support static and dynamic loads only without the necessity of containing pressure. Easy means for alignment and orientation of mating parts are desirable. See "Alignment and Orientation," Section III, G.

Flanges must be properly aligned and properly oriented to mate successfully. The major portion of flange alignment and orientation is usually provided by the remote handling equipment. Final close alignment may be provided by rabbets (Figure 3). Final close orientation and alignment may be accomplished by pilot pins (Figures 1 and 2).

Flanges must be straight and free from distortion or warpage in order to mate properly and to function successfully. Distortion and warpage of flanges may be caused by loads, pressures, and temperatures during operation, or by improper handling. Distortion and warpage may be reduced or held to a minimum by proper design, material selection, fabrication procedure, and handling procedure. Flange fasteners may be able to seal a warped flange sufficiently for successful service.

Large forces may be required to part or mate flanges containing rabbets or pilot pins if any of the following conditions exist:

(1) the flanges are not properly aligned; (2) the rabbet fits are too tight; (3) the pilot pin and pilot hole fits are too tight; (4) the length of engagement of close fits on either rabbet or pilot pins are too long; (5) either of the flanges are warped or distorted for any reason (in service, in handling, or in supporting); (6) displacement of metal occurs due to warpage or improper hardness; (7) flange is not rigid enough to handle; and, (8) lack of compliance in either the flanged components or in the handling equipment.

The final force required for mating a flange may be applied by tightening the flange bolts. The force required for parting a flange may, if large, be by means of jack bolts in the flange. Flanges have been known to accumulate fretting corrosion during operation. There is no known solution for this problem. In designing for circumferential flanges assume the following: (1) the flange is considered flexible, it bends as a restrained cantilever beam fixed at the bolt circle; (2) the cylinder has uniform thickness and diameter; (3) spacing S between flanges is great enough so that flanges do not mutually affect each other (Figures 4, 5, 6, and 6a). Spacing S shall meet the following condition:

$$\frac{S}{\sqrt{a_h}} > 5 \quad (\text{See Figure 4}) \quad (1)$$

Figure 5 shows the loads acting on both flange and casing (see also Figure 6).

M_o = Moment per unit of circumference transmitted between the flange and the cylinder (lb)

Q_o = Shear force per unit of circumference transmitted between flange and cylinder (lb/in.)

F = Axial force per unit of circumference (lb/in.)

p = Internal pressure (lb/sq in.)

$$\beta = \sqrt[4]{\frac{3(1-\mu^2)}{a^2 h^2}} \quad (\text{in.}) \quad (2)$$

β is a factor depending on the rigidity of restraint,

$$(2\beta + \frac{h}{Lt}) Q_o - 2\beta^2 M_o = p(1 - \frac{h}{L}) - \mu \frac{F}{a} \quad (3)$$

$$\left(\frac{t^3}{\beta^2 h^3} - Lt + \frac{td_h^2}{16b} \right) Q_o - 2 \left(\frac{t^3}{\beta h^3} + 1 - \frac{d_h^2}{16b} \right) M_o = F \left[1^2 - \frac{d_h^2}{8b} (1+b) \right] \quad (4)$$

Flange stresses

$$\text{Hoop stress} = \frac{a}{L} \left(\frac{Q_o}{t} + p \right) \quad (5)$$

$$\text{Maximum radial bending stress at bolt circle} \quad (6)$$

$$= \left(\frac{1}{1-dN} \right) \frac{6}{t} \left(M_o + Fl - \frac{Bd_h}{8} + \frac{Q_o t}{2} \right)$$

$$\text{Maximum shear stress} = \frac{3}{2} \frac{F}{t} \quad (7)$$

Cylinder stresses

Hoop stress at a distance from flange

$$= \frac{pa}{h} \quad (8)$$

Axial stress

$$\text{Average tensile stress} = \frac{E}{h} \quad (9)$$

Maximum bending stress at junction between cylinder

$$\text{and flange} = \frac{6M_o}{h^2} \quad (10)$$

$$\text{Maximum axial stress} = \frac{1/2}{h} (6M_o + Fh) \quad (11)$$

$$\text{Maximum shear stress} = \frac{3}{2} \frac{Q_o}{h} \quad (12)$$

Bolt stress

The bolt load, B, in pounds per inch of bolt circle is obtained by taking moments about the reaction, R, between flanges in a two dimensional approximation of the flange (Figures 4 and 5)

$$B = \frac{a}{b(a+1)} \left[F(1+b) + M_o + Q_o \frac{t}{z} \right] \quad (13)$$

$$\text{Bolt stress} = \frac{B}{NA}$$

b = Distance in inches from bolt circle to line of action of reaction between flanges (usually b = 2/3 of distance from bolt circle to outside edge of flange)

N = Number of bolts per inch of length (bolts/in.)

A = Root cross-sectional area of bolt (sq. in.)

When a tapered hub is used to connect the cylinder to the flange, it is recommended that an average value of the hub thickness, h, be used in Equations (3) and (4).

The length of the hub should be determined from Equations (14) and (15)

$$\begin{aligned} M_x &= -D_h \frac{d^2 w}{dx^2} \\ &= \frac{e B x}{B} \left[\beta M_o (\sin \beta x + \cos \beta x) - Q_o \sin \beta x \right] \end{aligned} \quad (14)$$

$$\text{Where } D_h = \frac{Eh^3}{12(1-\mu^2)} \quad (15)$$

With h = average thickness, the length being given by the first value of x which makes M_x equal to zero or an appropriately chosen small value.

The condition for $M_x = 0$ is

$$\cot \beta x = \frac{Q_o}{\beta M_o} - 1 \quad (16)$$

2. Other Types of Joints

The pressure-cooker joint consists of round flanges which mate and are held together by the rotation of a locking ring containing the equivalent of interrupted threads (described under fasteners). All the problems of alignment, orientation, and sealing are the same as those listed under flanges. This type of joint lends itself to remote handling although its weight and cost are considerably more than bolted flanges (Figure 7).

The V-clamp joint consists of two or more V-shaped members pulled together (in the form of a ring) over two mating flanges. This is fully described under fasteners. An example is the so-called Marman clamp. This type of joint is of very light construction and is used to join small, light, ducts. The V-clamp joint has not been successful as a remote sealing means, although much development work has been performed. This joint is not recommended for remote handling for sealing pressures (Figures 8 and 9).

Quick-disconnect fluid couplings modified for remote handling in sizes from 1/4 through 6 in. have been used very successfully for high fluid pressures at temperatures up to 400°F. All of these couplings contained organic seals. Some R & D work has been accomplished on metallic seals for quick-disconnect couplings for high temperatures and high radiation fields of neutron and gamma radiation. These metallic seals have not been successful to date. Quick-disconnect fluid couplings requiring metallic seals are not recommended without additional development. See Figures 10, 11, 12, and 13.

Joining of a number of small pipes and tubes has been accomplished remotely by leading them into flanges and then bolting the flanges. Parker-type fittings cannot be handled remotely.

Pipe threads cannot be handled remotely. Use bolted flange fittings or quick-disconnect couplings.

C. SEALS OR GASKETS

Organic seals such as rubber and plastics will not function successfully for any length of time at temperatures much above 400°F or in a high radiation field. Metallic seals must therefore be used for high temperatures and in high radiation environments. The following metallic seals have been suggested: Bar X (Lockheed) manufactured by Wiggins Oil Tool Co., for static and dynamic use; Cadillac, for both static and dynamic use; Skinner, for both static and dynamic use; metal "O" rings, both gas-filled and non-gas-filled, for static use only; and Coniseal, for static use only.

As far is known, no knowledge is available on the reuse of any of the above metallic seals.

These metallic seals have not been handled remotely as yet; however, it is believed that remote handling is possible. The mating seal seats must be highly finished, parallel, and clean.

D. FASTENERS

Joining two parts may be accomplished by bolts, rivets, welding, interrupted thread, V-clamps, toggle devices, and others. Rivets cannot be handled remotely.

1. Bolts and Nuts

The 12-point-head machine bolt is believed to be the easiest for remote handling, and is recommended. It is the smallest in size and weight and requires the smallest wrench clearance.

The regular hexagon machine bolt or cap screw is most economical and is readily available, but it requires more tool clearance than the 12-point bolt.

The socket-head cap screw has been used for remote handling and requires no more tool clearance than the 12-point bolt. However, it is more difficult to handle remotely and the wrenches do not stand up as well as those for the 12-point bolt.

The 12-point-beam-type locknut with the captive feature is recommended for remote handling. The free-spinning locknut appears to be desirable for reuse. The plain hexagon steel nut is only recommended where it may be tack welded in place, and where it can be manually replaced. Small, fine-thread bolts have a greater tendency to damage and cross-thread during remote handling than do larger and coarse-thread bolts.

Alloy steel or stainless steel heat-treated and hardened to 38-42 Rockwell C are most desirable bolt and nut materials for remote handling purposes. In most cases it is desirable to silver plate the threads of the bolt to provide lubrication during torquing. The thickness of the silver plate should be .0001 to .0002 in. on a side.

a. Captive Nuts and Bolts

Figures 20 through 26 show one type of captive bolt and nut. These bolts and nuts are made so that, when parted, they will not fall out of the flanges. To tighten, torque is applied to the bolt only. Flanges must be modified to accept this type of hardware.

The bolt drops through the flange when the flanges are parted. This is not a serious disadvantage. This type of captive bolt cannot be used when the bolt is too long because the torsional deflection of the bolt prevents it from being tightened properly with impact wrenches.

This captive bolt requires guidance to prevent cross threading. The captive nut provides this guidance. The captive bolt is, in general, not acceptable for use in tapped holes because of this lack of guidance.

Figure 27 shows captive barrel nuts. These are acceptable for remote handling.

Remotely replaceable captive bolts which do not drop through the flange when the flange is parted have been developed (Figure 28).

b. Standard Nuts and Bolts

Standard nuts and bolts cannot be used remotely without special provisions for handling. The General Electric Company developed a "nut and bolt machine" which handled standard nuts and bolts remotely, for the Air Force Aircraft Nuclear Propulsion Program.

The nut and bolt machine is an electrically controlled mechanical device using pneumatic and electrical power. It is used for remotely inserting standard bolts into holes in a flange, applying standard nuts to the bolts, and tightening the nuts to a predetermined torque. The machine also remotely removes nuts and bolts from a flange. The flange must be free of all external obstructions, as the machine must almost encircle it during operation. Bolt size is 1/4 in., flange diameter is about 60 in. See Figures 14 through 19.

The nut and bolt machine is lacking in two respects. It will handle only one size flange, and the flange must be free of external obstructions.

It is believed that a nut and bolt machine can be developed which will handle standard nuts and bolts, and the only contact with the flange would be one or two bolt spaces. A single machine could handle any size flange.

c. Clearances

(1) Bolt

The preferred clearances for captive bolts may be calculated by the following formulas (dimensions A, B, D, and F are disassembly wrench dimensions). The symbols used in the equations are defined in Figure 74.

$$\text{Preferred axial clearance, } AC_b = B + D + BL - CL + 1/4 \text{ in.}$$

$$\text{Preferred radial clearance, } RC_b = F + 1/8 \text{ in.}$$

Preferred center distance

For right-angle wrenches, $CD_b = 1/2 A + 1/8 \text{ in.} + HR$

For flat-angle wrenches, $CD_b = F + 1/8 \text{ in.} + HR$

The minimum clearances for captive bolts may be calculated by the following formulas only when substantial reduction in the weight of flanges is desired:

Minimum axial clearance, $AC_b = B + D + BL - CL + 1/8 \text{ in.}$

Minimum radial clearance, $RC_b = F + 1/16 \text{ in.}$

Minimum center distance

For right-angle wrenches, $CD_b = 1/2 A + 1/16 \text{ in.} + HR$

For flat-angle wrenches, $CD_b = F + 1/16 \text{ in.} + HR$

(2) Nut

The preferred clearances for captive nuts may be calculated by the following formulas (the symbols used in the equations are defined in Figure 75):

Preferred axial clearance for 1/4 through 7/16 in. sizes

$$AC_n = NL + NB + 7/8 \text{ in.}$$

For 1/2 through 5/8 in. sizes

$$AC_n = NL + NB + 1-1/8 \text{ in.}$$

For 3/4 through 1 in. sizes

$$AC_n = NL + NB + 1-3/8 \text{ in.}$$

Preferred radial clearance, $RC_n = SR + 3/16 \text{ in.}$

Preferred center distance, $CD_n = CW + SR + 1/8 \text{ in.}$

The minimum clearances for captive nuts may be calculated by the following formulas only when substantial reduction in weight of flanges is desired:

Minimum axial clearance for 1/4 through 7/16 in. sizes

$$AC_n = NL + NB + 3/4 \text{ in.}$$

For 1/2 through 5/8 in. sizes

$$AC_n = NL + NB + 1 \text{ in.}$$

For 3/4 through 1 in. sizes

$$AC_n = NL + MB + 1-1/4 \text{ in.}$$

Minimum radial clearance, $RC_n = SR + 3/32 \text{ in.}$

Minimum center distance, $CD_n = CW + SR + 1/16 \text{ in.}$

(3) Wrench

See Section IV, B.

