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PRODUCTION SLUG INJECTION MACHINE FOR FABRICATION OF HTGR FUEL RODS

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Abstract

A conceptual design of a production-scale slug injection machine for fabrication of HTGR fuel rods has been developed at Oak Ridge National Laboratory. This production machine employs the slug injection process, which has been demonstrated on a laboratory fuel rod machine. The proposed production machine has a projected fabrication rate of 35,000 to 70,000 fuel rods per day, and it is applicable in both contact processing systems for production of fuel rods from virgin fuel and remotely operated processing systems for production of fuel rods from recycled fuel.

Introduction

A pilot plant process is to be designed and operated at Oak Ridge National Laboratory (ORNL) to demonstrate the feasibility of commercial fabrication of HTGR fuel elements from recycled fuel. The slug injection process has been under development at ORNL for the past few years as a method for fabricating fuel rods from both virgin fuel in contact plants and recycled fuel in remotely operated plants.[1] This process, which is illustrated in Fig. 1, has been demonstrated on manual laboratory fuel rod machines and on the laboratory rod machine[2] illustrated in Fig. 2. This laboratory rod machine is the basis for the conceptual design of the production-scale fuel rod fabrication machine described herein. The

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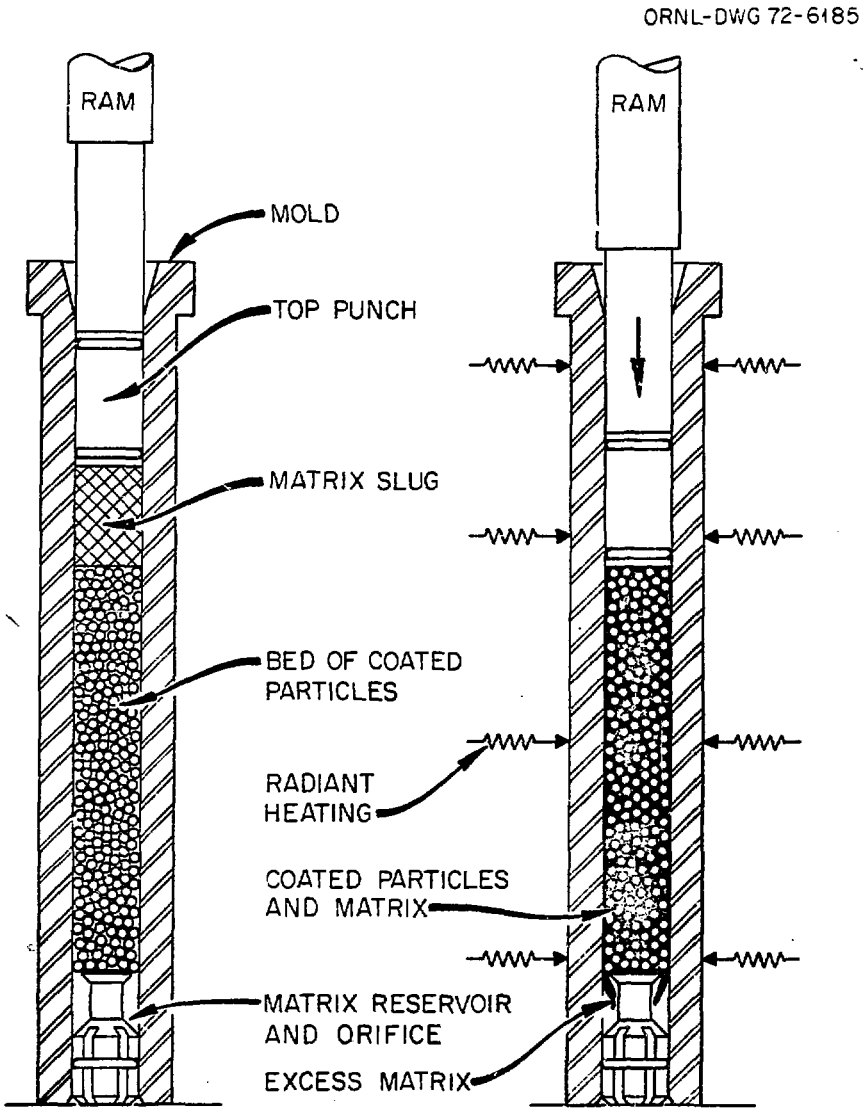

Fig. 1. Slug Injection Technique for Making Bonded-Bed Fuel Rods.

