DOE/OR/22524--1

Semi-Annual Report #1

**Development of an "Intelligent Grinding Wheel" for
In-Process Monitoring of Ceramic Grinding**

S. Malkin, R. Gao, C. Guo, B. Varghese and S. Pathare
Department of Mechanical and Industrial Engineering
University of Massachusetts
Amherst, MA 01003-2210

March 27, 1997

RECEIVED

MAY 01 1997

OSTI

U. S. Department of Energy
Identification Number: DE-FG05-96OR22524

Distributed to:

U. S. Department of Energy
Beth L. Holt, AD-421
Post Office Box 2001
Oak Ridge, TN 37831-8756

U. S. Department of Energy
Mary Rawlins, ER-111
Bldg. 4500 North, MS 6269, Rm. 230
Oak Ridge, TN 37831-8612

U. S. Department of Energy
R. B. Schulz, EE-32
5G-064/FORS
1000 Independence Ave., SW
Washington, DC 20585

Oak Ridge National Laboratory
Susan G. Winslow, MS6066
Post Office Box 2008
Oak Ridge, TN 37831-6066

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

un

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

Introduction

This is the first semi-annual report for the project "Development of an Intelligent Grinding Wheel for In-Process Monitoring of Ceramic Grinding". This report covers the period from September 1, 1996 to February 28, 1997.

The overall objective of this project is to develop sensor-integrated "intelligent" diamond wheels for grinding of ceramics. Such wheels will be "smart" enough to monitor and supervise both the wheel preparation and grinding processes without the need to instrument the machine tool. Intelligent wheels will utilize reusable cores integrated with two types of sensors: acoustic emission (AE) and dynamic force transducers. Signals from the sensors will be transmitted from a rotating wheel to a receiver by telemetry. Wheels will be "trained" to recognize distinct characteristics associated with truing, dressing and grinding.

Technical Progress

This overall project is divided into six tasks as follows:

- Development of miniaturized sensors and data transmission system
- Wheel design and sensor configuration
- Calibration of the sensor integrated wheel
- Training of the intelligent wheel
- Grinding tests
- Prototype demonstration.

The technical progress is summarized in this report according to the tasks. All the activity during this first reporting period has been concerned with the first two interrelated tasks, which need to be completed before undertaking the remaining tasks.

Task 1. Development of Miniaturized Sensors and Data Transmission System

As stated above, the overall objective of this project is to develop sensor-integrated "intelligent" wheels for grinding of ceramics. In-process measurement of the grinding forces and acoustic emission activity resulting from the interaction between the grinding wheel and the ceramic workpiece necessitate miniaturized force and acoustic emission sensors that can be mounted in the grinding wheel core. Force and acoustic emission sensors are commercially available from various suppliers (e.g. PCB, Kistler, B&K), but their relatively bulky size precludes their integration into a grinding wheel which may be only about 0.5 inch thick. In order to overcome this problem, miniaturized force and acoustic emission sensors are being developed which utilize piezoceramic chips having overall dimensions of about 5 mm x 2 mm x 2 mm.. For force measurement, these piezoceramic chips will be sandwiched between the wheel core and the

bonded abrasive wheel rim as shown in Figure 1.1. For acoustic emission measurement, such piezoceramic chips will be embedded into the wheel core away from the wheel rim.

The advantages of using miniaturized piezoceramic chips are twofold. Firstly, their small size facilitates relatively easy integration into the wheel core, without altering the functional behavior of the grinding wheel. Secondly, the high rigidity, sensitivity, and mechanical resonant frequencies of piezoceramic chips make it possible to use them for measuring both the force and acoustic emission. By using appropriate electronic filters, high frequency acoustic emission signals in the MHz range and lower frequency dynamic force signals in the ten to hundred kHz range can be conveniently separated, thereby allowing for a compact and highly efficient system.

One proposed configuration of sensors to be tested is shown in Figure 1.2. An aluminum disk has been fabricated which contains five identical piezoceramic chips mounted in slots on the wheel core periphery within one quadrant of the disk. The piezoceramic chips held in slots at the wheel periphery have wires soldered on both sides for making electrical connections. The disk will be subjected to a range of static and cyclically varying forces. The output of all the five piezoceramic chips will be measured simultaneously by a data acquisition system. The optimal location of the sensors will be determined by comparing the output signals in terms of amplitude, frequency composition and phase relationships. More details about the evolution of the disk geometry and testing procedure are presented in the next section (Task 2).

