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Detection and Discrimination of Surface Defects by Analyzing Diffraction Pattern of Laser Beam

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ABSTRACT

We have developed a new apparatus to cope with the surface inspection of products having even undulating or stepped surfaces. To realize such surface inspection, we combined the three dimensional shape measurement through laser beam scanning and the flaw and defect identification through diffraction light pattern analysis. This combination makes it possible to detect locations, sizes, kind and degrees of flaws or defects if any. A couple of parabolic cylindrical mirrors are used to scan the laser beam perpendicularly to the specimen transfer direction and to converge the diffraction light on a specifically designed photo-detecting sensor through a mechanism to maintain the inspecting surface at a constant level. A couple of cylindrical lenses are also used for a TV camera to improve the height measurement accuracy.

INTRODUCTION

The developments of image processing, pattern recognition and knowledge engineerings have stimulated the automation of inspection processes for manufactured products. However, for the inspection of product surfaces, the present state of the art is not mature and the visual check by inspectors is still a common practice at production lines because of the variety of surface flaws and defects of products and their complexity. The development of automated surface inspection system is therefore expected not only to replace the visual check but also to realize the production of flaw-and-defect free products through the identification of flaw-and-defect causes with the system.

This paper deals with such a surface inspection apparatus and a method developed on an experimental basis. The apparatus can cope with the inspection of products having even undulating or stepped surfaces on them and can detect locations, sizes and kinds of flows and defects if any. The inspection method applied here combines the three dimensional shape measurement of a product through a laser beam scanning and the analysis of diffracted light pattern of the projected laser beam light on the surfaces of the product.

CONVENTIONAL SURFACE INSPECTION WITH LASER BEAM.

Among the conventional surface inspection methods¹⁾²⁾, the flying spot method using a laser beam is preferable not only to detect the kind or nature of surface flaws and defects but also to measure locations and sizes of them. However, the application of conventional flying spot method is quite restricted to the inspection of limited products with simple plano-surfaces. This is because the diffracted light from any potion of a surface should enter a photo-detecting sensor fixed at a certain location to obtain a diffraction pattern image. This method requires therefore some mechanisms to maintain the surface of a specimen with undulating or stepped surfaces following the three dimensional shape measurement of the specimen.

Besides the above, the conventional photo-detecting sensors are too simple to obtain a sufficient two-dimensional distribution of the diffraction light pattern, and are only applicable to identify simple surface flaws and defects³⁾⁴⁾. If flaws and defects are overlapped at a same portion, they cannot be distinguished from each other and require the development of a more appropriate photo-detecting sensor to obtain the sufficient distribution of the diffracted light⁵⁾⁶⁾.

SURFACE INSPECTION APPARATUS

System Configuration To realise the surface inspectin of products with any shapes, we have developed a new inspection apparatus. This apparatus is so designed as to realize both the three dimensional shape measurement of a specimen and the detection of flaws and defects on its surfaces. Figure 1 shows a schematic configuration of the apparatus.

The apparatus has a light projection system including a laser generator(He-Ne 5mW) to emit a laser beam, a collimator lens to adjust the beam diameter, a vibrating mirror to change the beam direction for scanning specimen surfaces in direction Y, a parabolic cylindrical mirror to convert the scanning light from vibrating mirror into a parallel light beam.

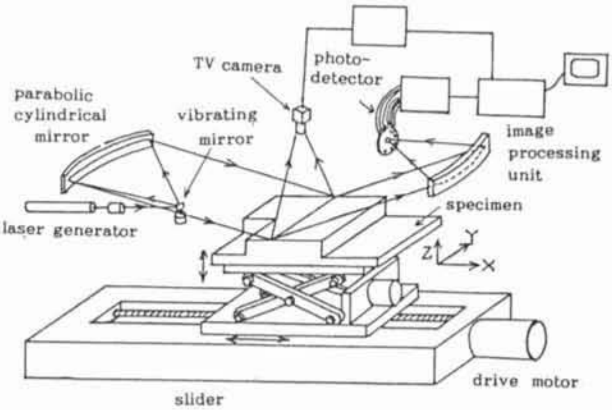

Fig.1 Schematic configuration of the developed apparatus

On the receiving side, the apparatus is provided with a photo-detection system including a TV camera located above the specimen, an image processing unit connected to the TV camera to obtain an image for three dimensional shape measurement, a parabolic cylindrical mirror to converge the scanning laser light reflected and scattered on the inspecting surface, a photo-detector to receive reflected and diffracted light through the parabolic cylindrical mirror, a data processing unit to judge the locations, sizes and nature of flaws and defects on the basis of the information from the image processing unit and a photo-detector, and a display to indicate the results of the judgement on flaws and defects.

