IMPROVEMENT OF THE CENTER BORING DEVICE FOR THE IRRADIATED FUEL PELLETS

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ABSTRACT

The temperature of the fuel pellet under the transient condition is one of the important parameters to study the safety margin of high burnup commercial fuels. Japan Atomic Energy Agency (JAEA) had the particular device to bore a hole into the center of irradiated fuel pellet for the measurement of pellet temperature by a thermocouple. The center temperature of the pellet is measured during power ramp test simulated the transient condition of power plant. The device can fix the fuel pellet with the frozen CO_2 gas (dry ice) during its boring process. At the Reactor Fuel Examination Facility (RFEF) in Tokai Research and Development Center, several improvements were applied for the previous boring device to upgrade its performance and reliability. The major improvements are the change of the drill bit, modification of the boring process and the optimization of the remote operability. With the performance test using the dummy pellet, it was confirmed that the new drill bit could reduce the total boring time as less than 16%. The device was installed into the hot cell in 2010, and the mock-up test was performed with the dummy pellets to confirm the benefit of the improvements.

Keywords: Power ramp test, Fuel pellet, Center Temperature, PIE, RFEF, JMTR

1. INTRODUCTION

The power ramp tests performed at JMTR in Oarai Research and Development Center are objected to study the safety margin of the high burnup nuclear fuels and their behavior under the transient condition. The high burnup commercial fuel rods (approx. 70GWd/t), which were irradiated in European research reactors, will be refabricated as the test rods with the several instrumentations to observe the fuel behavior during the power ramp test (Fig. 1). The center temperature of the fuel pellet is one of the important parameters to investigate the safety of commercial fuel during transient condition. The thermocouple and Mo sleeve should be installed into the pellet center position to measure the center temperature of the fuel. A hole was bored in the irradiated pellet by the boring device which has the drilling unit. In this drilling process, it is necessary to keep the pellet position and shape away from their collapses during the boring, because the irradiated fuel pellets were already cracked. Therefore, the center boring device previously developed at the JMTR Hot Laboratory [1]. Fig. 2 illustrates the processing steps of the device.

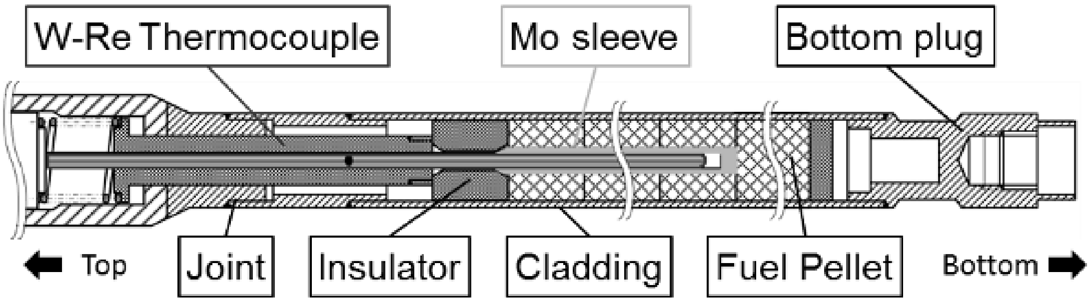

Fig. 1 Fuel rod for Power ramp test

This device consists of several units, such as the freezing unit, boring unit, cleaning unit and vaporizing unit. For the preparation of the pellet boring, the fuel rod is set into the rod chamber and CO_2 gas is injected into the chamber. The rod chamber is surrounded by the Dewar vessel filled with Liquid Nitrogen(LN_2) to cool down the CO_2 gas (Step 1). Therefore, the CO_2, which is spread into the pellet-clad gap and also the cracks inside of the irradiated pellet, is frozen as the dry ice and keeps the pellet position and shape away from their collapses during the boring. And next, the center of the fixed pellet is bored by the drill bit with the frequent cleaning of the turnings. The steps of the boring (Step 2) and the cleaning (Step 3) are repeated alternately until the boring depth reaches at 40mm. After these steps, the molybdenum sleeve is inserted into the hole to keep its shape, and the dry ice is vaporized by heating up with monitoring the humidity and CO_2 concentration in the vapored gas (Step 4). The processing is completed after the humidity and CO_2 concentration are decreased enough. This is one of the best processing ways to bore a hole to the irradiated fuel pellets which have many cracks inside.

At the RFEF, this type of the boring device has been improved and installed to supply the test fuels for the power ramp tests at the JMTR.