2. Welding

Welding has been used for remotely joining major components of reactor vessels which required machining for parting. Welding has also been used for remotely joining pipe. However, it is not recommended for remote operations except in very special cases.

3. Toggle Clamps and Other Devices

Toggle clamps and cam arrangements may be made to operate remotely but they are usually more expensive than other methods. In general, their use is not recommended for remote handling.

Joining by glue, rubber cement, or other organic means is not recommended for remote handling.

No satisfactory method for remotely replacing tapped-hole inserts has been devised. Tapped holes are, in general, to be avoided for remote handling.

E. LIFTING OR GRASPING POINTS

Parts and assemblies to be handled remotely require lift points. A lift point may be a bail or eyelet for a crane hook or other lifting device as shown in Figures 29 and 30. Lift points may be two, three, or four eyelets for a sling or lifting fixture as shown in Figure 31. A lift point

may be a bail, or a special shape or form made to accomodate a manipulator hand as shown in Figures 32, 33, and 34. Lifting points may be fixed or attached trunnions, as shown in Figure 35, or detachable eyelets, as shown in Figure 36. A lift point may be the underside of a flange, as shown in Figure 37, or it may consist of tapped holes in a component which are used for remotely attaching a lifting fixture.

Considerations in the design of lift points are location, accessibility, stability of the component being lifted, integrity of the component when being grasped, provision to permit component to grow or change shape during lifting, kind of lift points, allowable deviations of alignment during assembly, lifting method to be used, and ability to detect abnormal parting forces.

Lift points must be located so that they are readily accessible to lifting equipment. The lifting equipment may be an overhead crane, a manipulator hand, or a remote handling fixture. Lift points are usually located above a component and above the center of gravity, but they may be located below the center of gravity or to one side.

In one case, a girdle with a lifting eye and with trunnions was remotely attached to a large assembly and, with the aid of an overhead crane and an auxiliary support fixture, was used for upending the assembly into a vertical attitude with either end up.

Lift points must be accessible in order to attach lifting equipment remotely. For example, if the component is to be lifted by a crane hook, the lifting eye must have sufficient clearance to be able to remotely engage the hook. Slings for remotely lifting parts and components are usually made with rigid legs so that a manipulator can rotate them into lifting eyes with one circular motion. Space must be provided for this operation, as shown in Figure 38. Clearance must be provided for the engagement of a manipulator hand for lifting.

Lift points should be so located and the forces of lifting so directed that the component is stable during all phases of remote handling.

Parts and assemblies should be so designed that their distortion during assembly, disassembly, and remote handling will not exceed the elastic limits of their materials. The distortion of parts during remote handling may be caused by very rapid acceleration or deceleration, by mating parts sticking because of close fits of dowel pins or rabbets, unequal expansions due to temperature changes, by assembly bolts not completely removed, and others.

F. REST POINTS

The remote handling of parts and assemblies requires that the parts and assemblies be provided with a means of support when resting on the floor, bench, fixture, or other part, assembly, or component. The means of support on the part or assembly are known as rest points and may be a flat surface, flange, trunnions, legs, projections, or other portions of the part or assembly.

The same design considerations outlined for lift points should be given to rest points, namely, location, accessibility, stability, distortion, alignment, and assembly and disassembly forces where they apply.

Figures 37 and 39 through 47 show typical rest points.

These remarks on rest points apply to the instrumentation harness, piping, ducts, and pressure vessels as well as structures and mechanical parts.

G. ALIGNMENT AND ORIENTATION

Most assembled components require the following six degrees of motion for proper alignment for assembly: longitudinal motion, motion parallel to the axis of assembly (X-axis); transverse motion, motion at right angles to the axis of assembly (Y-axis); vertical motion, motion at right angles to the axis of assembly and at right angles to the referenced plane (Z-axis); pitch, the rocking motion of the component about the Y axis; yaw, the rocking motion of the component about the Z axis; and roll, the rotating motion of the component about the X axis.

A lifting device containing six degrees of motion may be used to assemble and disassemble nuclear power plants. Such a device usually requires position indicators, and may require automatic servo mechanisms as well as remotely operated gaging devices.

Handling equipment for remotely assembling and disassembling may be designed to eliminate the need for several degrees of motion.

Dowels or pilot pins may be designed to greatly assist in correct, final, close alignment and orientation of mating parts. Pilot pins assure correct repetitive mating of parts and assemblies. Illustrations of typical pilot pins are shown in Figures 1, 2, and 49 through 54.

The pilot pin should be long enough so that it engages the pilot hole prior to the engagement of any mating surfaces of the components. Pilot pins should be strong enough to take the full weight of a mating part plus the impact of a mating part swinging on a crane or manipulator (not always possible).

A minimum number of pilot pins should be provided to perform the function. Maximum clearance should be allowed between the pilot pin and the mating hole. Pilot-pin surfaces and pilot-hole surfaces should be hardened to 50-55 Rockwell C.

Check components containing pilot pins for assurance against binding during assembly and disassembly. Pilot pins cannot be used to mate nonrigid bodies unless special handling equipment is used which prevents deflection. Deflection of mating parts may cause binding of the pilot pin and mating hole, which may prevent either mating or separation.

Figure 55 shows pilot pins used for aligning a remote handling tool for a blind operation. Figure 56 shows a variation of this situation. Figure 53 shows an example of a visual method for rough orientation and aligning. Broad, colored, match marks or other visual indicators may be used for rough orientation of parts for remote assembly.

Long engagement joints such as splined shafts may require very close alignment in order to assemble. In this case, the longest possible tapers should be provided on the end of the external spline and on the end of the internal spline for ease in engagement (see Figures 57 and 58).

H. PARTING FORCES

It is desirable that the assembly and disassembly forces be known in order to avoid damage to parts and assemblies. This is especially true of close-fitting parts, rabbets, dowels, and captive bolts which are not completely disengaged.

Determinations of force indication in remote handling equipment are: (1) deflections of manipulators, (2) force-indication devices on crane hooks.

I. ELECTRICAL POWER AND INSTRUMENTATION

Electrical power lines and instrumentation are usually handled remotely in the form of a harness. The connection and disconnection of electrical lines are made remotely through multiple-pin, electrical, quick-disconnect couplings.

Standard, electrical, quick-disconnect couplings cannot be remotely operated without modification. They lack the necessary guidance, ruggedness, and grasping points required for remote handling.

The Cannon Electric disconnect shown in Figure 59 can be remotely disconnected, but it is too fragile to connect remotely.

Figure 60 shows the results of a very rugged electrical disconnect developed by the Anderson Electric Co. This disconnect has been tested for remote handling and is satisfactory; however, it has some minor deficiencies which must be overcome before it becomes operative.

Figure 61 shows a new concept in electrical connectors. It is a self-wiping, zero-entry type of connector which should hold great promise for remote handling. It is being produced by the E. B. Wiggins Oil Tool Co.

The standard Wiggins disconnect containing a cam-locking mechanism modified for remote handling has been used successfully for both fluids and electrical connections.

The Cole Electric Co. has developed a self-aligning contact pin which has been used very successfully in remotely operable electric disconnects. Figure 61a shows pin and self-aligning socket details. Figures 61b, 61c, 61d, and 61e show Cole Electric disconnects.

J. OVERALL ASSEMBLIES AND SYSTEMS

The remote removal of a major component from an engine containing hydraulic lines, ducts, conduits, and mechanical linkages mounted on the outside of the component, and which connect to the outside of an adjacent component, requires either complete removal or parting as shown in Figures 62 and 63. Complete removal is preferred.

Mechanical parts which connect two major components internally and which do not part readily are to be avoided (see Figures 64 and 65).

IV. REMOTE HANDLING EQUIPMENT

Remote handling equipment consists of viewing devices, torque wrenches, power tools, manipulators, vehicles, stands, slings, racks, cranes, turntables and other equipment.

A. VIEWING

Viewing remote handling by operating personnel is accomplished directly through highly leaded glass windows or through liquid-filled windows. The viewing of a particular operation is usually limited to one or two windows. Distances from the windows to the work are usually great, especially when handling large parts. Direct viewing may be aided by the use of binoculars. Shielded windows have a high index of refraction, allowing good overall visibility. Although the angle of vision is large, work should be performed directly in front of a window if possible. Viewing is excellent through shielded windows, but distances make depth perception difficult.

Mirrors may be used for indirect viewing when direct viewing is not possible, such as when looking down into a vertical vessel. Work performed with the aid of mirrors is difficult because the image is reversed.

Closed-circuit, two-dimensional television is available for indirect viewing. Resolution and depth perception is difficult with television. Intensity of lighting for television is critical. Television is far better than no vision and has been used for remote handling without windows, but is not nearly as good as direct window viewing. TV has been used to advantage for inspecting the inside surfaces of pipes and tubes. One of the disadvantages of TV for remote operations is that it is necessary to remotely handle the TV camera. Three dimensional television has not been successful to date.

Indirect viewing by periscope is exceptionally good. Periscopes usually magnify. They are very good for photographing closeups of "hot" (radio-active) parts.

The chief limitation of the periscope is that it is fixed in a definite location. It cannot cover a large area of a shop.

The fiber-glass bundle, another method under development for indirect viewing, has great promise for remote handling.

B. POWER WRENCHES

A power wrench may be converted to a remote handling wrench by altering it so that a manipulator hand can support it, and by changing the power connections so that they may be connected and disconnected remotely. Power wrenches that transmit a force to the manipulator hand (the manipulator hand that supports the wrench) in excess of the manipulator capacity cannot be used.

1. Types

There are three types of portable power wrenches: impact, clutch, and stall.

a. Impact

Impact wrenches have the ability to absorb the torque reaction of tightening a bolt rather than imparting this reaction to the manipulator hand which supports it. This ability to absorb reaction makes the impact wrench a very desirable and valuable remote handling tool.

An impact wrench operates something like a hammer and chisel and continues to tighten (or loosen as the case may be) the bolt or nut as long as power is applied. If the bolt is large, the wrench will tighten it to a point, after which additional application of power will have no effect. If the bolt is small, additional application of power will bring about bolt failure by shearing it off.

Torque control is usually accomplished with an impact wrench by controlling the period of time during which the wrench operates. The torque variation, by using this method, is very great. It may vary as much as 50%. The timing of impact wrenches for torque control is very unsatisfactory for remote handling.

Attempts have been made to control the torque of an impact wrench by torsion bar and other methods. With these methods, torque may vary as much as +20%. These torque controls are acceptable for remote handling.

Impact wrenches may be powered by either electric or pneumatic means. Manipulators are usually wired so that an electric impact wrench or other electrically operated power tool may be remotely connected to a power source at the manipulator-hand support, which eliminates trailing wires or hose.

b. Clutch Wrenches and Pneumatic-Stall-Type Wrenches

Clutch wrenches and pneumatic-stall-type wrenches may be used for remote operations for torques up to approximately 50 ft-lb when held by a Model 550 manipulator. Both of these wrenches transmit the forces (of tightening or loosening bolts) back into the manipulator hand that supports the tool. These forces must be well below the rated capacity of the manipulator, otherwise the manipulator might be damaged.

The clutch-type power wrenches may be either electrically or pneumatically powered. The stall type is available in the pneumatically powered version.

2. Clearances

Wrench clearances must be provided to assure capability of remote handling. Wrench clearances depend upon type of nuts and bolts, nut and bolt material, bolt spacing, required tightening and breakaway torque, flange configuration, and style and availability of power wrenches.

3. Selection of Power Wrenches

Select suitable power wrenches for assembly and disassembly from Tables 1 through 5. The wrench codes listed in the tables are explained below.

All wrenches listed in the tables having torques in excess of 25 ft-lb are impact type. Wrenches having torques less than 25 ft-lb are either clutch type or pneumatic-stall type.

Standard assembly and disassembly wrenches are usually shelf items, are readily obtainable, and cost the least of all power wrenches. They do not have torque control. They are reversible.

The flat-angle-type wrenches transmit torque to the socket by either a pawl and ratchet or a train of spur gears. This type of wrench requires less clearance than either the straight or right-angle types; but, in general, it is a high-maintenance tool and should be used only when other types cannot be used.

The following codes are used in Tables 1 through 5:

SS - Standard assembly and disassembly straight wrench
(See Figure 66)

SR - Standard assembly and disassembly right-angle wrench
(See Figure 67)

SF - Standard assembly and disassembly flat-angle wrench
(See Figure 68)

Special assembly wrenches have controlled torque. They are not reversible. Torque setting must be accomplished manually.

