AC 2007-2557: NON CONTACT SURFACE ROUGHNESS MEASUREMENT INSTRUMENTATION

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Development of Non Contact Surface Roughness Measurement Instrumentation

Abstract

This paper presents the design and implementation of a non-contact Surface Roughness probe from a pc based data acquisition system to a standalone measurement instrument system. The use of OrCAD PSpice is demonstrated for circuit design, analysis and PCB layout for the fabrication of the PCB board that will interface and drive the surface roughness probe.

Introduction: Need and Background

The demand for higher product quality requires continuous monitoring of various processes and product conditions. It is obvious that one of the essential aspects of quality control in many manufacturing operations is the measurement of surface finish quality of the machined parts during the manufacturing process. Variation in the texture of a critical surface of a part influences its ability to resist wear and fatigue, to assist effective lubrications to increase or decrease its friction and abrasive action with other parts, and to resist corrosion

Many techniques have been developed to measure surface roughness, which vary from the conventional profilometer to the recently developed laser diffraction technique. An attempt is made in this paper to present a simple, reliable and robust way of evaluating the roughness of an engineering surface regardless of the work piece orientation. The research has wide applications in manufacturing industries. One typical application suggested in this paper is the measurement of surface finish of an aircraft gas turbine rotor blade.

The original use of the Surface Roughness Probe was part of an inspection system, used on CNC / Robotic machines for Pratt and Whitney [1]. Currently, for analyzing surface roughness, the probe is connected to a PC via a data acquisition card running VisSim as shown in Figure 1. In this current configuration the probe is capable of reaching an instrument accuracy of ±0.025 μm for a Ra range of .05 to 0.4μm.

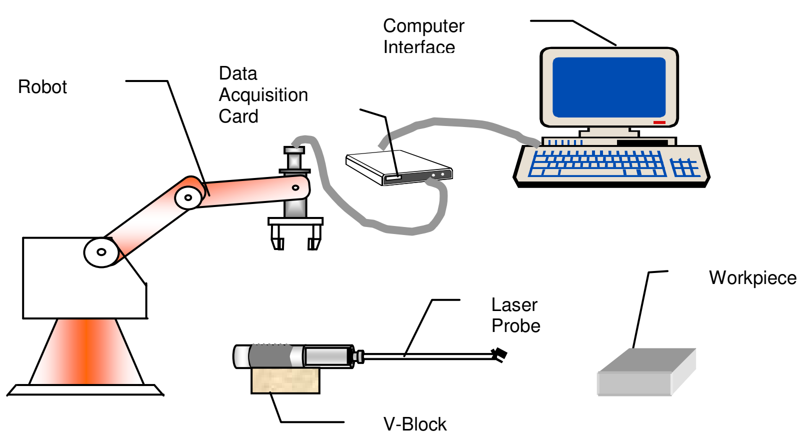

Figure 1. Surface Roughness Inspection system setup

One of the variations of this setup is to make it more self contained (and very low cost), hence this project. Of course more flexibility could be added by using an embedded processor.

Measurement of Surface Roughness

A traditionally machined surface consists of many components from different sources generated during the manufacturing process. It is the combination of these components that comprise surface texture. Figure 2 illustrates these components of a turned surface [2]. They are roughness, waviness, profile, error of form, flaws and lay.

