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Analysis of surface defects using a novel developed fiber-optics laser scanning system

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Abstract

Various methods of determining surface defects are being used in automated industrial manufacturing environments. This work presents the design and development of a new high-speed photoelectronic laser scanning system. Recent methods of surface defect detection involve the use of fiber-optic light-emitting and detection assemblies. A line of five emitting diodes and five receiving photodiodes were used as light sources and detectors, respectively. These arrays of emitting diodes and photodetectors were positioned opposite each other. A data acquisition card was used to capture the output signals from the photodiodes. Data capture was controlled and analysis performed using Labview. The advantages of this new system may be seen as faster detection, lower cost and greater resolution. Such a system will also occupy less space than conventional scanners. The detected signals of this system were examined to measure the dimensions of the surface defects, such as holes, and blind holes for different materials.

Keywords: Laser scanning; Surface defects; Fiber arrays

1. Introduction

Laser range finder and inspection systems have found many applications in different areas, including manufacturing and automated control systems. The design of a high-speed inspection system based on the laser scanning method has been an interesting issue. The main advantages of optical inspection methods are their ability to scan large areas, their applicability to in-process measurement, and their ability to perform fast measurements [1]. Advances in manufacturing automation have created the need to develop in-process measurement techniques for online quality control and online machining compensation [2]. Most component manufacturing cycles include an inspection stage to ensure agreement with design requirements [3]. Automated visual inspection is also rapidly becoming a major factor in manufacturing [4]. The main drive for research in this area today has been to produce a range optical-fiber based techniques, which can be used for a variety of different inspection sensors. This research holds the potential to provide an effective measurement technology which can compete with conventional inspection methods, especially for niche measurement solutions [5]. Non-contact measurement is also favored since high-speed measurements can be achieved and problem associated with vibration and friction can be eliminated [6]. One candidate for an optical surface defect measurement method is the use of laser source, where the laser light intensity reflected from the surface can be analyzed. A minimal set of optical components (i.e., a laser light source, an optical fiber, and a photodetector) may be used for a photodetection system of this type.

Laser scanning inspection system using triangulation technology is one of the most common and useful methods for 2D and 3D profiling where accurate repeatable height measurements are critical [7]. Laser scanning has been successfully implemented in the inspection of widely varied material surfaces. Continuous online inspection of moving sheet is one of the most active fields of optical inspection [8]. Examples of sheet materials for which optical inspection systems have been reported include paper webs, textile fabric, glass material, hot slabs and cold-rolled metal strip [9]. These systems are essential tools for modern statistical process control procedures. Non-contact methods of measuring thickness and distance with laser sensors have already been widely reported in the literature [10–13].

The present study examines the measurement of surface defects in several types of material using such a system. The reflected light intensity is measured with a fast response photodetector which allows sensor vertical displacement characteristic curves to be recorded. In order to achieve this, an experimental setup was designed and built.

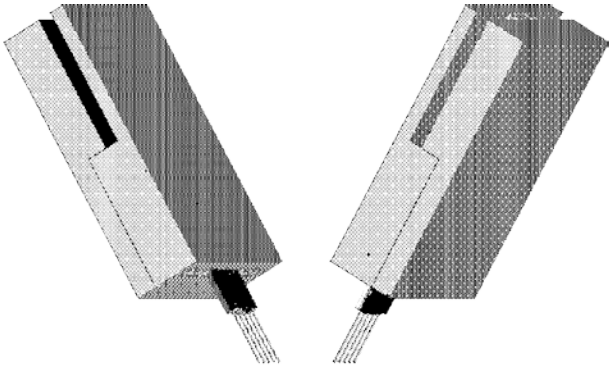

Fig. 1. Fiber scanning geometry schematic representation.

2. Experimental setup

2.1. Geometry of laser scanning system

The intensity of the detected light depends upon how far the reflecting surface is from the fiber-optic sensor. The sensor has five light-emitting fibers orientation at 60° to the vertical and five receiving fibers located as shown in Fig. 1. The geometric configuration of the fiber-optic sensor and its position relative to the surface is very important. To study the effect of sensor position on the measurement, it was found that an angle of 60° for the sensor setting gave the maximum sensor signal response. In order to minimize the effect of the oscillation occurring in the incident laser diode beam, an optical bench was used to fix the experiment equipment. The distance between the fiber end and the sample surface was varied to obtain maximum sensor response. Once the sensor response was maximized, this distance was fixed.

