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BURR SIZE MEASUREMENT USING A CAPACITANCE SENSOR

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Abstract

This paper involves the "on- line" measurement of burrs using a capacitance sensor. A non-contact capacitance gauging sensor is attached to an ultra precision milling machine which was used as a positioning system. The setup is used to measure burr profiles along machined workpiece edges. Experimental procedures and results as well as the basic theoretical principles of the capacitance sensor and specifications of related equipment are presented. The proposed scheme is shown to be accurate, easy to setup, and with minor modifications, readily applicable to automatic deburring processes.

KeyWords: Burr, Burr Sensing, Deburring Automation, Capacitance Sensor

1. INTRODUCTION

Burrs have been defined as undesirable projections of material beyond the edge of the workpiece due to plastic deformation during machining.[1] They cause many problems during inspection, assembly, and manufacturing automation of precision components.[2] Consequently, automation of the deburring process has become a prime objective as part of the drive to automate the entire manufacturing system.

One of the critical parts of deburring automation is burr sensing for burr detection and/or measurement and characterization of an existing burr. The main purpose of burr size measurement is to provide reliable information for a deburring controller to determine the depth of cut, and to verify the results of deburring. In addition to deburring, accurate measurements of burr size can provide a reliable database for burr formation models as well as for the setup of a burr expert system. Also, burr sensing devices are a useful tool to evaluate the quality of a machining operation on the factory floor.

Researchers have used several types of sensors or sensing systems in deburring: acoustic emission sensors [3], force and/or position sensor [4], laser distance sensor [5], laser vision sensor [6], color sensor [7], vision sensor [8, 9]. Force feedback is among the most popular choices in robotic deburring. Her and Kazerooni [4] used force feedback to control the cutting force and noraml force in a deburring system in which a rotary file is used to deburr a cylindrical part. A roller bearing was kept in continuous contact with the part edge using position feedback from the sensor. Dornfeld et al. [3] proposed to use AE (acoustic emission) signal to monitor the deburring process and serve as feedback for process control. The sensitivity of the AE signals

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to the deburring tool contact area with the workpiece was determined. They were able to use AE signals to detect the edge of a workpiece with a repeatability of 10 microns. AE signal was used as a feedback source to maintain a uniform chamfer or minimum chamfering during a deburring operation. However, it was found that once the chamfer size became greater than 0.7 mm, the AE signal saturated. When the size of chamfering is smaller than 0.5 mm, force sensor loses sensitivity, and thus, AE provides a reliable mean of deburring feedback. On the contrary, force feedback can be used reliably when the chamfer size is above the AE limit.

Shimokula and Liu [5] used a laser displacement sensor (LDS) to measure burr height for deburring feedback. A LDS was used to project a laser beam with a diameter of no greater than 230 microns onto a reflective surface. The sensor could estimate the travel distance of the laser beam between the target object and a receptor on the sensor with an accuracy as high as 0.5 microns when measuring a white, flat surface. In the case of burr measurement, the LDS projects a laser beam along burr height direction, and the distance between the point on the burr and the sensor was sensed as feedback for deburring control. A virtual link system was used to calculate the burr height. In the presence of noise, the measurement accuracy was found to be within 0.2 mm, which is not accurate enough for precision deburring.

Two types of machine vision systems (MVS) have been developed for burr size measurement. Lam [8] developed a MVS which uses a laser light source. A laser with a line-generation-lens projects a uniform, coherent strip across the edge of the workpiece generating two line segments, one on the front surface and the other on the top surface of the workpiece. A camera records the laser projections on both surfaces of the workpiece, and sends the analog image signal to a frame grabber board installed in a PC. The analog image is then converted into a binary black and white digital image by the board and is saved as an image file. Software, written in C code, is used to analyze the binary image to obtain the height of the burr at the point where the laser beam is intercepted. This method appears to be able to measure burrs height of 0.5 mm or above with acceptable accuracy. Bose-Roy [9] developed an improved version of the previous setup with an ordinary lamp as a light source. Unlike the previous system which measures an edge burr in a point-wise fashion, this system can measure a 6 mm segment of an edge at a time. Also, the resolution is improved compared to its previous version. However, the repeatability of this system was considered poor. Though machine vision systems can follow the contour of an edge burr profile within acceptable error, the resolution of these systems is not sharp enough for small burrs under 0.5 mm. They also lack the flexibility for automation, due to their complicated setup and difficulty of producing reliable results under industrial operating conditions.

