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MECHANICAL IMPROVEMENTS OF THE EBR-II FUEL UNLOADING MACHINE

by
James B. Waldo

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Printed in the United States of America

Available from

Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U. S. Department of Commerce
Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.65

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EBR-II Project

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November 1969

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MECHANICAL IMPROVEMENTS OF THE EBR-II FUEL UNLOADING MACHINE

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ABSTRACT

The EBR-II fuel unloading machine (FUM) transfers all reactor subassemblies between the sodium-filled primary tank and the interbuilding coffin. The machine is basically a self-propelled shield cask, which moves on rails between the primary-tank transfer port and the interbuilding-coffin pit. The FUM control panel and most of the mechanical equipment are located at the top of the shield cask. A subassembly gripper mechanism in the machine can be extended downward, through the shielding, into the primary-tank transfer port or into the interbuilding coffin to insert or remove a reactor subassembly. An automatic argon-circulating system provides subassembly cooling or heating and sodium blow-off capabilities while the subassembly is being handled by the FUM.

This report describes the mechanical changes and improvements made to the FUM since the publication of the original design report. These changes have evolved from continuous surveillance and engineering evaluation of the problems that have occurred with the machine during normal fuel handling.

EBR-II was originally intended as an engineering facility to determine the feasibility of the sodium-cooled fast breeder reactor for central-station, power-plant application. Recently the operating philosophy has changed, and EBR-II is now used primarily as a fast-flux irradiation facility. This change has greatly increased the operating requirements of all EBR-II fuel-handling equipment, including those of the FUM. The availability and reliability of the FUM were greatly enhanced by the modifications described in this report.

I. DESCRIPTION OF EBR-II FACILITY

The Experimental Breeder Reactor-II (EBR-II) is an unmoderated, sodium-cooled reactor with a design power level of 62.5 MW and an August 1969 operating level of 50 MWt. Through a conventional steam cycle, the reactor produces 14.7 MW of electricity at the 50-MWt power level. The main facilities are the reactor plant, the sodium boiler plant, the power plant, and the Fuel Cycle Facility (FCF). The reactor, the

primary-sodium-coolant system, and several auxiliary systems are housed in the reactor plant (shown in Fig. 1), which is a steel containment vessel, 80 ft in diameter and 140 ft high. The sodium boiler plant contains most of the secondary-sodium system, including the ac electromagnetic pump and the sodium-to-water steam generator. The power plant contains the turbine-generator unit, the conventional steam system, and the reactor control room.¹

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Fig. 1. EBR-II Reactor Plant

Through 1968, spent reactor fuel was reprocessed in the adjacent FCF by a melt-refining method and refabricated into new subassemblies for return to the reactor. Following this successful demonstration of a completely remote production line, the FCF was converted to an examination facility for irradiated specimens. It also serves for handling and shipment of spent fuel from EBR-II. Fresh fuel is now made from nonirradiated material in on-site and vendor facilities and is transferred between the FCF and reactor by the fuel unloading machine (FUM).

This report deals with modifications of the FUM gripper, the elevation-drive and jaw-actuator systems, the gripper-position-indicating system, and the rotary shielding valve. The original design features and subsequent modifications of these systems are discussed in detail. FUM systems and parts that were not appreciably modified are described in detail in the original FUM design report.²

II. DESCRIPTION OF REACTOR AND FUEL-HANDLING SYSTEM

A. Reactor

The reactor and the entire primary-sodium-coolant system (shown in Fig. 1) are submerged in the primary tank, which is approximately 26 ft in diameter and 27 ft high and contains 90,000 gal of sodium. The primary sodium coolant is pumped directly through the reactor from this sodium pool by two 5000-gpm centrifugal pumps. Sodium flows upward through the core and exits into the reactor outlet pipe, which connects directly to the shell side of the intermediate heat exchanger (also submerged in the pool). The reactor heat is transferred to the secondary-sodium system in the heat exchanger, and the primary sodium returns to the pool. The secondary-sodium lines to the intermediate heat exchanger are the only parts of the secondary system located within the reactor plant.²

The reactor assembly (shown in Fig. 2) consists of the reactor vessel, the inlet-plenum and grid assembly, and the vessel cover. A neutron shield surrounds the reactor, and both the reactor and the shield rest on the floor of the primary tank. The vessel cover is submerged under approximately 10 ft of sodium.

The inlet-plenum and grid assembly forms the support for the reactor subassemblies and also orifices the proper coolant flow to the different core and blanket regions. The grid (shown in Fig. 3) accommodates 637 hexagonal subassemblies spaced on a triangular pitch of 2.320 in. The August 1969 nominal reactor loading consisted of 57 enriched-uranium core and inner-blanket subassemblies, 2 safety subassemblies, 12 control-rod subassemblies, 20 fuel and structural experimental subassemblies, and 546 stainless steel and natural-uranium blanket subassemblies. Each subassembly (as shown in Fig. 4) is approximately 8 ft long, weighs about 140 lb, and, regardless of type, has a common handling fixture called the "upper adapter" attached to the top of the subassembly hexagonal can.

B. Fuel-handling System

The fuel storage basket and the fuel transfer arm (shown in Figs. 5 and 6) are also located in the primary tank, adjacent to the reactor and below the sodium level. The storage basket has a capacity for 75 subassemblies, rotates 360°, and moves vertically approximately 9 ft during

112-496 Rev. 1

Fig. 2. Reactor Assembly

112-4467 Rev. 1

Fig. 3. Reactor Arrangement

111-5157

Fig. 4. Core Subassembly

112-1998 Rev. 3

Fig. 5. Fuel-handling Mechanisms in Primary Tank

112-4625 Rev. 2

Fig. 6. Fuel-handling System

a subassembly loading or unloading operation. The transfer arm swings in an arc of about 180° . Along this arc are the core gripper, the storage basket, and the fuel transfer port. The fuel transfer arm can insert or remove a subassembly from any storage-basket position. Manual rotation of the transfer arm to one position (transfer) allows the subassembly to be taken by the core fuel-handling gripper; rotation to another position (under the transfer port) allows the subassembly to be taken by the gripper of the FUM. This latter action requires the FUM to be positioned over the transfer port; the gripper is then lowered through the FUM shielding and the transfer-port penetration to remove the subassembly from the transfer arm.³

The core fuel-handling gripper is used to transfer subassemblies between the reactor grid and the transfer arm. The core gripper and its associated holddown mechanism are mounted off-center on the small rotating plug (shown in Fig. 5), which is eccentrically located in the large rotating plug. These features, coupled with the rotational capability of the core gripper, allow the gripper and holddown to be positioned over any reactor grid location. The holddown mechanism restrains and spreads the subassemblies surrounding the one to be removed or inserted. The core gripper can then be raised sufficiently to allow transfer-arm engagement at the fuel transfer point (as shown in Fig. 7). The transfer point is a discrete combination of plug and gripper rotation that allows the transfer arm to engage the subassembly held by the core gripper.

113-1857

Fig. 7. Plan View of Fuel-handling Mechanisms

III. FUEL-HANDLING PROCEDURE

EBR-II fuel handling is normally performed in one of two modes. The first, called "unrestricted" fuel handling, begins immediately after reactor shutdown and includes all transfer steps between the reactor core and the storage basket. These steps are performed entirely below the sodium surface, thereby eliminating any special cooling requirements for high-burnup fuel subassemblies. A typical reactor refueling after a 1200-MWd run might require the replacement of 20 driver-fuel subassemblies and the movement or replacement of three to eight experimental or surveillance subassemblies. A complete transfer of a subassembly from core to basket and of its replacement from basket to core takes about 45 min. In certain cases, unrestricted fuel handling also includes the transfer of special subassemblies (i.e., control or safety-rod guide thimbles, oscillator rods, or special handling tools) directly between the FUM and the reactor core without an intermediate stop at the storage basket.