2.2. Detailed design

The schematic outline of the apparatus designed in this project is shown in Fig. 2. The measurement of the surface defect is based on the analysis of the reflection of an incident laser beam from the surface of the workpiece. The workpiece is placed on a base plate. Fibers were fixed on the *x*–*y*–*z* translation stages.

This sensor system was designed to operate as a photoelectric sensor and was used to recognize the defect on the surface of several material samples such as stainless steel, copper, brass, and polycarbonate. Defects are simulated here as holes of different sizes. The optical sensor system includes five 1300 nm wavelength laser diodes as light sources, operated in continuous wave (CW) mode. The fibers connected to these diodes had a core/cladding ratio of 65/125 and the reflected beams from the surface were collected by five optic fibers with a core/cladding ratio of 100/140. The PIN photodiodes collect the light reflected and scattered by the sample under inspection. These photodiodes have high responsivity within the wavelength (λ) range of 1300–1500 nm and supply analog outputs. A data acquisition card was used for analog to digital conversion for these outputs. Data analysis was performed using 'Labview' software.

All the signals from the photodiodes are converted from analog to digital and amplified before reaching the data acquisition system which continuously reads their values. Labview software is a high level, modular graphical

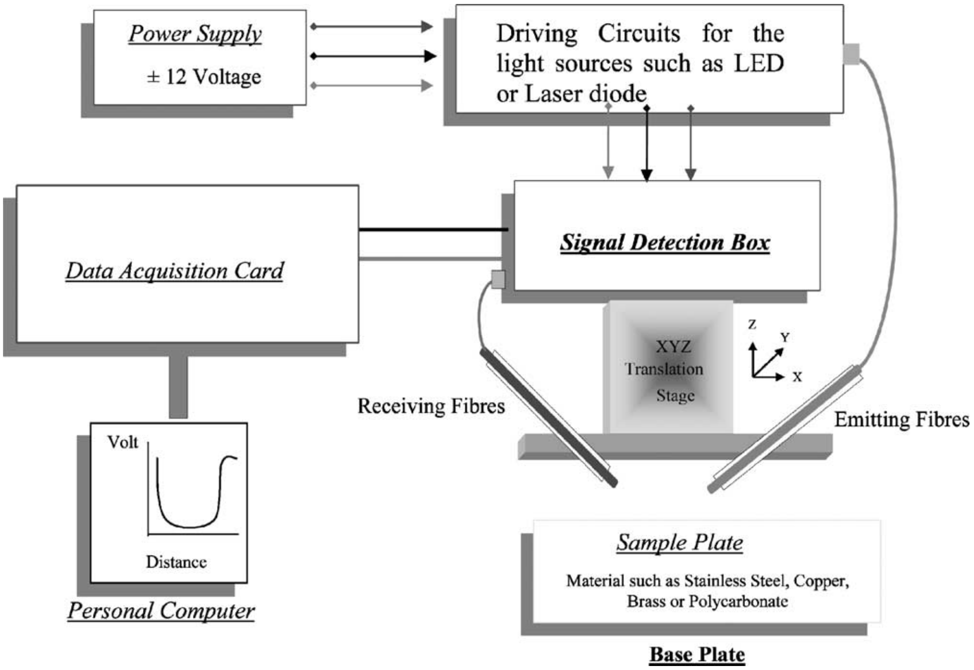

Fig. 2. Schematic outline of the experimental rig.

