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Investigations on machined metal surfaces through the stylus type and optical 3D instruments and their mathematical modeling with the help of statistical techniques

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ABSTRACT

The measurement of roughness on machined metal surfaces is of considerable importance to manufacturing industries as the roughness of a surface has a significant influence on its quality and function of products. In this paper, an experimental approach for surface roughness measurement has been based on the comparison of roughness values taken from the stylus and optical type instruments on the machined metal surfaces (turning, grinding and milling) is presented.

Following this experimental study, all measured surface roughness parameters have been analyzed by using Statistical Package for Social Science (SPSS 15.0) statistically and mathematical models for the two most important and commonly used roughness parameters R_a and R_z have been developed so that $R_a = R_a(F, P, C)$ and $R_z = R_z(F, P, C, M)$, whereas F expresses feed, P periodicity, C contrast and M the type of material. The statistical results from numerous tests showed that there has been a correlation between the surface roughness and the properties of the surface topography and there have been slight differences among three measurement instruments on machined metal surfaces in this experimental study.

1. Introduction

Surface roughness plays a vital role in determining the desired quality of a machined metal surface for today's engineering industry. The quality of assessment of engineering surfaces with respect to their functional and optical properties for different loading conditions is influenced by roughness parameters characterizing basically the surface microtopography [1]. It is traditionally defined by two parameters: arithmetical mean deviation of the assessed profile R_a and average maximum height of assessed profile R_z as they are one of the most commonly used and accepted by researchers and in industry as well. Surface roughness inspection is one of the essential quality control processes carried out to ensure that manufactured parts conform to specified standards [2].

The surface parameter used to evaluate surface roughness in this experimental study is the roughness average (R_a), the most widely used parameter for surface texture. The roughness average is the area between the roughness profile and its central line, or the integral of the absolute value of the roughness profile height over the sampling length. Determination of R_a is normally computed by the software but can be derived using the following formula:

$$R_a = \frac{1}{l_r}\int_0^{l_r} |z(x)|dx \tag{1}$$

where is $z(x)$ is the profile deviation from the mean line and l_r is the sampling length.

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The more common parameter for roughness is maximum height of profile (R_z). R_z is calculated by measuring the vertical distance from the highest peak to the lowest valley within five sampling lengths, then averaging these distances. R_z averages only the five highest peaks and the five deepest valleys – therefore extremes have a much greater influence on the final value.

The goal of this research work is to obtain mathematical models of R_a and R_z estimating the coefficients of the linear equation, involving a few independent variables (feed in mm, periodicity, type of material, contrasting, type of production process, etc.) with an analysis of variance (ANOVA) and regression analysis.

2. Surface topography techniques for the comparative study

Conventionally, surface roughness measurement has been performed by using a stylus instrument [3,4]. When a stylus traverses a surface, the vertical motion of the stylus is converted by way of a pick-up into an electrical signal. The pick-up is generally a linear variable differential transducer (LVDT). The electric signal is amplified and processed or converted into a digital signal via an A/D converter and then analysed using a computer. A schematic diagram of such a system is shown in Fig. 1.

In the diagram shown, the stylus is held stationary while the specimen surface is moved in a raster scan using precision *X*, *Y*-tables. The movement of the table is controlled via a computer, allowing numerous combinations of area size and data sample spacing to be selected [6].

The stylus measurement method is a contact type, the main drawback of which is that the loaded stylus can damage or scratch the surface being measured, especially on soft surfaces [7]. The transducer and stylus tips are often fragile, hence the instrument must be applied in a fairly vibration free environment. Consequently, this direct contact measurement method is not suitable to be used on a test object undergoing a machining process simultaneously [8].

These two main drawbacks of the stylus-based surface measurement technique make it necessary to develop non-contact optical methods that can be used for in-process measurement and the measurement of soft surfaces [9]. Stylus and optical type profilometers are, in a sense, different, that is; while traditional stylus method is used for height information, the optical method refers to areal. Optical technique as a complement to the stylus instrument, a non-destructive and non-contact method, appears to be a suitable alternative for carrying out measurement of surface quality including surface roughness [10].

New breakthroughs by the instrumentations have been made in recent years, to establish high-tech instruments which can acquire a 3D surface structure of the precisely machined surfaces to fulfill the requirements for the application in industrial environment. In this experimental study, both surface measuring systems will be examined with great many practical applications [11].

The measurements of optical systems were carried out by two different instruments in this experimental study. One is a new non-contact optical surface characterization technique called focus variation used by the infinite focus microscope (IFM) to build true color 3D images of surfaces and microscopic structures. Its operating principle combines the small depth of focus of an optical system with vertical scanning to provide topographical and color information from the variation of focus. The system delivers dense measurements over large areas with a density of 2 Mio – 25 Mio measurement points and a high vertical resolution up to 20 nm [12].

This non-destructive method utilizes coaxial white light which is provided by a light source delivered through a beam splitter to a series of selectable, infinity-corrected, high-Numerical Aperture (N.A.) objectives contained in a

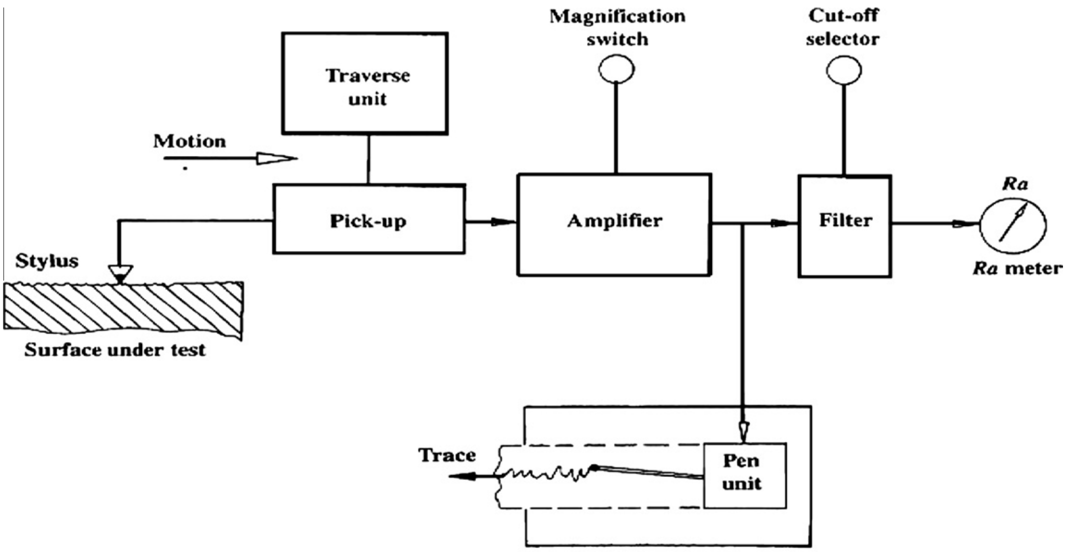

Fig. 1. Schematic diagram illustrating the major constituents of a stylus-type of surface texture measuring instrument [5].