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Development of a directly-driven thread whirling unit with advanced tool materials for mass-production of implantable medical parts

Masakazu Soshi [a,*], Franco Rigolone [b], Jennifer Sheffield [a], Kazuo Yamazaki (1)[a]

[a] Department of Mechanical and Aerospace Engineering, University of California Davis, One Shields Avenue Davis, CA, 95616, USA
[b] GILDEMEISTER Italiana S.p.A., Via G. Donizetti, 138, 24030 Brembate di Sopra BG, Italy

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ABSTRACT

Medical screws are a common mass-produced implantable medical component made of Titanium. To machine the threads of these types of components, thread whirling with carbide tools is typically used. However, tool wear and low cutting speed limit the productivity and increase the manufacturing cost of such medical parts. In this study, a direct motor driven thread whirling unit for an advanced Swiss-type CNC lathe was developed and it was used with advanced tool materials such as low binder content Cubic boron nitride (CBN) and Polycrystalline diamond (PCD) to find a cost-effective and more productive alternative to carbide tools.

1. Introduction

The need for more productive and cost effective medical manufacturing is rapidly increasing due to the aging population, higher standards for quality of life, and high healthcare costs. One example of a mass-produced, commonly implanted medical component is a medical screw made of titanium alloys as examples shown in Fig. 1. Threaded medical components are used in applications ranging from spinal surgery, orthopedics, dental, and maxillofacial applications.

Swiss-type machining is often utilized for manufacturing parts with high length to diameter ratios including medical screws. This is due to the use of a guide bush, pictured in Fig. 2, that offers the workpiece additional support and avoids deflections and vibrations. The guide bush supports the outer diameter of the stock material. Thus, radial operations such as turning or milling always occur near the guide bush. This allows for the tools to continuously be close to the guide bush.

Swiss-type turning is fundamental to produce threaded medical components. However, conventional single point thread turning causes some issues when applied to machining threads on a Swiss-type lathe. Since multiple passes are needed, the part loses the support of the guide bush after the first pass resulting in loss of rigidity and increased chance of deflection [1].

Fig. 1. Examples of medical screws.

The use of thread whirling, seen in Fig. 3, offers the benefit of completing the thread in a single pass. Since the thread is complete after one pass there is no loss of rigidity or support. In addition, the use of multiple cutting tools allows for a smaller chip load and therefore smaller cutting forces. Around 90% of all threads in the dental and medical industries are produced by thread whirling [2].

The principle of the thread whirling process is as follows. The workpiece is rotated at a relatively slow speed and fed in the Z-axis to control the pitch. The cutting is performed by multiple cutting inserts arranged within a whirling ring. The workpiece is positioned off-center to the whirling ring. The ring is inclined to the pitch angle and rotates at a high speed determined by the required cutting speed.

Thread whirling for titanium medical screws are typically done by a mechanical whirling unit with carbide tools. This limits the productivity mainly because of poor tool performance, low cutting speed, and existence of backlash in the whirling unit. Thus, an alternative approach is required for better manufacturing performance. Therefore, this research aims to achieve followings:

- To design and develop a thread whirling unit with a direct drive motor for advanced tool materials.
- To test performance of advanced tool materials in conjunction with the developed machine for improving manufacturability including higher productivity and cost effectiveness.

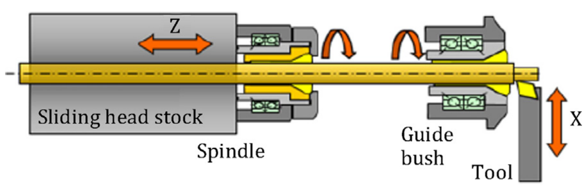

Fig. 2. Swiss-type machining configuration.

* Corresponding author.
E-mail address: msoshi@ucdavis.edu (M. Soshi).

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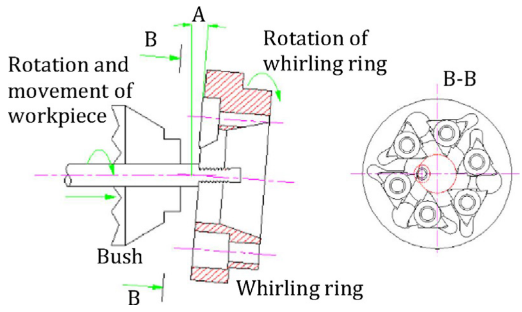

Fig. 3. Thread whirling on Swiss-type configuration [1].

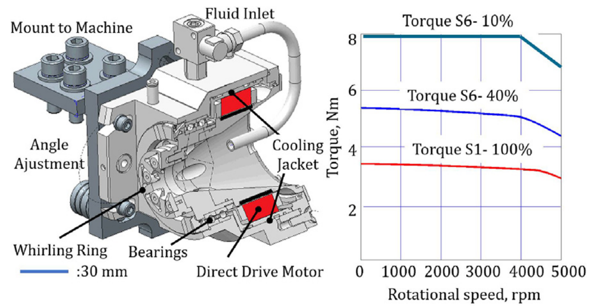

Fig. 5. Directly-driven thread whirling unit and its torque curve.