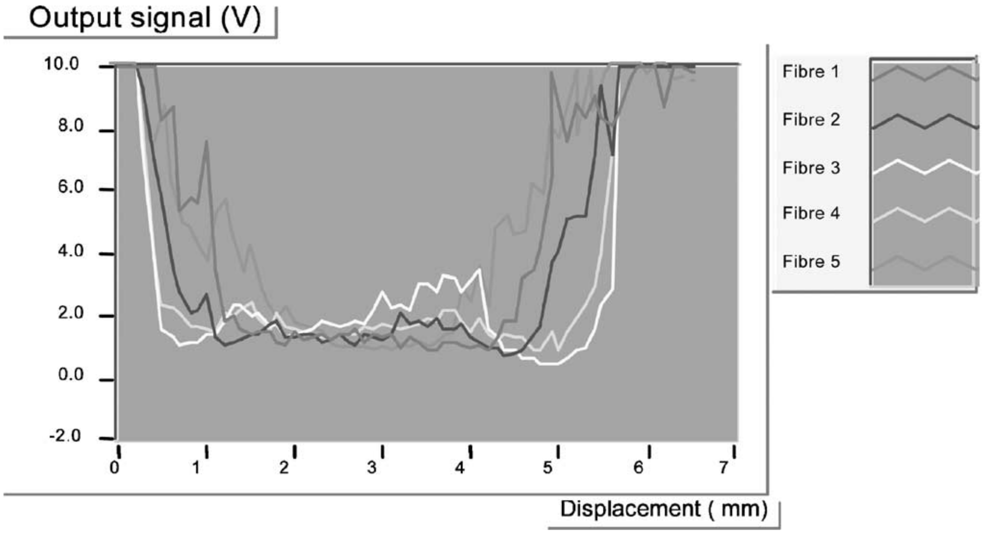

Fig. 3. Screen-captured photodiode output signals.

programming language that is often used to program real time data acquisition and data analysis systems. Fig. 3 shows a typical screen-captured of the recorded five signals from the test plot.

3. Measurement procedure and experimental results

The vertical displacement characteristics were studied to optimize how far the transmission and receiving fibers

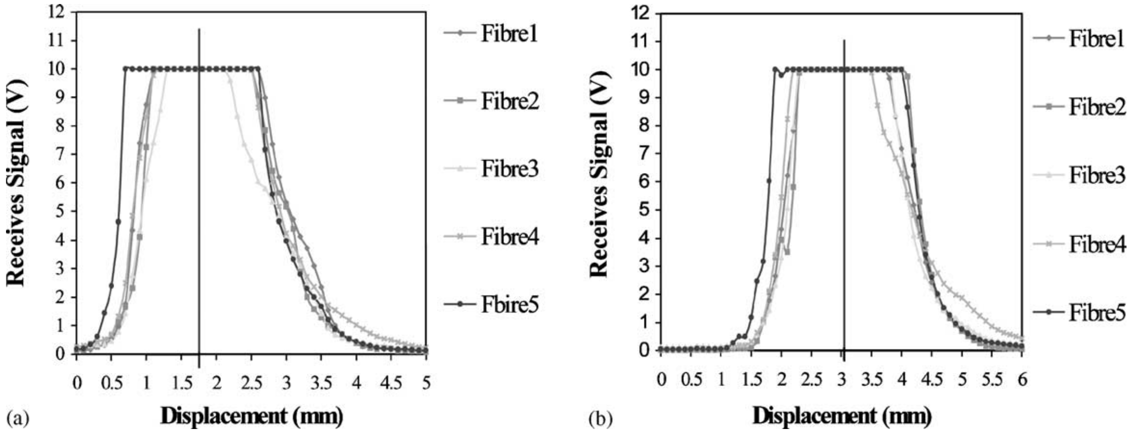

Fig. 4. Vertical displacement characteristics of (a) brass surface and (b) stainless steel surfaces.

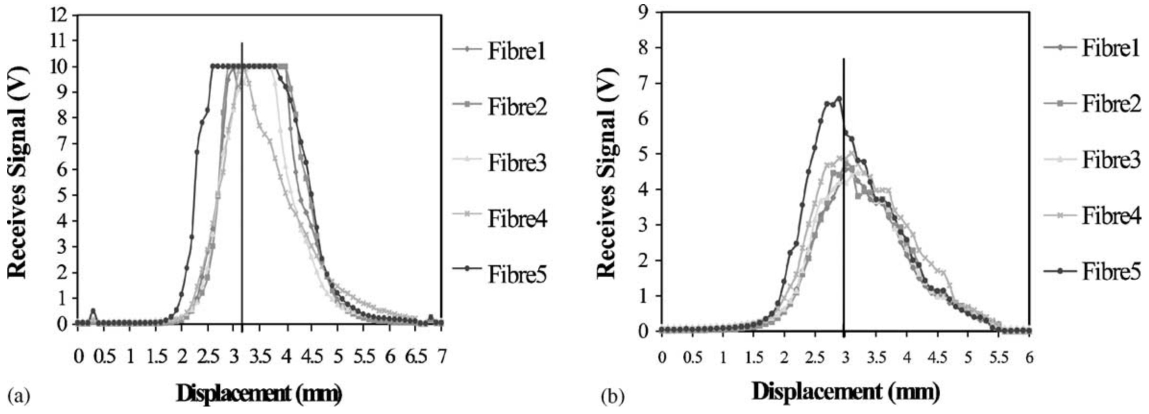

Fig. 5. Vertical displacement characteristics of (a) copper surface and (b) polycarbonate surfaces.