After the reactor has returned to power, the "restricted" mode of fuel handling is used to unload the spent subassemblies from the storage basket for transfer to the FCF. Concurrently, the storage basket is reloaded with new fuel subassemblies and experiments. Nominally a 15-day cooling period in the storage basket is used for spent driver-fuel subassemblies to allow the decay-heat generation rate to decline to a level at which the subassembly can be conveniently and safely gas-cooled. In the restricted fuel-handling mode, subassemblies are transferred from the storage basket to the fuel transfer arm, to the FUM, and then to the shielded interbuilding coffin (IBC), which carries the subassembly into the FCF. This procedure is reversed for loading fresh subassemblies into the storage basket. The usual restricted fuel-handling schedule during reactor operation consists of one round-trip transfer each day. A round trip is defined as transferring a new subassembly from the FCF to the storage basket and then removing a spent subassembly for return to the FCF. A single transfer into the storage basket normally requires approximately 3 hr; a single transfer out of the storage basket requires approximately 2 hr. A complete round-trip transfer can take as little as $3\frac{1}{2}$ hr if schedules allow the transfers to be done in the optimum sequence.

IV. DESIGN OF FUEL UNLOADING MACHINE (FUM)

Table I lists the design criteria initially established for the FUM; these requirements have been satisfied in actual operation over a period of years that have involved well over a thousand subassembly transfers.

The FUM (a cutaway view of which is shown in Fig. 8) consists of a 14-ft-high shielding cask, which rests on a self-propelled carriage. The carriage moves on rails between positions directly above the primary-tank

TABLE I. Initial Design Criteria for the FUM

-
1. The FUM shall incorporate a device called a gripper to grasp or release one fuel subassembly at a time.
  2. The gripper shall move vertically over a distance of 27 ft and shall operate in molten sodium at up to 700°F or in dry argon gas at 210-700°F.
  3. The gripper shall incorporate a sensing device, which will positively indicate the presence or absence of a fuel-subassembly, upper-adapter head between the gripper jaws.
  4. The gripper shall incorporate a feature enabling argon gas to be blown through the fuel subassembly.
  5. The gripper shall be remotely controlled and prevented from releasing a fuel subassembly accidentally at the wrong elevation or in the wrong sequence.
  6. The gripper-jaw drive and vertical drive shall incorporate power-limiting devices.
  7. Automatic controls shall stop the gripper at predetermined elevations.
  8. Lead shielding shall be provided around the fuel-subassembly location in the shielding cask and around all piping containing radioactive gas and particles.
  9. The argon-gas system of the FUM shall be leaktight to allow circulation of argon with less than 40 ppm of oxygen through the fuel subassembly.
  10. The bottom of the shielding cask shall incorporate a gastight shielding valve.
  11. A fail-safe gas seal shall be established between the shielding-cask bottom and the top of the transfer port or the top of the IBC.
  12. An argon purge shall be provided for the space created by the gas seal.
  13. A movable lead shield shall surround the gas seal.
  14. Gastight seals shall be provided for the shafts of the gripper drive atop the shielding cask where they penetrate the walls.
  15. All components of the FUM within the circulating argon flow shall be capable of operation in temperatures up to 450°F.
  16. The argon system shall incorporate sodium-vapor traps and fission-product filters.
  17. The carriage for the shielding cask shall be self-propelled.
  18. The shielding cask shall incorporate self-aligning fixtures for alignment with the transfer port and the IBC.
  19. In case of a power failure, the FUM shall be operated by the standby diesel power supply.
  20. An emergency power supply shall be available to operate the cooling section of the argon system.
  21. In case of a standby power failure, the FUM shall be operated manually.
-

113-1867

Fig. 8. Cutaway View of FUM

fuel transfer port (FTP) and the pit for the IBC. The shielding cask supports a subassembly gripper and its elevation-drive assembly. The gripper can be lowered by the drive system through a hexagonal-shaped vertical storage tube in the shielding cask and past the rotary shielding valve located in the bottom of the cask.

When the FUM is positioned over the IBC or the FTP, a gap of $1/8$ in. exists between the bottom of the cask and the unit below. During a subassembly transfer, this gap is sealed by a movable ring seal mounted on the bottom of the FUM cask (as shown in Fig. 9). For radiation shielding of this gap, a doughnut-shaped shield ring is also lowered around the top of the mating flange on the IBC or the FTP (as shown in Fig. 10).

The rotary shielding valve, located in the base of the cask (shown in Fig. 9), consists of a lead-filled, 7-in. wide, 13.5-in.-diam cylindrical plug. A 3.5-in.-diam hole, lined with a hexagonal can, is located in the valve (perpendicular to the cylindrical axis) to allow access into or out of the cask when the hole is turned to the vertical position. A 90° manual rotation of the valve seals the cask. A gap of 0.010 in. between the valve cylinder and the housing is sealed by four special $1/4$ -in.-diam O-rings. Each O-ring is fabricated with a $1/16$ -in. wire in the center that keeps the O-rings in the saddle-shaped circular grooves cut into the cylindrical periphery of the shielding cylinder. When the valve is closed, a removable "drip cup" faces upward into the hexagonal storage tube in the shield cask. Sodium droplets from the FUM gripper and the subassemblies collect in this drip cup instead of filling the 0.010-in. gap around the valve cylinder. An inwardly tilted series of baffles prevents gross sodium spilling when the valve is rotated to the open position. This drip cup is removed periodically for cleaning.

V. MECHANICAL IMPROVEMENTS OF THE FUM

A. FUM Gripper System

The FUM gripper must satisfy the first five requirements of the design criteria listed in Table I, with maximum reliability and minimum maintenance. The gripper must operate in a severe environment, being immersed alternately in 700°F molten sodium and in circulating argon gas at temperatures from ambient to 650°F and with oxygen contamination up to 40 ppm; the gripper is also exposed to trace amounts of moisture during IBC transfers. These conditions cause a granular coating of sodium oxide to be deposited on all internal and external surfaces of the gripper mechanism (shown in Fig. 11).

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Fig. 9. Shielding Valve and Bottom Ring Seal

113-1858

Fig. 10. Shield Ring

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Fig. 11. Appearance of Mark-III Prototype Gripper after 80 Transfers without Cleaning

Four gripper units have been designed for the FUM. The Mark-I and -II units were supplied initially with the machine. The prototype Mark III was designed as a replacement for the Mark-I and -II units and is the basis for the final Mark-III gripper. All three of these grippers have the following four basic components:

1. Gripper core or body.
2. Gripper outer shell or jaw actuator.
3. Gripper sensing rod.
4. Spring-loaded gas-cooling shell.

The Mark-I and -II grippers were similar in design, and both units shared a common problem: sticking of the gripper jaws and mechanical interlock. The Mark-I and -II grippers were interchanged, and several minor changes were made to try to achieve satisfactory operation. Late in 1966 it became evident that several basic design problems in the Mark-I and -II units could not be corrected by minor modifications. On the basis of the great amount of operating experience already accumulated with the FUM and the difficulties exhibited by the Mark-I and -II units, an entirely new gripper concept, designated the prototype Mark III, was designed and fabricated. This prototype gripper was installed in the FUM in May 1967. Initial testing showed that the gripper and a new, manual jaw-actuator system worked very well. Since the only real proof test of the unit was in actual fuel handling, the new gripper system was installed in the FUM, and a detailed, comprehensive surveillance of all FUM operations was initiated. Sufficient experience was accumulated with the prototype during the next two years to complete the design of the final Mark-III gripper. The Mark III should be installed before the end of 1969.