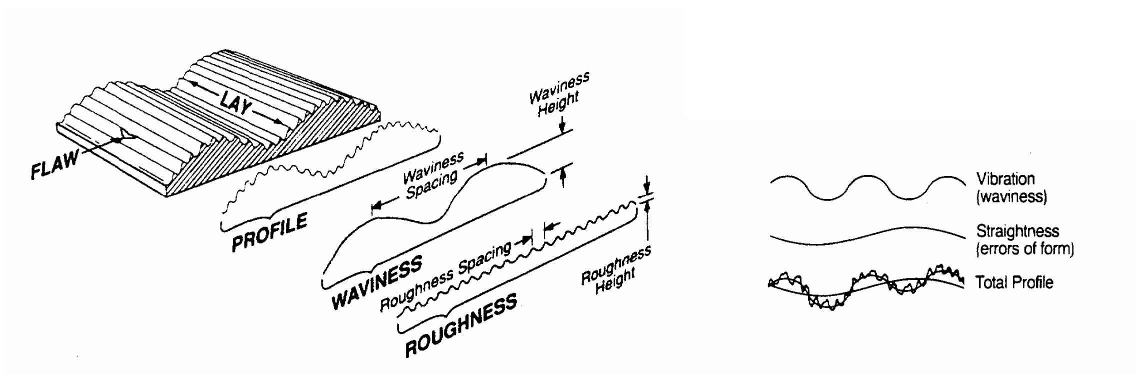

Figure 2. Surface Texture Components

In all, surface texture can provide information about the manufacturing process. In metal machining, for example, surface texture is generated by the "tool noise" and is related to the feed rate. However, it is also affected by many other variables such as vibration, cutting fluid quality and tool wear. Therefore measurement of surface texture components can potentially provide diagnostic information for process control applications.

Various techniques for surface roughness measurements exist which can be largely classified as contact and non-contact. For example the stylus technique[3] is a contact method in which the stylus is drawn over the sample in order to detect and record variations in surface geometry. Surface statistics can then be calculated from the profile record. The accuracy obtained by mechanical profilometer is quite high, with Ra values being in the order of micro meters. However this technique is limited by its low speed and the need to contact the surface being inspected. On the other hand, non-contact methods such as optical interferometry and light scattering techniques offer the advantage of high speed measurement without the need to contact the surface being measured.

Interferometry technique uses two coherent beams split by a partially transmitting mirror to observe the fringe patterns in an interferogram [4]. Interferometry has been found sensitive to measure high accuracy in the order of 1 nanometer. Thus this method is suitable to inspect very fine - close to mirror finish surfaces.

Light scattering technique uses a beam of light of known wave length that is projected onto a surface at an incident angle θ. Figure 3 shows the basic light scattering principle If the surface is perfectly smooth, the light will be reflected at the same angle as θ, according to the law of reflection. However, if the surface is rough, the reflection will be scattered around the direction of specular reflection.. The diffused light intensity has close to linear relationship with surface roughness. The necessary link between scattering light and surface topography can be made using either empirical correlation or an appropriate scattering theory [4][5]. For surfaces with Ra value of 2 μin., 95 percent or more of the incident radiation will be reflected specularly. For surfaces with Ra value of 20 μin., 95 percent or more of the incident radiation will be scattered [6].

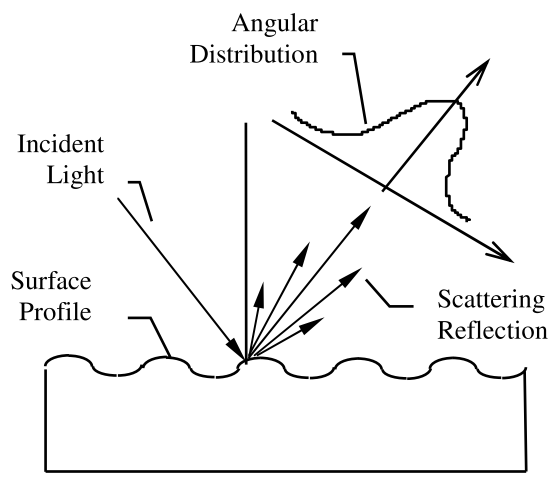

Figure 3. Basic Light Scattering Principle [7]

Many researchers have contributed to the development of reliable non-contact techniques using optical methods. Among these, Rovati et al. have developed an optical measurement system for measuring surface roughness of wood based panels [8]. Marx and Vorburger [9] have developed a non-contact method of measuring the specular and scattered reflection of a laser beam off the surface of a workpiece. This research was further enhanced by Shetty and Neault [10] by developing a non-contact surface roughness analyzer. The method developed by Shetty and Neault takes advantage of the fact that a light source reflected off the surface of a workpiece provides a signature pattern based on the roughness of the surface

Light scattering has significant promise as a practical tool for measuring surface finish. It is a quick, sensitive, area sampling, and accurate method, and unlike the stylus method, is completely non-destructive. The research discussed in the paper addresses the issue of transferring the light scattering technique into a practical on-line surface roughness inspection instrument.

