VARIOUS METHODOLOGIES FOR ASSESSMENT OF SURFACE QUALITY

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Abstract- In almost all manufacturing processes, surface roughness plays an important role for the assessment of quality of the product. In any production process, an evaluation of the surface roughness is very essential. Many ways of measuring the surface roughness have been explored at one time or another. Some of these methods have sunk without any trace, because of the inherent disadvantages. In other cases, additional methods have been developed to deal with difficult measurement problems. The roughness of a surface cannot be easily defined by a single parameter or by any intrinsic property of the surface. The surface roughness exists in two principal planes: one at right angles to the surface, which is characterised by some kind of height, and the second in the plane of the surface, which is characterised by some kind of wavelength. Thus, there are two sets of limitations to each roughness-measuring instrument or technique: (i) the largest and smallest difference of heights, which it will resolve and (ii) the longest and shortest wavelengths, with which it copes. In this paper, various methodologies adopted in the past and at present are discussed briefly.

key words: Surface Roughness, Surface Quality.

I. SIGNIFICANCE OF ASSESSMENT OF SURFACE QUALITY

The evaluation of surface finish is very essential for product quality control as well as process control The major areas of application of surface roughness measurement are: (i) Mechanical engineering related applications, (ii) Automobile Industry, (iii) Magnetic layered materials, (iv) MEMS, (v) Electronics, (vi) Optics, (v) Medical Science, (vi) Various applications related to Paper Industry, Military weapons, Space shuttles, Robotics, Solid lubricants etc.

In earlier measurement methods, the instruments were able to evaluate the surface roughness in only two-dimensions. The concept of three-dimensional measurement of roughness was introduced in 1998. Even thereafter, the methods of evaluation in three-dimensional area of surface were developed with a limited progress. The standards for three-dimensional roughness measurement parameters are also yet under preparation. At present, the use of three-dimensional roughness measurement methods is limited due to the cost of such instruments available and their complexity. From the various industries, the requirements for surface quality have now become more demanding and stringent. Therefore, there is a need for the development of a method of surface roughness measurement to cater the present needs of the industries.

II. HISTORICAL DEVELOPMENTS IN ASSESSMENT OF SURFACE QUALITY

The need for a detailed study of the area of surface roughness was felt as early as in the1900s. The initial attempts were made to evaluate surfaces of the machined parts with a view to improve their performance. Leonardo da Vinci, Amonton and Coulomb were all interested in the task of assessing the surface finish of the parts and to correlate it with their performance characteristics. However, their investigations were largely subjective. Perhaps, the first attempt to make an instrument to measure the surface roughness was in 1919 by Tomlinson [1]. A crude lever system was devised with the magnification of the surface profile obtained mechanically by a factor of about 20:1, just enough magnification to be able to observe the surface details.

Surface instrumentation was really started by Schmaltz, who developed the first Mechanical stylus instrument in 1929 and began experimenting with optical methods [2]. Schmaltz and Tornebohm have brought out a detailed treatise on engineering surfaces and have discussed some possible measurement approaches.

However, these developments stimulated Dr. Abbott [3] of Physics Research Inc. in 1933 to advance the technology by making the output from the probe in the form of electrical signals so that substantial magnifications could be achieved. Although, this output could be seen on a meter, a permanent record for use on the shop floor was not possible. Abbot and Firestone reported the development of the first electric tracing stylus instrument, which could provide an authentic profile of the surface in a magnified fashion. In 1939, R.E. Reason of Taylor Hobson [4], completed the jigsaw by adding on a chart recorder. This had given birth to the profile graph, which was possible by a racking mechanism to move the stylus across the surface. Thereafter, development of various stylus tracings gave a wide choice for the user [Perthen 1949]. The underlying principle of many of these instruments was to provide a 'two-dimensional profile of the actual three-dimensional surface'. A few instruments were also developed by Dreyhaupt 1954, Nlcolau 1937 to assess specific functional characteristics of three-

dimensional surfaces [5]. Evaluation of the profile geometry was considered to be a better proposition, as it is neutral to various functional applications of the surface. Most of the standards that had been put forward on surface finish have, therefore, taken the 'surface profile' for evaluation. Over the years, the search for some simple parameters to represent the surface profile had resulted in a large number of geometrical as well as statistical parameters for finish specifications. This scenario has been well presented by Whitehouse [6].

Mechanical stylus technique has its disadvantages. There are limits in the lateral resolution set by the size of the probe tip. The stylus probe technique measures the profile along a line of the surface, and, if the entire surface is to be mapped, then many such lines must be scanned. The major drawback of the stylus technique is that it involves contact of the stylus probe tip with the surface, and thus can damage or alter the surface and for many applications makes it unsuitable as a profiler.