1. Gripper Elevation Drive and Jaw-actuating System

In not only the Mark-I and -II, but also in the Mark-III design, the gripper moves vertically and opens or closes by means of a push-pull chain system (shown in Fig. 12). This system consists of two identical chains, which can be wrapped in one direction only. When these chains are placed back to back, they form a rigid bar-like structure with which they

113-1864

113-1861 Rev. 1

Fig. 12. Gripper Elevation Drive, Push-Pull Chain System

can exert push or pull forces together or separately. The rigidity and orientation of the chain assembly are independent of extended length as long as a guide or restraint is applied at both ends. In this case, the lower restraint is the connection of the chains to the gripper, and the upper guide is a guide-roller assembly (as shown in Fig. 13).

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Fig. 13. Cutaway View of Gripper Drive

The gripper chains are driven by two identical drive sprockets (shown in Fig. 13), which rotate in opposite directions. These sprockets are geared to an electrohydraulic power unit (shown in Fig. 14), which is part of the gripper-elevation-drive system. One sprocket is geared directly to the output of the main transmission shaft and is used to drive the gripper assembly up or down.

The other sprocket, used for operating the gripper jaws, is connected to the main transmission shaft through a differential gear system.

113-1866 Rev. 1

Fig. 14. Plan View of Gripper Elevation Drive

This system is composed of spur gears, two bevel gears, and (in the original design) one pinion gear. The spur gears transmit the torque from the main transmission shaft to the differential shaft in a 1:1 ratio. One differential bevel gear is fastened to the differential shaft. The other bevel gear is fastened to the shaft that drives the gripper-jaw drive sprocket. The differential pinion is mounted on an arm that can be rotated about the differential centerline. The differential pinion transmits the torque between the bevel gears in a 1:1 ratio when the arm is stationary; this causes the two chains to move together as the elevation drive moves the gripper up or down.

To operate the gripper jaws, the main transmission shaft is stopped; this action automatically immobilizes the bevel gear on the input side of the differential. The differential pinion arm is then rotated, and the planetary movement of the pinion produces rotation of the other bevel gear to operate the jaw-actuator drive sprocket. This rotation moves the jaw-actuator chain the proper amount in relation to the gripper-support chain to operate the gripper jaws.

Sensing-rod position was (and still is) transmitted by means of a sensing chain (shown in Figs. 15 and 16). This chain is kept in tension by a spring-driven takeup drum in the top of the FUM. The chain passes over an idler sprocket, which meters the vertical movement of the chain and relays the information to the control panel atop the FUM

2. Mark-I and -II Gripper Designs

The Mark-I and -II grippers were similar in design and identical in operation. Both consisted of the following major components: the outer shell, the core, the sensing device, and the gas-cooling shell (shown in Figs. 16 and 17).

The basic defects common in both grippers could be summarized as follows: (a) insufficient jaw-actuator travel; (b) complex mechanical-interlock design; (c) external jaw-actuator tube; and (d) design of the gripper jaws and support structure. Each of these defects is fully described below to show how slight amounts of sodium oxide buildup could make the grippers inoperative and how a new design was needed that would function in spite of this oxide buildup.

a. Insufficient Jaw-actuator Travel. The outer shell was a 5-ft-long tubular member, which surrounded most of the other gripper components, and whose main purpose was to act as the gripper-jaw actuating device. Spacers and guides maintained a concentric annulus between the outer shell and the gripper core. The lower end of the outer shell surrounded the three gripper jaws closely and pivoted them on 3/8-in.-diam Stellite balls when the outer shell was moved with respect to the core. An outer-shell movement of $1\frac{1}{2}$ in. pivoted the jaws about 5° . This $1\frac{1}{2}$ -in. stroke

113-1859 Rev. 1

Fig. 15. Mark-I and -II Mechanical Interlock Mechanism

113-1865 Rev. 1

Fig. 16. Photograph and Cutaway View of Mark-I Gripper Mechanism

113-1863 Rev. 1

Fig. 17. Cutaway View of Mark-II Gripper Mechanism

was divided into three equal zones: approach, action, and departure. Movement in the center $1/2$ in. of travel (action zone) caused the jaws to open or close. The travel at each end of the stroke was designed as an overtravel zone to maintain jaw position, even if a slight shift should occur between the core and the outer shell. This short jaw-actuator travel was one of the basic design problems that existed in both the Mark-I and -II units, as is explained below.

As the gripper was lowered during operation, the lengths of the drive chains between the sprockets and the gripper ranged from 10 to 27 ft. When the elevation drive was stopped and the gripper jaws were operated, both chains remained in tension because of gripper weight and possibly subassembly weight--but only if the jaw actuator operated freely in the gripper. If the jaw actuator bound in the opening direction, the jaw-actuator chain tension increased, but the gripper-support chain went from a tension to a compression condition. If this occurred when the chains were extended to 27 ft, the combination of increased tension on one chain and compression on the other could result in a relative (observed) jaw-indicator motion of $3/4$ in., with no motion in the gripper itself. This possible slack in the chain system was caused by buildup of clearances in the many pins, rollers, and links.

This slack in the chains caused a serious problem in the Mark-I and -II designs with their jaw-actuator travel of only $1\frac{1}{2}$ in. It was possible to operate the differential pinion the proper amount for total jaw movement and to get only $3/4$ in. or less of jaw-actuator movement in the gripper, and this might not move the jaws at all. Since the jaw-position indicator operated from the chain-drive sprockets, the operator could not tell positively whether the jaws had operated. This problem occurred often with both the Mark-I and -II grippers; several times, subassemblies were temporarily "lost" in either the FUM or the IBC.

b. Complex Mechanical-interlock Design. The sticking tendencies of the jaw actuator in the Mark-I and -II grippers were often caused, or at least aggravated, by improper operation of the gripper's mechanical-interlock mechanism (shown in Fig. 15). The mechanical-interlock was installed in the gripper to satisfy Item 5 of the FUM design criteria, which states: "the gripper shall be remotely controlled and prevented from releasing a fuel subassembly accidentally at the wrong elevation or in the wrong sequence." The interlock was designed so that the gripper jaws were operable only when a subassembly sensing rod was fully down or fully up. When the sensing rod was down, the gripper was empty, and the jaws could be safely operated for testing purposes without danger of dropping a subassembly. When the gripper jaws were supporting a subassembly, the sensing rod was in a midtravel area, called the CARRY position. In this position, the mechanical interlock prevented accidental opening of the jaws. To operate the jaws, the sensing rod had to be raised to the full UP position

in the gripper. This could be done only if the subassembly was supported by something other than the gripper jaws--for example, by the IBC or the transfer arm. This ensured that the subassembly could be released only at the proper time and sequence.

The mechanical interlock (shown in Fig. 15) consisted of a $3/8$ -in.-diam Stellite ball, a ball housing, and four ball seats or recesses. The ball housing was formed by a $3/8$ -in.-diam hole through the $1/4$ -in.-thick wall of the upper end of the gripper core. This housing left $1/8$ in. of the ball diameter uncovered. This $1/8$ in. could protrude either away from or toward the axis of the gripper. If the protrusion was away from the axis, the ball protruded into one of two ball seats on a steel block attached to the outer shell (jaw actuator), locking the gripper jaws in the closed or open position. If the protrusion was toward the axis, the ball protruded into one of two ball seats on the sensing rod and freed the jaw actuator for operation.

