Some results of flatness measurement

W. de Bruin and J. Meijer*

The flatness evaluation method which has been described in the previous paper in this issue makes use of the straightness measuring results obtained on lines of a rectangular grid pattern drawn on the surface[1]. In fact, any straightness measuring method may be applied, but experience of this institute has been in two particular methods: the straight edge method and the height-difference measuring method. Both methods are principally different. The first one gives straightness deviations at each grid point, so the measured values are independent of each other, while in the second method the deviation at a grid point is measured in comparison with the previous point.

Instrumentation

Although both measuring methods have been instrumentally refined and applied in fair competition so that at the moment the flatness measuring results on one and the same object are the same within measuring uncertainty, the height-difference measuring method is favoured and will be explained here in some detail. The preference is based on simpler instrumentation, higher speed, smaller value of measuring uncertainty and smaller restrictions on surface area.

Fig 1 shows an electronic level device (1) with its meter (2). The level head is mounted on a block (3) which rests on one fixed ball support (4) and a cylinder support (5). This cylinder is part of a rigid triangle blade (6) and is connected in (7) to the block by a spring blade, passing the fixed support (4). This blade (6) is pulled by a spring against the spindle face of a setting screw (8). On front of the block a displacement transducer (9) has been mounted. Varying the distance between (9) and (4) makes it possible to measure with grid meshes e_x, e_y or $(e_x^2 + e_y^2)^{1/2}$ on the surface from 70 mm to 200 mm.

The setting procedure is now as follows: once the pitch has been chosen and adjusted (eg e_y) the support (4) and the transducer (9) are placed on the first grid trace from (0;0) to (0;1). The level head is adjusted horizontally by the setting screw (8), which means zero-indication on the meter (2) in the most sensitive range of the apparatus. The reading of the displacement meter (10) is listed or printed. After moving the block in the measuring direction to the next grid trace (0;1) – (0;2) the setting and reading procedures are repeated.

Measuring in this way, a surface plate of 630 x 400 mm^2 with 9 x 6 grid lines can take only 45 min. A measuring report and a contour map drawn by the computer can be available 1½ h after the start of measurement. This measuring method is now being extended to include automatic adjustment of the instrument on the spot and bookkeeping of the measured values by a mini-computer so that in the future the whole flatness measurement will be able to be carried out by one person.

Long-term investigation of a granite surface plate

Although a lot of experience of flatness measurements coupled with the new computer evaluation method could be mentioned here, only one investigation will be described. It was inspired by some vague doubts about the stability of granite as a material for surface plates, guideways of modern measuring and production machines etc caused by: measurements on several plates of material from different origins and experience of form changes of optical glass, which is processed in about the same way and of which the chemical composition has some relationship to that of granite.

Dimensional stability of such materials received special attention from the CIRP (International Institution for Production Engineering Research), Scientific Technical Committee Q, as a joint research theme.

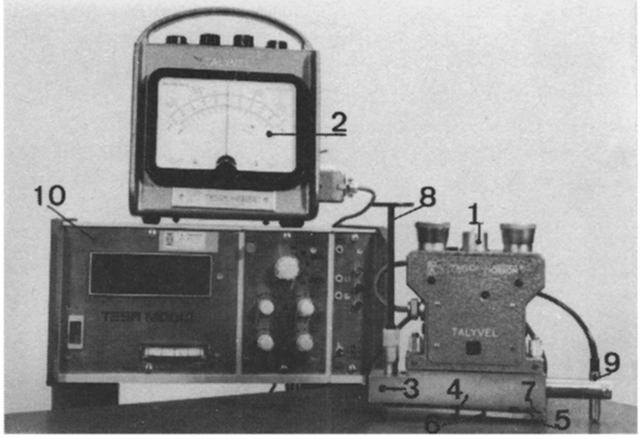

Fig 1 Instrumentation for the height-difference measuring method

In 1976, a deal was made with Mytri of Apeldoorn, the Netherlands, a manufacturer of granite surface plates etc, to order for quick delivery a block of granite from the usual quarry in Sweden and to process and finish it just after receipt. A surface plate of 630 x 400 x 80 mm^3 of quality O was made. Directly after finishing, the plate was carefully transported to the laboratory and its flatness was measured. There was a final finishing procedure *in situ,* and then the plate was installed on the same three manufacturing supports in a tent-frame covered with aluminium foil in an air-conditioned room. The plate was packed in insulating material on all sides except the functional upper surface. These measures were taken on grounds of rather surprising results of change of form due to temperature gradients in this material (eg caused by fluorescent tube illumination in a metrology room or workshop[2]). Because measurements need some light to find the grid points on the black surface, the lowest acceptable indirect illumination of a 18 W fluorescent lamp was used in the tent.