Optical profilers developed later can offer better lateral resolution, whole-field analysis, high-speed measurements and involve no physical contact with the surface to be studied. The preferred way was to use ***fringe methods*** notably by Linnich in 1944 and Tolansky in 1946. In this way, all area of the surface could be examined simultaneously, which was an advantage, and the output could only be viewed. The ***Atomic Force Microscope*** (AFM) and its variation the ***Scanning Force Microscope*** (SFM), are based on ***non-optical techniques.*** The ***optical methods*** have been used to amplify and measure the signal. The stylus and optical methods were developed along different paths, the stylus method being used for height information and the optical methods for areal information [5]. However, some problems began to arise, when both the methods were used on the same object, and gave the readings, which did not agree with each other.

Around 1960s, developments of

Digital processing of data have taken place and had shown the enormous potential of this approach in surface roughness evaluation. In the initial stages, surface profiles obtained from stylus instruments were digitised and then processed in a digital computer. Although there were limitations on speed and on the amount of data that could be handled, it was still possible to use this approach very effectively. Many different approaches for profile analysis were reported in the 1960s and 1970s, which were similar to those adopted in signal processing. Digitising gave considerable flexibility to the study and analysis of the profiles, thus eliminating the need to make hardware changes to evaluate finish in different ways. Dramatic improvements in their computational power together with their affordability have made **personal computers** (PCs) handy for digital processing of data and have allowed them to be used as the primary analysis modules for surface evaluation. All instruments that were hardware-oriented in their data analysis and evaluation have been switched over to software-based processing of data, and some of the research results based on data processing have almost now became a shop-floor reality. A standard roughness-measuring instrument has become a data logger connected to a PC, which analyses the data as parameter requirements of the customer.

In 1990s, many instruments have come up with the possibility of simultaneously tracing a number of parallel profiles of a surface with a stylus and displaying the results vividly in three- dimensions. Many of the **optical approaches,** which are excellent, can now be used together with data processing through CCD (charge coupled device) cameras to bring out a 3-dimensional view of the surface and also the roughness parameters related to two-dimensional profiles [7]. Another method based on grid projection for the three-dimensional visualisation of surfaces was also commercially available [Frankowski 1993]. Intuitively many feel that the transition from profile (two-dimensional) to areal (three-dimensional) data should provide a basis for expanding and improving functional correlations. In surface metrology, profile data are often termed as two-dimensional data and areal data as three-dimensional data [Frankowski 1993].

III. RECENT TECHNIQUES AND METHODS IN THE AREA OF OPTICAL MEASUREMENTS

Several non-contact techniques have been proposed for the measurement of surface roughness. Ultrasonic sensors, capacitance transducers, inductance transducers, and optical sensors are among the common alternatives to stylus profiling. With the availability of advanced digital processing techniques, the optical methods were considered very promising. An effective combination can be achieved between the modern optical and electronic methods [8].

3.1 Optical Surface Profiling Methods:

Over the last few years, there has been a significant increase in research into the development and applications of optical methods for surface roughness evaluation [9]. This has been due to a number of factors such as greater familiarity with laser techniques, the availability of new commercial equipments and developments in solid-state detector arrays and image processing. The optical techniques involve no physical contact with the surface under observation. Among the more promising optical methods for measuring the surface finish are *light scaterring* and *interferometry*. These include Scanning Electron Microscope (SEM), Light

scattering approaches, Light sectioning, and various Interferometric techniques such as fringes of equal chromatic order *(FECO),* Nomarski and Differential interference contrast *(DIC),* Tolansky multiple-beam interferometry, and Two-beam interferometry based on Michelson, Linnik and Mirau. A detailed description of different optical techniques for measurement of surface roughness can be found in Vorburger and Raja [10].

3.2 Speckle Techniques:

The *Electronic Speckle Pattern Interferometry (ESPI)* techniques are usually used for displacement and strain analysis and also for contouring purposes. These profilers offer excellent vertical resolution and are only suitable for continuous surfaces. Leopold et al. [11] has applied an optical method based on Electronic Speckle Pattern Interferometry (ESPI) for 3-D measuring and microscopic and macroscopic inspection of different sheet metal surfaces and also for the physical characterisation of the surface topography by using the intelligent methods like *Neural Networks and the Wavelet Analysis.*

3.3 White Light Interferometric (WLI) Techniques:

Phase-shifting interferometry (PSI) techniques are used to obtain three-dimensional images of surfaces. Optical profiling is a well-established technique for non-contact, 3D surface roughness and topography measurements. An optical profiler (like a conventional microscope) utilises the properties of light for topography measurements of surface heights from nanometres to several millimetres. The *white light interferometric* (WIL) techniques allow surface profiling with high accuracy. Using *Michelson interferometer setup,* a three-dimensional image of the surface profile can be mapped [12]. Many different techniques have been used with these profilers to speed up the analysis, including Fourier and phase-shifting methods.

