A FAST VERSATILE OPTICAL PROFILOMETER [1,2]

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We describe a new optical profilometer for the measurement of surface roughness of workpieces from the submicrometer range up to several tens of micrometers. The device has speed and sensitivity characteristics better than mechanical profilometers. It overcomes the randomness requirements which limit the use of optical devices working on angular diagrams or speckle correlation measurements.

The surface quality of a workpiece, as it is finished by the tooling machine, can be translated into a set of numbers (one or more) which depend on the specific measuring procedures. We illustrate this with respect to the three classes of profilometer techniques either available or suggested, namely: mechanical profilometers, detection of the angular scattering diagram, speckle correlation.

A mechanical profilometer yields a value of roughness averaged over the size of a diamond point which fingers the surface [1]. Furthermore, the diamond finger is cut at a given angle (e.g. 45°), and the measurement of a roughness profile steeper than that would give wrong values. Hence, associated information has a resolution limited by the above size and steepness requirements.

In the second case, using scattering techniques, the surface is illuminated by an e.m. wave (either at microwave or optical frequencies) and the angular distribution of the scattered intensity is associated with the average size of the scattering irregularities [2,3]. In such a case the ratio of the intensity values at two different angles give a parameter which can be put in one-to-one correspondence with each other. This is a very strong statistical requirement which is satisfied only by a limited class of tooling procedures.

Another possible technique is that of speckel correlation under coherent light illumination [4–7]. This again requires complete randomness of the scattering irregularities, not verified when a tool grinds a surface along a preferential direction.

Indeed, the limit of both angular diagram measurement and speckle correlation is that both rely on space ergodicity, that is, on the possibility of replacing the space integrals occurring in the formulation of the diffraction pattern, by ensemble averages over the probability distribution of surface heights [8] ‡.

Leaving to a later report [10] a detailed analysis of the lack of ergodicity, here we just hint heuristically by saying that when a grinding tool has a well oriented motion with an imposed periodicity, the surface has a periodic variation and the angular intensity distribution is mainly concentrated in discrete diffraction orders. Hence the comparison of the intensity scattered at two different angles contains mainly information on such a grating behavior and the relevant height information is lost.

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‡ The crucial problem of space ergodicity has been dealt with extensively in quite a number of papers. See ref. [9].

Here we describe a simple optical profilometer which is faster and with a better transverse resolution than the mechanical profilometer, and with a nominal longitudinal resolution of the same order as that possible with the latter device.

The optical profilometer is not affected by the statistical limitation of the two scattering techniques (angular diagram or speckle correlation), insofar as it transforms the space stochastic process (i.e., the electronic output of the position detector) which can then be processed by standard electronic techniques with no assumption on ergodicity.

Our profilometer consists of a large aperture objective through which a collimated light beam is shined on the surface. The backscattered light is collimated on a photodetector whose signal is maximum when the illuminated areola of the surface under examination is at the best focus. An electronic system controls the objective position until the signal reaches its maximum. At that point a reading is performed of that position, yielding the local value of the profile.

Fig. 1 shows the experimental set-up. A He-Ne laser is sent through a microscope objective onto the surface under test.

The back reflected light is collected through a beam splitter and a lens over a photodector. The objective is driven back and forth along the optical axis Y by a micrometric movement M_1 (see fig. 1) at a rate much faster than the transverse translation rate of the test piece along the X axis (driven by M_2).

M_1 gives a stroke of 100 μm. In a preliminary version, with a mechanical motor drive, the maximum speed was 2 Hz. In a later version we have replaced the motor by a suitable piezoceramic, thus increasing the speed up to more than 100 Hz.

At the point where the focus of the objective coincides with the surface underneath the photodetector output has a maximum. At the end of each stroke of the objective the position corresponding to that maximum is transferred at the output, where it may be classified on any kind of electronic sorter (recorder, correlator, computer, etc.). The sensitivity of this instrument depends on the size and depth of the focus, on the magnification of the optical system in front of the photodetector, on the photodiode sensitivity and the electronic amplification. With a N.A. = 0.85 the spot size and the focal depth are around 0.5 μm. A typical test curve is given in fig. 2, for a lens L of numerical aperture 0.65, a pinhole size of 25 μm and a linear photodetector. The bars show a resolution of 0.1 μm. The longitudinal error bar is due to the mechanical backlash in the micropositioner of the objec-

