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Non-Contact Type On-Machine Measurement System for Turbine Blade

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Abstract

In turbine blade machining from a near net shape (e.g., forged workpiece), it is difficult to use a touch trigger probe for measuring the mounting angle of the workpiece due to its uncertain free-form surface. Therefore, non-contact measurement is required to determine the setup condition of the workpiece. Recently a high-performance laser displacement sensor has been able to measure glossy metal surfaces because of the progress in its sensing device. Using such a high-performance sensor, the non-contact type on-machine measurement system has been developed. It was installed on the multi-functional machine tool to determine validity of the system. This system measured the turbine blade cross-section to compare with CAD data and the measurement data by coordinate measuring machine (CMM). As a result, validity of this system for measuring a turbine blade was proved. We have proposed some application using this measurement system. The application enables optimal machining of a turbine blade from a near net shape at an appropriate phase. This contributes to minimizing the size of expensive material and the machining time.

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Keywords: Laser; Sensor; Machine tool

1. Introduction

Nickel-base superalloy is widely used for turbine blade [1,2]. This material is 20 times more expensive than SC steel. Therefore, it is important to reduce removal amount in turbine blade machining. Machining from a near net shape (e.g., forged workpiece) proactively contributes to reducing waste of material. To machine a specified shape from an uncertain shaped forged workpiece, it is inevitable to accurately define the position of the workpiece that is mounted on the machine. Currently, to accurately define a workpiece position, a special fixture is used to hold the workpiece at the specified position, or a reference area is provided on the workpiece in advance for position measurement using a touch trigger probe [3]. However, manufacturing special fixtures for each turbine blade shape is costly, and additional time is required for designing and manufacturing these special fixtures. Moreover, the whole workpiece shape cannot be recognized by a touch trigger probe because it measures a reference area only. Due to this uncertainly in measurement, the near net shaped workpiece is manufactured larger than the actual dimension, which results in extra material cost.

To reduce this extra cost, the whole workpiece shape needs to be defined on a machine tool. Although a non-contact sensor is preferable, a widely known laser displacement sensor based on triangulation is not applicable to glossy metal surface measurement without powder splayed on the specular machined surface. Therefore, using a laser displacement sensor on a machine was not realistic [4].

On the other hand, controlling laser output for measuring glossy metal surfaces in real time is a recent trend [5].

In this paper, a non-contact type on-machine measurement system has been developed. This system enables to measure glossy metal surface by employing the latest laser displacement sensor with laser output control function and

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higher sensitivity of light receiving element. This system has been installed on the multi-functional machine tool.

The robustness for on-machine measurement was assessed through measuring a glossy metal surface of a gauge block, which used to be impossible to be measured with a conventional laser sensor. This system also measured the turbine blade cross-section to compare with CAD data and the measurement data by CMM. The comparison result proved the validity of this system for measuring a turbine blade.

This system can measure a workpiece whole shape clamped by the chuck on a machine tool. Furthermore, this paper shows solutions to determine the reference posture for machining by measuring multiple cross-sections of the turbine blade with this system.

2. Development of non-contact on-machine measurement system

The non-contact type on-machine measurement system developed in this paper has been installed on the NT4250 DCG multi-functional machine tool, which is widely used for turbine blade machining. Principal components of this system are follows:

- Sensor head mounted on the tool spindle
- Interface to upload measurement data using the sensor head and its position data to the control unit of a machine tool
- Time-delay circuit to synchronize timings for obtaining measurement data and sensor head position
- Software to calculate the 3D coordinate of a measurement point on a material surface from the measurement data and the sensor head position

An overview of this system is shown in Fig. 1.

Details of the main parts are described in the following sections.

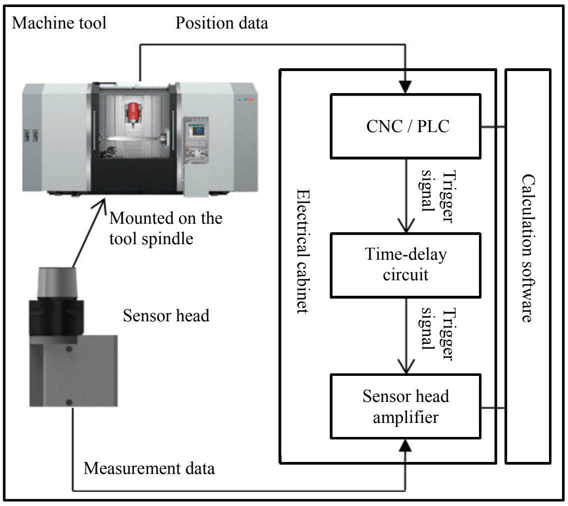

Fig. 1. Overview of this system

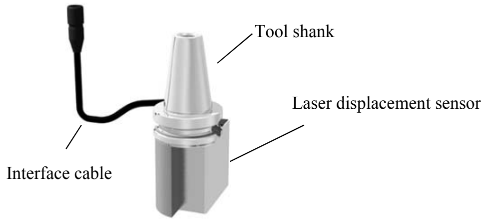

Fig. 2. Overview of sensor head

2.1. Sensor head

The sensor head developed in this paper for this system is shown in Fig. 2. This head composes of a tool shank, which is clamped to the tool spindle of a machine tool, a laser displacement sensor, and an interface cable for power supply and data transfer. This head is mounted on the tool spindle and the interface cable is connected to the machine, so that the laser beam is emitted from the laser displacement sensor to start measurement based on the principle of triangulation [6]. A safety circuit is incorporated in the system to detect cable connection and control rotation of the tool spindle. The sensor head always has a little inclination with respect to the tool spindle axis. When a phase of the tool spindle changes, the spot at which the laser beam is emitted is shifted. Therefore, the tool spindle is always oriented to the same rotary position during measurement.

Major specifications of the laser displacement sensor are shown in Table 1. In the triangulation method based on diffuse reflection detection, measurement ability for a glossy metal surface depends largely on laser power and sensitivity [7]. Using laser displacement sensor has the highly sensitive CMOS sensor in the light receiving unit, which enables the laser displacement sensor to control laser output so that the light receiving unit always receives optimum amount of light. Therefore, even if a small amount of light is reflected from specular machined surfaces to the light receiving unit, measurement values can be obtained due to enhanced laser output and sensibility of the CMOS sensor. This sensing function plays a crucial role in non-contact type on-machine measurement.

Table 1. Major specifications of the laser displacement sensor.

Reference distance	50mm
Measurement range	20mm (+/- 10mm)
Spot diameter at reference distance	50µm
Repeatability	0.025µm

The laser displacement sensor has a measurement range of 20 mm, which makes it possible to measure surface profiles smaller than its measurement range with linear motion only (Fig. 3).