Further the apparatus has two sliders with drive motors to transfer a specimen stage in direction X and to maintain the inspecting surface at a constant level on direction Z. The slider for direction Z is inevitable to obtain the converged image of the reflected and diffracted light on a photo-detecting sensor at a fixed location following the information of three dimensional shape measurement described below.

Photo-detector To identify the kind or nature of flaws and defects as shown in the example of Fig.2, it is required to obtain a sufficient information on the diffraction light pattern and to measure the energy of the diffraction light. Figure 3 shows a schematic diagram of our developed photo-detecting sensor.

Three thousand of optical fibers of 0.5mm diameter each on the light receiving side are grouped into 48 blocks which constitute a half disk with an alignment of four blocks in radial direction and twelve blocks in circumference direction of half concentric circles. The other ends of blocked optical fibers are connected each to photo diodes. The area of each fiber block is so designed as to become same from block to block. To the other half of the disk, three another optical fibers of 1 mm diameter each attached to measure accurately the energy of even feeble diffraction light at any three points through photo-multipliers. For obtaining more precise diffraction light pattern from the inspecting surface, it is possible to separate easily the optical fibers into more blockes.

Three dimensional Shape Measurement The picture image taken by the TV camera with a couple of cylindrical lenses is used in the manner as follows. The laser beam scanning by the vibrating mirror is synchronized with the video signal of the TV camera, so that the inspecting surface in the obtained picture image comes out as a dark surface with bright linear stripes of the laser beam as in the fashion of slit light projection by the light chopping method for three dimensional shape measurement. Since the angle of the incidence of the laser beam and the TV camera position are known beforehand, the height of the inspecting surface can be determined by calculations based on the principle of triangulation using the laser beam position in the obtained picture image.

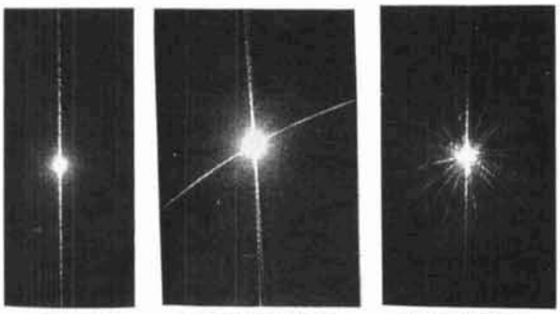
normal scratched flaw grazed flaw

Fig.2 Examples of diffraction light patterns.

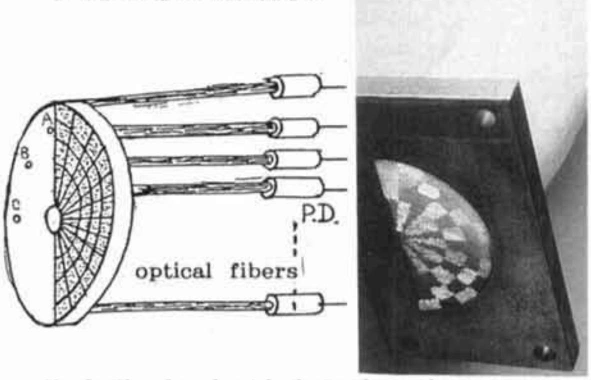

Fig.3 The developed photo-detecting sensor.

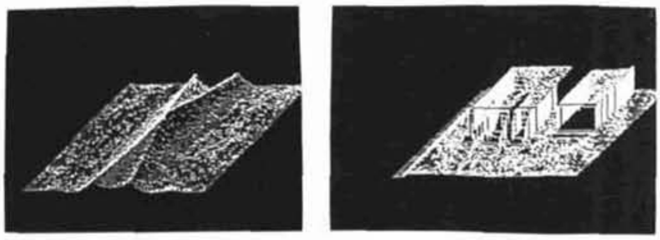

Fig.4 Examples of three dimensional shape measurement.