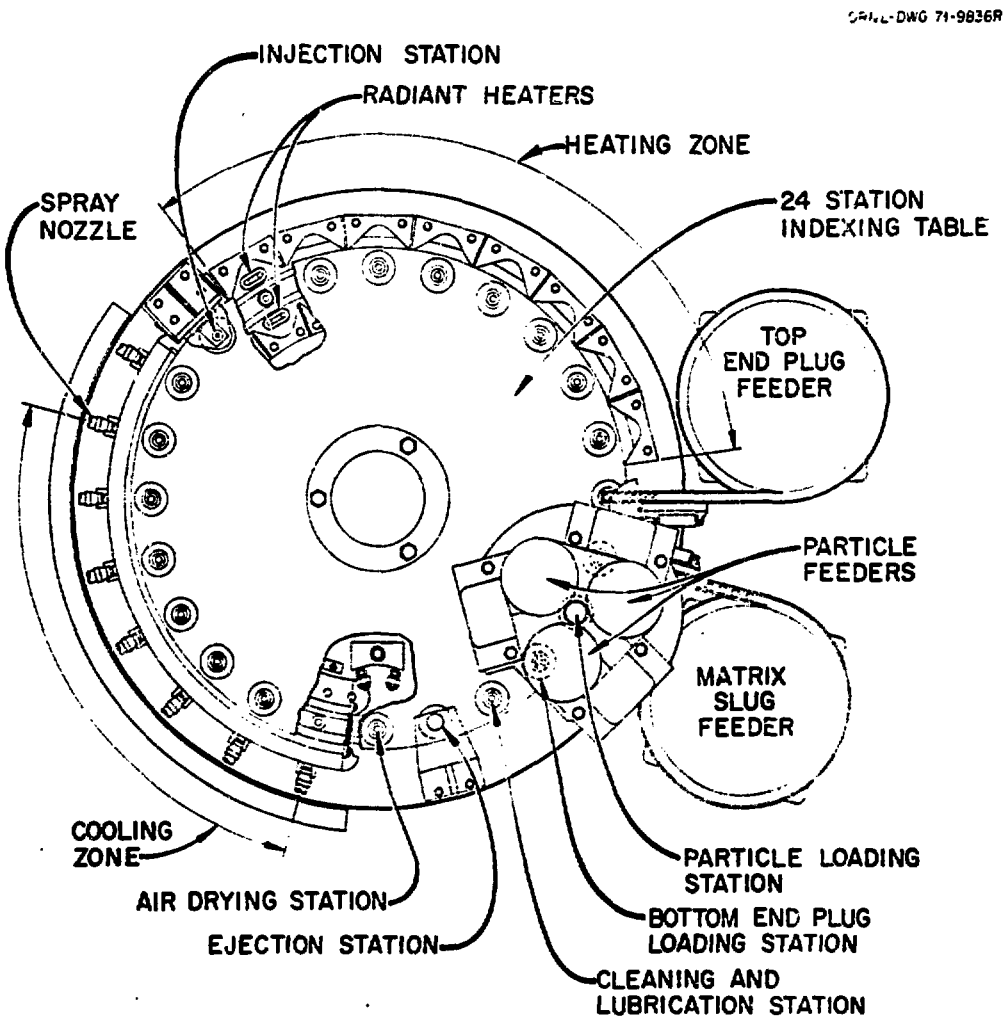

Fig. 2. Schematic Diagram of the Laboratory Fuel Rod Machine.

production slug injection machine will perform the major processing steps of particle blending, loading, and fuel rod forming at a projected rate of 35,000 to 70,000 rods per 20-hour day.

Basis of Design

The laboratory fuel rod machine is comprised of operating stations positioned around a rotary index table to which molds are permanently affixed. This type of system is used extensively in automatic assembly operations in which the operating time for each station is more or less the same. The fabrication rate for this type of system is obviously controlled by the cyclic time of the longest operation.

