한국공작기계학회 '99년도 추계학술대회 논문집 pp.560~564

SENSORS IN DEBURRING AUTOMATION

Seoung Hwan Lee

Department of Mechanical Engineering
Hanyang University

ABSTRACT

Burr sensing for burr size measurement and deburring process control is one of the essential elements in an automated deburring procedure. This paper presents the implementation of capacitance sensing and acoustic emission (AE) to deburring . The first application is 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. The proposed scheme is shown to be accurate, easy to setup, and with minor modifications, readily applicable to automatic deburring processes. As the second example, AE signals were sampled and analyzed for the sensor feedback of a precision deburring process - laser deburring -. The results, such as the sensitivity of AE signals to burr shapes and edge detection capability show a clear correlation between physical process parameters and the AE signals. A subsequent control strategy for deburring automation is also briefly discussed.

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 the control of deburring processes and burr measurement/detection of an existing burr. For the process control, two sensor feedback problems will exist during automated deburring: the design of a process control for stable metal removal and the development of a stable control method for tracking the edge of a part with unknown geometry [3]. In burr size measurement, the precise system implementation to get reliable data sets is important, as the data will provide information for a deburring controller to determine the depth of cut, and to verify the results of deburring.

In this paper, two burr sensing applications -burr measurement using a capacitance sensor and acoustic emission (AE) for laser deburring - are shown to exemplify the two cases.

2. SENSORS IN DEBURRING

Researchers have used several types of sensors or sensing systems in deburring: force and/or position sensor [3], acoustic emission sensors [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 [3] 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. [4] 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 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. 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.

Machine vision systems (MVS) have been used for burr size measurement [8, 9]. 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.

3. BURR SIZE MEASUREMENT USING A 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, identical calibration results for conductive materials (if geometry is the same) and the breadth of usable range.

In this section, an on-line burr measurement scheme using a capacitance sensor is described for burr detection and computer process control during automated deburring processes.

3-1. EXPERIMENTAL SETUP

For the on-line experiment, rectangular- shaped carbon steel ANSI 1045 machined workpieces with burr and/or breakout along one side was 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. 1).

TABLE 1. EXPERIMENTAL EQUIPMENT

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

3-2. 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. 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.

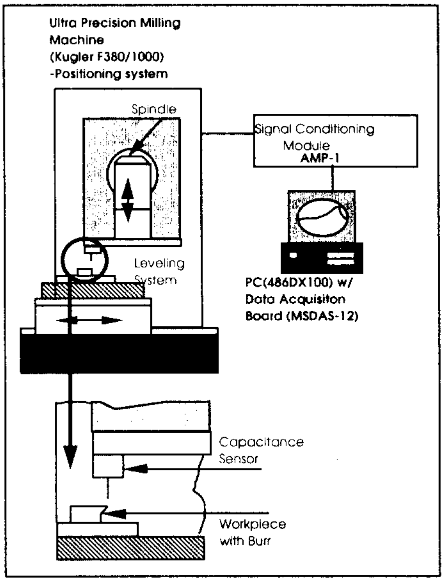


FIG. 1 THE EXPERIMENTAL SETUP FOR BURR SENSING

3-3 RESULTS AND DISCUSSIONS

Fig. 2 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, 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 µm) 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 µm from the burr calibration chart (see Table 2). 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.

TABLE 2. CALIBRATION DATA

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

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.

