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Novel machining method to fabricate a large size turbine disks with mandrel type fixturing jig and EDM on a multi-tasking machine

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Abstract
Turbine disk is important parts of gas turbine engine or jet engine. However, the manufacturing process of turbine disk is complicated. It needs several times of changeover and expensive equipments. Then, we developed a novel machining method for a large size turbine disk using a multitasking machine. A special jig called "mandrel type fixturing jig" which clamps the turbine disk from the inner side of the bore hole of the turbine disk was developed. In addition, a wire electrical discharge machining unit was introduced on the multi-tasking machine for rough machining of fir tree slots. Then, a complete turbine disk can be machined without changing the setup on one machine tool.

Key Words: Multi-tasking machine, Turbine disk, Cutting, Wire EDM

1. Introduction

A gas turbine engine has turbine disks to which are attached turbine blades. Manufacturing process of turbine disk is very complicated and time consuming [1]. It is usually machined on a vertical lathe and its one side is machined, and then the other side is machined after inverting the disk. It is repeated several times to minimize the distortion caused by the residual stress induced during the machining process [2] and the forging process [3]. Subsequently, the fir tree slots are manufactured utilizing a broaching process. This process is also expensive and time consuming.

To solve these problems, a new method to fabricate a large size turbine disk using a multi-tasking machine (multi-tasking lathe) is developed in this study. The proposed machining method is composed of two kinds of machining strategy. First, a special mandrel type fixturing jig which clamps the turbine disk from inner side of the bore hole of the turbine disk was developed. As a result, the both side surfaces and the circumference of the turbine disk can be machined by milling tools or turning tools on the multi-tasking machine without any setting changes. Several microns of distortion was caused when the chucking force was released but it was within the tolerance.

Secondly, a wire electrical discharge machining (EDM) unit was introduced on the multi-tasking machine for rough machining of fir tree slots. A trial disk was machined with the proposed system successfully. Developed machining method can contribute to both machining efficiency and accuracy.

2. Turning of turbine disk using mandrel type fixturing jig

Figure 1 shows the configuration of mandrel type fixturing jig. Target diameter of the turbine disk is larger than 600 mm. A mandrel type fixturing device is composed of a long shaft and a fixturing device which clamps the turbine disk by expanding the inner side of the bore. The jig is 2700 mm in length, and it was set to the multi-tasking machine (Mazak INTEGREX e-650H-SII) as shown in Fig.2. Then the turbine disk is clamped at the centre of the jig. The employed multi-tasking machine equips the milling spindle, second turning spindle and the work piece rest. The peripheral face and both side faces can be machined by the turning tool attached on the milling spindle. Two side

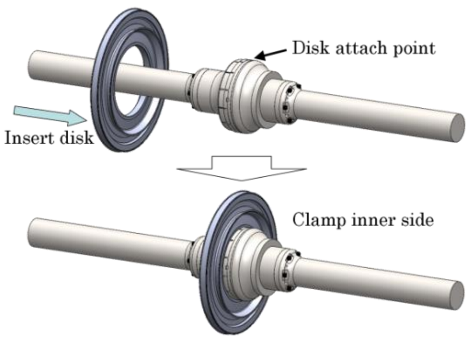

Figure 1. Configuration of mandrel type fixturing jig

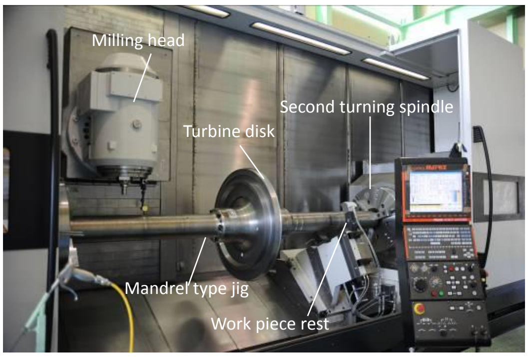

Figure 2. Set up for machining on multi-tasking machine utilizing mandrel type fixturing jig

surfaces and outer peripheral surface can be machined from rough cutting to finish cutting without any set up change if the inner bore of the turbine disk is machined in advance. In addition, if the clamping force acting on the inner bore of the turbine disk is set appropriately, the out-of-plane deformation of the thin turbine disk can be avoided. In order to minimize the distortion of the turbine disk originated from the residual stress induced during the forging process, it is necessary to repeat to machine two side surfaces alternatively. But these processes can be automated in the proposed method.