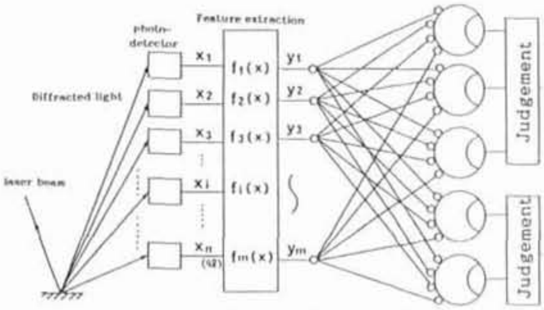

Fig.5 Schematic diagram of neural network.

The information of the three dimensional shape measurement not only permits to move the specimen mounting stage up and down for maintaining the scanning position of the laser beam at a constant level but also helps detect surface irregularities and cracks which cannot be detected by the analysis of the diffraction light. The reflected and diffracted light might fail to enter the photo-detection system in case of a flaw or a defect in a deep position or in case of a crack, which failure makes the detection of flaws and defects infeasible through the diffraction light analysis.

The use of the cylindrical lenses is to improve the accuracy of height measurement more about ten times than that of conventional measurement with ordinary lenses. For synchronizing the signal of the mirror vibration and the video signal of the TV camera, we have also developed a special signal control circuit.

Data Handling and Analysis of Diffraction Light Pattern A great amount data of the diffraction light pattern is obtained through the laser beam scanning. Moreover the diffraction light pattern varies from flaw to flaw and defect to detect as shown in Fig.2. Therefore a method of high-speed data handling and analysis of the diffraction light pattern should be developed for on-line surface inspection at production lines. Our method for this objective is as follows.

One 48-bit memory is provided for a diffraction light pattern data of one inspection point along the scanning line. The output signals of each diffraction light through photo-diodes should be therefore binalized based on an appropriate threshold value. The amount of data to be stored becomes about 1.5 M bytes on the basis of 512 points of sampling along each scanning line and 480 times of transfer of the specimen in direction X. For the high-speed analysis of the diffraction light patterns using the data obtained above, we have been testing a neural network method with a three-layer structure, because the method has an attractive advantage to accumulate knowledge on flaws and defects through its self-learning function. Figure 5 shows a schematic diagram of our neural network.

Apparatus Performance The shape measurement accuracy depends on laser beam scanning, specimen transferring, image processing and photo detecting mechanisms. The developed apparatus can sample data at maximum points of 512 along each scanning line with the maximum width of 200 mm. The width resolution becomes therefore not more than 0.4 mm. The depth resolution is determined by the pitch of specimen transfering and becomes 0.01 mm at the minimum. The data sampling time is 40 microseconds per one scanning point and becomes about 20 miliseconds per one line scanning. The height resolution is not more than 0.1 mm due to the use of a couple of cylindrical lenses for TV camera. The time required for the flaw-and-defect identification depends on the neural network performance. The neural network for our apparatus is now constructed in a software manner and takes several seconds for the judgement of flaws and defects. This time consuming fault is not fatal because such neural network could be easily realized in a hardware manner.

EXAMPLE OF FLAW INSPECTION

We have tested the flaw and defect identification performance of the developed apparatus using aluminium specimens with several flaws and defects on their flat surfaces. The surface inspection was carried out by measuring the energy and the pattern of the diffraction light.

The diffraction light energy was measured at three points with radial angles of 5° ,45° and 90° through photomultipliers and quantized 255 grades by eight-bit A/D converters. Figure 6 shows the obtained three images of the diffraction light enegy in three radial directions. The logical operation over these image data makes it possible to judge the kind of flaws or defects on the specimen surface with some confidence, because such a scratched flaw has a unique diffraction light pattern oriented to a certain direction as shown in Fig.2. Figure 7 shows the result of the logical EXOR operation over these image data and demonstrates the identification of the scratched flaw. For the identification of a grazed flaw, logical AND operation over these image data

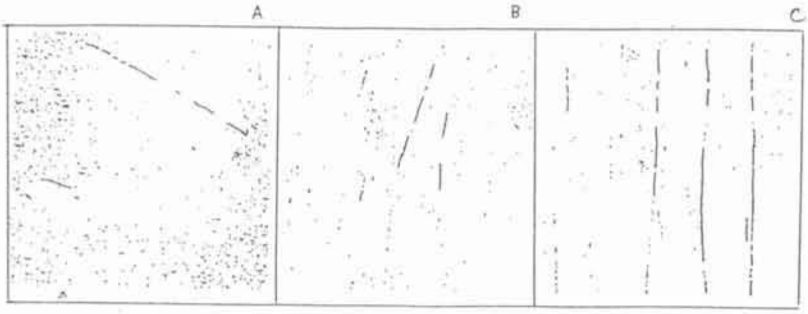

Fig.6 The diffraction light energy in three radial directions over the specimen surface.