The operation requiring the most time in fuel rod fabrication is injection of the matrix. The actual time needed for injection of the matrix is somewhat uncertain at this writing, but the operation will probably require about 20 seconds for completion. If a 20-second cyclic time is assumed for this operation, the maximum fabrication rate obtainable with the laboratory fuel rod machine operated with single-station indexing is about 4000 rods per day. However, since the average cyclic time required for each of the operations at the other stations is about 4 seconds, the fabrication rate for this type of machine could be increased to about 10,000 rods per day by using multiple matrix injection stations and a more complex indexing cycle.

To achieve a fabrication rate better than that obtainable with a machine employing molds affixed permanently to a rotary index table, the approach used in the conceptual design of the production slug injection machine is similar to that used in the bottling and canning industry. In this concept, the molds are free members which are transported from station to station via conveyor for processing as are bottles on a bottling machine. This system permits simultaneous multiple-rod injection while retaining the single-rod processing feature so important to interfacing with other operating stations, thereby providing a greater degree of flexibility than is obtainable with a fixed rotary system.

The fabrication rate of the production machine is dependent only upon station multiplicity and the speed of the transfer system. A fabrication rate greater than 100,000 rods per day per machine can be achieved. However, a production machine with this rated capacity is not proposed at this stage of development, but the cost scaling factor should be considered in future development work.

Design Description

The production fuel rod machine with a fabrication rate of 35,000 to 70,000 rods per day by the slug injection process is illustrated schematically in Fig. 3. The fuel rod molds are conveyed to the operating stations as free members on a nonsynchronous conveyor. Each operating or processing station is a single-purpose component that is relatively independent of the other stations. In this concept, repair, modification, or replacement of a component is relatively simple, requiring a minimum of process downtime.

The basic fuel rod mold is a simple, hardened stainless steel cylinder with a polished bore that is sized to produce a green fuel rod of the correct diameter. The bottom end of the cylinder is pressed into a circular disk or base to provide stability as the mold travels along the conveyor.

During machine operation, each mold is a separate, independent unit that travels along the conveyor from station to station. A mold is first cleaned and coated with a film of lubricant that later serves as a release agent. The mold is then conveyed to the next station where a spool piece is inserted and driven to the bottom of the mold. The appropriate fuel loading is dispensed, blended, and loaded into the mold by the dispenser-blender unit; a matrix slug is inserted in the mold by the matrix slug feeder; and a top punch is inserted in the mold by the top punch feeder. At each of these stations, the bottom position of the insertion ram is monitored. If the stack-up dimension of the inserted parts does not fall within a preset tolerance, the mold is directed from the conveyor by a reject gate.