Recently, capacitance sensing has become a viable option for non-contact sensing, especially for dimensional gauging problems. In this paper, an on-line burr measurement scheme using a capacitance sensor is described for burr detection and computer process control during automated deburring processes.

2. CAPACITANCE SENSOR

The measurement of distance as estimated from variations in electrical capacitance has gained popularity. In its simplest form, the capacitance sensor consists of a pair of parallel-plate electrodes separated by a dielectric media. The capacitance between the electrodes is proportional to the area of plates and inversely proportional to their separation distance. In addition to the advantage of non-contact sensing, capacitance sensing offers other advantages such as high frequency (upto 100kHz) response, high resolution, the same calibration for conductive material (if geometry is the same) and the breadth of usable range.

Early pioneers like Sherwood and Crookall [10] utilized this technology for surface roughness measurement. In their applications, surface roughness was usually obtained by comparing the capacitance of measured surfaces to that of calibrated surfaces. The sensitivity of such a sensor is proportional to the sensor probe area and falls away rapidly with increasing separation distance between probe surfaces. Garbini et al. [11] measured surface profile with reasonable accuracy using a different type of capacitance sensor. The electrode of the sensor is made of a thin metal plate which is bonded between layers of ceramic material. The electrode is kept perpendicular to the target surface. The ceramic material is used to prevent contamination and mechanical damage, as well as to obtain high accuracy by protecting it from adverse environmental conditions. Greenslet and Minis [12] extended the use of this type of sensor to measure surface roughness on a real-time, turning operation using an Extrude Hone Capscan sensor.

TABLE 1. THE SPECIFICATION OF MIDAS PROBE

Probing Force	0 Grams
Sensor Size	3 mm (Diameter)
Frequency Range	0.1-25 KHz
Frequency Range	100 m minimum
Range	2.5 mm maximum
Mounting	M 8x1.25 thread

The capacitance sensor used in this experiment is a Midas capacitance probe made by Extrude Hone company (Fig. 1). The sensor probe tip diameter is 3mm with resolution upto 0.05 microns. Frequency responds ranges from 100Hz to 25KHz. The electrodes for the Midas capacitance probe are a spherical sensor tip and the target surface of the workpiece (Fig. 2). Similar to two-plate electrodes cases, the capacitance field of this sensor is also inversely proportional to the stand-off distance h. In the case of a sphere and a plane, the capacitance has been found to be [13]:

$$C = 4\pi\varepsilon r[1 + \frac{r}{2(r+h)} + ...] \qquad (1)$$

where r is the radius of the sphere and is the dielectric constant. Higher order terms are ignored. By taking the first derivative of the capacitance with respect to h, the sensitivity as a function of standoff distance can be expressed as

$$\frac{\partial C}{\partial h} = -\frac{2\pi\varepsilon r^2}{(r+h)^2} + ... \qquad (2)$$

It is clear that the sensor is most sensitive when the probe tip is infinitely close to the workpiece surface. These characteristics are shown in calibration charts (Fig. 6, Fig. 7) presented in the next section.

FIG. 1 MIDAS SENSOR

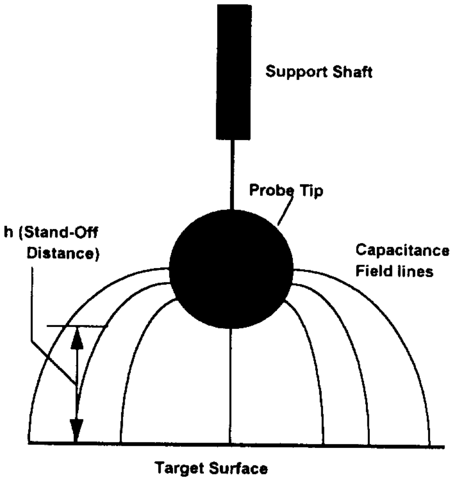


FIG. 2 MIDAS PROBE TIP AND THE CAPACITANCE FIELD

3. EXPERIMENTAL SETUP

For the on-line experiment, rectangular-shaped carbon steel ANSI 1045 and gray cast iron machined workpieces with burr and/or breakout along one side were used. An ultra precision Kugler milling machine, which controlled the position of the sensor probe to within sub-micron range, was used for the positioning system. The capacitance sensor, fixed to the positioning system, was moved and sampled burr size along the burr edge. Using a data acquisition system connected to the sensor unit, the sensing signal was obtained (Fig. 3).