The configuration of the data processing and transmission circuitry is shown in Figure 1.3. The charge amplifiers convert the electrical charge from the sensors to a voltage signal proportional to either the

amplitude of the applied forces or the acoustic emission. Signals from the charge amplifiers are filtered to limit their bandwidths to a known range and remove the irrelevant noise. The Analog/Digital conversion module, operating at a sampling rate of about 2 MHz, will log the data into the Digital Signal Processor (DSP). After analyzing the data, the DSP will send out only the relevant part of the signal through its serial output port to a data transmitter which operates in the 900 MHz range. Since this is an ISM band, no special license for RF operation is required for systems whose power output is below 1 W. The transmitted signal is received and fed through interface module to a PC data logging and processing.

Task 2. Wheel Design and Sensor Configuration

As stated above, the “intelligent” grinding wheel will consist of a disk-shaped wheel core with abrasives in a resin bond on its periphery. The wheel core houses the piezoceramic sensors and the associated electronics necessary for data conditioning and transmission.

Two approaches were considered for mounting the sensors. The initial design concept was to utilize sensors mounted in a number of cavities milled in the disk-shaped core and firmly held in place by a wedge arrangement (Figure 2.1). The deformation of each cavity under an applied grinding force causes an electrical charge on the surface of the piezoceramic sensor. The electrical charge is fed to the charge amplifier and converted to a voltage signal. The magnitude of the voltage signal is proportional to the force.

The response of the sensors is highly dependent on the system compliance, which in turn depends on the dimensions of the cavity and its location. The influence these parameters on the sensor response was analytically investigated by using a finite element (FEM) analysis. A finite element model of the

wheel with six force sensors, mounted 60 degrees apart, was developed using ANSYS in order to determine the sensor response and optimize the cavity location (Figure 2.2). The specification of the wheel and the corresponding material properties of the core and the abrasive are listed in Table 2.1. Only half of the wheel was modeled in order to keep the computation within reasonable limits without loss of accuracy. The grinding action was simulated by applying a concentrated line force across the width of the wheel at its periphery. Separate static analyses were conducted at different angular locations of the wheel in order to simulate the effect of wheel rotation. The sensor response was determined by calculating the deformation of the cavity walls under the influence of an applied load.

The first set of numerical simulations was performed to investigate the response of the force sensors to a rotating load at a fixed radial location (0.19 inch from the wheel surface) of the cavity. At first, the force was applied directly under the cavity and the static response of the all the sensors (deformation of the cavity) was determined by using the finite element method. The load was then moved to a different angular location and the static solution was repeated. Figure 2.3 and 2.4 show some of the typical results obtained from the finite element analysis. As seen in Figures 2.5, the response of the sensor rapidly diminishes as the load moves away from the sensor location. Virtually no response was visible for most of the angular locations of the load. This result indicates that the arrangement of the sensors on the wheel is critical, especially when the roundness and waviness of the wheel during the grinding process are to be monitored.

One possible way to enlarge the region of sensor response is to relocate the sensors radially inward away from the grinding wheel periphery. However, this will lead to a reduction in sensitivity. To investigate the relationship between the radial location of the sensors and their response, numerical

studies were conducted by FEM simulation of the structural response of the wheel at various locations. The results are shown in Figures 2.6 and 2.7. The sensitivity showed a rapid decrease (Figure 2.6) as the sensor was moved radially inward with no appreciable increase in the region of sensor response (Figure 2.7).

The results from this finite element analysis suggest the need for more sensors. The second design concept is based upon increasing the number of sensors. In order to increase the number of sensors, the sensor cavity was modified into a narrow slot located at the periphery of the disk (wheel core). Such an arrangement permits a large number of slots and sensors around the periphery of the wheel as seen in Figure 2.8. With this arrangement the piezoceramic sensors will be glued in the slots at the core periphery where the bonded abrasive rim is attached. The proximity of the sensors to the grinding wheel surface also increases the sensitivity.