Standalone Surface Roughness Analyzer

Overview

The proposed standalone surface roughness probe consists of a laser diode and 4 photo resistor detectors. Light from the laser diode shines down onto the work surface. Reflected light coming back into the probe is read by the detectors (4) and converted to a proportional voltage output (in the 2 volt range) by internal voltage divider circuits. These analog voltages are then added and converted to an equivalent digital quantity and displayed in numerical format. Refer to the block diagram below Figure 4.

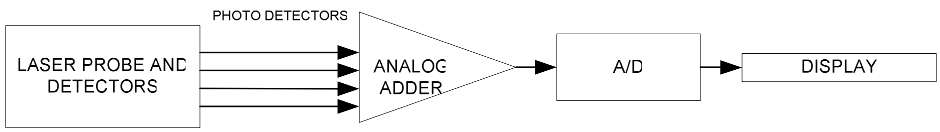

Figure 4. Overview of the self contained Surface Roughness Analyzer

The Surface Roughness Analyzer is divided into five subsections: the probe, power supply, adder circuit, A/D circuit and the display circuit (including MOSFET decimal point driver circuit).

Probe

The probe as shown in Figure 5 is comprised of the following components. A 1 milliwatt solid state laser is used as a light source. The beam of light emitted from the laser passes through a series of optical lenses and a mirror. The focused and collimated light impinges normal to the surface of the workpiece to be measured. The distance between the probe and the workpiece is fixed. The tube which is internally coated with reflective material is employed to collect the diffused reflection and send it to an array of highly sensitive photoelectric sensors. The sensors convert scattered light intensity into electric voltage signals.

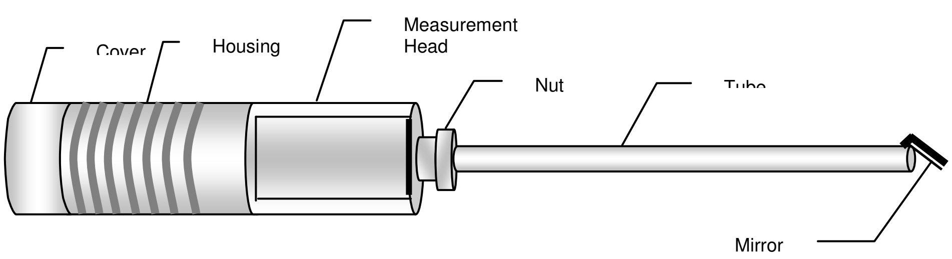

Figure 5. Overall assembly of probe

The amount of scattered light received by the photoelectric sensors will be proportional to the degree of roughness of the surface. Outputs from the photoelectric sensors are added to produce a single output.

Completed Circuit

Figure 6 shows the completed circuit. It was designed using the OrCAD CAPTURE utility. This has many advantages over the traditional paper and pencil approach. Parts (contained in built-in libraries) are easily placed on the workspace. If one decides to change components, it as easy as high lighting the old part, deleting it and inserting the new part, as opposed erasing the old part, drawing in the new part and then adding any nomenclature. If working with active components (IC's, transistors etc) this would all have to be done while referencing the manufacturers datasheets to get the proper pins assignments and nomenclature.

It should be noted that had a PSpice model for the A/D converter been available, the captured schematic could have also been simulated.