The following codes are used in Tables 1 through 5:

CS - Special, controlled-torque, straight-assembly wrench
(See Figure 69)

CR - Special, controlled-torque, right-angle-assembly wrench
(See Figure 70)

CF - Special, controlled-torque, flat-angle-assembly wrench
(See Figure 71)

The special, high-torque disassembly wrenches have maximum torque capacities as charted. They are not reversible, and are a high-cost and high-maintenance tool. These wrenches are used only when wrench clearance is a problem, such as when the size of bolts and flanges must be as small as possible for weight reduction. They are usually a necessity when beam-type locknuts, which require very high break-away torques for disassembly are used.

The following codes are used in Tables 1 through 5:

HR - Special, high-torque, right-angle-disassembly wrench
(See Figure 72)

HF - Special, high-torque, flat-angle-disassembly wrench
(See Figure 73)

C. MANIPULATORS

Manipulators take the place of human hands for many tasks in areas where radiation levels are too high to permit manual work. Manipulators are controlled remotely from outside the "hot" area. Manipulators are used to lift and move parts and components, connect and disconnect power sources, guide crane hooks, attach and part slings and handling equipment, support and operate power wrenches and power tools, handle captive nuts and captive bolts, and for many other purposes.

Manipulators have been developed and are being manufactured with lifting capacities of from a few pounds to several hundred pounds. A general description of available manipulators follows.

1. Master-Slave Manipulator

Master-slave manipulators are fixed, wall-mounted machines containing "feel" for handling light loads (see Figure 76). They usually have a maximum lifting capacity of about 5 lb, although they are available with greater capacities. Working areas for these machines are limited to about 3 cu ft. They are an excellent tool for handling and examining very small, light parts.

The master-slave manipulator is a mechanical machine. An operator located outside the wall of a "hot" area applies motions to a master portion of the manipulator which in turn transmits it to a slave portion inside the "hot" area. The slave is usually a parallel hand, but it may be other special types of hands. Disadvantages of the master-slave manipulator are its limited working area and its small capacities.

2. Servo Manipulator

The Argonne National Laboratory developed a servo-master-slave manipulator which is controlled electrically outside a "hot" cell. It is constructed so that the slave may be positioned any place within the cell at the will of the operator. The capacity of this device is the same as that of the master-slave manipulator, and the operator has a "sense of feel" as does the operator of the master-slave manipulator. The means of obtaining the sense of feel electrically is known as a servo mechanism. As far as is known, this manipulator is not in production and is, therefore, not available.

The General Engineering Laboratory of the General Electric Company designed and built the large, two-handed, servo-manipulator shown in Figure 106. This manipulator contained a two-armed, master-control unit and a large, two-armed, slave unit. The slave hands can lift 200 lb. All slave motions have hydraulic drives. The servo system, which contains 20 motions, requires additional development in order to provide proper counterbalance and accurate force feedback (feel).

3. Electro-Mechanical Manipulator

Electro-mechanical manipulators of 40- to 500-lb capacity consist of, in general, a mechanical arm mounted on the lower end of a telescoping hoist, the upper end of which (the hoist) is supported by a carriage mounted on a bridge. The capacity noted above is the maximum weight a manipulator hand will support in any position. Various models of these manipulators are listed below:

- 40-lb General Mills Model 100 (Figures 77, 78, and 79)
- 40-lb Lee Model 6A (Figures 80 and 81)
- 45-lb Koelsch Model 122B (Figures 82 and 83)
- 50-lb General Mills Model 150 (Figures 84, 85, and 86)
- 65-lb General Mills Model 300 (Figures 87, 88, and 89)
- 80-lb PAR Model 1000 (Figures 90, 91, 92, and 92a)
- 100-lb General Mills Model 550 (Figures 93, 94, 95, and 96)
- 160-lb PAR Model 3000 (Figures 97, 98, 99, and 99a)
- 400-lb PAR Model 6000 (Figures 100, 101, and 102)
- 500-lb General Mills Model 700 (Figures 103, 104, and 105)

D. VEHICLES

Vehicles, shielded and unshielded, manned and unmanned, for handling "hot" radioactive materials are described below.

1. Shielded Locomotive

The General Electric Company built, for the AEC, the shielded locomotive shown in Figures 107 and 108. The shielded locomotive is located at the National Reactor Testing Station, Arco, Idaho. It is used as a personnel carrier and as a prime mover of equipment. Specifications for the locomotive are as follows:

<u>Weight, lb</u>	
Total locomotive	430,000
On drivers	224,800
Per driving axle, front truck	57,400
Per driving axle, rear truck	55,000
Per idle axle, front truck	114,700
Per idle axle, rear truck	90,500
<u>Ratings</u>	
Tractive effort at 30% adhesion	67,440 lb
Tractive effort at continuous rating of motors	22,700 lb
Maximum speed	15 mph
<u>Shielding</u>	
Front	36-1/2 in. of water 9-1/2 in. of lead
Rear	22-1/2 in. of water 2-1/8 in. of lead
Sides	26 in. of water 3-1/8 in. of lead
Bottom	26 in. of water 2-1/8 in. of lead

2. Beetle

The beetle, a shielded-cab vehicle with manipulators, is a completely self-contained, manned, mobile, remote handling station. It is a mobile mount for two manipulators and environmental protection for their operator. It consists of a shielded cab mounted on a track-laying chassis. The cab has two manipulators mounted on it. The cab is capable of rotating 420° with respect to the chassis, and it may be elevated 15 ft from its lowest position. The manipulators are capable of lifting 100 lb in any direction.

General specifications of the beetle are as follows:

Weight	85 tons
Maximum ground pressure	55 psi
Tractive effort	80,000 lb
Maximum speed	10 mph
General dimensions	see Figure 109
Manipulator motions	see Figure 110
Manipulator hands	see Figures 111 and 112
Shielding	equivalent of 12 in. of lead on top, bottom, and all sides of the shielded cab
Viewing	Direct viewing through five high-leaded-glass windows A periscope which has 1.5 and 6 magnification with vertical scan $+80^{\circ}$ and azimuth range of 230° . Closed-circuit TV
Radiation level monitoring system	Outside the cab 0 to 100,000 R/hr Inside the cab 0 to 1,000 MR/hr
Air sampling system for monitor- ing air entering the cab	
Air conditioning including humidity control and temperature control for air inside the cab.	
Air inside cab filtered through a high-efficiency filter	
Two-way radio and public address system unit provided	

Figure 113 is a photograph of the Beetle.

3. Mobot

The Hughes Mark II Mobot is a mobile, remotely controlled (by coaxial cable), unmanned, vehicle containing two manipulator arms and two TV cameras. The vehicle and manipulators are remotely controlled by a console containing two TV monitors.

Figure 114 provides an overall view of vehicle which is 59 in. long, 29 in. wide, and 43 in. high. Figure 115 shows manipulator capacities.

4. Little Ranger

Figure 116 shows a General Mills Little Ranger mobile, remotely controlled (through electric cable), vehicle containing a General Mills Model 150 manipulator and two TV cameras. The vehicle, manipulator, and TV cameras are remotely controlled by a console containing two TV monitors. See Figure 117 for dimensions and 117a for specifications.

5. Lee Model MM-1

Figure 118 illustrates, and provides general dimensions of, the Lee Model MM-1 remotely controlled (through electric cable), mobile vehicle with manipulator and TV camera.

6. Koelsch Models 601RC and 602RC

Figures 119 and 120 show Koelsch Models 601RC and 602RC, respectively, remotely controlled (through electric cable), mobile vehicles with manipulator.

E. OTHER REMOTE HANDLING EQUIPMENT

The following illustrations show examples of remote handling equipment including slings, stands, adapters, alignment fixtures, centering fixtures, reactor refueling machine, reactor disassembly machine, storage racks, handling tong, storage tray, personnel shield, and positioning fixture:

Slings, Figures 121 through 137

Stands, Figures 138 through 146

Adapters, Figures 147 through 148

Alignment fixture, Figure 149
Centering fixtures, Figures 150 and 151
Reactor refueling machine, Figure 152
Reactor disassembly machine, Figure 153
Cartridge handling tool, Figures 154 and 155
Cartridge storage rack, Figures 156 and 157
Activator storage tray, Figure 158
Control rod tong, Figure 159
Transport rod removal tool, Figure 160
Rod pool basket, Figure 161
Rod cask basket, Figure 162
Turbojet upending fixture, Figure 163
Positioning fixture, Figure 164
Personnel shield, Figure 165
Core removal fixture, Figure 166
Power plant disassembly machine, Figure 167
Upending machine, Figure 168
Engine disassembly fixture, Figure 169

In addition to power wrenches for tightening and break-away torque there are nut and bolt handling tools, shearing tools, and abrasive cutoff tools (Figures 170 through 182). Figure 183 shows a tool stand.

V. HANDLING EQUIPMENT FOR NERVA

The handling system for the NERVA includes an engine-installation vehicle which is propelled by a locomotive. Both the installation vehicle and the locomotive are operated from a shielded, manned, self-propelled, control car. In addition, a remote handling system is located in the E-MAD (shielded maintenance) building. This system consists of an overhead positioning subsystem, a wall-mounted handling subsystem, and a floor-mounted handling subsystem. The complete NERVA handling system is described below.

A. VEHICLES

1. Installation Vehicle

The engine-installation vehicle is a conventional railway flat car with attached superstructure. It is to be used for transporting the NERVA engine, the future upgraded 3.5 NERVA engine, the systems irradiation effects experiment, or the Radiation Effects Facility (REF) reactor between the R-MAD (maintenance, assembly, and disassembly) building and the E-MAD (maintenance, assembly, and disassembly) building, or between either of these buildings and a test-stand complex or designated hold area. The engine-installation vehicle can carry the test-stand engine interface adaptor simultaneously with the engine or the irradiation effects experiment, or it can carry the adaptor separately. Figure 219 shows the installation vehicle.

2. Locomotive

The locomotive is a railway prime mover. It is a diesel-electric, 56-1/2-in.-gage, 80-ton, 0-4-4-0-wheel unit with a dual power plant. The general specifications of the locomotive are as follows:

Total weight	165,000 lb
Weight per driving axle	41,250 lb
Overall length	37 ft
Height	12 ft 6 in.
Overall width	9 ft 9 in.
Track curvature radius, minimum	100 ft

Speed, maximum	25 mph
Tractive effort at 30% adhesion	48,000 lb
Tractive effort at continuous rating	20,000 lb
(See Figure 220)	

3. Manned Control Car

The manned control car is a shielded cab for two people mounted on a self-propelled railway car and containing controls for itself, the locomotive, the engine-installation vehicle, the mobile crane, and other vehicles. See Figure 221.

General specifications for the manned control car areas follows:

Weight of manned control car	250,000 lb
Weight per axle, maximum	40,000 lb
Overall length	21 ft
Overall width	15 ft
Height above rail, less antenna	20 ft
Standard AAR track gage	56-1/2 in.
Track curvature radius, minimum	100 ft
Speed, maximum	6 mph
Tractive effort	15,000 lb
Inside cab width	6 ft
Inside cab length	8 ft
Inside cab height	6 ft 9 in.

The cab is shielded to allow a maximum radiation level of 2 MR/hr inside from a gamma radiation source of 1.75×10^6 MR/hr 40 ft from the cab and from a photo-neutron source of 9.7×10^2 M-REM/hr 40 ft from the cab.

Viewing is possible through windows in the front, on the sides, and in the rear of cab. Viewing is also possible by closed-circuit TV.

Radiation monitoring for gamma and neutron radiation is provided inside the cab. Air sampling is provided for monitoring air entering the cab. Airconditioning and temperature control are provided inside cab. Air entering the cab is filtered through a high-efficiency filter. Two-way radio and an emergency air supply are also provided in the cab.

The cab contains controls for the following: manned control car, locomotive, engine installation vehicle, and mobile crane.

4. Remotely Controlled Mobile Crane

Figure 222 illustrates the remotely controlled mobile crane. Its overall dimensions and lifting capacity are as follows:

Overall length (not including boom)	25 ft 6 in.
Overall width, outriggers extended	16 ft 6 in.
Height (not including boom)	14 ft
Weight, approximate	150,000 lb
Full revolving	
Wheel mounted	
Pneumatic rubber tires	
Boom length	60 ft
Capacity, 25 tons at a radius to clear 15 ft in diameter by 30 ft long (with the long axis vertical)	
Remotely controlled through cable 150 ft long	

5. Remotely Controlled Bulldozer

Figure 224 shows a remotely controlled bulldozer. Its general specifications are as follows:

Horsepower	225
Weight	71,000 lb
Speed, low 3 mph drawbar pull	70,000 lb
Speed, high 6 mph drawbar pull	48,300 lb
Speed, reverse 4.3 mph drawbar pull	66,500 lb
Length	21 ft 10 in.
Height (bucket down)	8 ft 10 in.
Width	9 ft 3 in.
Ground clearance	16-3/8 in.
Height (bucket up)	17 ft 11 in.
Ground pressure	12.5 psi
Max bucket capacity	4 cu yd

B. E-MAD REMOTE HANDLING SYSTEM

The E-MAD remote handling system consists of overhead-positioning, wall-mounted and the floor-mounted subsystems.

