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# Dimensional measurement based on rotating wire probe and acoustic emission

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Due to increasing trends of miniaturization, components with micro-scale features are in high demands. Dimensional measurement of these parts is important but conventional systems are quite costly and time consuming. Therefore, a new cost-effective way for dimensional measurement is needed. This study presents a novel concept of three dimensional measurements using a rotating wire as a probe and acoustic emission (AE) for contact sensing. Experimental results show that the probing system can measure a part with high repeatability. A controller algorithm has been developed for automated scanning within a machine tool. The performance is verified against calibration artifacts.



## 1. Introduction

Increasing trends of product miniaturization and needs for 3D complex geometry with relative accuracy of $10^{-3}$–$10^{-5}$ demand appropriate quality control of fabricated micro-scale features and components. For dimensional control, most available systems in the market are coordinate measuring machines (CMMs) and vision or laser systems, and atomic force microscopes (AFMs). These are confined within the scope of macro-scale and nano-scale parts, respectively. For systems developed to measure meso/micro-scale features and components, it is difficult to justify the high cost and large size of these systems for dimensional verification of the miniature parts with 3D features. Therefore, a new cost-effective way of measuring meso/micro-scale components and features is needed.

Probing technologies using micro-scale probes have been introduced by many researchers and in general they fall mainly into two categories: first method is by touching an object surface with sensing elements such as probe tip and the other is to detect the surface based on non-contact methods using laser or optical sensors [1]. Since devices based non-contact methods tend to be high in cost and their accuracy depends on part surfaces, this paper focuses on the tactile probing method. Various probing systems with piezoresistance sensors have been developed with cost-effective and robust transducers allowing easy and accurate measurements [2–4]. However, for 3D measurements, three sensors are needed for the probe, which makes the probing units large and complex. Alternative methods have also been adopted for 3D contact micro-probing system such as micro-probe with optical position detector based on three diode lasers, which limit the probing force less than 1 mN [5–10].

Recently, a new probing system that consists of a wire probe and an acoustic emission (AE) sensor for touch detection has been reported [11]. It was demonstrated that use of a rotating wire and AE sensor can be quite promising as a cost-effective and accurate probing system. The wire probe is relatively easy to fabricate, and the AE-based detection method is very cost-effective and highly sensitive. Besides, the spinning probe overcomes the "snap-in" and adhesion of the probes to the workpiece surface during

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the touching operation, which is a major problem for typical micro-scale probes. However, only the feasibility of the new probing system was reported, and in-depth evaluation of the system as well as automated scanning capability has not been demonstrated.

In this study, the automated scanning system using a rotating wire probe and AE sensor for coordinate measurement is presented. The organization of the paper is as follows: the basic concept of AE based sensing mechanism along with the wire probe geometry is addressed. Automatic part measurement algorithm is introduced and experiments are conducted to study the effects of different parameters associated with the wire probe on repeatability, probe wear and surface damage. The system is then evaluated against calibration artifacts, followed by measurements of machined component features.

## 2. Rotating wire probe and sensing mechanism

Fig. 1 shows a diagram of the wire probe structure. A stainless steel high strength wire with diameter of 0.102 mm (0.004″) is bonded to the end of the stylus. The wire is then bent at an angle, $\beta$, 45° such that, as the stylus spins, the rotational diameter of the wire tip becomes the probe effective diameter ($D_e$). The effective diameter ($D_e$) can be written as:

$$D_e = 2R_e = 2L\sin\beta \tag{1}$$

The effective diameter ($D_e$) determines the smallest feature size that can be measured with the probe. As shown in Eq. (1), the effective diameter depends on the length and angle of the wire. Fabrication of small diameter probe can be achieved simply by attaching a short length wire. As long as the wire extends out farther than the edge of the stylus, the wire probe can be used for contact sensing. The effective diameter $D_e$ has to be calibrated to identify the position of the probing element.

For the probe tip structure, simple and low-cost interchangeable probe was fabricated, as shown in Fig. 1. Thin stainless steel wire with diameter of 177 μm was bonded into a stainless steel tube with the inner diameter of 254 μm. The wire is then bent at the angle of 45°. Fig. 2 shows an SEM image of the probe and the wire tip. An edge can be seen at the end of the wire because the wire is cut using a cutter. Some burrs are also visible on the wire tip caused by wire cutting.

The contact sensing method using a wire probe and an AE sensor is illustrated in Fig. 3. The probe is rotated and commanded to approach the object at a given approaching feed. As soon as the rotating wire makes contact with the part surface, the AE sensor picks up a burst of generated AE signal. The AE signal is generated due to the rubbing or impact between rotating wire and the part surface. For contact sensing, the AE signal is sampled at 20 kHz and sent to the designed control software. The signal processing module determines the point of contact between the probe and the component. When the magnitude of AE signals crosses the threshold point, contact is detected, and the wire probe is stopped by calling a function in command manager to generate a command for the CNC controller. Pulses generated due to subsequent AE generation are neglected. The contact coordinates of the probe are also recorded and the probe immediately goes back to the start position.

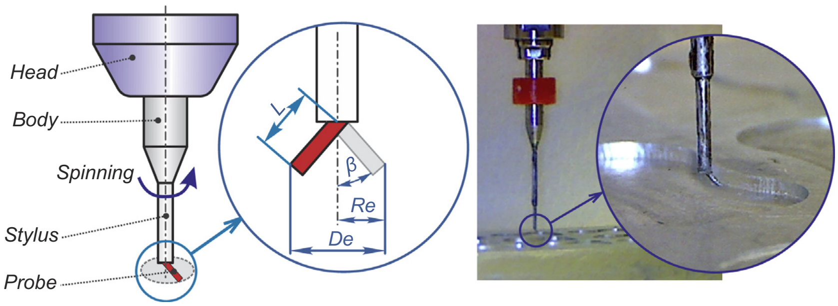


**Fig. 1.** Diagram of the wire probe tip and geometry.

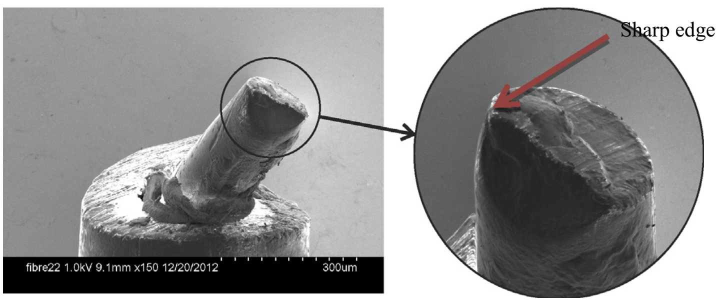


**Fig. 2.** SEM image of a typical robe tip ready for measurements.