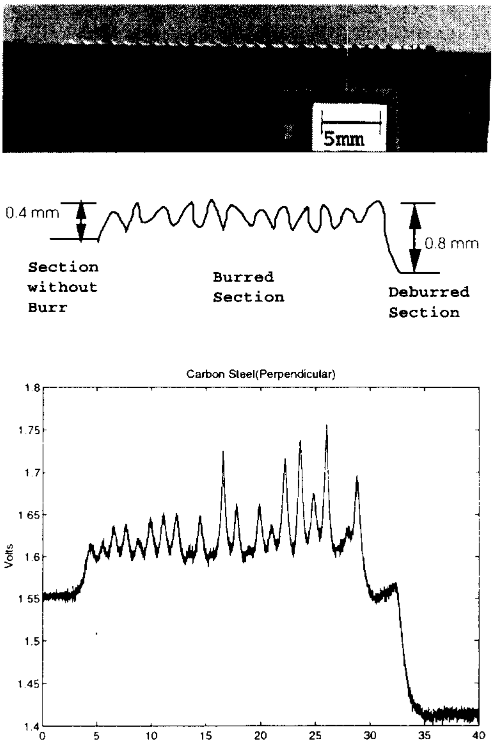


FIG. 2 SURFACE PROFILE AND BURR MEASUREMENT DATA(CARBON STEEL)

4. AE FEEDBACK FOR PRECISION LASER DEBURRING

In conventional machining processes, the cutting tool geometry is known and used to create specific part features on the workpiece. In laser machining, however, the depth of cut is not set, but is the result of the interaction between the laser beam and the material for certain length of time. During that time, the laser beam may fluctuate, material (thermal) properties may change, and other influential parameters may change so that the desired cutting geometries can not be accurately predetermined. Therefore, it is desirable to know this interaction during machining so that the process can be adapted to the actual laser/material behavior and thus produces the desired cutting shape[10]. This problem calls for sensing techniques developed for the control of laser machining processes. For precision laser deburring [11], which requires good surface quality and accurate dimensions, the necessity of a real time feedback sensing control can not be overemphasized because it is one of the key elements that govern the flexibility of automated precision deburring [4].

In this part of the paper, acoustic emission (AE) signals are proposed for the control of metal removal and edge tracking and detection in laser deburring. The correlation between the AE signal generated during laser machining/deburring and the process parameters as well as the implementation of AE sensing feedback scheme in an automated laser deburring system are discussed.

4-1. LASER MACHINING AND ACOUSTIC EMISSION SENSING

Acoustic emission refers to the transient elastic stress waves generated due to the rapid release of strain energy from a localized source(s) within a material. The source mechanism can be generated by elastic, plastic or microplastic deformation, crack nucleation, crack propagation, phase transformation, phase change, friction and other mechanically, chemically or thermally activated events [12]. These low intensity, high frequency (100kHz-1MHz) elastic waves propagate in all directions through the structure to a detector on the surface of the workpiece. The AE detector uses a piezoelectric transducer to convert surface wave velocity or displacement to an electric signal, which is then amplified and processed. A goal of using the acoustic emission technique is to be able to use the information carried by the AE signal to determine the exact nature of the source.

From the literature [13, 14], it has been shown that the AE signals and physical parameters in laser machining , such as laser power and feed rate, are closely related. This characteristic can be utilized for laser deburring, as it is essentially an application of laser cutting to remove burrs from part edges.

4-2. EXPERIMENTAL SETUP

Fig. 3 shows a schematic of acoustic emission sensor feedback for precision laser deburring. Preliminary tests were made on rectangular- shaped AISI 1045 carbon steel workpieces using a 1500W CO_2 laser, with a three dimensional positioning system.

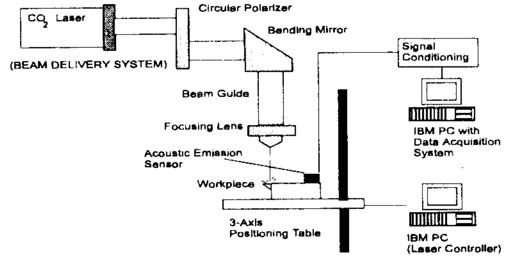


Fig. 3 Experimental Setup

4-3. AE RMS DATA

Fig. 4 shows AE rms data for laser deburring/grooving. In the Figure, which represents the data from actual deburring a workpiece edge, burr shapes along the edge are accurately represented, that is, increase in signal amplitude correlates with increase in burr thickness.