1. Overhead-Positioning Subsystem

The overhead-positioning subsystem consists of a bridge, trolley, telescoping mast, auxiliary manipulator, and five positioning heads. Figures 184 and 185 show the overhead-positioning subsystem.

The overhead-positioning subsystem can remotely and accurately locate any one of its five positioning heads (within the limits of its travel), and can rotate the head about its vertical centerline. The function of this system is to remotely lift and position NERVA engines, engine parts, and engine assemblies for disassembly, storage, inspection, and assembly.

The overhead positioning subsystem contains an auxiliary manipulator capable of lifting 500 lb in its hand in any position. The manipulator may be used when the positioning heads are not in use.

The following AMF sketches for preliminary design of the overhead-positioning system are listed for reference only and are not incorporated in this manual.

- SK 3469 - Mast Assembly
- SK 3481 - Trolley Assembly
- SK 3480 - Bridge Assembly
- SK 3472 - Upper Mast Assembly
- SK 3473 - Upper Internal Movable Assembly
- SK 3474 - Lower Internal Movable Assembly
- SK 3470 - Lower Mast Movable Guide Section
- SK 3471 - Manipulator Guide Frame
- SK 3467 - Top Shield Positioning Head
- SK 3466 - Turbopump Assembly Positioning Head
- SK 3463 - Upper Thrust Structure Positioning Head
- SK 3464 - Lower Thrust Structure Positioning Head
- SK 3465 - Pressure Vessel Positioning Head

2. Wall-Mounted Subsystem

The wall-mounted subsystem consists of two carriages mounted on each of two walls of the E-MAD building. The carriages are capable of traveling the length of the building. A manipulator capable of reaching past the center of the shop is mounted on each carriage. The manipulator can extend and retract. It is mounted on a second carriage capable of vertical travel on the first carriage. The manipulator is also hinged in two directions so that it rotates through both vertical and horizontal angles. The manipulator may be replaced remotely with manipulators of 40-, 50-, 65-, 100-, 160-, and 500-lb capacity. (See Figures 184 through 188.)

3. Floor-Mounted Subsystem

The floor-mounted subsystem consists of the following remote handling equipment:

- Mobile carriage (Figure 189)
- Reactor core stand (Figure 190)
- Hot-engine hold and checkout stand (Figure 191)
- Remote handling dolly (Figure 192)
- Nozzle stand (Figure 193)
- Pressure-vessel stand (Figure 194)
- Subsystem stand (Figure 195)
- Portable turntable (Figure 196)
- Control-rod stand (Figure 197)
- Control-rod drive mechanism and instrument stand (Figure 198)
- Turbopump stand (Figure 199)
- Roll-nozzle stand (Figure 200)
- Pneumatic-tank stand (Figure 201)
- Reflector-segment stand (Figure 202)
- Gimbal-actuator stand (Figure 203)
- Top-shield stand (Figure 204)
- Lower-thrust-structure stand (Figure 205)
- Pressure-vessel-head stand (Figure 206)

Shutoff-valve stand (Figure 207)

Engine-test-stand, interface-adapter stand (Figure 208)

Upper-thrust-structure stand (Figure 209)

Ducting and wiring harness stand (Figure 210)

Handling yoke (Figure 211)

Positioning-head stands (Figure 212)

4. Auxiliary E-MAD Remote Handling Equipment

In addition to the overhead-positioning system, the wall-mounted manipulators, and the floor handling subsystem, the E-MAD building has a 40-ton overhead crane, viewing windows, two builtin turntables, a two-rail railroad track system, power supply, light, heat, airconditioning system, etc. Figures 217, 217a, and 218 show the plan and the elevation of the E-MAD building.

TABLE 1

TORQUE AND WRENCH RECOMMENDATIONS FOR LOW-CARBON-STEEL
BOLT AND PLAIN NUT OR THREADED HOLE

Bolt Size		Assy Torque*	Low-Temp Disassy Torque**	High-Temp Disassy Torque***
Outside Diameter of Screws	Number of Threads per Inch			
1/4	20	67-80 in.-lb SF4****	120 in.-lb SR1	150 in.-lb SS1
↓	↓	CS1	SF9	SR1
1/4	20	CR1		SR13
		CF1		
1/4	28	84-100 in.-lb SF6	150 in.-lb SR1	184 in.-lb SS1
↓	↓	CS1	SF13	SR1
1/4	28	CR1		SF14
		CF1		
5/16	18	117-140 in.-lb SF11	210 in.-lb SS1	257 in.-lb SS2
↓	↓	CS2	SR1	SR2
5/16	18	CR1	SF16	SF17
		CF2	HF1	HF1
5/16	24	135-150 in.-lb SF12	225 in.-lb SS1	285 in.-lb SS2
↓	↓	CS2	SR2	SR2
5/16	24	CR1	SF16	HF1
		CF2	HF1	
3/8	16	209-250 in.-lb SS1	375 in.-lb SS2	459 in.-lb SS2
↓	↓	SR1	SR2	SR2
		SF16	HF2	HF2
		CS5		
3/8	16	CR2		
		CF3		

* Assembly torque values - 50 to 60% of yield strength, "Torque Manual," P.A. Sturtevant Company.

** Low-temperature torque values - approximately 150% of assembly torque.

*** High-temperature torque values - approximately 200% of assembly torque.

**** Codes for recommended wrenches are explained in Section IV, B, 3 of the text.

TABLE 1 (cont.)

Bolt Size		Assy Torque	Low-Temp Disassy Torque	High-Temp Disassy Torque
Outside Diameter of Screws	Number of Threads per Inch			
3/8 ↓ 3/8	24 ↓ 24	230-275 in.-lb SS1 SF17 CS5 CR2 CF3	415 in.-lb SS2 SR2 HF2	505 in.-lb SS2 SR2 HF2
7/16 ↓ 7/16	14 ↓ 14	334-400 in.-lb CS7 CR4 CF4	600 in.-lb SS3 SR2 HF2	734 in.-lb SS3 HF3
7/16 ↓ 7/16	20 ↓ 20	355-425 in.-lb CS8 CR4 CF4	640 in.-lb SS3 SR2 HF2	780 in.-lb SS3 HF3
1/2 ↓ 1/2	13 ↓ 13	459-550 in.-lb SS2 SR2 CS4 CR5 CF4	825 in.-lb SS3 SR3 HF3	1010 in.-lb SS4 SR3 HR1 HF3
1/2 ↓ 1/2	20 ↓ 20	480-575 in.-lb SS2 SR2 CS4 CR5 CF4	865 in.-lb SS3 SR3 HF3	1055 in.-lb SS4 SR3 HR1 HF3
9/16 ↓ 9/16	12 ↓ 12	605-725 in.-lb SS3 SR2 CS8 CR5 CF4	1090 in.-lb SS4 SR3 HF3	1330 in.-lb SS5 SR3 HR1 HE3
9/16 ↓ 9/16	18 ↓ 18	667-800 in.-lb SS3 SR2 CS8 CR5 CF4	1200 in.-lb SS4 SR3 HF3	1330 in.-lb SS5 SR3 HR1 HF4

TABLE 1 (cont.)

<u>Bolt Size</u>		<u>Assy Torque</u>	<u>Low-Temp Disassy Torque</u>	<u>High-Temp Disassy Torque</u>
<u>Outside Diameter of Screws</u>	<u>Number of Threads per Inch</u>			
5/8 ↓ 5/8	11 ↓ 11	1044-1248 in.-lb SS4 SR3 CS10 CR6	1875 in.-lb SS5 SR4 HR1	2250 in.-lb SS7 SR5 HR1
5/8 ↓ 5/8	18 ↓ 18	1176-1392 in.-lb SS5 SR3 CS11 CR6	2100 in.-lb SS6 SR5 HR1	2570 in.-lb SS7 SR6 HR1
3/4 ↓ 3/4	10 ↓ 10	1320-1716 in.-lb SS5 SR3 CS11	2575 in.-lb SS8 SR6 HR1	3040 in.-lb SS10 SR7 HR1
3/4 ↓ 3/4	16 ↓ 16	1416-1680 in.-lb SS5 SR3 CS11	2520 in.-lb SS8 SR6 HR1	3100 in.-lb SS10 SR7 HR1
7/8 ↓ 7/8	9 ↓ 9	2184-2616 in.-lb SS8 SR6 CS12	3925 in.-lb SS12 SR8	4800 in.-lb SS13 SR8
7/8 ↓ 7/8	14 ↓ 14	2184-2604 in.-lb SS8 SR6 CS12	3905 in.-lb SS12 SR8	4790 in.-lb SS13 SR8
1 ↓ 1	8 ↓ 8	3228-3700 in.-lb SS12 SR7 CS13	5850 in.-lb SS14 SR8	7130 in.-lb SS15 SR9
1 ↓ 1	14 ↓ 14	2916-3492 in.-lb SS11 SR7 CS13	5240 in.-lb SS13 SR8	6410 in.-lb SS15 SR9

TABLE 1 (cont.)

Bolt Size		Assy Torque	Low-Temp Disassy Torque	High-Temp Disassy Torque
Outside Diameter of Screws	Number of Threads per Inch			
1 1/8	7	4656-5580 in.-lb	8370 in.-lb	10240 in.-lb
↓	↓	SS13	SS15	SS15
1 1/8	7	SRB	SR9	SR9
		CS14		
1 1/8	12	4404-5280 in.-lb	7920 in.-lb	9685 in.-lb
↓	↓	SS13	SS15	SS15
1 1/8	12	SR8	SR9	SR9
		CS14		
1 1/4	7	5904-7080 in.-lb	10620 in.-lb	12985 in.-lb
↓	↓	SS15	SS15	SS15
1 1/4	7	SR9	SR9	
		CS14		
1 1/4	12	5400-6480 in.-lb	9720 in.-lb	11880 in.-lb
↓	↓	SS15	SS15	SS15
1 1/4	12	SR9	SR9	
		CS14		

TABLE 2

TORQUE AND WRENCH RECOMMENDATIONS FOR HIGH-CARBON-STEEL BOLT
AND PLAIN NUT OR THREADED HOLE

Bolt Size		Assy Torque*	Low-Temp Disassy Torque**	High-Temp Disassy Torque***
Outside Diameter of Screws	Number Of Threads per Inch			
1/4	20	100-120 in.-lb	180 in.-lb	220 in.-lb
↓	↓	SF8****	SS1	SS1
↓	↓	CS2	SR1	SR1
1/4	20	CR1	SF14	SF16
		CF1	HF1	HF1
1/4	28	115-140 in.-lb	210 in.-lb	255 in.-lb
↓	↓	SF6	SR1	SS1
↓	↓	CS1	SF13	SR1
1/4	28	CR1		SF14
		CF1		
5/16	18	200-240 in.-lb	360 in.-lb	440 in.-lb
↓	↓	SS1	SS2	SS2
↓	↓	SR1	HF1	SR2
↓	↓	SF16		HF2
5/16	18	CS3		
		CR2		
		CF2		
5/16	24	215-250 in.-lb	375 in.-lb	465 in.-lb
↓	↓	SS1	SS2	SS2
↓	↓	SF16	HF2	SR2
↓	↓	CS3		HF2
5/16	24	CR2		
		CF2		
3/8	16	350-430 in.-lb	645 in.-lb	780 in.-lb
↓	↓	CS7	SS2	SS3
↓	↓	CR4	SF2	
3/8	16	CF3	HF2	

* Assembly torque values - 50 to 60% of yield strength, The Holm-Krome Screw Corporation Selector.

** Low-temperature torque values - approximately 150% of assembly torque.

*** High-temperature torque values - approximately 200% of assembly torque.

**** Codes for recommended wrenches are explained in Section IV, B 3 of the test.

TABLE 2 (cont.)