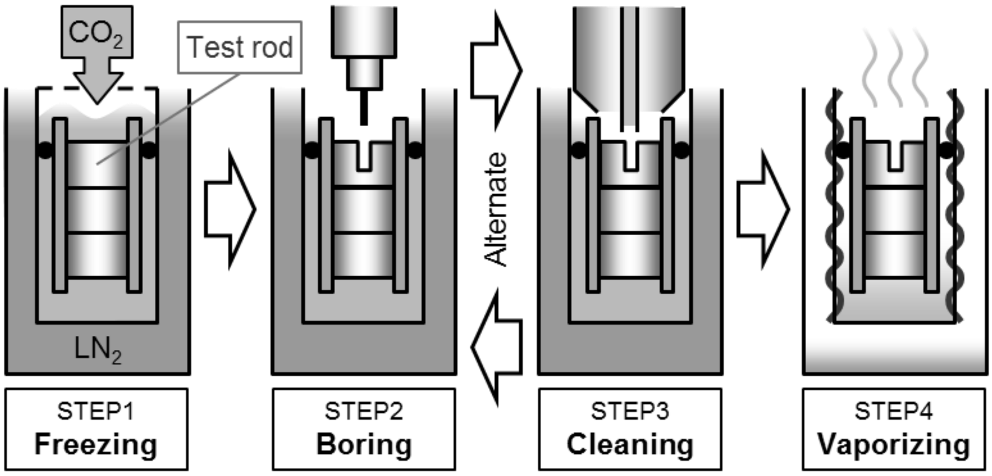

Fig. 2 Processing steps of center boring device

2. IMPROVEMENTS

The preliminary tests were performed with the prototype device and the dummy pellets. The test results indicated that the boring performance and the reliability of the device could be upgraded.

2.1 Reduction of boring time

For this boring device, one of the most important points to be considered is how to prevent the breakage of the drill bit. Once the breakage occurred, it is difficult to pick out the broken bit (or tip) from the bored hole and that pellet cannot be used anymore for the test rod.

The diameter of the drill bit is decided as φ2.5mm for the insertion of the φ2.3mm molybdenum sleeve. To bear against the rotation torque with this thin drill bit, the cylindrical drill bit with brazed chip was selected for the prototype device as shown in Fig. 3 (upper image). The slit was processed at the top of the straight shank and the diamond tip was brazed into that slit. However, the bored hole is the blind and that drill bit didn't have the function to eject the turnings due to its shape. The turnings remained at the bottom of the bored hole and they blocked the boring itself. Therefore the frequent cleanings of the turnings were necessary with the frequent interruptions of the boring. As a result, it took over 20 hours to bore a single hole. Additionally, the diamond tip at the bit top was sometimes broken off from the shank and remained inside of the hole. It could be estimated that the turnings remaining increased the frictional resistance during the boring and the slit part at the bit top, which is weaker than the shank part, cannot bear the rotation torque.

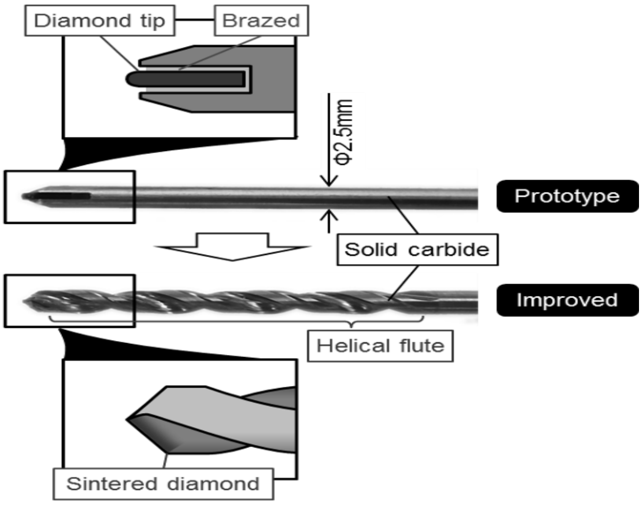

Fig. 3 Comparison of drill bits

To improve these drawbacks, the twist drill bit with diamond sintered head was selected shown as Fig. 3 (lower image). The helical flutes of the drill bit functions as the turnings outlet due to the drill rotation so that the turnings are automatically ejected through these flutes without the interruption of the boring. And the cutting edge at the bit top is sintered to the shank as solid so that it has the enough strength to bear against the rotation torque. Therefore, it is expected that the new drill bit can reduce the boring time dramatically without the breakage of the drill bit.

2.2 Turnings collection

As described above, most of the turnings are ejected automatically from the bored hole. Meanwhile the ejected turnings were piled up beside to the bored hole placed at the top side of the pellet. These turnings should be collected to keep the device and the hot cell away from the contamination as possible. Therefore, the dedicated turnings cleaner was designed as shown in Fig. 4.