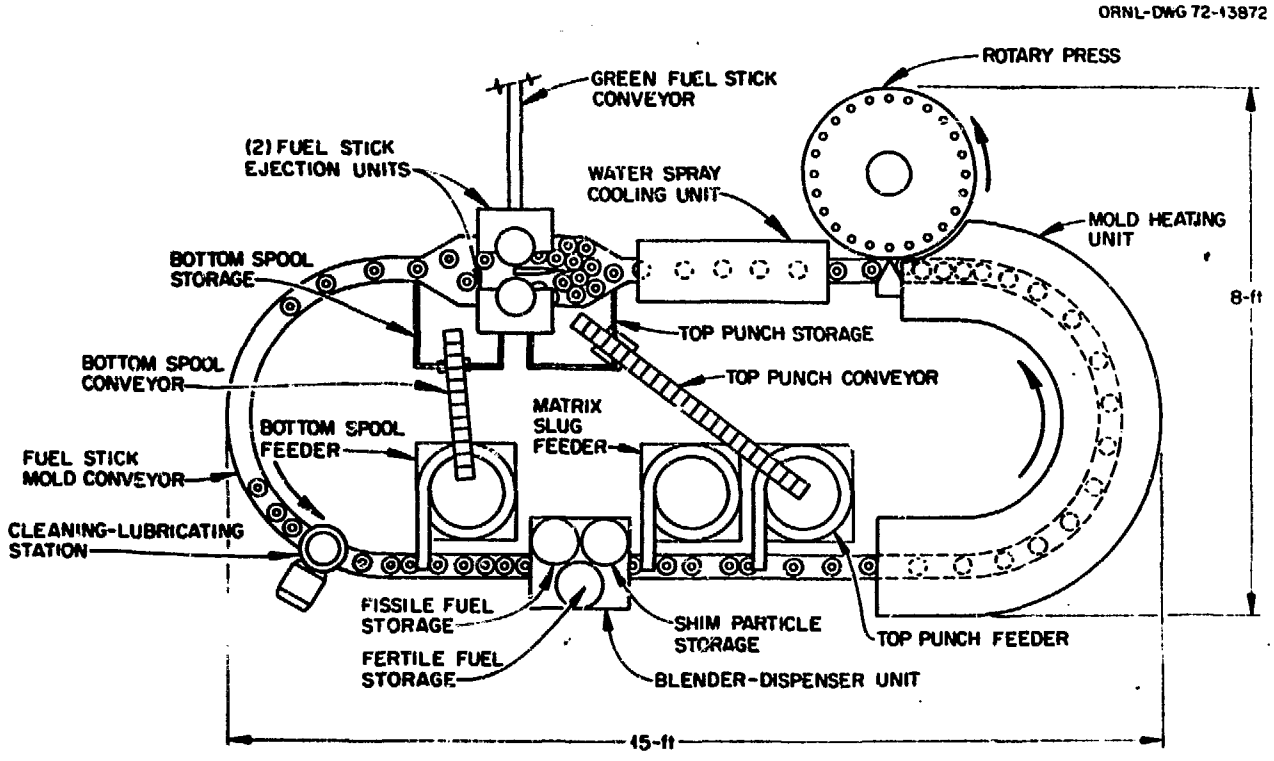

Fig. 3. Schematic Diagram of Production Fuel Rod Machine.

The acceptable molds are conveyed through a heating zone wherein the temperature of their contents is elevated to the desired pressing temperature of about 200°C. The molds then enter a rotary press where the matrix slug is forced through the particle bed. Leaving the rotary press, the molds are conveyed through a cooling unit to the ejection units where the spool pieces, top punches, and molded fuel rods are ejected and separated. The spool pieces and top punches are cycled back to their respective feeders, and the molded fuel rods are cycled to the next station in the fuel element fabrication process.

Estimates of the processing rate of each operating station or component of the production slug injection machine are given in Table 1, and each major component and function of the machine is discussed in the following paragraphs.

Mold Conveyor

The fuel rod mold conveyor is a commercial conveying system adapted to suit the needs of the production machine. The conveyor track or belt will run continuously at a constant rate equivalent to approximately 1.1 times the nominal fabrication rate of the machine. Fuel rod molds will be held up temporarily at the operating stations as each station component performs its function. The conveyor will continue to run, causing the molds to slide on the belt until each is accepted by the station component. This conveying system is relatively simple and should have a high degree of reliability.

Cleaning and Lubrication

The fuel rod molds are cleaned and lubricated at one operating station on the conveying system. Each mold conveyed to this station is intercepted by a mechanical arm, and lubricant is sprayed into the top of the mold. Cleaning and lubricating is accomplished by a rotary nylon-bristle brush which is traversed vertically within the mold. No cleaning solvent is required.

Table 1. Estimated Processing Rates for Components of the Production Slug Injection Machine

Component	Single Component Processing Time		Number of Components Required for Fabrication of	
	Cycle (sec)	Rods per Day	35,000 Rods per Day	70,000 Rods per Day
Cleaning-lubricating	2	35,000	1	2
Bottom spool feeder	1	70,000	1	1
Dispenser-blender				
Volumetric dispensing	4	17,500	2	4
Incremental blending	5	14,000	3	5
Matrix slug feeder	1	70,000	1	1
Top punch feeder	1	70,000	1	1
Heating unit	a		1	1
Rotary press	a		1	1
Cooling unit	a		1	1
Ejection-separator	4	17,500	2	4

[a]Component can be designed to meet rated capacity of machine.