Bolt Size		Assy Torque	Low-Temp Disassy Torque	High-Temp Disassy Torque
Outside Diameter of Screws	Number Of Threads per Inch			
3/8	24	370-455 in.-lb	685 in.-lb	825 in.-lb
↓	↓	CS7	SS2	SS3
3/8	24	CR4	SR2	
		CF4	HF2	
7/16	14	600-720 in.-lb	1080 in.-lb	1320 in.-lb
↓	↓	SS3	SS4	SS5
↓	↓	SR2	HF3	SR3
↓	↓	CS7		HF3
7/16	14	CR5		
		CF4		
7/16	20	620-745 in.-lb	1120 in.-lb	1365 in.-lb
↓	↓	SS3	SS4	SS5
↓	↓	SR2	HF3	SR3
↓	↓	CS8		HF3
7/16	20	CR5		
		CF4		
1/2	13	950-1140 in.-lb	1715 in.-lb	2090 in.-lb
↓	↓	SS4	SS5	SS6
↓	↓	CS10	SR3	SR5
1/2	13	CR6	HR1	HR1
		CF5	HF4	HF4
1/2	20	970-1165 in.-lb	1750 in.-lb	2135 in.-lb
↓	↓	SS4	SS5	SS6
↓	↓	CS10	SR3	SR5
1/2	20	CR6	HR1	HR1
		CF5	HF4	HF4
9/16	12	1275-1530 in.-lb	2295 in.-lb	2805 in.-lb
↓	↓	SS5	SS6	SS9
↓	↓	SR3	SR5	SR6
9/16	12	CS11	HR1	HR1
		CR7		
9/16	18	1340-1605 in.-lb	2410 in.-lb	2945 in.-lb
↓	↓	SS5	SS7	SS9
9/16	18	SR3	SR5	SR7
		CS11	HR1	HR1

TABLE 2 (cont.)

<u>Bolt Size</u>		<u>Assy Torque</u>	<u>Low-Temp Disassy Torque</u>	<u>High-Temp Disassy Torque</u>
<u>Outside Diameter of Screws</u>	<u>Number Of Threads per Inch</u>			
5/8 ↓ 5/8	11 ↓ 11	2250-2700 in.-lb SS7 SR5 CS12	4050 in.-lb SS12 SR8	4950 in.-lb SS13 SR8
5/8 ↓ 5/8	18 ↓ 18	2380-2850 in.-lb SS7 SR5 CS12	4275 in.-lb SS13 SR8	5230 in.-lb SS13 SR8
3/4 ↓ 3/4	10 ↓ 10	3250-4500 in.-lb SS11 SR7 CS13	6750 in.-lb SS15 SR9	7750 in.-lb SS15 SR9
3/4 ↓ 3/4	16 ↓ 16	3350-4460 in.-lb SS10 SR7 CS13	6690 in.-lb SS15 SR9	7810 in.-lb SS15 SR9
7/8 ↓ 7/8	9 ↓ 9	5900-7080 in.-lb SS14 SR8 CS14	10620 in.-lb SS15 SR8	12980 in.-lb SS15
7/8 ↓ 7/8	14 ↓ 14	5900-7060 in.-lb SS14 SR8 CS14	10590 in.-lb SS15 SR8	12960 in.-lb SS15
1 ↓ 1	8 ↓ 8	8050-9660 in.-lb SS15 SR9 CS15	14490 in.-lb SS15 SR8	17710 in.-lb
1 ↓ 1	14 ↓ 14	7740-9250 in.-lb SS15 SR9 CS15	13875 in.-lb SS15 SR8	16990 in.-lb

TABLE 3

TORQUE AND WRENCH RECOMMENDATIONS FOR ALLOY OR STAINLESS
STEEL BOLT AND FREE-SPINNING NUT

Bolt Size		Assy Torque*	Low-Temp Disassy Torque**	High Temp Disassy*** Torque
Outside Diameter of Screws	Number of Threads per Inch			
1/4	20	70-100 in.-lb	150 in.-lb	250 in.-lb
↓	↓	SF5****	SS1	SS1
1/4	20	CS1	SR1	SF16
		CR1	SF13	HF1
		CF1	HF1	
1/4	28	95-125 in.-lb	190 in.-lb	315 in.-lb
↓	↓	SF7	SS1	SS2
1/4	28	CS2	SR1	HF1
		CR1	SF16	
		CF1	HF1	
5/16	18	105-140 in.-lb	210 in.-lb	350 in.-lb
↓	↓	SF9	SS1	SS2
5/16	18	CS3	SR1	SR2
		CR1	SF16	HF1
		CF2	HF1	
5/16	24	130-170 in.-lb	255 in.-lb	425 in.-lb
↓	↓	SF12	SS2	SS2
5/16	24	CS4	SF17	SR2
		CR1	HF2	HF2
		CF2		
3/8	16	190-250 in.-lb	375 in.-lb	625 in.-lb
↓	↓	SS1	SS2	SS3
		SR1	HF2	SR2
		SF16		HF2
		CS5		
3/8	16	CR2		
		CF3		

* Assembly torque values - 50 to 60% of yield strength, Klincher Locknut Corporation.

** Low-temperature torque values - approximately 150% of assembly torque.

*** High-temperature torque values - approximately 250% of assembly torque.

**** Codes for recommended wrenches are explained in Section IV, B, 3 of the text.

TABLE 3 (cont.)

<u>Bolt Size</u>		<u>Assy Torque</u>	<u>Low-Temp Disassy Torque</u>	<u>High-Temp Disassy Torque</u>
<u>Outside Diameter of Screws</u>	<u>Number of Threads per Inch</u>			
3/8	24	255-340 in.-lb	510 in.-lb	850 in.-lb
↓	↓	SF17	SS2	SS3
3/8	24	CS4	HF3	SR3
		CR2		HF3
		CF3		
7/16	14	320-425 in.-lb	640 in.-lb	1065 in.-lb
↓	↓	CS7	SS3	SS4
7/16	14	CR4	SR2	SR3
		CF4	HF3	HF3
7/16	20	420-550 in.-lb	825 in.-lb	1375 in.-lb
↓	↓	SS2	SS3	SS5
		CS8	HF3	SR3
7/16	20	CR4		HF3
		CF4		
1/2	13	540-720 in.-lb	1080 in.-lb	1800 in.-lb
↓	↓	SS2	SS4	SS5
		SR2	SR3	SR3
		CS9	HR1	HR1
1/2	13	CR5	HF4	HF4
		CF4		
1/2	20	720-960 in.-lb	1440 in.-lb	2400 in.-lb
↓	↓	SS3	SS5	SS7
		SR2	SR3	SR5
		CS10	HR1	HR1
1/2	20	CR6	HF4	HF4
		CF5		
9/16	12	840-1100 in.-lb	1650 in.-lb	2750 in.-lb
↓	↓	SS4	SS5	SS9
		CS10	SR3	SR6
9/16	12	CR6	HR1	HR1
		CF5	HF5	HF5
9/16	18	1080-1400 in.-lb	2100 in.-lb	3500 in.-lb
↓	↓	SS4	SS6	SS11
		CS11	SR5	SR7
9/16	18	CR6	HR1	HF5
		CF5	HF5	

TABLE 3 (cont.)

<u>Bolt Size</u>		<u>Assy Torque</u>	<u>Low-Temp Disassy Torque</u>	<u>High-Temp Disassy Torque</u>
<u>Outside Diameter of Screws</u>	<u>Number of Threads per Inch</u>			
5/8 ↓ 5/8	11 ↓ 11	1200-1560 in.-lb SS4 CS12	2340 in.-lb SS7 SR5 HR1	3900 in.-lb SS12 SR8
5/8 ↓ 5/8	18 ↓ 18	1536-2040 in.-lb SS5 SR3 CS12	3060 in.-lb SS10 SR7 HR1	5100 in.-lb SS14 SR8
3/4 ↓ 3/4	10 ↓ 10	2340-2520 in.-lb SS7 SR5 CS12	3780 in.-lb SS12 SR8	6300 in.-lb SS14 SR9
3/4 ↓ 3/4	16 ↓ 16	2700-2880 in.-lb SS8 SR6 CS12	4320 in.-lb SS13 SR8	7200 in.-lb SS15 SR9
7/8 ↓ 7/8	9 ↓ 9	3960-4320 in.-lb SS12 SR8 CS13	6480 in.-lb SS14 SR9	10800 in.-lb SS15 SR9
7/8 ↓ 7/8	14 ↓ 14	4320-4680 in.-lb SS14 SR8 CS13	7020 in.-lb SS15 SR9	11700 in.-lb SS15
1 ↓ 1	8 ↓ 8	5760-6120 in.-lb SS14 SR8 CS14	9180 in.-lb SS15 SR9	15300 in.-lb SS15
1 ↓ 1	14 ↓ 14	6480-6840 in.-lb SS15 SR9 CS14	10260 in.-lb SS15 SR9	17100 in.-lb SS15

TABLE 4

TORQUE AND WRENCH RECOMMENDATIONS FOR ALLOY OR STAINLESS
STEEL BOLT AND BEAM TYPE LOCKNUT

Bolt Size		Assy * Torque	Low-Temp Disassy [*] Torque	High-Temp Disassy ^{***} Torque
Outside Diameter of Screws	Number of Threads per Inch			
1/4	20	30-60 in.-lb	90 in.-lb	180 in.-lb
↓	↓	SF1	SF6	SS1
1/4	20	CS1	HF1	SR1
↓	↓	CR1		SF14
1/4	28	CF1		HF1
↓	↓			
1/4	28	36-70 in.-lb	105 in.-lb	210 in.-lb
↓	↓	SF1	SF7	SS1
1/4	28	CS1	HF1	SR1
↓	↓	CR1		SF16
1/4	28	CF1		HF1
↓	↓			
5/16	18	70-110 in.-lb	165 in.-lb	360 in.-lb
↓	↓	SF6	SF13	SS2
5/16	18	CS2	HF2	SR2
↓	↓	CR2		HF2
5/16	24	CF2		
↓	↓			
5/16	24	80-130 in.-lb	195 in.-lb	495 in.-lb
↓	↓	SF7	SR1	SS2
5/16	24	CS2	SF16	SR2
↓	↓	CR2	HF2	HF2
5/16	24	CF2		
↓	↓			
3/8	16	160-210 in.-lb	315 in.-lb	735 in.-lb
↓	↓	SS1	SS1	SS3
3/8	16	SR1	HF3	HF3
↓	↓	SF14		
3/8	16	CS3		
↓	↓	CR2		
3/8	24	CF3		
↓	↓			
3/8	24	190-230 in.-lb	345 in.-lb	805 in.-lb
↓	↓	SS1	HF3	SS3
3/8	24	SR1		HF3
↓	↓	SF16		
3/8	24	CS3		
↓	↓	CR2		
3/8	24	CF3		

* Assembly torque valves - those used on turbojet engines.

** Low-temperature torque values - approximately 150% of assembly torque.

*** High-temperature torque values - 300% of assembly torque values for 1/4 in.,
325% of assembly torque values for 5/16 in., 350% of assembly torque values
for above 5/16 in.

Table 4

Sheet 1 of 3

TABLE 4 (cont.)

Bolt Size		Assy Torque	Low-Temp Disassy Torque	High-Temp Disassy Torque
Outside Diameter of Screws	Number of Threads per Inch			
7/16	14	250-320 in.-lb	480 in.-lb	1120 in.-lb
↓	↓	CS4	SR2	SS4
7/16	14	CR4	HF4	HF4
7/16	20	290-360 in.-lb	540 in.-lb	1260 in.-lb
↓	↓	CS4	SR2	SS4
7/16	20	CR4	HF4	HF4
7/16	20	CF4		
1/2	13	420-510 in.-lb	765 in.-lb	1785 in.-lb
↓	↓	SS2	SS3	SS5
↓	↓	CS8	SR2	SR3
1/2	13	CR4	HF5	HR1
↓	↓	CF5		HF5
1/2	20	480-570 in.-lb	855 in.-lb	1995 in.-lb
↓	↓	SS2	SS3	SS5
↓	↓	CS8	HF5	SR4
1/2	20	CR5		HR1
↓	↓	CF5		HF5
9/16	12	576-684 in.-lb	1025 in.-lb	2380 in.-lb
↓	↓	SS2	SS4	SS7
↓	↓	SR2		SR5
9/16	12	CS9		HR1
↓	↓	CR5		
9/16	18	660-780 in.-lb	1070 in.-lb	2730 in.-lb
↓	↓	SS3	SS4	SS8
↓	↓	SR2		SR6
9/16	18	CS9		HR1
↓	↓	CR5		
5/8	11	840-960 in.-lb	1440 in.-lb	3360 in.-lb
↓	↓	SS3	SS5	SS11
↓	↓	CS10	SR3	SR7
5/8	11	CR6	HR1	
5/8	18	984-1140 in.-lb	1710 in.-lb	3990 in.-lb
↓	↓	SS3	SS4	SS8
↓	↓	SR2		SR6
5/8	18	CS9		HR1
↓	↓	CR5		

TABLE 4 (cont.)