The duplex pipe is employed on this cleaner. The dry air from the inner pipe blows the turnings up and the blown turnings are suctioned into the outer pipe at the same moment. The cleaner is inserted into the rod chamber instead of the drill head and sealed hermetically to prevent the leak of the blown turnings. The suctioned turnings are caught by the subsequent filter of 5μm mesh and collected after the boring. Additionally, the air used for the blowing is dehydrated to dry up the turnings and to prevent the turnings attachments inside of the surface of blowing pipe.

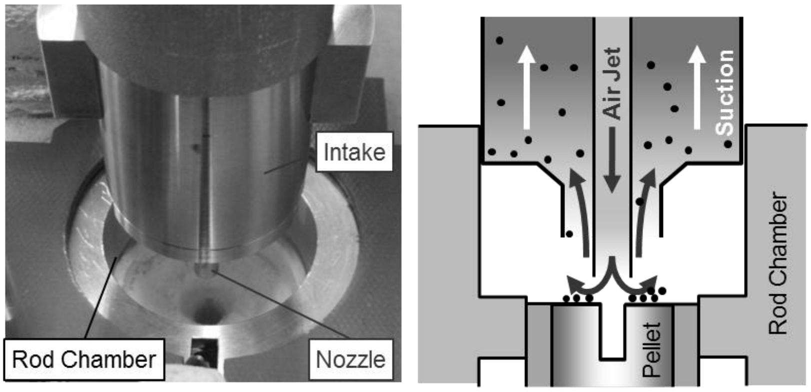

Fig. 4 Turnings cleaner

2.3 Reduction of frictional heat

Another improvement was applied for the loading system of the drill head to upgrade the processing accuracy.

As is the same as other boring or cutting devices, the frictional heat is generated by the contact of the drill bit with the pellet during the boring. Especially for this boring device, the frictional heat is one of the serious problems, because it may cause the dissolve of the dry ice and the unfixing of the pellet (and the fuel rod). The previous device applied the constant load on the drill bit during the boring, and this load was continuously applied until the next cleaning. It means that the longer boring time makes the unfixing risk higher.

For the improvement of the unfixing risk, the inching motion was added to the head loading system, which moves the drill bit slightly up and down. The inching motion can save the contact time in the same manner as the generating of the frictional heat.

2.4 Defrosting device

As described in chapter 1, the sample rods were held with the dry ice frozen by LN_2. During the preliminary tests, a mass of the frost was observed on the Dewar lid as shown in Fig.5 (upper-left image), due to the temperature difference between R.T. and the surface of the Dewar vessel. That frost blocked the maneuvering of the drill loading systems and made it difficult to bore the hole correctly. Similarly, the LN_2 level detector was also frosted so that it led its malfunction due to the ice clogged.

To avoid the frost, the dedicated heater was equipped on the Dewar lid and the LN_2 level detector as shown in Fig. 5 (lower-right image). The shape of the Dewar lid is quite complicated and the space remaining under the maneuvering area is quite tight. And it is also needed to prevent the conflict with the drill bit. Therefore, the rubber heater was hired according to its flexibility, thickness and cost. With this improvement, no condensation was observed during the processing and it made possible to ensure the correct maneuvering of the driving system for the accurate boring.

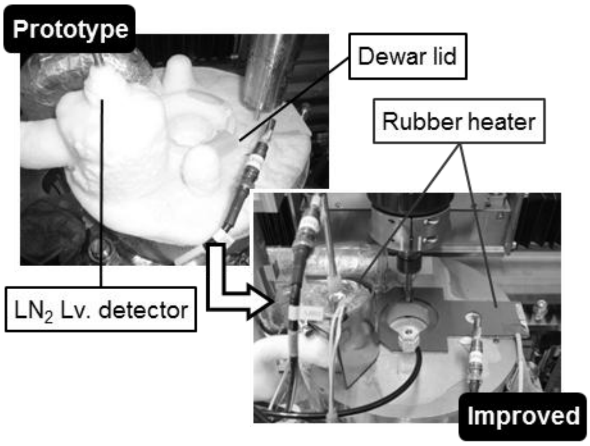

Fig. 5 Rubber heater on the Dewar lid

2.5 Other improvements

Fig. 6 shows the outside view of the improved boring device. The most of the boring processes, such as the cooling, boring, turnings removal, sleeve insertion and un-freezing, are automated for the easy operations by the master-slave manipulators.

The upper unit, which includes the processing unit and the turning cleaner, can be disconnected from the bench of the hot cell by the remote operation, and the vacant space can be furnished as the flat surface with the cover plate. It is beneficial for the easy maintenance and decontamination of itself, and also for the efficient utilization of the hot cell.

