Development of a precise drilling machine for a nuclear fuel pellet

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1. Introduction

When a new nuclear fuel is developed, an irradiation test needs to be carried out in the research reactor to analyze the performance of the new nuclear fuel. In addition, to check the performance of a nuclear fuel during the burn up test in the test loop, it is necessary to attach sensors near the fuel rod and connect them with instrumentation cables to the measuring device located outside of the reactor pool. In particular, to check the temperature fluctuation of a nuclear fuel during an irradiation test, a C-type thermocouple should be instrumented at the center of the nuclear fuel. Therefore, a hole needs to be made at the center of the fuel pellet to put in the thermocouple. However, because the hardness and density of a sintered UO2 pellet are very high, it is difficult to make a small fine hole on a sintered UO2 pellet using a simple drilling machine.

The author developed an automated drilling machine which makes a fine hole in a fuel pellet without changing tools or breakage of the workpiece. Its performance is then verified by primary experiments using sintered Alumina, which has a similar hardness and density with a sintered UO2 pellet.

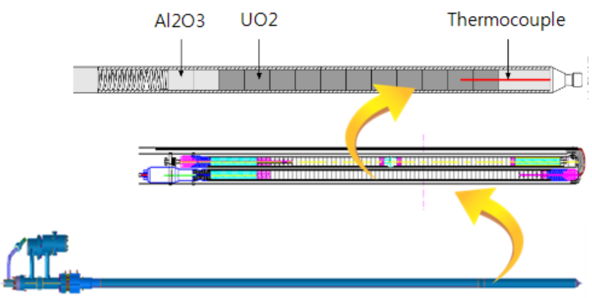


Fig. 1. Section view of fuel rod in the IPS

2. Development of a drilling machine

2.1 Material properties of a fresh fuel pellet

Materials and their properties used in this study are as follows.

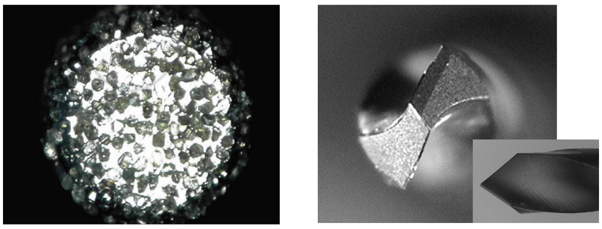
(1) Workpiece: sintered UO_2 (cylindrical/annular), sintered alumina (Al_2O_3)
- Diameter: ϕ8.0~15.0
- Height: 10.0mm

(2) Material property:
- Density 10.3g/cm3
- Hardness 700Hv (HRC 61)
- Yield stress 370MPa

(3) Tooling type:
- hole drilling
- hole diameter ϕ0.7~ ϕ1.2 (±0.05)
- hole depth 1.0~15.0mm (±0.1)

2.2 Drilling tip

As shown in Fig. 2(a), a flat type cylindrical drill tip made by a diamond plated method is conventionally used in making a hole on a fuel pellet. However, because a flat-type drill tip cannot eliminate chips generated during drilling process, the chips stick to the drill tip and clog its movement. Therefore, the drill tip is rapidly worn out and the machine needs to stop and changes drill tip two or three times in making only one hole on a fuel pellet. To avoid this problem, a twist type drill tip coated with diamond is selected in this study as shown in Fig. 2(b). The drill tip is made of WC (Tungsten carbide), whose diameter is ϕ1.0, and the thickness of the diamond coating is 12 μm.



(a) Flat type cylindrical tip (conventional)   (b) Twist type tip

Fig. 2. Drill tip for nuclear fuel

2.3 Design and development of a drilling machine

Fig. 3 shows the modeling of the drill machine and its implemented machine. First, a fuel pellet can be fixed on a chuck assembled on the X-Y table to adjust the position to be drilled. A drill tip is attached to a high-frequency spindle and has 2.2kW power and 30,000 rpm. To remove the heat generated by a high speed rotation, 21℃ cooling water is circulated by a chiller. And, the drill tip is vertically fed to the fuel pellet whose position and feed rate are controlled with a step motor, a ball bearing, and two LM guides. Feeding is controlled by up to 0.01mm, and the feed rate is controlled by up to 0.1mm/min.