<u>Bolt Size</u>		<u>Assy Torque</u>	<u>Low-Temp Disassy Torque</u>	<u>High-Temp Disassy Torque</u>
<u>Outside Diameter of Screws</u>	<u>Number of Threads per Inch</u>			
3/4	10	1620-1800 in.-lb	2700 in.-lb	6300 in.-lb
↓	↓	SS5	SS8	SS14
3/4	10	SR3	SR6	SR8
		CS12	HR1	
3/4	16	1800-1980 in.-lb	2970 in.-lb	6930 in.-lb
↓	↓	SS5	SS9	SS15
3/4	16	SR4	SR7	SR9
		CS12	HR1	
7/8	9	2460-2760 in.-lb	4140 in.-lb	9660 in.-lb
↓	↓	SS8	SS12	SS15
7/8	9	SR6	SR8	SR9
		CS12		
7/8	14	2820-3180 in.-lb	4770 in.-lb	11130 in.-lb
↓	↓	SS10	SS13	SS15
7/8	14	SR6	SR8	SR9
		CS12		
1	8	3600-4080 in.-lb	6120 in.-lb	14280 in.-lb
↓	↓	SS11	SS14	SS15
1	8	SR7	SR8	
		CS13		
1	14	4200-4800 in.-lb	7200 in.-lb	16800 in.-lb
↓	↓	SS12	SS15	
1	14	SR8	SR9	
		CS13		
1-1/8	7	4980-5760 in.-lb	8640 in.-lb	18800 in.-lb
↓	↓	SS13	SS15	
1-1/8	7	SR8	SR9	
		CS14		
1-1/8	12	5820-6780 in.-lb	10170 in.-lb	22050 in.-lb
↓	↓	SS14	SS15	
1-1/8	12	SR8	SR9	
		CS14		
1-1/4	7	7200-8400 in.-lb	12600 in.-lb	27300 in.-lb
↓	↓	SS15	SS15	
1-1/4	7	SR9		
		CS15		
1-1/4	12	8280-9600 in.-lb	14400 in.-lb	31300 in.-lb
↓	↓	SS15	SS15	
1-1/4	12	SR9		
		CS15		

TABLE 5

TORQUE AND WRENCH RECOMMENDATIONS FOR ALLOY AND STAINLESS
STEEL BOLT WITH .25% EXTENSION AND BEAM TYPE LOCKNUT

Bolt Size		Assy * Torque	Low-Temp Disassy Torque**	High-Temp Disassy Torque***
Outside Diameter of Screws	Number of Threads per Inch			
1/4	20	90-120 in.-lb	180 in.-lb	360 in.-lb
↓	↓	SF8	SS1	HF1
↓	↓	CS1	SR1	
1/4	20	CR1	SF14	
		CF1	HF1	
1/4	28	100-130 in.-lb	195 in.-lb	390 in.-lb
↓	↓	SF9	SS1	HF1
↓	↓	CS2	SR1	
1/4	28	CR1	SF16	
		CF1	HF1	
5/16	18	200-220 in.-lb	330 in.-lb	715 in.-lb
↓	↓	SS1	HF2	SS3
↓	↓	SR1		SR2
↓	↓	SF16		HF2
↓	↓	CS3		
5/16	18	CR1		
		CF2		
5/16	24	210-240 in.-lb	360 in.-lb	780 in.-lb
↓	↓	SS1	HF2	SS3
↓	↓	SR1		SR2
↓	↓	SF16		HF2
↓	↓	CS3		
5/16	24	CR2		
		CF2		
3/8	16	345-385 in.-lb	580 in.-lb	1350 in.-lb
↓	↓	CS4	SS2	SS5
↓	↓	CR4	SR2	SR3
3/8	16	CF3	HF3	HF3
3/8	24	375-415 in.-lb	625 in.-lb	1450 in.-lb
↓	↓	CS4	SS3	SS5
↓	↓	CR4	SR2	SR3
3/8	24	CF3	HF3	HF3

* Assembly torque values - those which will produce .25% bolt extension

** Low-Temperature torque values - approximately 150% of assembly torque

*** High-Temperature torque values - 300% of assembly torque values for 1/4 in., 325% of assembly torque values for 5/16 in., 350% of assembly torque values for above 5/16.

TABLE 5 (cont.)

Bolt Size		Assy Torque	Low-Temp Disassy Torque	High-Temp Disassy Torque
Outside Diameter of Screws	Number of Threads per Inch			
7/16	14	725-785 in.-lb	1080 in.-lb	2750 in.-lb
↓	↓	SS3	SS4	SS9
↓	↓	SR2	HF4	SR6
7/16	14	CS8		HF4
↓	↓	CR5		
7/16	20	CF4		
7/16	20	765-825 in.-lb	1240 in.-lb	2890 in.-lb
↓	↓	SS3	SS4	SS9
↓	↓	CS8	HF4	SR6
7/16	20	CR5		HF4
↓	↓	CF4		
1/2	13	980-1070 in.-lb	1605 in.-lb	3750 in.-lb
↓	↓	SS4	SS5	SS12
↓	↓	CS11	SR3	SR7
1/2	13	CR6	HF5	HF5
↓	↓	CF5		
1/2	20	1040-1130 in.-lb	1695 in.-lb	3950 in.-lb
↓	↓	SS4	SS5	SS12
↓	↓	CS11	SR3	SR7
1/2	20	CR6	HF5	HF5
↓	↓	CF5		
9/16	12	1435-1535 in.-lb	2300 in.-lb	5370 in.-lb
↓	↓	SS5	SS7	SS13
9/16	12	SR3	SR5	SR8
↓	↓	CS12	HR1	
9/16	18	1520-1640 in.-lb	2460 in.-lb	5740 in.-lb
↓	↓	SS5	SS8	SS13
9/16	18	SR3	SR5	SR8
↓	↓	CS12	HR1

Figure 1

Guide Pin

Figure 2

Guide-Pin Detail

Figure 3

Rabbet-Design Flange

Fig. 4 Flange

Fig. 5 Flange Force Diagram

Fig. 6 Flange Force Diagram

Figure 6a

Flange Detail

Figure 7

Pressure-Cooler-Type Fastener

Fig. 8 Marman-Type Coupling

Fig. 9 Marman-Type Coupling

Figure 10

Wiggins Fluid, Quick-Disconnect Coupling

Inst-O-Matic[®]

Figure 11

Wiggins Fluid Quick-Disconnect Coupling

Figure 12

Thompson Fluid Quick-Disconnect Coupling

Figure 13

Thompson Fluid Quick-Disconnect Coupling

Figure 14

Nut and Bolt Machine

Figure 15

Nut and Bolt Machine

Figure 16

Nut and Bolt Machine

Figure 17

Nut and Bolt Machine

Figure 18

Control Console for Nut and Bolt Machine

Figure 19

Control Console for Nut and Bolt Machine

Fig. 20 Captive Nut

Fig. 21 Captive Nut

Figure 22

Captive Bolt

Fig. 23 Captive Nut and Bolt

Fig. 24 Captive Nut and Bolt

Figure 25

Captive Nut and Bolt

Figure 26

Captive Nut and Bolt

Figure 27

Captive Barrel Nut

Figure 28

Captive Bolt

Fig. 29 Typical Bail for 100-Ton Hook

Fig. 30 Typical Bail for 10-Ton Hook

Figure 31

Eyelets for Lifting

Fig. 32 Bail for 500-Lb General Mills Manipulator Hand

Fig. 33 Bail for 65-Lb General Mills Manipulator Hand

Figure 34

Grooves and Flats for 65-Lb General Mills Manipulator Hand

Fig. 35

Trunnion

Fig. 36

Detachable Eyelet

Figure 37
Flange Lift Point

2

Figure 38

Rigid Sling

Fig. 39 Bail for Lifting

Fig. 40 Eyelets for Lifting

Fig. 41 Flange Rest Point

Fig. 42 Rest Point

Fig. 43 Rest Points

Fig. 44 Rest Point

Fig. 45 Rest Point

Fig. 46 Rest Points

Fig. 47 Rest Points

Figure 48

Degrees of Motion for Alignment

Fig. 49 Pilot Pin

Fig. 50 Pilot Pin and Guide Ring

Fig. 51 Pilot Pin Clearances

Fig. 52 Pilot Pin Clearances

Figure 53

Pilot Pins

Figure 54

Pilot Pins

Fig. 55 Pilot Pins for Registering in Blind Hole

Fig. 56 Rabbet as Registering Point

POOR DESIGN

Fig. 57 Splines

IMPROVED DESIGN

Fig. 58 Splines

Figure 59

Cannon Electric Disconnect

Figure 60

Anderson Electric Disconnect

Zero Entry[®]

OPEN
No Critical
Alignment
of Contacts

MATED
Zero Entry
No Pin Friction

FULLY ENGAGED
Self-wiping Contacts —
Zero Disconnect Force

Figure 61

Wiggins Wiper-Type Disconnect

Figure 61a

Cole Electric Pins and Self-Aligning Sockets

Figure 61b

Cole Electric Disconnect

Figure 61c

Cole Electric Disconnect

Figure 6ld

Cole Electric Disconnect

Figure 6le

Cole Electric Disconnect

Fig. 62 Service Line Connections

Fig. 63 Service Line Connections

Fig. 64 Mechanical Linkage

Fig. 65 Mechanical Linkage

No.	Torque Rating, in. - lb.	Dimension, in.					Bolt Size, in.
		A ^a	B ^a	C	D	E	
SS 1	240 ^b	5/8 - 3/4	1-1/4 - 1-1/2	0.875	1.125	4.500	1/4 - 3/8
SS 2	576 ^b	7/8 - 27/32	1-1/2 - 1-1/2	1.125	1.375	5.000	1/4 - 1/2
SS 3	840 ^b	27/32 - 7/8	1-1/2 - 1-1/2	1.125	1.375	5.000	5/16 - 9/16
SS 4	1200 ^c	3/4 - 1-1/8	1-1/2 - 1-1/2	1.440	1.750	6.750	3/8 - 5/8
SS 5	1980 ^b	3/4 - 1-5/16	1-1/2 - 1-1/2	1.500	1.750	5.000	3/8 - 3/4
SS 6	2220 ^b	1-1/4 - 1-7/16	1-7/8 - 1-3/4	1.625	1.875	6.000	7/16 - 3/4
SS 7	2400 ^c	1-1/4 - 1-11/16	1-7/8 - 2	1.660	1.930	7.720	7/16 - 7/8
SS 8	2700 ^b	1-1/4 - 1-11/16	1-7/8 - 2	1.625	1.940	7.000	7/16 - 7/8
SS 9	2940 ^b	1-1/4 - 1-13/16	1-7/8 - 2	1.690	2.000	7.000	7/16 - 1
SS 10	3120 ^b	1-1/2 - 2-1/8	1-3/4 - 2-1/8	1.815	2.065	7.125	1/2 - 1
SS 11	3600 ^b	1-1/2 - 2	1-3/4 - 2-1/8	1.625	1.940	8.100	1/2 - 1
SS 12	4200 ^c	15/16 - 1-3/4	1-1/2 - 1-3/4	1.500	2.000	8.250	1/2 - 1
SS 13	5700 ^c	15/16 - 2-1/8	1-1/2 - 2-1/4	1.875	2.125	8.250	9/16 - 1-1/8
SS 14	6240 ^b	2-1/8 - 2-1/4	2-1/16 - 2-5/8	1.940	2.250	11.000	5/8 - 1-1/8
SS 15	13200 ^b	2-1/8 - 2-1/2	2-5/16 - 2-3/4	2.065	2.375	7.500	7/8 - 1-1/4

^aDimensions in columns A and B correspond to minimum and maximum under volt size.

^bPower - 90 psi air.

^cPower - 110-120 volts.

Figure 66

Dimensions of Standard Straight Wrench SS1 Through SS15

No.	Torque Rating, in. - lb.	Dimension, in.						Bolt Size, in.
		A ^a	B ^a	C	D	E	F	
SR 1	216 ^b	19/32 - 19/32	1-1/4 - 1-1/2	1.250	1.815	7.000 ^d	0.563	1/4 - 5/16
SR 2	720 ^b	27/32 - 27/32	1-1/2 - 1-1/2	1.318	2.410	7.940	0.875	5/16 - 1/2
SR 3	1,800 ^b	7/8 - 1-3/8	1-1/2 - 1-1/2	1.875	2.875	14.20 ^d	0.875	3/8 - 3/4
SR 4	2,040 ^b	1-1/4 - 1-1/2	1-7/8 - 2	1.781	3.125	10.53	1.035	7/16 - 3/4
SR 5	2,400 ^c	7/8 - 1-5/8	1-1/2 - 1-5/8	2.100	2.375	9.00	0.907	7/16 - 7/8
SR 6	2,820 ^c	7/8 - 1-5/8	1-1/2 - 1-5/8	1.875	2.815	11.00	1.125	7/16 - 7/8
SR 7	3,600 ^c	15/16 - 1-3/4	1-1/2 - 1-3/4	2.100	2.375	12.00	0.907	1/2 - 1
SR 8	6,000 ^b	1-1/2 - 2-1/4	1-3/4 - 2-1/4	1.781	3.125	11.04	1.035	9/16 - 1-1/8
SR 9	10,800 ^b	2-1/8 - 2-1/2	2-1/16 - 2-3/4	3.000	5.500	21.88 ^d	2.000	5/8 - 1-1/4

^aDimensions in columns A and B correspond to minimum and maximum under bolt size.