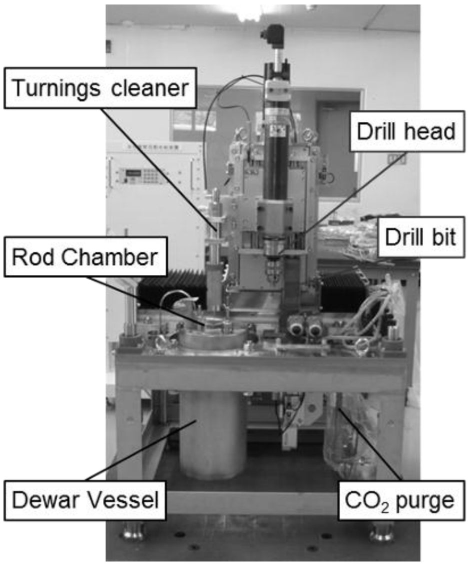

Fig. 6 Improved center boring device

3. PERFORMANCE TEST

The cold tests were performed with the dummy pellets to confirm the efficiency of the improvements of the center boring device. Based on the hardness of the irradiated pellets, the dummy pellets were made of barium ferrite and the target dimension of the boring is 40 mm in depth, 2.5 mm in diameter.

Fig. 7 shows the test result of the cold test to compare the boring speed between by the prototype device with the improved device. In case of the prototype device, the boring speed was slowed down repeatedly due to the blockage by the remained turnings. As a result, it took approximately 19 hours to bore a single hole. On the other hand, the boring speed by the improved device was kept constant during the whole process and the total boring time can be reduced 3 hours, less than 16% of prototype. It means that the boring blockage by the remains of turnings could be avoided by the ejection function of twist drill bit. And it was confirmed that the twist drill bit has the enough strength to bear against the rotation torque, because no breakage of the twist drill bit occurred.

Regarding the newly designed turnings cleaner, its collection rate achieved over 95% with the air filter of 5 μm mesh and the mist separator of 0.3 μm mesh. Therefore, it is suggested that the turnings cleaner will be able to keep the contamination minimum also in the hot cell environment. With the inching motion, the hole was bored precisely at the pellet center without the unfixing of the pellets and the rubber heater made it possible to ensure the correct maneuvering of the driving system for the accurate boring.

With the X-ray radiography, it was confirmed that the hole was bored correctly at the pellet center and there is no movement of the pellets during the boring.

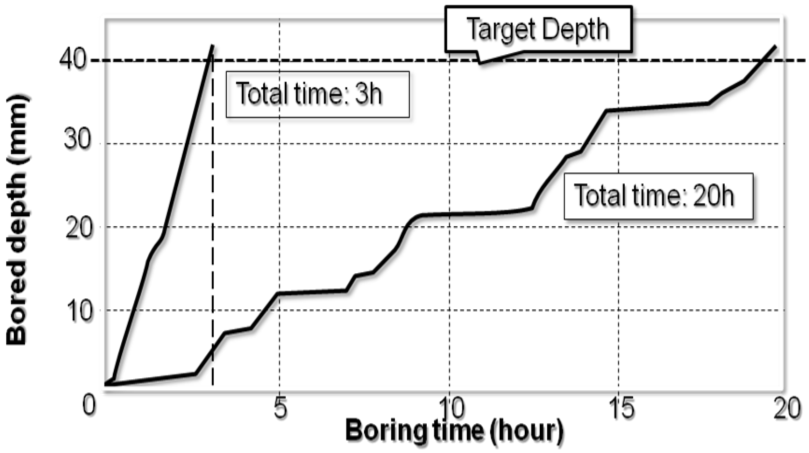

Fig. 7 Comparison of boring speed between improved and prototype drills

4. CONCLUSIONS

The center boring device for the irradiated fuel pellet was improved to fabricate the fuel rod for the power ramp test. Based on the preliminary test with the prototype device, several improvements were applied to upgrade its boring performance and reliability.

With the performance test using the dummy pellet, it was confirmed that the new drill bit could reduce the total boring time as less than 16% of prototype without the breakage of the drill bit, and the newly designed turnings cleaner could collect over 95% of the turnings. Furthermore, the inching motion and the rubber heater made it possible to ensure its processing reliability with the enough boring accuracy. Additionally, the other improvements were beneficial for the remote operation, and the utilization of the hot cell.

The improved device was installed into the hot cell to perform the hot test with the irradiated fuel pellet for the confirmation of its boring reliability and also its remote operability. After this confirmation, the test rods will be fabricated to provide them to the power ramp test.

ACKNOWLEDGMENT

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REFERENCES

[1] M. Shimizu et al, Development of Thermocouple Re-instrumentation Technique for Irradiated Fuel Rod, **JAERI-Tech 95-037** (1995) (In Japanese)