When the gripper was lowered onto a subassembly, the sensing rod was raised 1 to $1\frac{3}{8}$ in. by contact with the upper adapter of the subassembly. This brought the lower seat on the sensing rod into alignment with the ball and freed the gripper jaws for operation.

After the gripper jaws were closed around the top adapter, the gripper had to be lifted $1/2$ in. before the support surfaces actually started to lift the subassembly. During this $1/2$ in. of travel, the tension in the sensing chain acted through a reversing loop (shown in Fig. 15) to force the sensing rod to follow the subassembly. The downward movement of the sensing rod with respect to the gripper core put the sensing rod in its "carry" position and forced the Stellite ball to be seated toward the outer shell and the gripper jaws. The locked condition remained as long as the subassembly was supported by the jaws.

To release a subassembly, the gripper was lowered until the subassembly was supported by the transfer arm or the IBC. An extra $1/2$ in. of downward gripper travel then cleared the ball interlock and allowed the jaws to be opened.

Operation of the gripper jaws depended on the free operation of all the parts related to the ball-interlock system, including the jaw actuator itself. If the actuator dragged because of sodium oxide during an opening or closing operation, the ball seats in the outer shell might not align with the ball housing because of slack in the chain system, even though the jaw-position indicator showed that the jaws were fully open or closed. If the ball seat was not properly aligned, the ball interlock would then prevent normal sensing-rod operation, and all gripper components would jam until no part of the gripper could be operated. The problem occurred most frequently during attempts to release a used subassembly in the IBC. The jaw

actuator would jam and thereby lock the sensing rod; this locking prevented the subassembly from being released. The FUM would then have to be returned to the transfer port, and the subassembly would have to be lowered onto the transfer arm in the primary tank. Usually the jaws could be opened after the gripper was allowed to soak for several minutes in the 700°F bulk sodium. The gripper would then have to be removed from the FUM and cleaned before the subassembly transfer could be completed.

c. External Jaw-actuator Tube. Two more problems with the Mark-I and -II designs were caused by using the entire outer shell of the gripper as the jaw actuator (shown in Figs. 16 and 17). To start jaw movement, the jaw actuator had to slide around or inside many other stationary parts, such as the gripper core, the internal liner of the transfer port or IBC, and the spring-loaded gripper cooling shell. The most severe of these was the movement of the jaw actuator inside the gripper cooling shell. At both the transfer port and the IBC, the cooling shell was restricted in movement by the surrounding members; therefore, the jaw actuator had to move inside the cooling shell as well as inside the hexagonal tube around the upper part of the gripper. In the jaw-closing direction, the actuator also had to compress the cooling-shell spring to close the jaws. The inherent design of the jaw-actuating differential in the elevation drive system limited the mechanical advantage available for moving the jaw actuator. Any small friction load or the spring load had a great effect on operation if the gripper was already binding.

The second problem with having the outer shell act as the jaw actuator occurred whenever the gripper hit an obstruction (sodium oxide, or a valve corner) while running up or down. Since the jaw actuator was also the exterior of the gripper, any binding or jamming of the outer shell, while changing elevation, would open or close the gripper jaws. Actual jaw operation was supposed to be prevented by the ball-interlock mechanism, but the impact loads that usually were applied before the gripper elevation drive stopped were sufficient to damage or jam the interlock mechanism. If the shock of the gripper hitting an obstruction of sodium oxide was severe, the ball interlock would deflect far enough to allow impact loading of the comparatively weak differential gears in the jaw-actuator drive atop the FUM. Many times the load was severe enough to shear the teeth off the differential side gears or pinion gear or both. When this occurred, further movement or release of a subassembly was impossible, and the unit would have to be repaired in place immediately if subassembly gas cooling was required. This repair operation required at least 4 hr and could be done only by selected people who were not normally available on the back shifts.

d. Design of the Gripper Jaws and Support Structure. The final problem with the Mark-I and -II designs concerned the design of the gripper jaws and the structure that supported them. Figures 16 and 17 show cutaway views of the gripper jaws and the gripper core. In both designs, the jaw ends

had to move into recesses cut into the gripper core. The jaws essentially filled these recesses when they were at the end of their rotational travel. If a piece of sodium oxide was carried into one of these recesses, the jaws had to crush this piece of obstruction to attain full jaw travel. Because of the very low mechanical advantage and the high friction usually encountered with sodium oxide-covered parts, a very small obstruction could prevent jaw operation, even if great forces could be applied. Attempts were made to alleviate these problems in both grippers by modifying the opening and closing cams and the gripper jaws, and finally by cutting larger recesses around the jaw extremities. Some of these changes seemed to help slightly, but none of them brought about the operating dependability that was needed.

As fuel-loading requirements increased, the operation of the FUM system could not be predicted reliably. Often only two or three transfers could be completed before the gripper would stop operating at the IBC. The entire FUM would then have to be cooled down to room temperature to permit removal and steam cleaning of the radioactive-sodium-covered gripper. The entire cycle of FUM cooldown, gripper removal, cleaning, inspection, and reinstallation required at least 8 hr. The FUM would then have to be purged and reheated after reinstallation; this procedure required several more hours. Occasionally the gripper could not be released from the subassembly. When this happened, the gripper and subassembly had to be removed as a unit. Fortunately, this problem never occurred with a highly irradiated subassembly; this problem would have made the removal very complicated and time-consuming. As the effect of the FUM problems on reactor-loading and FCF-production schedules became quite severe, the maintenance effort required to keep the machine in operation increased. The Mark-III gripper design was initiated to solve these chronic problems.

3. Mark-III Gripper Design

Two new grippers, designated the prototype Mark III and the Mark III, were designed for the FUM. In May 1967, the prototype Mark III was installed in the FUM as a test. The final Mark-III unit will replace the prototype. Both units are identical in all operating respects, and are interchangeable in the FUM without changes to the machine. Both units are also identical in design principle; only minor differences are seen in assembly or disassembly.

The design objectives for the Mark-III grippers included the first five requirements of the FUM design criteria, listed in Table I. Added to these original design criteria were eight new objectives, based on the operating experience gained with the Mark-I and -II grippers. Table II lists these improvements.

TABLE II. Improvements of Original Design Criteria for the FUM

1. Jaw-actuator travel should be increased sufficiently to provide positive verification of jaw position with $3/4$ in. of possible error or slack in the jaw actuator and chain system.
2. The ball mechanical interlock should be eliminated in favor of a different interlock mechanism that operates directly on the gripper jaws.
3. The reverse-motion feature in the sensing chain and sensing-rod system should be eliminated.
4. Operation of the sensing rod should be made independent of jaw-actuator position.
5. The external jaw-actuator tube (outer shell) should be eliminated so that all exposed surfaces are part of the gripper body that supports the gripper jaws. This would require a completely internal jaw-actuator tube and would remove all elevating loads from the jaw-actuator drive chain.
6. To obtain full jaw travel, the gripper jaws and jaw actuator should be self-cleaning with no engagement of parallel surfaces.
7. All internal adjustments to the gripper should be eliminated.
8. Disassembly, assembly, and cleaning should be simplified.

a. Prototype Mark-III Gripper. Figure 18 shows the prototype Mark-III gripper components (without the subassembly cooling shell and spring). The upper tube in the figure is the gripper body that supports all the component parts. The center tube is the jaw actuator that operates inside the gripper body. The lower shaft is the sensing rod and mechanical-interlock mechanism that operates inside the jaw-actuator tube. The small parts at the bottom of the photo are, from left to right: the gripper jaws, the gripper-body upper end cap, the gripper-jaw pivot pin, and four screws for attaching the upper end cap. Also included in the assembly, but not in the photo, is the subassembly guide cap that is welded into the lower end of the gripper body.