Parts Feeders

The components that feed the bottom spool pieces, matrix slugs, and top punches to the molds are conventional vibratory feeders commonly used in commercial automatic assembly equipment. Physically, the three feed components are very similar. They utilize a gravity feed tube which receives the cylindrical parts in a horizontal attitude and delivers them to the shuttle in a vertical attitude. The only difference in the feeders is necessitated by the orientation requirement of the bottom spool piece. The feed rates of the components are limited by the combined cycle time of the shuttle and placement ram at each operating station. The three components have feed rates of approximately 60 parts per minute.

Particle Dispensing and Blending

The particle dispensing and blending component has a vertically arranged internal processing line which discharges the desired volume of blended fissile, fertile, and shim particles into each fuel rod mold. Operation of the processing line within this component involves volumetric dispensing of the particles and incremental blending by means of a splitter. This operating system was selected because of its relatively short cycle time. However, a gravimetric dispensing and air blending system could be substituted without affecting the operation of other components within the machine.

In the present concept, three storage hoppers located at the top of the vertically arranged processing line contain the fissile, fertile, and shim particles. Each of these hoppers is connected directly to a pneumatically operated pinch valve which acts as both a closure valve for the hopper and a volume measuring device. Each pinch valve is mounted above a common dump valve, and each can be adjusted vertically relative to the common dump valve to adjust the volume of particles retained in the tube between the pinch point and the dump valve. The particle flow rate of

each measured volume is controlled by the diameter of the outlet orifice to the dump valve. The diameter of each orifice is sized in proportion to the volume of each type of particle to be loaded in a fuel rod mold.

In operation, volumetric measurements are made by simultaneously closing the dump valve and opening the three pinch valves, allowing the particles to flow from the storage hoppers into their respective tubes whose volumes have been predetermined. Restoration of the air supply to the pinch valves locks the particles within each pinch valve, shutting off flow from the hoppers. When the dump valve is opened, the three measured volumes of particles simultaneously flow from their outlet orifices into a conical funnel in which blending occurs.

The particles released by the dump valve and blended in the conical funnel are divided into ten fractions by a decade splitter. The splitter has a cylindrical orifice which directs the particles onto the apex of a cone whose base is divided circumferentially to separate the charge into ten reservoirs. These reservoirs are discharged individually in a sequential order so that the second fraction of particles released is that fraction in the reservoir located diametrically opposite the first released. This order of discharge is continued so that each fraction released is followed by that fraction located most nearly diametrically opposite it to assure that any segregation of particles around the decade splitter will be distributed throughout the particle column. After all ten particle fractions have been released, the decade splitter returns to the closed position to await the next particle charge.

Each fraction of particles discharged from the splitter reservoirs falls into a mixing cone beneath the splitter where further blending occurs. The blended particles fall from the cone through a fill probe into the fuel rod mold. The lower end of the fill probe is located within the mold at a point just above the top of the full particle column so that no particles will contact the lubricated sidewall of the mold above the full level of the particle column. Operation of the ten-way splitter slide valve is timed to allow one fraction of particles to come to rest in the mold prior to release of the next fraction. After all ten particle fractions have been loaded in a fuel rod mold, the fill

probe retracts to allow the mold to be advanced to the matrix slug and top punch feeders.

Heating Unit

The filled fuel rod molds are conveyed from the top punch feeder through a heating zone into a holding oven prior to delivery to the rotary pressing station. The heating zone is equipped with a series of radiant heaters to elevate the temperature of the contents of the molds to approximately 200°C. The molds are then permitted to reach thermal equilibrium in a forced hot air holding oven. This holding oven also serves as a temporary storage zone for the molds being conveyed to the pressing station.

Rotary Press

A rotary press concept is used at the matrix injection station, where the matrix slug is injected or pressed into the fuel particle bed. As previously discussed, the number of pressing stations required for a particular fabrication rate is dependent upon the time required for matrix injection. The concept described here has 24 stations, with 19 of these being active pressing stations. This press can process one fuel rod every second for a injection time of 19 seconds or one fuel rod every two seconds for an injection time of 38 seconds.