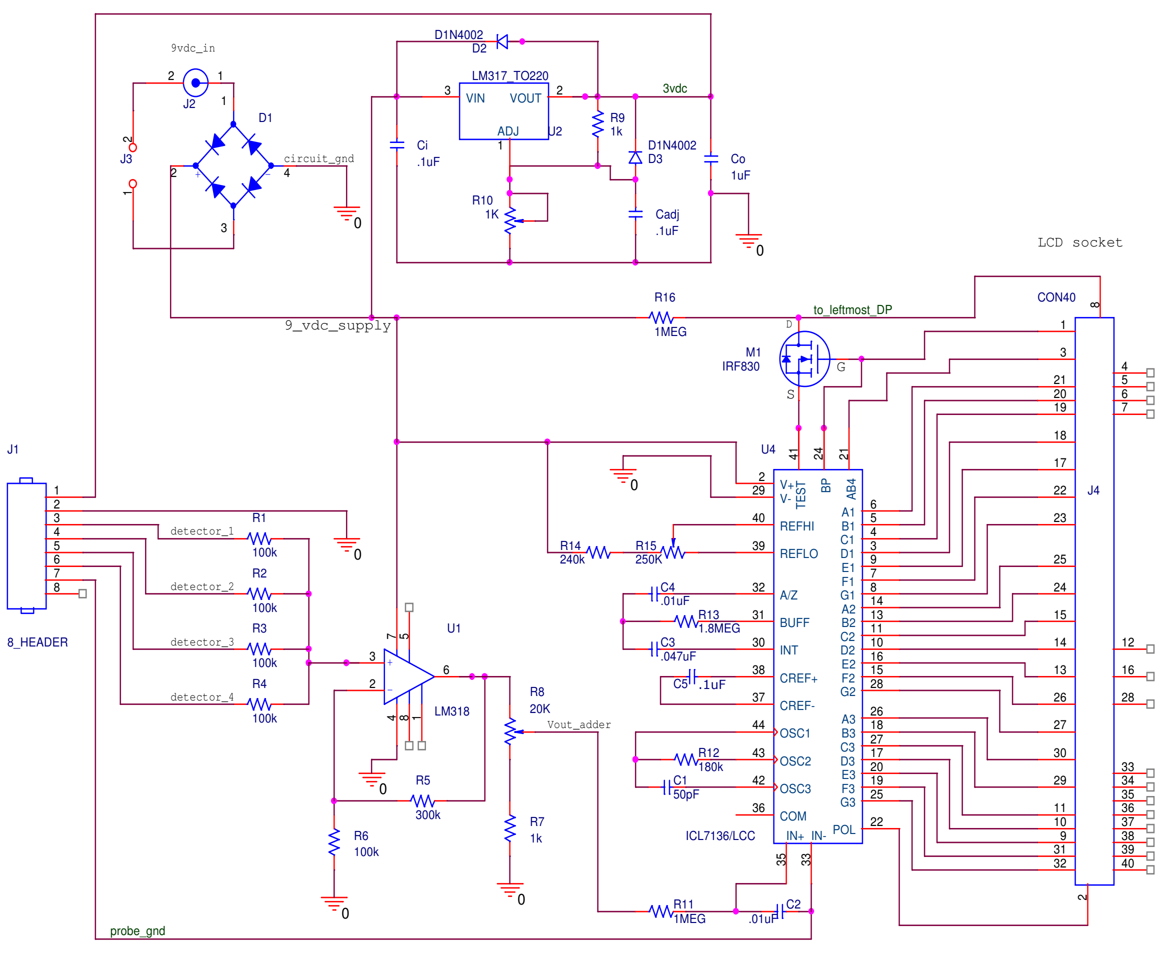

Figure 6. Completed Circuit

PCB Layout and Fabrication

From the PSpice schematic created in Capture CIS, the PCB layout is done using OrCAD LAYOUT. The user need only designate where all the componets are to be placed, resistor and capacitor size and configuration (axial or radial leads) and pad spacing for items such as wires and connectors. LAYOUT does all the traces automatically. The completed layout is shown below in Figure 7. A two layered board was generated in this case.