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Fig. 18. Prototype Mark-III Gripper (Disassembled)

(1) Gripper Body. The gripper body consists of a tube of Type 304 stainless steel with a 2.5-in. OD and a 0.120-in. wall thickness. Slots are milled at intervals along its length for argon-gas flow. Fastened to the upper end of the gripper body is a larger-diameter tube that accepts an Inconel cap. This upper end cap has an attachment point for the gripper elevating chain, and slots to position and guide the upper ends of the jaw-actuator tube and the sensing-rod extension.

Six slots are milled at 60° intervals in the lower end of the body to accept six guide pins from the cooling shell. The cooling shell and spring from the Mark-II gripper were used on the prototype Mark III. Stellite weld buttons are formed on the lower OD of the body to center the cooling shell and to help it move up and down smoothly.

The lower end of the gripper body carries a subassembly guide cap. This cap centers the gripper as it engages a subassembly upper adapter and provides a mechanical stop for the upper adapter when it has been inserted the proper distance. The stop is sufficiently strong and positioned properly to prevent damage to the gripper internals if higher-than-normal forces are applied. The guide cap also has holes in the periphery to allow argon flow through the gripper internals and into the subassembly. Just above the guide cap (in the gripper body), pin bosses are provided to support a 7/16-in.-diam pin. This pin, used as the gripper-jaw pivot point, is constructed of hard-chrome-plated tool steel. The pin is retained by two stainless steel internal lockrings.

(2) Gripper Jaws. Two identical gripper jaws (shown in Figs. 19 and 20) are carried on the 7/16-in. pin in the bottom of the gripper body. The jaw pair is centered laterally in the gripper body by the pivot-pin support bosses with a nominal side clearance of 0.035 in. The jaws, of single-piece Inconel construction, have 0.010-in. diametrical clearance on the pivot pin. The opening and closing cams are machined on the outsides of the jaws and use very gradual approach angles (19° opening--16° closing)

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Fig. 19. Mark-III Gripper Jaws, Jaw Actuator, and Sensing Rod (Body Removed)

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Fig. 20. Mark-III Gripper Assembly

with an approach lever arm of approximately $7/16$ in. The jaws are relieved in the inner area to allow space for the sensing-rod tip, which moves vertically inside the jaw pair. The jaws allow a subassembly upper adapter to move $1/2$ in. above the normal support position while the jaws are closed on the adapter. Tips are provided on the upper ends of the jaw pieces to operate in conjunction with a mechanical interlock fork on the sensing rod.

(3) Jaw Actuator. The jaw-actuator tube is shown in Figs. 19 and 20. The actuator is supported against rotation by the jaw-pivot-pin bosses and by a close-fitting rectangular hole in the upper end cap of the gripper body. The rectangular hole allows passage of a rectangular extension piece that is welded in the top of the actuator tube and connects the tube to the jaw-actuator chain. A slot in the upper end of the actuator tube allows passage of an extension piece for the sensing rod, which operates inside the jaw actuator.

The jaw-actuator cams are made from $5/16$ -in.-diam Stellite-6B rods and welded to the Type 304 stainless steel jaw-actuator tube. The rounded inner surfaces of the Stellite rods operate the gripper jaws. The outer (with respect to the gripper axis) surfaces of the Stellite rods are ground to form bearing surfaces on the outside of the jaw-actuator tube. Under conditions of a high, jaw-operating load, these bearing surfaces limit radial deflection of the lower end of the jaw actuator by contacting the inside of the gripper body.

The total $3\frac{5}{8}$ -in. jaw-actuator travel in the Mark-III designs can be divided into three zones: (a) JAWS-CLOSED overtravel of $1\frac{1}{8}$ in., (b) jaws-opening and -closing zone of $1\frac{5}{8}$ in., and (c) JAWS-OPEN overtravel of $7/8$ in. The external drive mechanism is adjusted to give $3\frac{3}{8}$ in. of jaw-actuator movement in the gripper during operation. Nominally, this allows $1/8$ in. of clearance from the mechanical stop at both ends of the jaw-actuator travel.

The greatly increased travel allows the operator to verify positively that the gripper jaws are fully open or closed, even with $3/4$ in. of total slack in the actuator-indicator system. For example, if the jaws were hard to open, but the indicator showed OPEN, the JAWS-OPEN overtravel region of $3/4$ in. ($7/8$ in. minus $1/8$ in. clearance) could possibly be reduced to zero, but the jaws would still be held fully open. This is the worst possible condition. In the closing direction, the overtravel is even greater, but the worst possible error is still only $3/4$ in. Without friction, all gripper-jaw movement occurs in the central action zone, which is only $1\frac{5}{8}$ in. long; the remaining 2 in. is divided into the open and closed overtravel regions. This feature eliminates the possibility of the jaws not being as the indicator shows them to be.

(4) Sensing Rod. The gripper sensing rod in the Mark-III design is greatly simplified in design and operation (as shown in Figs. 18-20). The ball-interlock mechanism has been eliminated, as well as the reverse-motion chain and idler wheel that were used in the Mark-I and -II units. The Mark-III sensing rod consists of the following parts: (a) a lower section, which is slotted to operate over the gripper-jaw pivot pin and has a sub-assembly orientation blade; (b) a "boxed-fork" type of mechanical interlock (part of the same piece of stainless steel as the orientation blade); (c) a weighted tube section; and (d) a small extension bar for connection to the position-indicator chain.

Vertical motion of the sensing rod is limited by the length of the sensing-rod slot through which the gripper-jaw pivot pin goes. When the gripper is empty, the sensing rod rests on the pivot pin. When a properly oriented subassembly is inserted fully into the gripper's guide cap, the bottom of the sensing-rod slot is just clear of the pivot pin and prevents the application of an external force to the pivot pin.

The total travel of the sensing rod is $1\frac{1}{8}$ in. When the jaws are open and the sensing rod is down, the sensing indicator reads zero. Before the gripper jaws operate, the sensing rod must be raised $1\frac{1}{8}$ in. above the DOWN position by a subassembly upper adapter. This raises the boxed-fork-type interlock away from the interlock tips on the gripper jaws and allows the jaws to be closed around the upper adapter. At this point, the sensing-rod orientation blade has entered the upper-adapter slot, the mechanical interlock is clearing the jaw-interlock tips by $1/8$ in., and the support surface of the upper adapter is $1/2$ in. above the gripper-jaw support surfaces. As the gripper is raised, the subassembly and sensing rod move down in relation to the gripper body until the upper adapter seats on the gripper jaws; the gripper and subassembly then move as a unit. In this raised position (see Fig. 19), the sensing rod is in the subassembly CARRY position ($1/2$ in. above empty) and the fork-type interlock has entered the space between the jaw-interlock tips with $3/8$ -in. engagement. It is now physically impossible for the gripper jaws to be opened without raising the sensing rod. The gripper jaws can only be opened when the subassembly is supported elsewhere; thus the fifth item of the FUM design criteria (in Table I) is satisfied.

The long sensing tube, above the mechanical interlock, is loaded with a machined slug of depleted uranium. The uranium was used to get the maximum weight in the confined space available in the gripper. The tube is leaktight to prevent exposure of the uranium to the sodium coolant. An extension bar is attached at the top of the sensing-rod tube. This bar extends up through the jaw-actuator tube and through a slot in the gripper-body end cap to connect to the sensing chain.

The weight of the sensing-rod assembly is approximately 60 lb. The spring-tension device in the top of the FUM was reworked to apply an average upward force of 20 lb on the sensing chain. This results in a net driving force of 40 lb to ensure satisfactory operation of the sensing rod and drive the sensing-rod-indicator mechanism.