A series of experiments will be conducted to test this design. Figure 2.9 shows a schematic of the proposed experimental setup. The test disk with sensors glued in the slots will be mounted on an Instron testing machine which provides static or cyclical loads. An abrasive layer will be attached to the disk periphery using a two-component epoxy. The epoxy also helps to protect the sensors. A preliminary set of tests will be conducted to evaluate the sensor arrangement. For these initial experiments, the sensors will be directly wired to the data acquisition system. This will be followed by full scale testing with telemetric data transfer.

Publications

None to date.

Trips and Meetings

Stephen Malkin attended a meeting at ORNL on September 11-12, 1996 to make a presentation describing this project.

Personnel

- Stephen Malkin, Sc.D., Professor, Principal Investigator
Overall project management, grinding test and analysis.
- Robert Gao, Ph.D., Assistant Professor, Co-Principal Investigator
Design of miniaturized sensors, telemetry, and microelectronics; testing, and prototype demonstration.
- Changsheng Guo, Ph.D., Senior Research Fellow, Co-Principal Investigator
Mechanical design, setup, testing and prototyping of grinding wheel.
- Biju Varghese, Graduate Research Assistant, Ph.D. Student
Mechanical design, calibration, training and testing of the grinding wheel prototype
- Sumukh Pathare, Graduate Research Assistant, M.S. Student
Sensor development, electronic circuits design, implementation, and testing.

Wheel Dimensions	
Outer diameter	12 inches
Inner diameter	5 inches
Width	0.5 inches
Abrasive thickness	0.125 inches

Abrasive properties	
Elastic modulus	$2 \times 10^{-6} \text{ N/mm}^2$

Sensor holder (core) properties	
Elastic modulus	$10 \times 10^{-6} \text{ N/mm}^2$

Table 2.1 Wheel dimensions and material properties

Figure 1.1 Schematic view of a sensor-embedded grinding wheel

Figure 1.2 Configuration of the disk for testing the arrangement of sensors

Figure 1.3 Configuration of the data processing and transmission system

6.	Sensor
5	Lower Wedge
4	Upper Wedge
3	Nut
2	Cover Plate
1	Grinding Wheel

8	Sensor
7	Grinding Wheel
6	Lower Wedge
5	5mm Deep Slot
4	Through-Hole
3	Upper Wedge
2	Through-Cavity
1	Cover Plate

Sensor Mounting.	
(Electromechanical Sys. Lab)	
Drawn by:	Sumukh Pathare
Checked by:	Prof. Robert Gao
Date:	12/6/96

Figure 2.1 Sensor arrangement using cavities on the wheel core

1

ANSYS 5.3
MAR 26 1997
14:26:32
ELEMENTS
TYPE NUM

XV =1
YV =1
ZV =1
DIST=5.501
YF =-3
ZF =.25
Z-BUFFER

Figure 2.2 Finite element model of the grinding wheel

ANSYS 5.3
MAR 26 1997
14:59:37
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UX
RSYS=1
DMX =.005696
SEPC=55.251
SMN =-.005618
SMX =.633E-04
A =-.005302
B =-.004671
C =-.00404
D =-.003409
E =-.002777
F =-.002146
G =-.001513
H =-.884E-03
I =-.252E-03

Figure 2.3 Simulated sensor response at 2 degrees

ANSYS 5.3
 MAR 26 1997
 14:55:30
 NODAL SOLUTION
 STEP=1
 SUB =1
 TIME=1
 UX
 RSYS=1
 DMX =.443E-03
 SEPC=47.765
 SMN =-.325E-03
 SMX =.273E-04
 A =-.305E-03
 B =-.266E-03
 C =-.227E-03
 D =-.188E-03
 E =-.149E-03
 F =-.110E-03
 G =-.068E-04
 H =-.314E-04
 I =.774E-05

Figure 2.4 Simulated sensor response at 16 degrees

Figure 2.5 Sensor response versus angular position

Figure 2.6 Sensor response versus radial loaction of cavity

Figure 2.7 Sensor response versus location of load

Figure 2.8 Aluminum disc (wheel core) for mounting sensors

(All Dimensions in inches)

Figure 2.9 Schematic diagram of the experimental setup