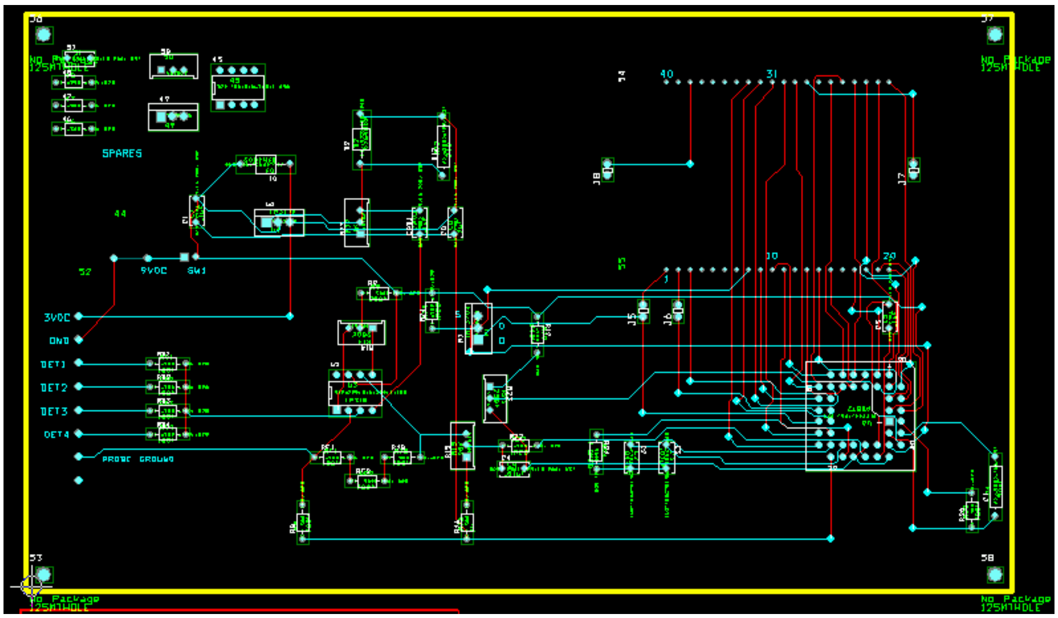

Figure 7. Circuit board layout

Once the layout is complete OrCAD will also generate all the files needed to cut the board to size, place and drill the holes and route the board (including any text or numbering). The files were then sent to a PCB fabricator who made the board on a CNC machine. The manufactured board as received from the fabricator is shown in Figure 8. The completed board with all the components soldered onto the board is shown in Figure 9.

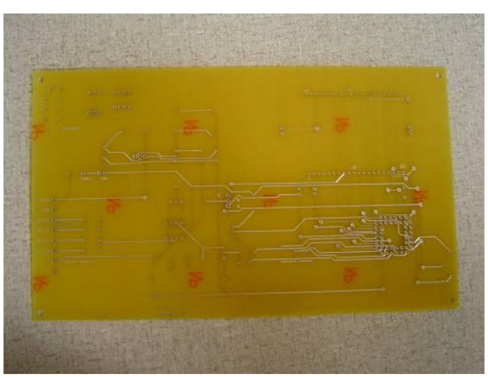

Figure 8. Manufactured board

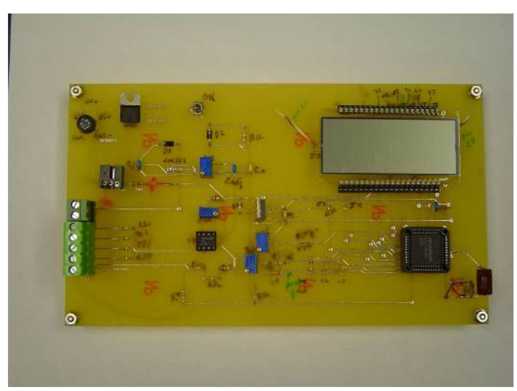

Figure 9. Completed board with components installed

Test and Results

The experimental test setup for measuring surface roughness is shown below in Figure 10. The completed board was connected to the probe through the screw terminals. With power applied to the system, the measurement instrument operation is verified through the lcd display and calibration is performed.

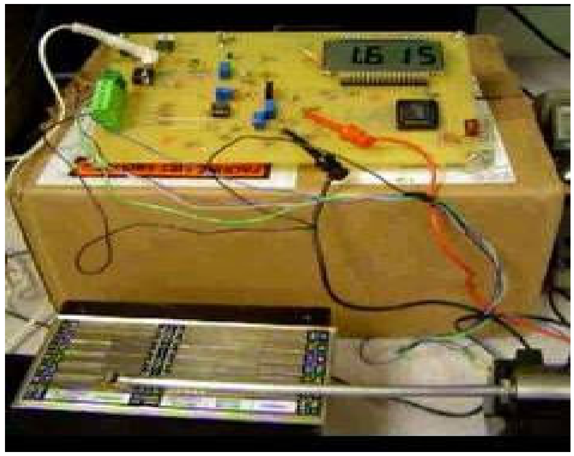

Figure 10. Board and probe experimental test setup

A series of test measurements were performed using a surface roughness standard. Calibration is initially performed for the range of readings to be taken. Readings were taken on the ground samples from 0.1 to 1.6 μm. Results of the test readings using the standalone surface roughness analyzer are shown in Figure 11.