(5) Cooling Shell. In the prototype Mark-III gripper, the hexagonal cooling shell and the Inconel spring from the Mark-II gripper were used with only slight modifications. The operation of the cooling shell is shown in Fig. 20 and is explained in detail in the FUM design report.² The spring loading causes the cooling shell to engage the top of the subassembly hexagonal can, thus forcing the circulating argon gas to go through the inside of the subassembly.

b. Final Mark-III Gripper. Operation with the prototype Mark-III gripper has been very satisfactory. On the basis of the many transfers performed without difficulties, the design of the final Mark-III gripper remains almost identical to that of the prototype, and both are completely interchangeable. The changes in the final gripper are listed in Table III.

TABLE III. Final Changes in the Mark-III Gripper

-
1.	A redesigned attachment method for the cooling shell.
2.	A revised lower-end cap and closer sensing-rod side clearances to ensure smoother insertion of the gripper orientation blade into the subassembly upper adapter.
3.	A stronger jaw-actuator lower tube, along with relieved corners on the gripper jaws to accommodate a tube with heavier wall thickness.
4.	A change in jaw-opening cam-approach angle from 19 to 17°, with a longer lever arm at the initial contact point for smoother operation in the opening direction.
-

All other features of the gripper remain identical to those of the prototype.

The Mark-II gripper cooling shell (used on the prototype) was attached to the gripper body by six threaded Inconel pins. These pins held the cooling shell in the proper orientation and allowed vertical movement by sliding in the slots that were milled in the gripper body. The threaded pins were locked in position by small socket-head setscrews. This pin and setscrew lock system was susceptible to damage during assembly and disassembly, and presented the possibility that a screw might loosen sufficiently to jam the gripper in the hexagonal tube (FUM or FTP) in which

it operates. In the final design of the Mark-III gripper, these threaded pins were replaced with shouldered Stellite-6B pins. The cooling shell and spring were installed on the gripper; then the new pins were inserted and welded into the cooling-shell body. This makes the cooling shell nonremovable. To allow removal of the gripper-jaw pivot pin, access ports have been provided in the cooling-shell walls. The ports are closed by seal plates to prevent gas flow from bypassing the subassembly internals.

The gripper lower-end cap was revised to center the subassembly upper adapter more fully before it could engage the sensing-rod orientation blade. Some difficulty was encountered in the prototype when the orientation blade momentarily missed the upper-adapter slot until the adapter was more fully centered; then the blade fell into the slot. The side clearance between the sensing rod and the surrounding gripper jaws was reduced to ensure that the orientation blade was centered in the gripper body.

The jaw-actuator tube and gripper jaws were changed to increase the strength of the tube ends that carry the Stellite actuator rods. All other changes were minor and should not change the operation of the gripper.

B. Other Improvements of the FUM Mechanical System

1. Elevation Drive and Manual Jaw-actuator System

In the Mark-I and -II grippers, the jaw-actuating arm in the elevation-drive differential was operated by an electric motor, with push-button controls located on the FUM operating panel. The electric motor, through a slip clutch, ran a leadscrew and nut arrangement that operated the differential arm directly (as shown in Fig. 14). A straight leadscrew could be used since the rotational travel of the arm needed to be only 13.5° to get the 1.5-in. jaw-actuator travel in the Mark-I and -II grippers. This electric-drive system was satisfactory as long as the gripper jaws operated without difficulty. However, as soon as trouble was encountered, the electric drive became a hindrance because it would jam the gripper mechanism, and then the clutch would slip. This drive system removed all "feel" and made it difficult to tell what was happening in the gripper itself.

The increased jaw-actuator travel ($3\frac{5}{8}$ in.) used in Mark-III grippers required a different jaw-actuator drive system because the existing leadscrew and electric motor drive could not be adapted to handle the larger rotation that would be required by the differential arm. Since manual operation of the gripper jaws was advantageous, the electric system was replaced by a simple manual arm-and-lock mechanism for operating the gripper jaws.

The differential arm was extended, and a spring-loaded pistol grip handle with detent fingers on both sides was added. The arm operates

through a detent plate that has two locking positions, 31° apart. One detent is used for JAWS CLOSED, and the other for JAWS OPEN; each has a function switch, which can be triggered only when the detents on the pistol grip are seated completely in the detent plate. The only adjustment available is to position the detent plate in the support structure. This adjustment allows centering the total movement of the actuator to equalize the available overtravel at the extreme ends of the jaw-actuator stroke (in the gripper). Moving the arm over the 31° angle between the detent points moves the jaw actuator in the gripper $3\frac{3}{8}$ in. This leaves $1/8$ -in. overtravel at each end of the stroke when the detent plate is properly adjusted.

As another part of this modification, a new differential center-bearing support was designed to accept a second differential pinion gear opposite the original gear. This change greatly increased the load-carrying and wearing capabilities of the differential and limited the deflection of the side gears under load.

Gripper operation with the manual system has been very satisfactory. The system is simple, requires minimal maintenance, and is faster than an electric drive. The capability for "feeling" the movement of the associated mechanisms was also helpful in locating other problem areas in the chain-drive system that were not apparent or observable with the electric jaw drive. One of these problems was associated with the chain-guide roller assembly (shown in Fig. 12), which is attached to the top of the hexagonal liner tube in which the gripper operates. The roller assembly is placed below the chain-drive sprockets to maintain the rigidity and alignment of the large chain pair as this pair is extended downward. In the original installation, the back-to-back clearance between chains was small, especially when the chains were heated by the hot argon and then retracted through the cold guide-roller assembly. The chains also seemed to be wearing and galling where they rubbed together during jaw actuation. This galling condition was severe at the two normal elevations (in relation to the guide rollers) where the gripper jaws were operated. In the Mark-I and -II units, the galling between the chains was aggravating the gripper-sticking problems. Often the jaws would not work at all at the normal transfer elevations, but they would operate at other points.

Complete FUM disassembly revealed two problems: (1) The rollers were mounted in bronze bushings with no provision for lubrication, and (2) operation in the warm argon and mild sodium-vapor environment had caused all four rollers to seize. The box was reworked to carry modified rollers in sealed ball bearings. The roller diameters were decreased to give the chains more back-to-back clearance. The side surfaces of the rollers were also relieved to give the chains more side clearance. These modifications greatly reduced the friction encountered by the elevation-drive and jaw-actuator systems.

2. Improved Gripper-position Indicator

a. Old Indicator. Figure 21 shows the gripper-position indicator used with the Mark I and II and initially with the prototype Mark III. This indicator gave a clock-type display of all gripper functions, i.e., gripper elevation, jaw-actuator position, and sensing-rod position. Three shafts extending from the chain-drive housing were used to transmit the gripper information to the indicator. Two of the shafts carried the gripper-drive sprockets (shown in Fig. 13), so movements of these shafts reflected the position of the gripper body and the jaw actuator. The third shaft was an idler, which was driven by the sensing-rod chain. Movement of that chain reflected actual movement, not only of the sensing rod, but also of the gripper body (which supported the sensing rod). The other two shafts transmitted information on the theoretical position of the gripper and jaw actuator based on revolutions multiplied by the drive-sprocket diameters. This feature caused a discrepancy in sensing-rod indication, which could not be corrected. Other functions of the indicator (elevation and jaw position) were satisfactory, but difficult to read and interpret by an operator trainee.