At the rotary press station, the heated molds are singularized on the conveyor by an escapement mechanism and placed on the rotary table of the press where spring keepers maintain the position of the molds relative to the pressing rams located over the mold positions. With a mold in position, the pressing ram for that position is actuated and lowered into the mold by a cam-operated control valve during the first indexing step of the rotary table. The rotary table is indexed on a one-second interval. The force being applied by the pressing ram is continued throughout the indexing sequency until the mold approaches the unloading station. During the indexing step prior to arrival at

the unloading station, the cam-operated control valve is closed and the pressing ram is retracted from the mold. When positioned at the unloading station, the mold is withdrawn from the rotary table by the unloading mechanism and deposited on the conveyor for further processing. A shroud around the press may be needed to maintain the temperature of the mold contents at 200°C during the pressing cycle.

Cooling Unit

Fuel rod molds coming from the rotary press are conveyed through a cooling unit to reduce the temperature of the contents of the molds. A series of nozzles direct refrigerated air at the molds as they pass through the unit. Water was considered as a cooling medium because of its high heat capacity and high heat transfer coefficient, but its use could create a possible criticality control problem.

Ejection-Separator Component

At the ejection station, the molds are channeled into a single file and removed singularly from the conveyor by a cam on a 90-degree indexer. A ram is then activated to eject the spool piece, fuel rod, and top punch from the mold into the separator, which is located directly beneath the base of the ejection station. As the ejection ram is retracted, the indexer rotates and moves the mold back onto the conveyor for delivery to the cleaning and lubricating station.

The molded fuel rods, spool pieces, and top punches ejected vertically downward into the separator from the ejection station are separated and delivered to their appropriate transfer devices. The molded fuel rods are cycled on to the next machine or processing station in the fuel element fabrication process. The spool pieces and top punches are reusable and need only minimal cleaning and lubricating before being transferred back to their respective feeders. Any excess matrix accumulation within the reservoir of the spool piece is removed in solid form in the separator. The spool pieces and top punches are ejected from the

separator directly into their respective storage hoppers from which they are transferred by a conventional parts elevating and conveying system to their feeders. Further cleaning and lubricating of the parts is accomplished during this transfer.

Control System

The production slug injection machine has independent systems to control each of the individual operating stations, and these individual systems are coordinated by a master control system. This master control system is a relatively simple permissive series controller. Conventional control and sequencing devices, as well as indicators, are incorporated in the processing equipment to assure that a particular event has occurred before the next is begun. This will prevent continuation of machine operation if one of the sequential steps malfunctions. The machine is also equipped with the interlocks necessary to insure continuity of operation and operating personnel safety.

Quality Assurance

Neither inspection points nor rejection points for out-of-specification fuel rods are indicated in the schematic layout of the production slug injection machine (Fig. 3). However, the placement ram at each part feeder station is equipped with tolerance limit indicators or linear displacement indicators to assure that the correct quantity of parts or particles has been placed in the mold. The rotary press is equipped with linear displacement indicators to verify the final length of the molded fuel rod.

Each operating station with an inspection device is equipped with a rejection gate to direct a rejected mold from the conveyor. The fuel from these rejected molds is reclaimed and recycled through the process. Fuel rod molds can be removed from the conveyor between operational steps for fuel rod analysis to verify machine performance.

Installation and Maintenance

Each operating component of the production slug injection machine is an essentially independent plug-in type of unit that can be set up and maintained separately from the conveying system. All precise alignments are made within the individual components, and no precise alignment is required to link the components with the conveyor. All molds, punches, and spool pieces are readily accessible for inspection and cleaning.

This design approach simplifies the installation of components and permits the removal of disabled components for repair and replacement with a minimum of process downtime. A disabled conveyor would pose the greatest removal and replacement problem. The conveying system is therefore designed to permit removal and replacement of the most vulnerable parts, such as the drive unit and the conveyor belt. The other parts of the system, the framework and guide rollers, have a high degree of reliability.

Proposed Development

The production slug injection machine is presently in the conceptual design stage. The current plan is to design, fabricate, and operate a slug injection machine as part of the HTGR Refabrication Pilot Plant Process to be located in the Thorium-Uranium Recycle Facility at Oak Ridge National Laboratory. Although the production rate of the process is proposed to be only 8000 to 10,000 fuel rods per day, this application of the slug injection machine will provide an opportunity for operation of a prototype machine prior to final design of a production-scale unit.

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