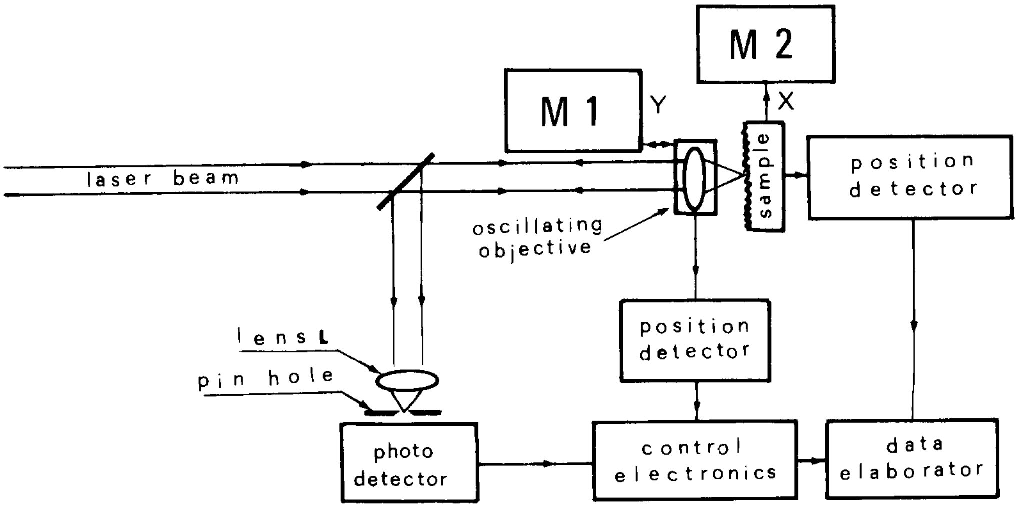

Fig. 1. Experimental setup.

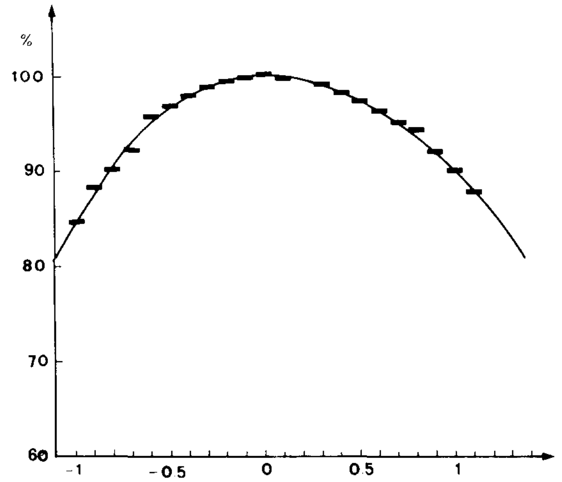

Fig. 2. Sensitivity curve. The objective position is reported on the abscissa, whose zero is the coincidence point of the focus with the surface. The photodiode output is reported on the other axis.

tive holder. This error practically vanishes for the piezoceramic drive, hence the ultimate resolution can be estimated to be less than 10^{-1} μm.

Fig. 3 shows the block diagram of the electronics. To detect the position in the mechanical version of M_1 it was sufficient to key a variable resistor on the micrometer screw through which the motor drove the objective. The associated sensitivity is 60 mV/μm. A similar system yields the X position of the workpiece. In the piezoceramic version of M_1 the indication is given by the voltage applied to the ceramic.

The elaboration of the circuitry is motivated by a large dynamical range of the signal from the detector. Indeed, due to local variation of reflectivity of the sample, the detected signal can change by two orders of magnitude. The signal from the photodiode is first amplified and then sent simultaneously to the non inverting input (n.1) of a comparator and to the input of a peak detector whose output is connected to the other input (n.2) of the comparator. As the signal goes up the two comparator inputs arise simultaneously so that the output does not change. As soon as the signal reaches the peak the signal at input n.1 becomes lower than the signal at input n.2. The comparator output changes its state and hence the monostable yields a pulse of given duration. This pulse drives the next circuit which samples and holds the position of the potentiometer at that moment. To be sure to sample the potentiometer position relative to the highest peak along the whole stroke, the transfer to the XY plotter is done only when the potentiometer reaches its end of stroke A. When the potentiometer gets to the other end of stroke B, the device is reset to its initial condi-