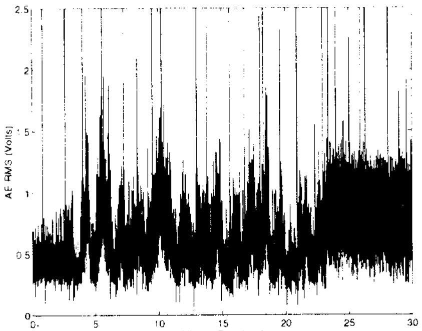


Fig. 4 AE rms from Laser Deburring Experiments (at Burr root (Deburring); Power=400W, Feed rate=2.5 mm/sec., Time Const.= 0.5 msec.)

Fig. 5 shows a typical plot of the AE rms signals for edge detection. As the laser moves into the workpiece from the outside in the perpendicular direction to the burr, three distinct level signals are observed. These levels represent before cutting, through cutting (burr section) and grooving (inside the workpiece), respectively. This shows the edge detection capability of the AE sensing technique for laser machining. Regardless of process parameter variations (such as laser power and feed rate), the sensor repeatedly detects the start of the laser cutting (i.e., the burr edge) within 25 microns.

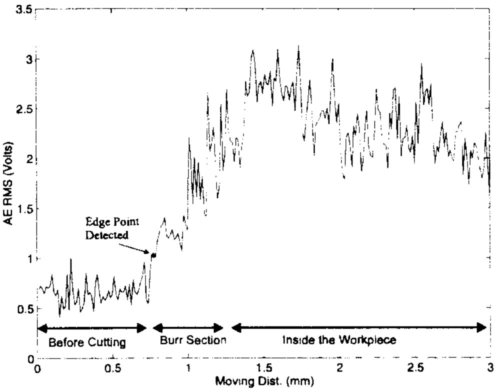
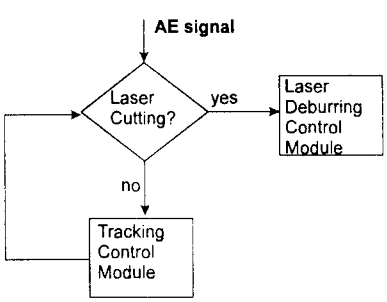
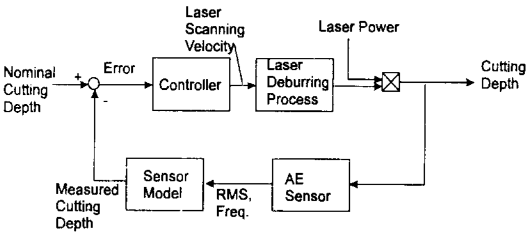


Fig. 5 AE rms for Edge Detection
(Power=300W, Feed Rate=2.5mm/sec., Time Const. = 50 μs)

With the above results, it is shown that the AE method has the sensing feedback capability required for an automated deburring system. A possible scenario for an implementation of the sensing scheme to real feedback control is as follows: assume that (1) burr edge is aligned to the laser beam scanning direction. (2) process information, such as burr thickness and laser power required to remove the burr is provided by consulting other modeling elements such as burr characterization [15], burr formation modeling [16] and deburring process modeling [11]. With the AE feedback, the cutting stage of laser deburring can be determined whether it is in pre-cutting stage, cutting the burr or cutting inside the workpiece. If the laser is not directed to the burr section, it can be corrected using a tracking module which can position the laser beam inside the burr region (Fig. 6 (a)). By employing a closed loop control scheme (Fig. 6 (b)), the deburring cut can be assured inside the burr section throughout the laser deburring process.



(a) Flow Chart for the Control Scheme



(b) An Example of Laser Deburring Control
Fig. 6 Laser Deburring Control Scheme

CONCLUSION

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.

For sensing feedback for an automated precision laser deburring process, an AE technique has been proposed. The data sampled during experiments are analyzed using AE rms. A subsequent control strategy for deburring automation is also proposed and briefly discussed. From the analyzed results of the experiment, it is shown that AE sensor feedback can be useful both for controlling metal removal and detecting/tracking the workpiece (burr) edge. Connected to the laser deburring system with a proper control scheme, this AE sensing technology could be a viable means for automating precision deburring operations.

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