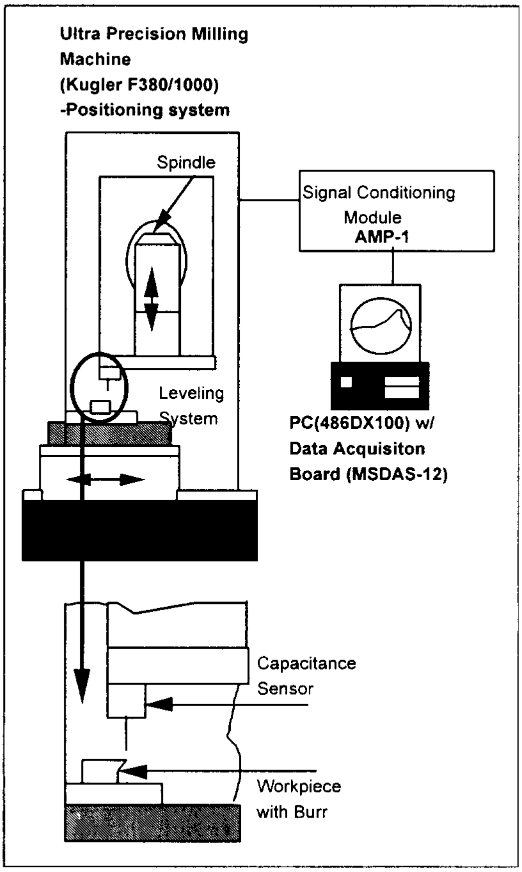
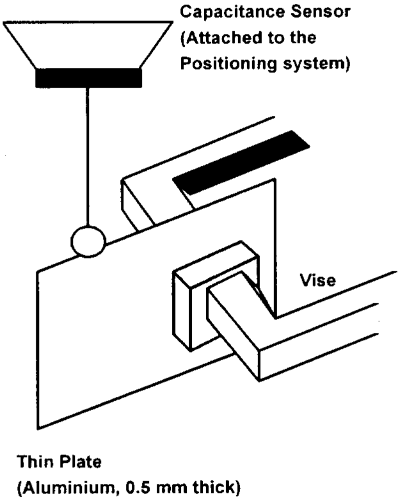


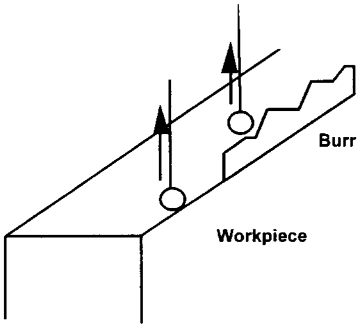
FIG. 3 THE EXPERIMENTAL SETUP FOR BURR SENSING

TABLE 2. EXPERIMENTAL EQUIPMENT

Kugler F380/1000	Travel speed: Transverse: 28-800 mm/min. Vertical: 0- 430 mm/min. Vertical Resolution: 0.1 ㎛
AMP 1 (Amplifier/Filter)	Gain: upto 1000, Low pass filter : 0.1-25KHz
Analogic MSDAS-12	12 bit, 16 channel, Max. Sampling Freq.: 200KHz



(a) Thin Plate



(b) Workpiece with burr

FIG. 4 SENSOR CALIBRATION

4. CALIBRATION

An important issue in the discussion of burr sensing is the calibration of the capacitance sensor. Detailed calibration charts for various part geometry can be generated by using this setup. During calibration, the sensor tip is placed to the side surface or burr height direction (Fig. 4). The calibration starts when the probe tip and the workpiece are in contact. The voltage output of the sensor is recorded either continuously in dynamic (continuous motion of the sensor tip) cases, or at incremental position in static (incremental motion) cases. In actual calibrations, the data shows that calibration results differ under various sensing conditions, such as specimen geometry and sensor scanning directions. For instance, Fig. 6 shows that calibration result for the burr part is different from that of a burr free workpiece. Also, dynamic cases and static cases show different results (Fig. 5). As mentioned earlier, since the sensitivity is higher when the stand-off distance is small, it is important that the probe tip be as close as possible in applications to get the most accurate results.