^bPower - 90 psi air.

^cPower - 110-120 volts.

^dOver-all length of the wrench.

Figure 67

Dimensions of Standard Right-Angle Wrench

No.	Torque Rating, in. -lb.	Dimension, in.						Bolt Size, in.
		A ^a	B ^a	C	D	E	F	
SF 1	54	0.470	0.280	5.750	0.500	7.000	0.375	1/4
SF 2	60	0.470	0.280	5.750	0.500	7.000	0.407	1/4
SF 3	66	0.470	0.280	5.750	0.563	10.00	0.469	1/4
SF 4	72	0.470	0.280	5.750	0.563	10.00	0.500	1/4
SF 5	84	0.550	0.320	5.750	0.563	10.00	0.563	1/4 - 5/16
SF 6	90	0.550	0.320	5.750	0.563	10.00	0.625	1/4 - 5/16
SF 7	108	0.470	0.280	5.750	0.500	7.000	0.375	1/4
SF 8	114	0.550	0.320	5.750	0.563	10.00	0.782	1/4 - 5/16
SF 9	120	0.550	0.320	5.750	0.500	7.000	0.407	5/16
SF 10	120	0.470	0.280	2.062	0.800	9.500	0.375	5/16
SF 11	132	0.550	0.320	5.750	0.563	10.00	0.469	5/16
SF 12	144	0.550	0.320	5.750	0.563	10.00	0.500	5/16
SF 13	168	0.625	0.375	5.750	0.563	10.00	0.563	5/16 - 3/8
SF 14	180	0.625	0.375	5.750	0.563	10.00	0.625	3/8
SF 15	180	0.625	0.375	2.375	0.750	8.500	0.970	3/8
SF 16	228	0.625	0.375	5.750	0.563	11.50	0.783	3/8
SF 17	264	0.625	0.375	5.750	0.563	11.50	0.907	3/8

^aDimensions in columns A and B must be specified when purchasing.

^bPower - 90 psi air.

Figure 68

Dimensions of Standard Flat-Angle-Wrench SF1 Through SF17

No.	Torque Rating, ^a in. - lb.	Dimension, in.					Bolt Size, in.
		A ^d	B ^d	C	D	E	
CS 1	20-110	19/32	1-1/4	1.000	1.250	8.000	1/4
CS 2	72-214 ^b	19/32 - 19/32	1-1/4 - 1-1/2	1.065	1.375	9.875	1/4 - 5/16
CS 3	120-360 ^b	19/32 - 5/8	1-1/2 - 1-1/2	1.065	1.375	9.875	5/16 - 3/8
CS 4	144-600 ^b	19/32 - 27/32	1-1/2 - 1-1/2	1.315	1.625	7.500	5/16 - 1/2
CS 5	175-310 ^c	27/32 - 27/32	1-1/2 - 1-1/2	1.500	2.000	12.25	5/16 - 7/16
CS 6	240-1080 ^b	27/32 - 1	1-1/2 - 1-1/2	1.375	1.625	12.00	5/16 - 9/16
CS 7	275-500 ^c	27/32 - 27/32	1-1/2 - 1-1/2	1.500	2.000	12.25	3/8 - 7/16
CS 8	300-960 ^b	27/32 - 7/8	1-1/2 - 1-1/2	1.315	1.625	10.50	7/16 - 9/16
CS 9	460-870 ^c	27/32 - 7/8	1-1/2 - 1-1/2	1.500	2.000	12.25	1/2 - 9/16
CS 10	600-1320 ^c	27/32 - 1-1/4	1-1/2 - 1-1/2	1.500	2.000	12.25	1/2 - 5/8
CS 11	600-1800 ^b	1-1/8 - 15/16	1-7/8 - 1-1/2	1.500	1.750	14.19	1/2 - 3/4
CS 12	1200-4200 ^a	2-1/8 - 2-1/8	2-1/8 - 2-5/16	1.940	2.250	16.25	1/2 - 7/8
CS 13	1800-6600 ^b	2-1/8 - 2-1/8	2-1/8 - 2-1/2	2.000	2.375	26.44	9/16 - 1
CS 14	3600-7200 ^b	2-1/8 - 2-1/2	2-5/16 - 2-3/4	2.065	2.500	16.63	7/8 - 1-1/4
CS 15	6000-10800 ^b	2-1/4 - 2-3/4 ^e	2-3/4 - 3-1/4 ^e	2.375	2.750	16.75	1 - 1-1/2

^aRange of controlled-torque settings (torque setting tolerance varies from $\pm 5\%$ to $\pm 20\%$ dependent upon the type of bolt and nut combination).

^bPower - 90 psi air.

^cPower - 120 volts, regulated voltage required.

^dDimensions in columns A and B correspond to minimum and maximum under bolt size.

^eApproximate dimensions for splined socket.

Figure 69

Dimensions of Special, Controlled-Torque,
Straight-Assembly-Wrench CS1 Through CS15

No.	Torque Rating, ^a in. - lb.	Dimension, in.						Bolt Size, in.
		A ^e	B ^e	C	D	E	F	
CR 1	25-225 ^b	19/32 - 19/32	1-1/4 - 1-1/4	0.625	1.563	9.500	0.656	1/4 - 5/16
CR 2	175-310 ^c	27/32 - 27/32	1-1/2 - 1-1/2	1.375	2.200	14.000	0.815	5/16 - 3/8
CR 3	180-240 ^d	19/32 - 5/8	1-1/4 - 1-1/2	0.350	1.875	14.500	0.750	5/16 - 3/8
CR 4	275-500 ^c	27/32 - 27/32	1-1/2 - 1-1/2	1.375	2.200	14.000	0.815	3/8 - 7/16
CR 5	460-870 ^c	27/32 - 7/8	1-1/2 - 1-1/2	1.375	2.200	14.000	0.815	7/16 - 9/16
CR 6	600-1320 ^c	27/32 - 1-1/4	1-1/2 - 1-1/2	1.375	2.200	14.000	0.815	1/2 - 5/8

^aRange of controlled-torque settings (torque setting tolerance varies from $\pm 5\%$ to $\pm 20\%$ dependent upon type of bolt and nut combination).

^bPower - 90 psi air.

^cPower - 120 volts, regulated voltage required.

^dPower - 60 psi air, must be controlled to control torque and prevent damage to manipulator.

^eDimensions in columns A and B correspond to minimum and maximum under bolt size.

Figure 70

Dimensions of Controlled-Torque, Right-Angle-Assembly-Wrench
CR1 Through CR6

No.	Torque Rating, ^a in. - lb.	Dimension, in.						Bolt Size, in.
		A	B	C ^d	D	E	F	
CF 1	36-132 ^c	0.470	0.280	2.500	0.563	14.50	0.440	1/4
CF 2	72-240 ^c	0.560	0.320	2.500	0.625	14.50	0.500	5/16
CF 3	156-420 ^c	0.625	0.370	2.500	0.690	14.50	0.565	3/8
CF 4	240-840 ^b	0.815	0.440	2.750	0.750	14.50	0.690	7/16
CF 5	420-1140 ^b	0.940	0.470	3.000	0.815	14.50	0.815	1/2

^aRange of controlled-torque settings (torque setting tolerance varies $\pm 5\%$ to $\pm 20\%$ dependent upon type of bolt and nut combination).

^bPower - 90 psi air.

^cPower - 110-120 volts.

^dMinimum dimension.

Figure 71

Dimensions of Special, Controlled-Torque, Flat-Angle-Assembly-
Wrench CF1 Through CF5

Torque		Dimension, in.						Bolt Size, in.
No.	Rating, in.-lb.	A	B	C	D	E	F	
HR 1	3300 ^a	7/8 - 1-3/8	1-1/2 - 1-1/2	1.375	2.200	14.00	0.815	7/16 - 3/4

^aPower - 110-120 volts.

Figure 72

Dimensions of Special, High-Torque, Right-Angle-Disassembly-Wrench HRL

No.	Torque Rating, in.-lb.	Dimension, in.						Bolt Size, in.
		A	B	C	D	E	F	
HF 1	390 ^a	0.470	0.280	2.500	0.563	14.50	0.440	1/4 - 5/16
HF 2	780 ^a	0.580	0.320	2.500	0.625	14.50	0.500	5/16 - 3/8
HF 3	1450 ^a	0.690	0.370	2.500	0.690	14.50	0.565	3/8 - 7/16
HF 4	2900 ^b	0.870	0.440	2.750	0.750	14.50	0.690	7/16 - 1/2
HF 5	3950 ^b	1.000	0.470	3.000	0.815	14.50	0.815	1/2 - 9/16

^aPower - 110-120 volts.

^bPower - 90 psi air.

Figure 73

Dimensions of Special, High-Torque, Flat-Angle-Disassembly-Wrench
HF1 Through HF5

BL: Total bolt length including head (max.) CL: Captive length of bolt (min.) HR: Head radius (max.) AC _b : Minimum axial clearance RC _b : Minimum radial clearance CD _b : Minimum center distance		Standard Pressed Steel Company, Aircraft/Missile Div. Bolt, external wrenching, series HI PSI EWB 22.	
FPD standard "R" series bolt - 12 point head		Bolt Size	HR
Bolt Size	HR	Catalog No.	
1/4 - 28	0.224	HIPSIEWB22-4	0.238
5/16 - 24	0.255	HIPSIEWB22-5	0.298
3/8 - 24	0.286	HIPSIEWB22-6	0.363
7/16 - 20	0.349	HIPSIEWB22-7	0.415
1/2 - 20	0.380	HIPSIEWB22-8	0.475
9/16 - 18	0.411	HIPSIEWB22-9	0.528
		HIPSIEWB22-10	0.598
		HIPSIEWB22-12	0.713
		HIPSIEWB22-14	0.823
		HIPSIEWB22-16	0.940
		HIPSIEWB22-18	1.050
		HIPSIEWB22-20	1.178

Figure 74

Symbols for Bolt Clearances

NL: Total nut length (max.)	Nut Size	NB	SR	CW
SR: Nut shoulder radius (max.)	1/4	0.296	0.230	0.325
AC_n : Minimum axial clearance	5/16	0.333	0.286	0.405
RC_n : Minimum radial clearance	3/8	0.365	0.320	0.455
NB: Nut body length (max.)	7/16	0.385	0.395	0.559
CW: Center of nut to wrenching point (max.)	1/2	0.512	0.415	0.587
CD_n : Minimum center distance	9/16	0.553	0.478	0.676
FPD Special Esna Lock Nut	5/8	-	-	-
	3	-	-	-

Figure 75

Symbols for Captive Nut Clearances

Figure 76

Master-Slave Manipulator

Figure 77

40-Lb General Mills Model 100 Manipulator

Figure 78

40-Lb General Mills Model 100 Manipulator

MECHANICAL	
HAND:	
Opening	4 inches
Open-Close Speed	12 to 40 ipm
Grip Force	50 pounds
HOOK:	
Opening	2¾ inches
Open-Close Speed	12 ipm
Grip Force	250 pounds
WRIST:	
Torque	72 lb in
Rotational Speed	3 to 50 rpm
Rotation	Continuous
ARM:	
Pivot Speed	1 to 2 rpm
Pivot Arc (total)	270 degrees
Rotational Torque	55 lb-ft
Rotational Speed	1.5 to 2.5 rpm
Rotation	900°
TELESCOPING HOIST:	
Extension/Retraction Speed	9 to 20 fpm
Travel Range	56 inches
CRANE BRIDGE:	
Maximum Length (center to center of rails)	16 feet
Travel Speed	3 to 9 fpm
CARRIAGE:	
Travel Speed	6 to 15 fpm
ELECTRICAL	
POWER SOURCE:	
Voltage	115 v
Frequency	60 cps
Phase	1
POWER REQUIRED	
	2 0 kva
LOAD CAPACITY	
Arm (In any position)	40 pounds
Arm Vertical (with hook)	200 pounds

TRAVEL RANGES, LOAD CAPACITIES AND SPEEDS ARE NOM-
INAL MAXIMUM VALUE SPEEDS LISTED ARE "NO LOAD".