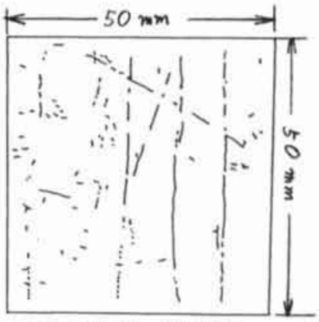

Fig.7 The result of logical EXOR operation for flaw-and-defect identification.

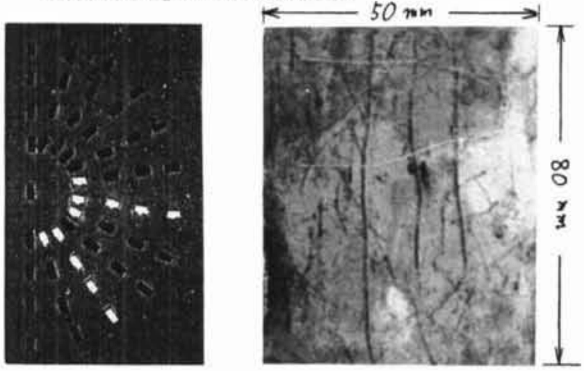

Fig.8 Example of diffraction light pattern for scratched flaws (left) and the identified flaws on the specimen surface (right).

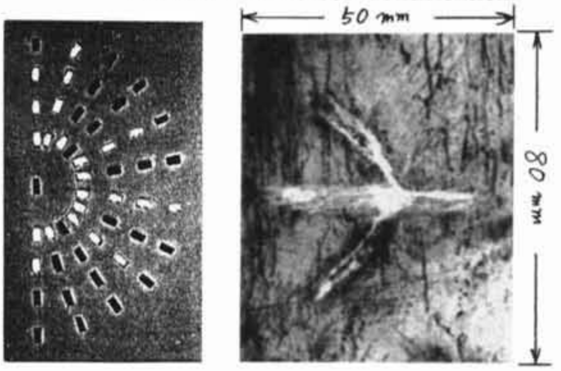

Fig.9 Example of diffraction light pattern for grazed flaws (left) and the identified flaws on the specimen surface (right).

becomes effective, because the diffraction light is oriented to many directions. Although the measurement of the diffraction light energy has demonstrated its effectiveness to identify flaws or defects, the measurement in three radial directions is still insufficient to identify each flaw or defect out of variety of flaws and defects. Therefore it seems better to use the energy information supplimentaly for judging the degree of flaw or defect. This is because the kind of flaw or defect is more efficiently detected through the analysis of the diffraction light pattern as described as follows.

Fourty eight photo-diodes are embodied in the photo-detector to obtain the diffraction light pattern for any point of the inspecting surface along the scanning line. Figure 8 is an example of the pattern obtained from an aluminium specimen with both roll marks and scratched flaws on its surface and shows a duplicated pattern of diffraction light due to a roll mark and a scratched flaw. This duplication does not devaluate the obtained data, because the diffraction pattern of roll mark is easily obtained from the measurement of a flaw-free specimen and can be masked out by a hardware manner. Figure 9 shows another diffraction light pattern obtained for the specimen with grazed flaws on its surface. These diffraction patterns over specimen surfaces are to be analyzed by the neural network method and provide the information on the kinds of flaws and defects.

CONCLUDING REMARKS

We have developed a new apparatus to cope with the surface inspection of products having even undulating or stepped surfaces. To realize such surface inspection, we combined the three dimensional shape measurement through laser beam scanning and the flaw-and-defect identification through the diffraction light pattern analysis. This combination makes it possible to detect locations, sizes, kinds and degrees of flaws or defects if any.

To realize on-line surface inspections at production lines further studies are required on the neural network method including the construction of a hardware network and the algorism of identification for flaws and defects .

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