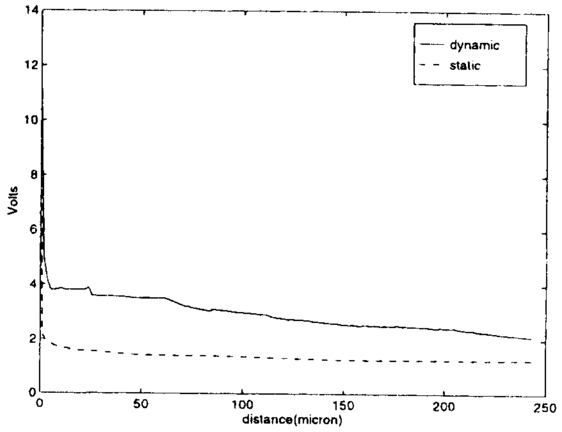


FIG. 5 CALIBRATION CHART FOR THIN PLATE

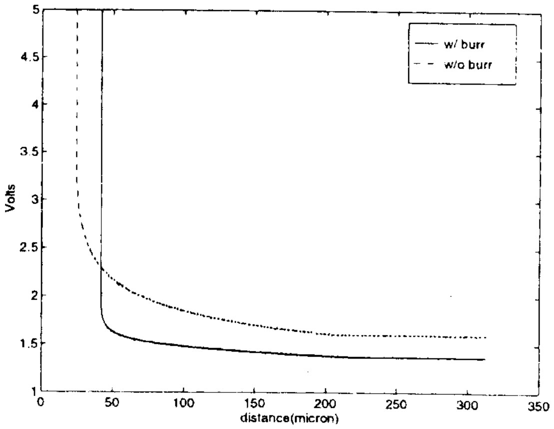


FIG. 6 CALIBRATION CHART FOR CARBON STEEL WORKPIECE (DYNAMIC).

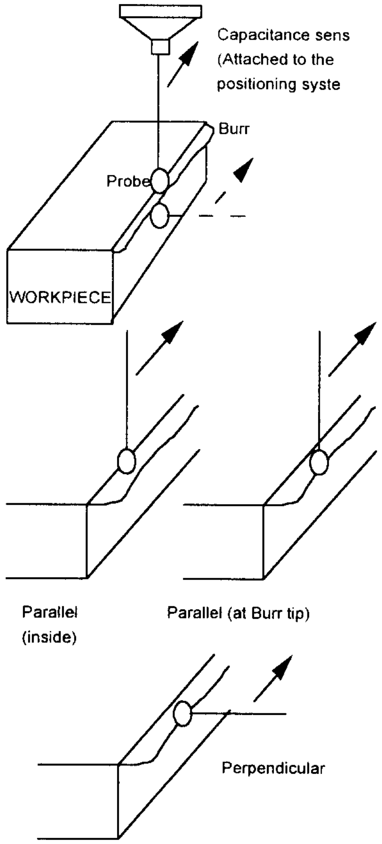


FIG. 7 SCHEMATIC OF THE BURR SENSING

5. BURR MEASUREMENT

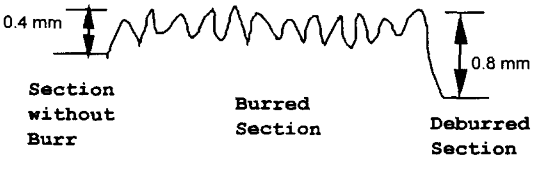
In the experiment, the sensor probe was tested in various orientations to obtain the most accurate burr data such as the burr profile along the workpiece edge and typical burr heights (Fig. 7). First, the probe was placed at a minimal distance from the workpiece edge without touching the workpiece, then moved along the workpiece in the plane of the burr height (parallel move). Similarly, it was also placed and translated in the perpendicular plane (perpendicular move). In the perpendicular move, three different paths (inside the burr, in the middle of the burr and at the burr tip) were tested to see how well the sensor could detect the differences. The signal output can be converted into physical dimensions (e.g., burr height in microns) using a calibration chart made for each specific workpiece geometry. Scanning feed rate was 1.3 mm/sec and sampling frequency was 100 Hz with gain 100. Also, the total scanned distance was 44 mm for carbon steel and 58 mm for cast iron.