3.4 Optical Scattering Techniques:

In light scattering experiments, a light beam of a certain wavelength is made incident on the surface under test at a controllable angle of incidence. When the surface is rough, a part or whole of the incident beam will be scattered away from the specular region, providing a diffuse beam.

Commercial instruments based on light scattering are now available. A recent paper by Vorburger et al. suggests appropriate optical measurement schemes for different roughness ranges. Other significant contributions have been made by Beckmann et al., Bennett, Broadmann et al., Church, Ceilo, Clarke et al., Inasaki, Rakels, Shiraishi, Takeyama et al., Tanner et al. and Thomas allow for a better understanding of optical roughness measurement. Some innovative *signal processing approaches* (such as neural network based inspection using laser scattering) are demonstrated by Gruber et al. and Villalobos et al. Cuthbert et al., Lo Casto et al. and Luk et al. propose the application of vision systems for optical measurement of surfaces. Other recent works citing the use of vision in roughness measurements include Damodarswamy et al., Sunder et al. and Gupta et al.

3.5 Differential Light-scattering Techniques:

Differential Light-scattering Techniques [13] involve the quantitative measurement of the intensity of the scattered light as a function of scattering angle. These techniques inherently average over a region of the test surface and cannot directly obtain surface profiles.

3.6 Laser Techniques:

Optical scattering technique provides a large area profiling capability but requires lasers, sometimes an array of detectors, a light reflective surface and also provides only limited (micron-scale) vertical depth range. Harding has reviewed various laser scatter techniques for surface finish measurement. These approaches include *laser speckle correlation, reflectance distribution, fringe contrast and correlations techniques.* This paper also reviews the range of optical surface roughness techniques currently available. Ramesh et al. have used a *laser optical diffraction technique* for the measurement of surface finish. A beam from a helium-neon laser is passed through the slit formed between a smooth knife-edge and the cylindrical turned component (test piece). This results in a diffraction fringe pattern and is then captured on a high- resolution image monitor, using a CCD (charge coupled device) camera and is stored on a disk. The image is then analysed using the Matrix vision processor. The method is especially useful for turned and ground surfaces.

3.7 Interferometry Techniques:

The optical interferometric techniques are believed to be most promising for non-contact surface measurement. These techniques give a direct measure of surface height. With suitable computer analysis, these can be used to completely characterise a surface. Bennett [14] has developed an interferometric system employing multiple-beam fringes of equal chromatic order. Wahl et al. [15] have proposed a *hybrid measurement technique* for high-precision surface inspection. The technique uses an interferometer to image microscopic surface defects. Wyant et al. have reported a non-contact technique for measuring two-dimensional surface roughness using a *Mirau interferometer* [16]. An *electronic phase-measurement technique* was used with a linear, solid state, detector array to provide digital profile data. Using this, they have developed a three-dimensional profiler.

3.8 Vision Systems:

El-Hakim et al. have presented a comparative evaluation of the performance of passive and active

Three-dimensional (3-D) vision systems. Radhakrishnan et al. have emphasised the significance of surface finishes of manufactured parts. It has been shown that the focus is gradually shifting to the three-dimensional evaluation of the surface. Huynh has developed a non-contact measurement technique to measure the surface finish of machined parts. The system uses a machine vision system to capture the magnified image of a surface which is illuminated by a white light source at a shallow gazing angle. These techniques are useful in the measurement of surface finish in nanometre (nm) rang

Gupta et al. have discussed the feasibility of a *Machine Vision System* using optical parameters for the characterisation of surface roughness. Other recent works citing the applications of machine vision in roughness measurements include those by Damodarswamy et al. Sunder et al. An *Intelligent Visual Evaluation System* for mirror-finished surfaces of heat-treated steel using neural network has been described by Kato et al.

CLOSURE

From the literature review presented here, it can be seen that a large number of techniques of surface quality measurement are available and number of devices based on these techniques have been developed. However, very few techniques and devices can satisfy the present requirements of the industries in the area of surface quality assessment. The present requirements are,

i. Surface quality measurement of machined parts on shop-floor.
ii. Assessment of surface quality on a large portion or an entire area of the surface of the machined parts rather than along a straight path of a small length (as obtained using earlier devices).
iii. The method of assessment of surface quality of the large surface of machined parts should be low cost, high-speed and contactless type for 100% inspection.

As such, the focus of the recent research work has to be on the development of a surface quality assessment method, which can satisfy most of the above mentioned requirements of the industries.

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