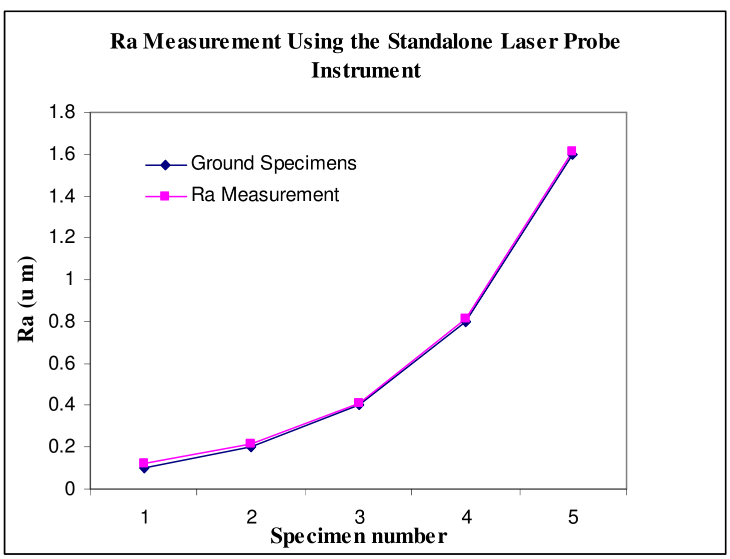

Figure 11. Ra measurements using standalone laser probe instrument

Results from the test measurement show a good correlation with the surface roughness value of the ground specimen. Measurements show that the accuracy of the instrument to be within ±0.025 μm which was the accuracy reached by the PC based data acquisition measurement system.

Conclusion

The implementation of a non-contact Surface Roughness probe to a standalone measurement instrument system has been demonstrated in this paper. It is a portable low cost non-contact surface roughness measurement system solution achieving the same reading accuracy as compared to the existing pc based data acquisition measurement system. In particular the use of Orcad PSpice and Layout has been shown for the design, analysis and fabrication of the PC board.

References

[1] Han, Qingwen "Methodology and Modeling of a Laser Based In-Process Surface Finish Inspection Instrument", Masters Thesis, Mechanical Engineering, University of Hartford, 1997

[2] Federal Product Catalog (1996)

[3] S.M. YOO, D.A. DORNFIELD and R.L.LEMASTER (1990) Analysis and Modeling of Laser Measurement System Performance for Wood Surface, Journal of Engineering for Industry, Vol. 112, p.69-76

[4] M.M. BENNET(1976) Measurement of the RMS Roughness, Applied Optics, Vol. 15, No. 11, p.2705-07

[5] M. SHIRAISHI(1981) In Process Measurement of Surface roughness in Turning by Laser Beam, Trans. of ASME J. of Ind. Eng., Vol. 103, p.203-209

[6] D.G. JANSSON, J.M. ROURKE and A.C. BELL(1984) High-Speed Surface Roughness Measurement, Journal of Engineering for Industry, Vol. 106, p.34-9

[7] P. BROADMANN and G. THURN(1986)Roughness Measurement of Ground, Turned and Shot-Peened Surfaces by the Light Scattering Method, Wear, 109, p.1-13

[8] Rovati, L., Pollonini, L., Zanasi, M., Sivien, D., Badiali, M., "Design of an Optical Sensor for Surface Roughness Measurements of Wood based Panels", Slcont04 - Sensors for Industry Conference New Orleans, Louisiana, USA, 27-29 January 2004

[9] Marx, E., and Vorburger, T.V., 1990, "Direct and Inverse Problems for Scattered by Rough Surfaces," Applied Optics, Vol. 29, No. 25, pp. 3613-3626.

[10] Shetty, D., and Neault, H., 1993, "Method and Apparatus for Surface Roughness Measurement Using Laser Diffraction Pattern," United States Patent, Patent Number: 5,189,490.