6. RESULTS AND DISCUSSION

Fig. 8 shows the burr profile and burr measurement data for the carbon steel workpiece using the capacitance sensor. The specimen was prepared from a rectangular shaped workpiece. By face milling, burrs were made along a part of one workpiece edge (see Fig. 4(b)), and then a portion of the burred edge was deburred (chamfered). Consequently, the specimen consists of three sections: the original edge (without burr), a burred portion and a deburred part. The average burr height from the original workpiece edge base is approximately 0.4 mm (400 m) and 0.8 mm from the deburred edge base. In the perpendicular measurement data, the signal output was 1.55 volts for the original edge and 1.4 volts for the deburred section which corresponds to burr heights of 0.4 mm and 0.8 mm in the burr- free calibration chart, respectively. For the burred region the signal read approximately 1.6 to 1.75 volts which corresponded to values of 34-44 m from the burr calibration chart (see Table 3, also Fig. 6). From the results, it was verified that the average burr height and burr profile can be accurately measured on-line using this setup. Also, the number of peaks in the perpendicular move case is identical to the number of burrs in the picture of the specimen. For the parallel move data, scanning near the burr base (inside-the-burr) case shows better results than those of scanning at burr tip case, which implies that setting a proper scanning path of the sensor is important. The parallel motion data can be used along with perpendicular data for the detailed burr profile along the burr section.

TABLE 3. CALIBRATION DATA

Distance(m)	w/ Burr(Volts)	w/o Burr(Volts)
33.5	1.74	
44.2	1.60	
400		1.55
800		1.4



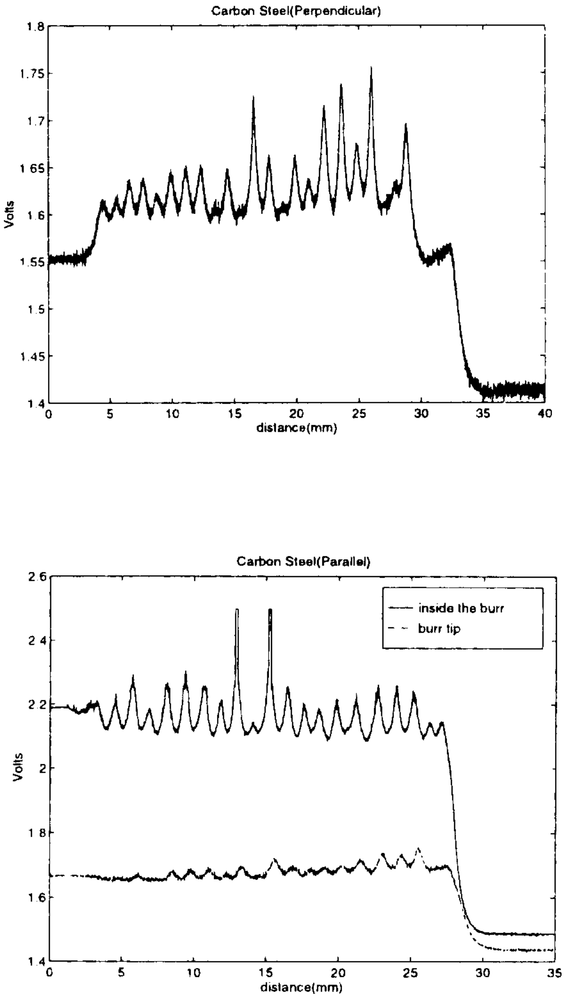


FIG. 8 SURFACE PROFILE AND BURR MEASUREMENT DATA(CARBON STEEL)