Figure 79

Figure 80

40-Lb Lee Model 6A Manipulator

Figure 81

40-Lb Lee Model 6A Manipulator

Figure 82

45-Lb Koelsch Model 122B Manipulator

Figure 83

45-lb Koelsch Model 122B Manipulator

Figure 84

50-Lb General Mills Model 150 Manipulator

Figure 85

50-Lb General Mills Model 150 Manipulator

SPECIFICATIONS

HAND:	
Open-Close Speed	20 ipm
Force	0-75 pounds
Opening	2½ inches
WRIST:	
Pivot Speed	2 rpm
Pivot Arc	320°
Rotational Torque	30 lb.-in.
Rotational Arc	Continuous
ELBOW:	
Pivot Speed	2 rpm
Pivot Arc	320°
SHOULDER:	
Pivot Speed	2 rpm
Pivot Arc	255°
Rotational Torque	15 lb.-ft.
Rotational Speed	3 rpm
Rotational Arc	Continuous
CAPACITY (in any position)	
	.50 lbs.
POWER SOURCE:	
Voltage	115 volts
Frequency	60 cps
Phase	1
POWER REQUIRED	
	1.0 kva

Travel ranges load capacities and speeds are nominal maximum values. Speeds listed are "no load."

Figure 86

50-Lb General Mills Model 150 Manipulator

Figure 87

65-Lb General Mills Model 300 Manipulator

Figure 88

65-Lb General Mills Model 300 Manipulator

Three steps in speed and power sequence are provided. Travel ranges, load capacities and speeds are nominal maximum values. Speeds listed are "no load."

Figure 89

65-Lb General Mills Model 300 Manipulator

Figure 90

80-Lb Par Model 1000 Manipulator

Figure 91

80-Lb Par Model 1000 Manipulator

MODEL 1000
MANIPULATOR

SCALE = 1 FT.

Figure 92

80-Lb Par Model 1000 Manipulator

MOTION SPECIFICATIONS

Hand (note 1)

PARALLEL JAW GRIP

TRAVEL	4 INCHES
FORCE	200 LBS.
VELOCITY (OPEN-CLOSE).....	20 IN/MIN.

Wrist

ROTATION

TRAVEL (BOTH DIR.).....	CONTINUOUS
TORQUE.....	420 IN. LBS.
VELOCITY.....	7 RPM

EXTENSION (NOTE 2)

TRAVEL (IN-OUT)	4 INCHES
FORCE (PUSH-PULL)	100 LBS.
VELOCITY.....	45 IN/MIN.

Shoulder

PIVOT

TRAVEL.....	220°
TORQUE.....	1920 IN. LBS.
VELOCITY.....	1.5 RPM

ROTATION

TRAVEL (BOTH DIR.).....	CONTINUOUS
TORQUE.....	2200 IN. LBS.
VELOCITY.....	4.5 RPM

Figure 92a

Figure 93

100-Lb General Mills Model 550 Manipulator

Figure 94

100-Lb General Mills Model 550 Manipulator

Figure 95

100-Lb General Mills Model 550 Manipulator

Figure 96

100-Lb General Mills Model 550 Manipulator

Figure 97

160-Lb Par Model 3000 Manipulator

Figure 98

160-Lb Par Model 3000 Manipulator

MODEL 3000
MANIPULATOR

SCALE = 1 FT.

Figure 99

160-Lb Par Model 3000 Manipulator

MOTION SPECIFICATIONS

Hand (note 1)

PARALLEL JAW GRIP

TRAVEL	4 INCHES
FORCE	200 LBS.
VELOCITY (OPEN-CLOSE)	20 IN/MIN.

Wrist

ROTATION

TRAVEL (BOTH DIR.)	CONTINUOUS
TORQUE	420 IN. LBS.
VELOCITY	7 RPM

EXTENSION (NOTE 2)

TRAVEL (IN-OUT)	4 INCHES
FORCE (PUSH-PULL)	100 LBS.
VELOCITY	45 IN/MIN.

PIVOT

TRAVEL	310°
TORQUE	1920 IN. LBS.
VELOCITY	2.5 RPM

Elbow

PIVOT

TRAVEL	270°
TORQUE	1920 IN. LBS.
VELOCITY	2.5 RPM

Shoulder

PIVOT

TRAVEL	250°
TORQUE	1920 IN. LBS.
VELOCITY	1.5 RPM

ROTATION

TRAVEL (BOTH DIR.)	CONTINUOUS
TORQUE	2200 IN. LBS.
VELOCITY	4.5 RPM

Figure 99a

Figure 100

400-Lb Par Model 6000 Manipulator

Figure 101

400-Lb Par Model 6000 Manipulator

Figure 102

400-Lb Par Model 6000 Manipulator

Figure 103

500-Lb General Mills Model 700 Manipulator

KEY	COMPONENT	MOVEMENT RATE	REMARKS
A	Bridge	100 ft/min	12 ft long
B	Trolley	50 ft/min	8 ft wide
C	Arm	25 ft/min	Telescope to 23 ft 4 in.
D	Arm	0.56 rpm	Azimuth 720 degrees
E	Arm	0.75 rpm	Elevation from -90 to +60 degrees
F	Arm extension	1-1/2 in./sec	Telescopes 24 in. maximum
G	Arm	1 rpm	Rotates 300 degrees
H	Wrist		Bends 90 degrees
I	Wrist		Torque 300 ft-lb
J	Hand	20 rpm	No limit to rotation

Figure 104

500-Lb General Mills Model 700 Manipulator

Figure 105

500-Lb General Mills Model 700 Manipulator

Figure 106

G.E. Servo Manipulator

Figure 107

G.E. Shielded Locomotive

Figure 108

G.E. Shielded Locomotive

Figure 109

Overall Dimensions of Beetle

Figure 110

Beetle Manipulator Motions

Figure 111

Beetle Manipulator Hand

Figure 112

Beetle Manipulator Hand

Figure 113

Beetle

Figure 114

Hughes MARK II Mobot

MARK II ARM UNIT— SPECIFICATIONS AND CHARACTERISTICS

LOAD CAPACITY	25 lb. in any position	WRIST	
**FINGER PAD PRESSURE	pressurized finger pads adjustable from 0-15 lbs./sq. in.; finger area 5¼ sq. in.; maximum force with full finger area engaged—80 lbs.	Torque	500 in. lb.
		Speed	2 RPM (max.)
		Coverage	hemispherical
FINGER CLOSE SPEED	⅓ in/sec	ELBOW	
HAND ROTATE		Torque	1500 in. lb.
Stall Torque	400 in. lb.	Speed	¾ RPM (max.)
No Load Speed	10 RPM (max.)	Coverage	hemispherical
Rotation	continuous	SHOULDER	
HAND TELESCOPE		Torque	3000 in. lb.
Stall Thrust	450 lb.	Speed	⅓ RPM (max.)
No Load Speed	½ in/sec (max.)	Coverage	hemispherical
Stroke	3½ in.	ARM CLEARANCE	6½ in. dia. hole

Figure 115

Hughes MARK II Mobot

Figure 116

General Mills Little Ranger

Figure 117

General Mills Little Ranger

SPECIFICATIONS

Vehicle Height (Retracted)	45"	Winch Capacity (Optional)	500 pounds
Vehicle Width	24"	Vehicle Speed—Maximum	100 fpm
Vehicle Length	30"	Operational	58 fpm
Vertical Reach	96"	Minimum	8 fpm
Horizontal Reach	41 5" R	Ground Pressure (average)	5 psi
Manipulator Capacity	50 pounds	System Gross Weight	900 pounds
Hoist Capacity (Optional)	100 pounds		

Figure 117a

Specifications for General Mills "Little Ranger"

Figure 118

Lee Mobile Manipulator

Figure 119

Koelsch Mobile Manipulator

Figure 120

Koelsch Mobile Manipulator

Figure 121

Cold-Duct Sling

Figure 122

Tank-Assembly Sling

Figure 123

Upper Auxiliary-Shield Sling

Figure 124

Combustor-Shield Sling

Figure 125

Core and Plug Alignment Fixture Sling

Figure 126

Cage-Transition Sling

Figure 127

Rear-Tube-Sheet Sling

Figure 128

Front-Tube-Sheet Sling

Figure 129

Actuator Storage Tray Sling

Figure 130

Turbine-Scroll Sling

Figure 131

Turbojet-Scroll Sling

Figure 132

Turbojet Sling

Figure 133

Turbine-Cone Sling

Figure 134

Engine Lifting Fixture

Figure 135

Engine Lifting Sling

Figure 136

Turbine-Wheel Sling

Figure 137

Nozzle-Diaphragm Lifting Fixture

Figure 138

Cold-Duct Stand

Figure 139

Hot-Duct Stand

Figure 140

Combustor Stand

Figure 141

Combustor Sling and Stand

Figure 142

Erection Stand

Figure 143

Reactor-Handling Stackup

Figure 144

Reactor Sling Stand

Figure 145

General-Purpose Rigid Sling Assembly Stand

Figure 146

Decontamination Stand

Figure 147

Top-Cocoon Adapter

Figure 148

Rod and Cask Adapter (Tool)

Dimensions in inches

Weight: 19,000 lb

Load: Inner rings ~ 40,000 lb

4 legs ~ 80,000 lb

Materials: 10-in. schedule 150 and schedule 80 pipe

Low-carbon plate

ASTM-A7-55T

Figure 149

Alignment Fixture

Dimensions in inches

Weight: 4350 lb
 Load: None (Center core removal fixture
 on plug only)
 Materials: ASTM A7-55T low-carbon steel

Note

Ring continuous but cut to illustrate construction

Figure 150

Centering Fixture

Figure 151

Centering Fixture

Figure 152

Reactor Refueling Machine

Figure 153

Reactor Disassembly Machine

Figure 154

Cartridge Handling Tool

Figure 155

Cartridge Handling Tool

Figure 156

Cartridge Storage Rack

Figure 157

Cartridge Storage Rack

Figure 158

Activator Storage Tray

Figure 159

Control-Rod Tong

Figure 160

Transport Rod Removal Tool

Figure 161

Rod Pool Basket

Figure 162

Rod Cask Basket

Figure 163

Turbojet Upending Fixture

Figure 164

Pilot Positioning Fixture

Figure 165

Personnel Shield

Figure 166

Core Removal Fixture

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Power Plant Disassembly Machine

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Upending Machine

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Engine Disassembly Fixture

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Electric Straight-Impact Wrench

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Flat-Angle-Impact Wrench

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Controlled-Torque, Right-Angle-Assembly Wrench

Figure 173

Bolt Handling Tool

Figure 174

Bolt Handling Tool

Figure 175

Nut Handling Tool

Figure 176

Nut Handling Tool

Figure 177

Bolt-Retaining-Ring Remover

Figure 178

Bolt-Retaining-Ring Remover

Figure 179

Nut With Broken Bolt Remover

Figure 180

Nut With Broken Bolt Remover

Figure 181

Abrasive Cut Off Tool

Figure 182

Shearing Tool

Figure 183

Tool Stand

E-MAD REMOTE HANDLING SYSTEM

Figure 184

E-MAD REMOTE HANDLING SYSTEM

Figure 185

E-MAD REMOTE HANDLING SYSTEM

Figure 186

Figure 187

Wall-Mounted Manipulators

To Be Supplied

Figure 188

Wall-Mounted Manipulators

Figure 189
Mobile Carriage

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Reactor Core Stand

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Hot Engine Hold and Check-out Stand

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Remote Handling Dolly

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Nozzle Stand

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Pressure Vessel Stand

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Sub-System High Position Support Stand

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Portable Turntable

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Control Rod Stand

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Control Rod Drive Mechanism
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Turbo Pump Stand

Figure 200

Roll Nozzle Stand

Figure 201

Pneumatic Tank Stand

Figure 202

Reflector Segment Stand

Figure 203

Gimbal Actuator Stand

TOP SHIELD STAND

Figure 204

Figure 205

Lower Thrust Structure Stand

Figure 206

Pressure Vessel Head Stand

Figure 207

Shut Off Valve Stand

Figure 208

Engine Test Adapter Stand

Figure 209

Upper Thrust Structure Stand

Figure 210

Duct and Wiring Harness Rack

Figure 211

Handling Yoke

Figure 212

Typical Positioning Head Stands

To Be Supplied

Figure 213

Position Head Stand

To Be Supplied

Figure 214

Position Head Stand

To Be Supplied

Figure 215

Position Head Stand

To Be Supplied

Figure 216

Position Head Stand

Figure 217

Figure 218

LOCOMOTIVE

Figure 220

Prime Mover System - Locomotive

Figure 221

Prime Mover System - Manned Control Car

Figure 222

Remotely Controlled Mobile Crane

Figure 224

Remotely Controlled Bulldozer

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