During the drilling process, because the heat generated by friction between the drill tip and workpiece affects the tool wear and oxidation of a fuel pellet, cooling water should be continuously supplied to the drill tip. In addition, because this cooling water will be mixed with chips from the nuclear fuel, it is circulated in a closed loop so as not to pollute the circumstance of the tools, and then filtered with an HEPA filter.

To enhance the tool life by completely removing chips generated during the drilling process, a step motor that controls the position of the spindle is programmed to feed a drill tip stepwise and come back to the initial position. The cooling water then eliminates the chips remained in the hole and lets the drill tip cool down. This stepwise tooling is repeated until the drill tip reaches the target depth.

Finally, the tooling part is doubly encapsulated by the plastic panel to prevent the spread of chips and to enhance the safety of the human body from the potential danger of broken tools.

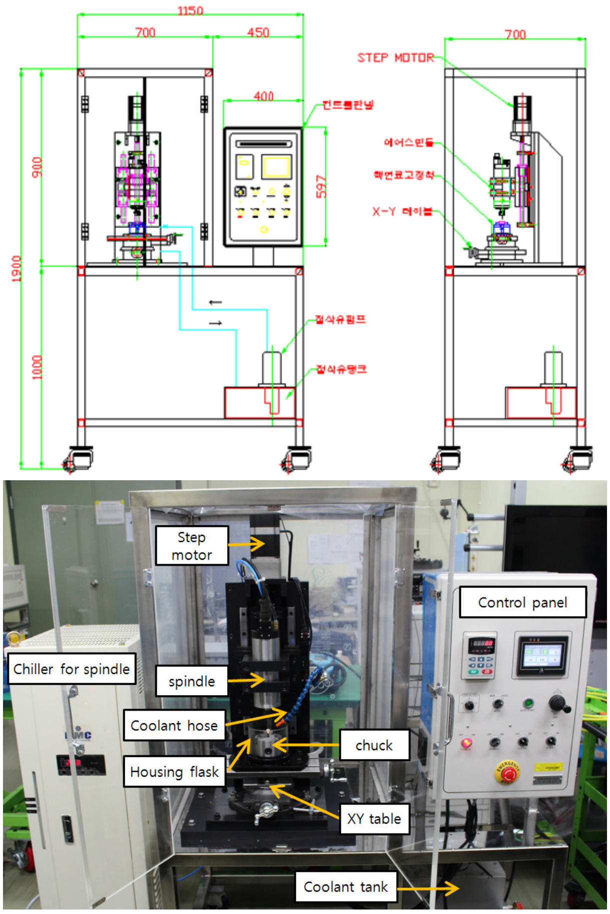


Fig. 3. Modeling and implemented drilling machine

3. Primary test results

A primary drilling test was carried out with an Alumina, whose properties are higher than a fresh nuclear fuel pellet. Referencing the previous study, which uses a flat-type cylindrical tip, the rotating speed of the spindle was set to 8000rpm. Also, the total feed was 12mm, which considers tooling margin, and the amount of feed rate was 5mm/min and step feed was 0.15mm/step.

Fig. 4 shows the results of drilling on a sintered alumina block (99.7%), which shows that a fine hole whose diameter is ϕ 1.004mm was made with the implemented machine in this study. In addition, it takes 30 minutes and only one drill tip to make a hole on the alumina, which needs more than 16 hours and three drill tips in the conventional study.

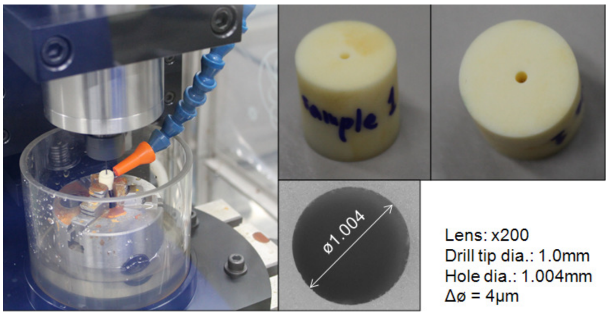


Fig. 4. Drilling experiment using a sintered alumina

4. Conclusions

In this study, an automated drilling machine for making a hole on a nuclear fuel pellet to install a thermocouple and an instrumentation cable was implemented, and a primary test was carried out using sintered alumina, which has similar properties to a fresh nuclear fuel pellet. As a result, a fine hole could be drilled with a single drill tip in 30 minutes.

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