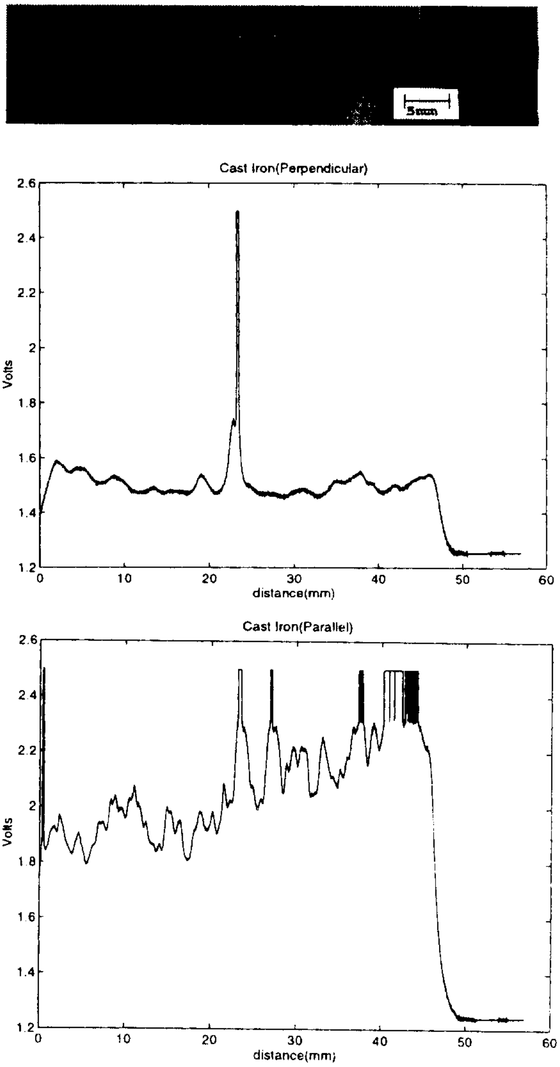


FIG. 9 SURFACE PROFILE AND BURR MEASUREMENT DATA (CAST IRON)

Fig. 9 shows the specimen and experimental data for gray cast iron. In this case, one edge of a rectangular shaped workpiece was used. Burrs were made all along the edge by face milling. The results also represent the burr shape accurately along the workpiece edge. Specially, the workpiece had an inclination to the scanning direction, which shows in the parallel move data.

From the results of the experiment, the on-line burr measurement scheme using the capacitance sensor and ultra precision milling machine is quite accurate for burr height measurement and burr profile detection. Because this sensor is not designed for burr measurement, one may need a special probe to get detailed information for each burr. But, for burr profile of a whole workpiece it shows ready applicability to a flexible manufacturing system.

As a reminder, since the calibration result is sensitive to the variation of part geometry, specific calibration data should be used. For example, for the scanning along the edge of a machined workpiece which has a combination of burr-edge and burr- free edge, one should use separate calibration chart for the burr section and burr- free section to interpret data along the entire workpiece. Also, several different sensing directions should be considered.

7. CONCLUSION

In this paper, a non-contact capacitance gauging sensor is successfully introduced to measure burr profiles. This experimental work proved the capabilities of the sensor and its applicability to an on-line burr detection and measurement scheme, which is one of the crucial part of deburring automation, when mounted to an ultra precision milling machine. Combined with an effective deburring technique, this burr sensing technology could be a very useful element of an automated deburring process.

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커패시턴스 센서를 이용한 버 감지 및 측정

한양대학교 기계공학과
이성환

초록 : 버 (burr)는 가공 중 소성 변형의 결과로써 가공 후 모서리 부분에 발생하는 물체의 원치 않는 돌출부 (projection) 라고 정의 된다. 버는 생산 부품의 검사, 조립 및 정밀 부품의 공정 자동화 등에 있어 많은 문제점들을 야기시키므로, 효과적으로 제거되어야 하며 (deburring), 특히, 생산 공정 자동화의 관점에서 보면 디버링 공정의 자동화가 전체 공정 자동화를 실현 시키는 중요한 한 부분으로 인식되어 이에 대한 다각적인 연구가 진행되고 있다. 이중 버의 감지 및 크기 측정을 위한 버 센싱은 디버링 자동화 연구 중 필수적인 한 분야인데, 본 연구는 커패시턴스 센서를 사용한 버 크기의 "on line" 측정에 관한 것이다. 비 접촉식 커패시턴스 센서가 초정밀 밀링 머신 (위치 제어 시스템으로 사용)에 부착되어 절삭 가공 후 발생된 버의 형상을 측정하는데 사용되었다. 사용된 센서의 작동원리 및 적용, 연관 실험 장비, 실험 방법 및 결과 등이 설명되었다. 제안된 방법은 정확한 측정 결과를 제공하며, 장치가 간편하고, 최소한의 장치 변형만으로 디버링 자동화 시스템에 곧바로 적용시킬 수 있는 장점을 가진다.