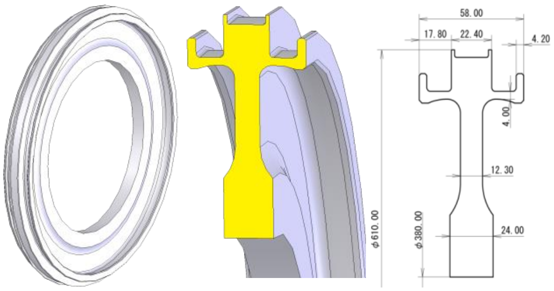

Figure 3. Appearance and cross section of the turbine disk

Utilizing the proposed fixturing jig, a turbine disk was machined. Figure 3 shows the appearance of the turbine disk and its cross section. Its diameter is 610 mm and minimum thickness is 1.8 mm. It also has 17.8 mm overhanging seal arms in both sides. Material is Ti-6Al-4V. After the rough machining, the finish cutting with depth of cut 0.2 mm was conducted. Over hanging seal arms was machined utilizing inclination control of B-axis of the multi-tasking machine with L-shaped tool. Then the whole outer surfaces were machined without changing the fixture. No chattering was observed even though the object was thin. Surface roughness was about 0.4 μmRa. Run out of the outer peripheral and out-of-plane displacement of the side surface was about 5 μm. After it was released from the fixturing jig, the circularity of the outer peripheral was 0.015 mm and dimension accuracy was within $\pm$ 0.1 mm.

Machining accuracy was rather high and the out-of-plane deformation caused by the unbalance of the residual stress was avoided, but some deformation occurred when the disk was released from the fixturing jig. Especially on the part of the seal arm, the side surface inclined toward the inside. It seems that the release of the clamping force affected the slight deformation of the seal arm. The clamping force should be securely set to support the workpiece against the cutting force and the centrifugal force. However, excessive clamping force leads to a deformation of the disk. Appropriate level of the clamping force should be studied as the future work.

3. Slot machining with wire-EDM on multi-tasking machine

A wire-EDM unit was installed on the multi-tasking machine to enable the rough slots machining. It substitutes the broaching which is time consuming and expensive process [4]. As the affected layer by high temperature is generated on the EDM process, we assume that a finish machining with formed milling cutter is necessary. Figure 4 shows the configuration of a wire-EDM unit on the multi-tasking machine. U-shaped wire holding unit was attached to the milling head. It guides the EDM wire and it also holds fluid supplying nozzle. Water tank was set under the turbine disk and then the EDM machining point to cut a slot was submerged in the water. Power source of EDM unit, wire feeding unit, EDM fluid supplying unit, filtering unit with ion-exchange resin were settled outside of the multi-tasking machine.

Figure 5 shows the machining point and the machined slots on Inconel 718 turbine disk. Feed speed was set constant 1.35 mm/min. As the servo feed control to keep the spark gap constant, which is popular on the conventional EDM, wasn't employed in the developed system, the feed speed was set low enough to avoid the short circuit between the wire and the work piece. Then, slots were machined successfully without the breaking of the wire. As the stiffness of the U-shaped wire holding unit was not high enough, the machining accuracy was not so high. However, it is enough for rough machining. The slots can be finished by the formed milling tool without the change of fixturing state of the turbine disk just after the EDM rough slot machining.

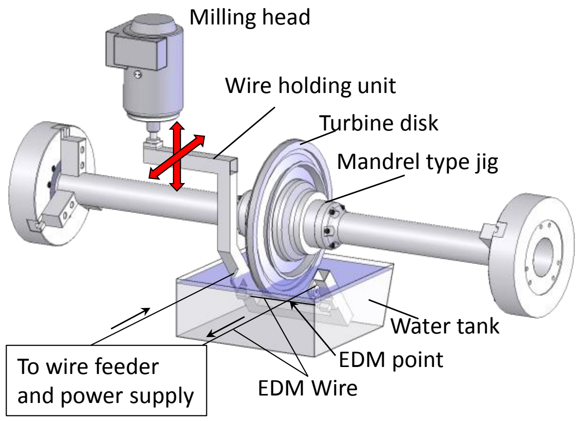

Figure 4. EDM unit installed in the multi-tasking machine

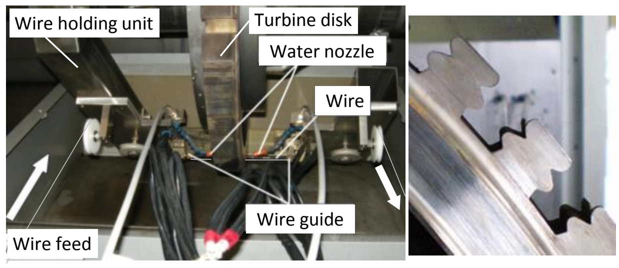

Figure 5. Machining point and machined fir tree slots by EDM

4. Summary

The results of this study can be summarized as follows.

1) A special mandrel type fixturing jig which clamps the turbine disk from inner side of the bore hole of the turbine disk was developed.
2) Two side surfaces and outer peripheral of the large size thin turbine disk can be machined without changing the fixturing state using the proposed mandrel type fixturing jig utilizing the multi-tasking machine.
3) A wire-EDM unit was introduced on the multi-tasking machine for rough cut of fir tree slots. A trial disk made of Inconel 718 was machined with the proposed system successfully.

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