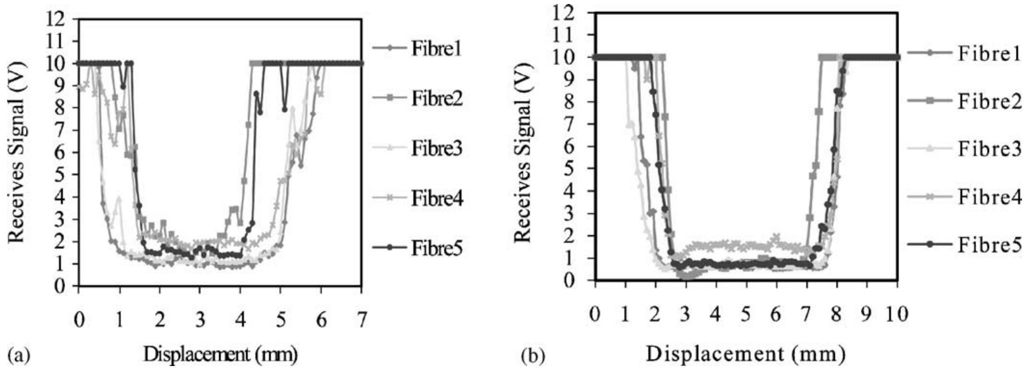

Fig. 6. Displacement characteristics of (a) 0.6 mm thick brass plate and (b) 1.6 mm thick stainless steel plate.

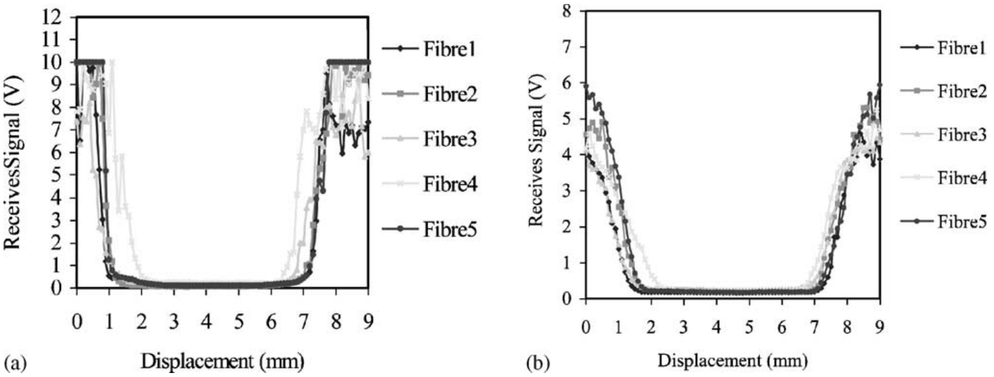

Fig. 7. Displacement characteristics of (a) copper plate and (b) polycarbonate plate.

should be positioned from the workpiece surface. The results of this study are shown in Figs. 4 and 5 for different materials. Peak values for stainless steel were obtained at a distance of 1.75 mm from the sample surface (Fig. 4(a)) and for the brass were obtained at a distance of 3 mm (Fig. 4(b)). Peak values of the copper were obtained at a distance of 3.2 mm (Fig. 5(a)) and for the polycarbonate were obtained at a distance of 3 mm (Fig. 5(b)).

In the second part of this experiment the translation stages was arranged so that a surface map of the area of the hole and the surrounding surface area could be recorded. Figs. 6 and 7 show the readings, which were taken by displacing