Good sensing-rod indication is the most critical part of proper operation of the FUM gripper. If the sensing rod is not positioned properly in the gripper, the jaws cannot be operated. The sensing-rod indicator is also used to indicate gripper contact with a subassembly or, while the gripper is carrying a subassembly, to show contact with an obstruction or with the bottom of a coffin. Another original design function of the sensing-rod indicator was to drive switches that automatically operated relays controlling such things as the flow path of the argon cooling system, the gripper electrical interlocks, and the fuel-handling-sequence interlocks. These switches, especially that for the argon flow path, operated automatically and depended on whether the gripper was empty or loaded. Figure 21 shows how the gripper JAWS LOADED switch was mounted with an inclined-cam arrangement that was operated when the sensing shaft moved in relation to the gripper shaft.

The sensing-rod-indication problem arose because one part of the indicator read the theoretical gripper elevation and compared it with the actual elevation of the sensing rod. When the position indicator showed the gripper to be extended 26 ft (theoretical), it was actually $3/8$ in. lower than indicated. This error was caused by the buildup in pin and link clearances as the elevation chain was extended. The difference in sensing-rod elevation for the gripper-loaded versus the gripper-empty conditions was only $1/2$ in. However, the $3/8$ -in. error that accumulated as the gripper was extended reduced to $1/8$ in. the effective JAWS LOADED travel for operating the switch. This prevented adjustment of the JAWS LOADED switch to have it operated consistently over the entire vertical travel of the gripper. The problem was solved by removing the automatic JAWS LOADED switch and replacing it with a manual switch on the FUM control panel.

- 1 - ROLLER CHAIN (JAWS)
- 2 - ROLLER CHAIN (GRIPPER)
- 3 - ROLLER CHAIN (SENSING)
- 4 - GRIPPER ELEVATION POINTER ($360^\circ = 30^\circ$)
- 5 - SENSING POINTER
- 6 - JAW POSITION POINTER
- 7 - GRIPPER ELEVATION POINTER ($360^\circ = 12^\circ$)

- 8 - DRIVE PINS
- 9 - "JAWS LOADED" SWITCH
- 10 - JAWS SHAFT
- 11 - GRIPPER SHAFT
- 12 - SENSING SHAFT WITH INCLINED CAM SPROCKET HUB
- 13 - GEAR TRAIN

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Fig. 21. Old Position-indicator System

However, this loss of automatic switch operation was not convenient from an operation standpoint, for it increased the difficulty of controlling the argon-cooling-system flow paths. Also, since the sensing-rod indication varied with elevation, it was difficult for anyone not intimately familiar with the FUM to determine the exact position of the sensing rod at a given time.

b. New Indicator. An entirely new position indicator was designed, fabricated, and installed. This unit, which is operated from the same three driveshafts by another roller-chain system, replaces the clock-type indicator. The new design had to accomplish the following:

- (1) Eliminate the variation of sensing-rod indication with changing elevation.
- (2) Automate the operation of the JAWS LOADED and JAWS EMPTY switches.
- (3) Replace the clock-type elevation indicator with a direct-reading digital indicator.
- (4) Provide potentiometer-driven meter indicators for gripper-jaw position and sensing-rod position, and provide indicating lights for completion of functions.
- (5) Provide smoother, more reliable operation while requiring very little drive torque.

Figure 22 shows the design of the improved position indicator. The entire system is housed in a small aluminum case, which is installed in approximately the same location as was the previous unit. The existing chain-drive connections drive the new indicator. The case can be removed for maintenance by disconnecting the three drive chains and an electrical connector and removing four bolts.

The central shaft in the case is connected to the gripper-elevation driveshaft. It is geared directly, with the appropriate reductions, to a digital indicator, which displays gripper elevation to the nearest 0.1 in. Also mounted on this shaft is a gear that drives one side gear in each of two small-bearing differentials. The side gears on the other halves of the two small differentials are driven by the jaw-actuator chain and the sensing-rod chain. The differential pinion gears are mounted on rotating cages that drive individual indicator shafts for sensing-rod and jaw indication. The chain drives and gearing in the case prevent motion of either differential cage as the gripper is driven up or down. Only when one side of a differential is rotated, while the other is held stationary, does the differential cage rotate.

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Fig. 22. Improved Position-indicator Gearbox

The cages each drive a shaft that operates a one-turn potentiometer and two position switches. The movement occurs only when the jaw actuator or the sensing rod moves with respect to the gripper body. The gearing is selected to give approximately 120° rotation of the indicator shafts for full travel of the jaw actuator ($3\frac{3}{8}$ in.) or the sensing rod (1 in.). This rotation is sufficient to drive the functional JAWS CLOSED, JAWS OPEN, GRIPPER EMPTY, and GRIPPER LOADED switches and to operate the one-turn potentiometers connected to the position meters on the operating panel.

The gripper positioning error previously noted was proportional to the distance the gripper was extended downward and reached a maximum of $3/8$ in. at 26 ft of extension. This error was corrected by installing a simple gear train (ratio 784/783) in the gearcase between the sensing-rod-position shaft and the drive side of the sensing-rod-position differential (as shown in Fig. 22).

Installation of the new position indicator has satisfied the design requirements. Gripper elevation is read easily on the digital indicator (shown in Fig. 23). Gripper-jaw and sensing-rod positions are indicated on individual 0-100% meters with indicator lights to show completion of steps. Since the sensing-rod indication remains constant as the

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Fig. 23. FUM Operator Control Panel (Revised)

gripper elevation changes, a return to automatic operation of the gripper JAWS LOADED switch is allowed. The entire indicator system uses ball-bearing shafts, precision gears, and close tolerances, resulting in a low torque requirement and minimum backlash for each part of the indicator system.

3. Modification of Bottom Shielding Valve of the FUM

The bottom shielding valve has had some minor modifications to reduce the required maintenance. Whenever a subassembly is removed from the primary tank by the FUM gripper, droplets of sodium are carried up into the FUM. After the shielding valve is closed, any further sodium that drops off the subassembly or the gripper is deposited on top of the valve. A hexagonal recess is provided in the top of the valve (in the closed position) to accept a snap-in-type drip cup. This drip cup is designed to catch the sodium and to prevent it from building up in the annulus of the valve. If all the sodium does not fall into the cup or the cup is filled, the annulus starts filling with sodium and sodium oxide; soon the torque required to operate the valve becomes very high.

To reduce the frequency of valve maintenance, the capacity of the drip cup was doubled by increasing the depth of the hole and by changing from a hexagonal to a circular cup. The circular cross section is much easier to fabricate, gives some overlapping around the edges of the FUM hexagonal tube, and increases the capacity. To facilitate the maintenance job, the manual drive for operating the valve was also modified to allow access to the drip cup without disassembling the drive. Previously it was necessary to remove the drive to allow rotation of the valve to the maintenance position.

To perform a minor cleaning of the valve and drip cup, the bottom-ring seal assembly and lower O-ring seat are removed; this allows access to the drip cup and three of the four O-rings for cleaning. Before the modification, this minor cleaning job was required approximately every 25 transfers and took 12 to 14 man-hr to perform. After the modification, the minor cleaning requirement was reduced to once every 60 transfers and took 8 man-hr.

If the minor cleaning of the valve is performed as soon as the torque to rotate it goes above 50 ft-lb, major disassembly is not usually required. Operating experience has shown that the frequency of major disassembly is directly related to the number of times the drip cup has been overfilled. When the torque reaches 50 ft-lb, overfilling is just starting to occur. A major disassembly of the FUM valve takes approximately three days. The combination of valve modifications and greater emphasis on timely minor maintenance and cleaning has reduced this difficult job from about six times a year to only once a year or approximately every 400 transfers, whichever occurs first.