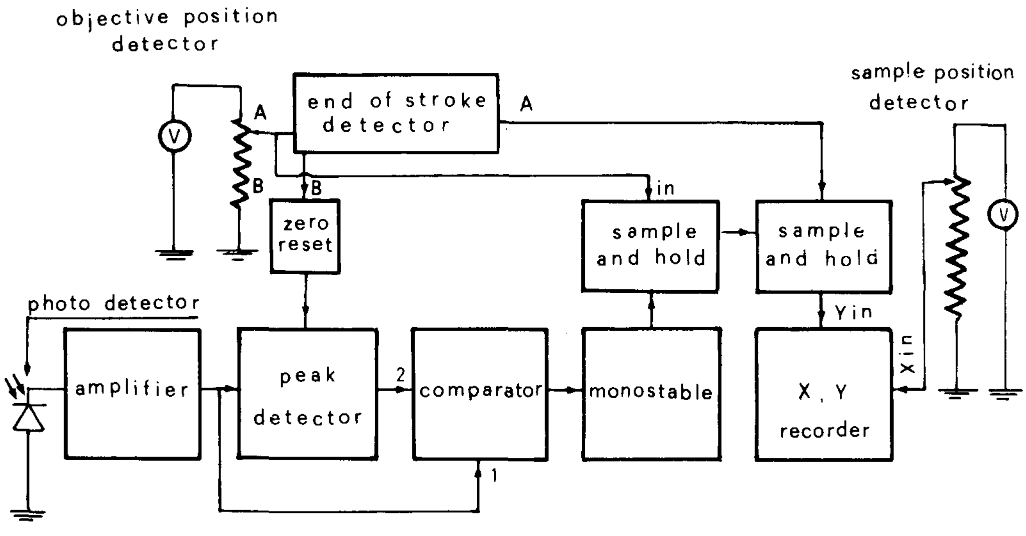

Fig. 3. Control electronics.

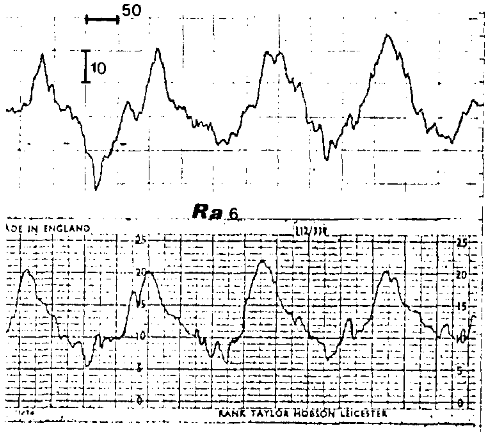

Fig. 4. Profiles of a 6 μm roughness sample obtained with the optical profilometer and Talysurf profilometer, respectively. Horizontal and vertical scales are the same for both plots. R_a stays for the average surface roughness and is defined in international standards as the average of the absolute value of the local deviations from the average profile.

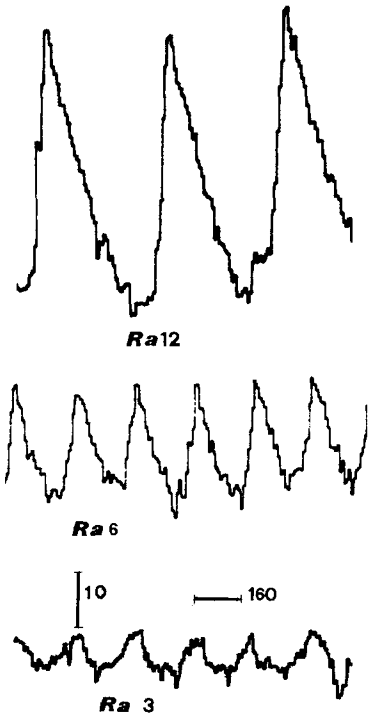

Fig. 5. Profiles of samples obtained with the optical profilometer.

tion. In the meantime the surface under test has moved along (10 μm in our tests).

Fig. 4 shows the profiles of a test sample of 6 μm R_a, obtained respectively with a conventional diamond point profilometer and with our optical profilometer. Small differences are due to the fact that the sample was not scanned exactly along the same line because of the extremely small dimension of the probes, which forbids an exact repositioning of the sample.

Fig. 5 shows the profiles of samples with R_a = 3, 6 and 12 μm respectively, obtained with the optical profilometer.

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