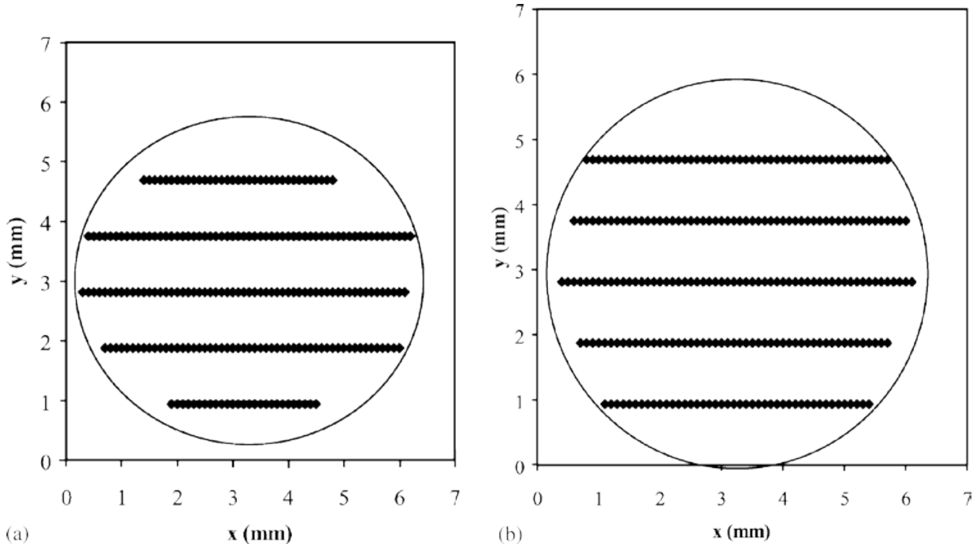

Fig. 8. Surface maps through 6 mm diameter holes in (a) brass and (b) stainless steel.

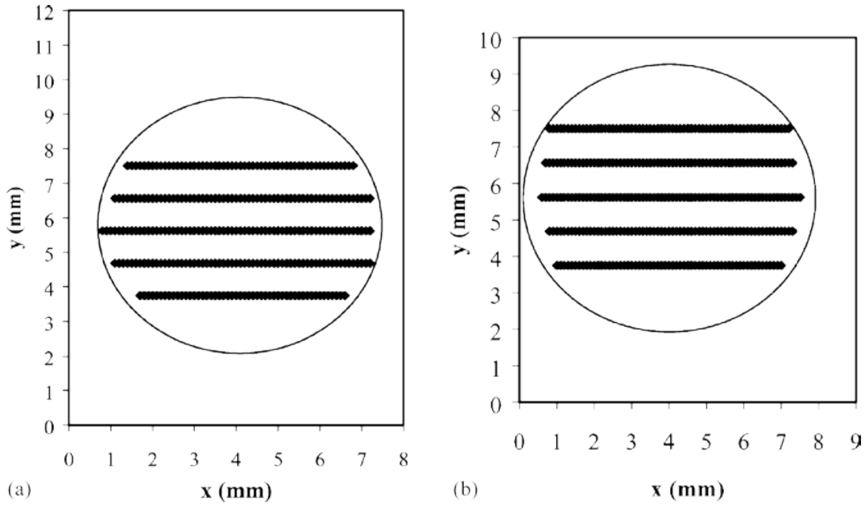

Fig. 9. Surface maps through holes of (a) copper 6 mm diameter hole and (b) polycarbonate 7 mm diameter hole.

the *x*-stage through 0.1 mm increments. Each reading is compared with a cut-off voltage level. Photodetector voltage levels below this cut-off voltage were used to represent the presence of a hole for the surface mapping routine. A high intensity reflected light signal was measured from brass plate, stainless steel plate, and copper plate. It is clear from Fig. 7(b) that the polycarbonate plate has a diffusely reflecting surface.

The surface maps generated by these scans are shown in Figs. 8 and 9. The cut-off voltage of 2 V is not suitable for all the sample plates. As we can seen from Fig. 6(a) and (b) some of the reflected light form shallow holes, or thin plates with through holes, is detected. These indicated that the intensity of the reflected light is very high and that the photodiodes can detect signal over 1 mm below the specimen surface. The surface maps presented show that the sensor scanned the entire through hole with different sizes successfully.

Several factors affect the accuracy and the resolution of optical defect measurement system. Some of these factors have already been addressed here. Factors that were seen to affect the system were cleaving the fibers, holder deigned, alignment of the fibers, fiber cleaning, distance between the fibers, the selected cut-off voltage level, and distance from fibers to the surface.

4. Conclusions

In this paper, a novel design for fiber-optic laser scanning inspection system was presented. This system has high response and accuracy. The experimentally obtained results from several materials show the system's ability to recognize defects. The achieved results show that even though this system is capable of 2D scanning it may also be operated as a limited 3D vision inspection system. The fiber-optic laser scanning system, which has been discussed in this paper offers an effective means of highly accurate measurements, high resolution, and flexibility to capture the output signal reliably.

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