2. Directly-driven thread whirling unit

A good machine tool is essential for a better manufacturing result. It was reported in past CIRP papers that a tool life can be improved by stabilizing rotational speed of a machine tool spindle [3–5]. In the case of the thread whirling, the whirling unit is the main source of generating cutting speed and thus a key unit for the application.

2.1. Conventional mechanical whirling unit

To rotate the whirling ring, a mechanical unit as shown in Fig. 4 as a typical example has been used. A drive motor is connected to a drive shaft and then the rotational movement and torque from the drive motor are transmitted to a thread whirling ring. A gear box is usually adopted to achieve a desired torque and speed. Because of the complexity of the mechanical components and existence of a gear backlash, the maximum speed is typically limited (up to 3000 rpm), and vibrations during machining were a typical problem.

2.2. Developed directly-driven whirling unit

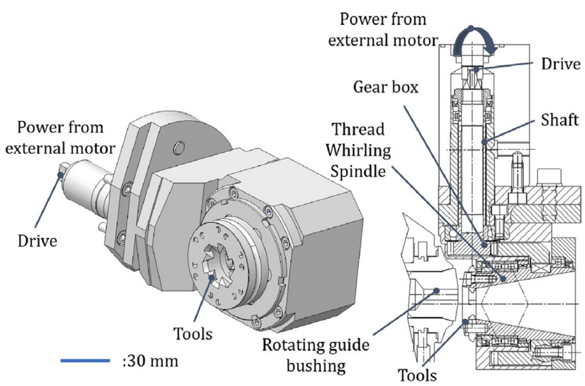

Fig. 4. Overview (left) and section view (right) of conventional mechanical thread whirling unit.

A new whirling unit was developed to overcome the drawbacks of the mechanical unit. The schematic and torque curves of the developed unit are shown in Fig. 5. S1 in the torque curve indicates continuous duty cycle while S6 denotes continuous operation with periodic duty. A synchronous motor was directly built in to the thread whirling spindle. Hence, there is no backlash and it provides stable rotation during machining which also provides more stable machining than the conventional whirling unit. The thread whirling device is controlled on speed loop by a driver without an encoder. Based on the back EMF that the synchronous built-in motor generates when rotating, an algorithm measures the actual speed and adjusts it to get the commanded reference speed. The sensor-less control allows following benefits:

- To achieve a much compact and simplified mechanical design – easier assembly into machine tool working area
- To increase system reliability – no sensor into the thread whirling device
- To guarantee the higher max. speed (up to 5000 rpm) for cutting process optimization by mean of new inserts using advanced tool materials.

2.3. Performance comparison test

After successfully developing the direct drive thread whirling unit, a comparison study was conducted. The base machine used for this and the rest of experiments in this paper is the DMG MORI SPRINT 20|8 linear automatic lathe with a Swiss-type kit shown in Fig. 6. This machine is equipped with a linear motor for the X1 linear axis for high speed and high dynamic performance. Experiments were conducted with the conventional and newly developed direct drive whirling units using common cutting conditions for thread whirling of Ti–6Al–4V which was also the material used for this study. The same cutting conditions shown in Table 1 were adopted to the both cases with TI25 carbide tools manufactured by HORN. The key dimensions of the screw thread are shown in Fig. 7.

The machining results in terms of number of parts machined over surface roughness of the thread is shown in Fig. 8. Surface roughness was selected to observe because it usually determines the quality of the produced parts and the life of the cutting tools.

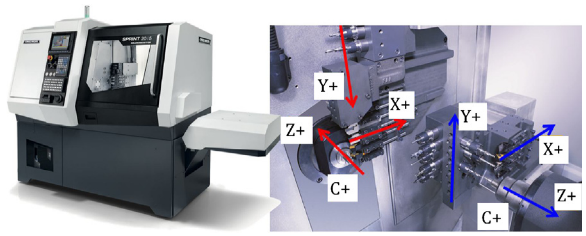

Fig. 6. Overview of the Swiss-type machine and its workspace.

Table 1
Cutting conditions for the comparison test.

Insert material (& edge preparation)	Cutting speed (m/min)	Feed rate (mm/rev × z)
Carbide TI25 (honed)	100	0.012

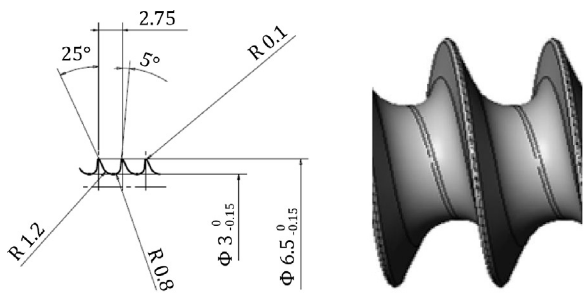

Fig. 7. Bone screw thread dimensions and geometry.