VI. REVISED OPERATING PROCEDURES FOR THE FUM

A. Revised Procedures for Gripper Operation

The Mark-III gripper and the improved position indicator required several changes in the original operating procedures. With the new digital readout for gripper elevation, all important elevations are now specified in inches only, rather than in feet and inches, as were used with the clock-type indicator. When the gripper is engaged on a subassembly upper adapter, the sensing-rod-position indicator gives a direct determination of sensing-rod position, instead of requiring interpretation of the movement of pointers. When the sensing rod is lifted high enough to allow gripper-jaw operation, the meter reads 95-100%. When the subassembly is supported by the gripper jaws, the meter drops back to 50%, which is the CARRY position. This also indicates that the mechanical interlock is in effect. When the gripper is empty, the meter reads 0%. These readings remain constant over the vertical travel of the gripper.

The gripper jaws are now operated manually, and the electric jaw-drive motor and controls have been removed. Jaw position is indicated by a meter that reads 0% at the OPEN position and 100% at the CLOSED position. To energize the JAWS OPEN or JAWS CLOSED relay circuit, the manual jaw-actuator handle must be locked in the appropriate position, and the proper switch in the position-indicator system must be actuated by movement of the jaw-actuator driveshaft.

B. Other Revisions of the FUM and the Argon Cooling System (ACS)

Several other revisions have been made to the operating procedures for the FUM and the ACS. The 650°F heating cycle at BLOWING AND HEATING, which is used for melting the sodium bond in a new fuel subassembly, has been increased from 15 to 30 min to lessen the thermal shock to which the subassembly is subjected as it enters the 700°F bulk sodium. This heating cycle is made even longer for specially orificed experimental subassemblies.

The argon-blowing operation, performed when the FUM gripper (either empty or loaded) is being removed from the primary tank, has also been changed. After the drip period, the gripper used to be stopped at BLOWING AND HEATING for a 10-min blowing cycle to clean the gripper and subassembly. The argon flow path was downward through the FUM and the fuel-transfer port for 1 min, then only through the transfer port for the remaining 9 min. This has been changed to flow through the FUM and the transfer port for 7 min, then only through the transfer port for 8 min. The reason for this change is that the sodium seemed to adhere to the gripper much more than to the subassemblies. The increased blowing time through the entire gripper has lowered the cleaning requirements of the bottom shielding valve and has decreased oxide formation on the gripper.

Another change was made in fuel-handling sequence K, which involves the transfer of subassemblies from the FUM to the transfer arm in the primary tank. The final step in the sequence of loading a subassembly onto the transfer arm required returning the empty FUM gripper to the UP position before the subassembly could be placed in the storage basket. If a used subassembly was to be removed from the basket in the next loading step, this requirement was not desirable, because it required running the gripper to the UP position (which takes 25 min with dripping, blowing, etc.) and then back down for the next loading. The circuitry was changed, and a new gripper-elevation switch was added to give the operator the option of leaving the gripper immersed in the bulk sodium while transfer in and out of the storage basket was completed. If a spent subassembly is to be returned to the FUM after each basket insertion is completed, this change saves approximately 30 min on each round-trip transfer and eliminates many unnecessary steps. Designated as "25 FT," this alternate gripper-stopping elevation locates the gripper approximately 6 in. above the transfer-arm engagement elevation and keeps most of the gripper submerged, while allowing rotation of the transfer arm with a subassembly in it. This modification cuts in half the number of times the gripper is inserted into the bulk sodium for a loading-unloading operation, and thereby decreases the wear on the elevation-drive chain system.

VII. FUM OPERATING PERFORMANCE

Figure 24 is a compilation of subassembly transfers performed each month by the FUM since sodium filling in 1963. The peak of 164 transfers that occurred in September 1963 was the exchange of temporary filtering subassemblies for fuel and blanket subassemblies in preparation for the wet-critical experiments. The high transfer rate during March 1967 was caused by changing two rows of reactor reflectors during the EBR-II power-coefficient anomaly. Table IV shows the average monthly transfer load if these peak transfer periods are neglected.

Fig. 24. Monthly History of FUM Transfers

TABLE IV. Average Monthly Transfer Load, Excluding Peak Transfer Periods

Year	Average Transfers per Month
1963 (late)	24
1964	4
1965	19
1966	29
1967	32
1968	39

The trend toward increased fuel-handling loads has been accelerated by the change in purpose from that of a power demonstration plant to that of a fast-flux irradiation facility. Each experimental program that is initiated increases the fuel-handling load and also the reactor surveillance required. Reactor surveillance, such as flux mapping or temperature monitoring, is performed, in many cases, with special surveillance or test assemblies that further increase the required fuel handling.

Normally, the FUM is used five days each week for transfers to and from the FCF. This means that each day lost because of unscheduled

Fig. 25. Unscheduled FUM Downtime Caused by Gripper and/or Elevation-drive Difficulties

repairs reduces the monthly FUM availability by about 5%. If many problems are encountered with the FUM, a heavy fuel-handling schedule cannot be met. Figure 25 shows the loss of availability of the FUM (in days per month) because of unscheduled maintenance or repair of the gripper and associated elevation drive. This does not include loss of availability for other reasons. Before installation of the Mark-III gripper, for many months the FUM was available less than 50% of the time. This had a severe effect on fuel-transfer scheduling for both the reactor and the FCF.

Most of the downtime was caused by the need for frequent gripper cleaning. After installation of the Mark-III gripper, the need for cleaning dropped radically (as may be seen from Fig. 11). Previously, with the Mark I and II, cleaning was required after every 10-20 transfers and often more frequently. After initial checkout with the Mark III, the FUM was operated for eight months and performed over 300 transfers without cleaning or inspection. After this successful operating period, a maintenance procedure was started that now requires cleaning of the gripper once every six months (if it is not removed and cleaned for other reasons during the period) and an annual disassembly of the entire gripper and chain-drive system for inspection and for maintenance as required. The new system has allowed the scheduling of almost all FUM maintenance in advance, permitting the work to be done during periods when the FUM is not required for fuel transfers. This has reduced greatly, if not eliminated, scheduling problems involving the FUM.

Figure 26 shows loss of FUM availability in days per month because of scheduled and unscheduled maintenance and cleaning required by the bottom shielding valve. The modifications that were performed on the valve

Fig. 26. FUM Downtime Caused by Shielding-valve Maintenance

keep the machine operating is high, even when it operates well. The important point, not shown by the table, is that before May 1967 all maintenance was of the demand (unscheduled) type. Since the installation of the Mark-III gripper and other modifications, at least 75% and possibly more of the maintenance time is scheduled in advance and performed when the FUM is not needed. Also not shown by this table is the increased number of transfers required each month. Table V compares average maintenance hours required for each sub-assembly transferred for 1965 through 1968.

This comparison shows the overall improvement in FUM performance due to the modifications that have been performed. Most of the 1.15 man-hr required for maintenance during each transfer are scheduled; few unscheduled or emergency repairs are now needed during FUM operations.

are intended to increase the number of transfers that can be performed without maintenance and to decrease the downtime when maintenance is required. Since these modifications were made in January 1969, sufficient fuel handling has not been performed to determine if they are successful.

Figure 27 shows the estimated maintenance (in man-hours per month) required to keep the FUM operating from January 1965 through May 1969. This is a sum of both scheduled and nonscheduled maintenance. The maintenance required to

Fig. 27. Monthly History of Total FUM Maintenance

TABLE V. Average Maintenance Hours Required per Transfer

Year	Transfers per Month (avg)	Average Maintenance Time, man-hr/month	Maintenance per Transfer, man-hr (avg)
1965	19	64	3.4
1966	29	46	1.6
1967 (early) ^a	32	88	2.75
1967 (late)	32	34	1.06
1968	39	45	1.15

^aBefore Mark III.

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