Since the day after the installation of the plate (24 December 1976) flatness measurements have been repeated as near as possible under the same conditions (Fig 2).

**Twente University of Technology, Enschede, The Netherlands*

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The 'childhood'-period

Making use of the new facilities of the computer program for calculating the dimensionless bowrise parameters b_s and b_t due to real sphericity and real torsion, the results of measurement (1 to 15) with intervals of 3½ days and (16 to 18) with intervals of one week are plotted in Figs 3 and 4.

There is a decreasing trend in the b_s-parameter due to real sphericity, which continued after measurement No. 18. In those days, however, the only means available for comparing flatness measuring results were a 'matrix' of height-deviations in the grid points of the surface with respect to a regression plane and/or a contour map. The b_t-parameter due to real torsion and the angle ϕ of the torsion vector τ remained more or less constant during this period.

Experiments with illumination

Measurement Nos. 19 and 20 show the steady state when the upper surface is illuminated with a normal 40 W filament lamp at 1 m above the centre of the plate. Between Nos. 19 and 20 the bulb was turned over 180° along its vertical axis in order to eliminate the asymmetric lux-profile on the surface. During measurement Nos. 21 and 23 a 40 W fluorescent tube was mounted at 1 m, parallel to one diagonal of the plate, whereas during measurement No. 22 it was above the other diagonal. These measurements only resulted in a change of sphericity (Fig 3). The rise Δb_s of about 2 μm/m can be derived fully from the temperature difference between the upper and lower surface of only +0.25 K, the coefficient of linear expansion ($\alpha = 5.6 \times 10^{-6}$ K^{-1}) and the thickness of the plate (80 mm). The sign and magnitude of this effect has been confirmed elsewhere[2,3].

Experiments with humidity

For some reason it was decided at the end of March 1977 to increase the relative humidity within the aluminium tent around the surface plate up to a level of 80 to 85%. Although there were changes in the character of the contour maps of those measurements (Nos. 24 to 31) the parameter b_s in Fig 3 shows that these phenomena were due more to the original trend than to humidity. Nevertheless, it was decided to go to the utmost by putting wet towels on the upper surface for 24h and then to measure immediately after removal. Fig 5 shows the result of this measurement (No. 32) as a contour map. Effects of curvature can be estimated better from Figs 3 and 4.

During the flatness measurement the temperature of the upper surface increased about 0.6 K. The general temperature in the tent rose from 17.8°C to 18.0°C. At the start, relative humidity was 83% and at the end of measurement No. 32 it was 78%. From these data, the dewpoint was 15 ± 2°C. Evaporation of a water film from the surface would make the upper surface cooler than the lower surface which would tend to make the surface plate concave. The measured temperature rise tends to indicate that this effect did not play a role. However, chemically and physically bonded water in the upper surface and in between the crystal grains in the surface layer cause internal compressive stresses. This effect (also demonstrable in optical glass) causes a convex upper surface which is probably mainly responsible for the shape of contour map No. 32. If this bonded water is released slowly (it takes days) this compressive stress in the surface layer will disappear too. Other investigators have mentioned this effect also, always with the same sign of curvature (convex), but with various magnitudes[4-6]. The magnitude seems to be dependent on the chemical and structural composition of the granite material. As for our black granite, it is a plutonic rock (Gabbro), mainly composed of Labrador feldspar with 65-70% anorthite (Fig 6).

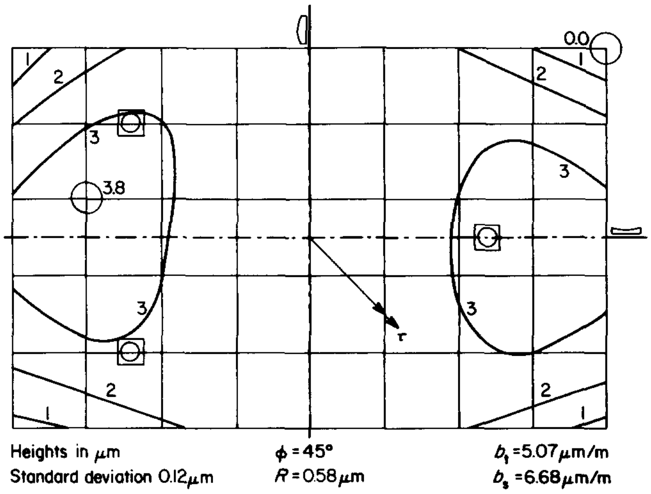

Fig 2 Contour map from measurement No. 1

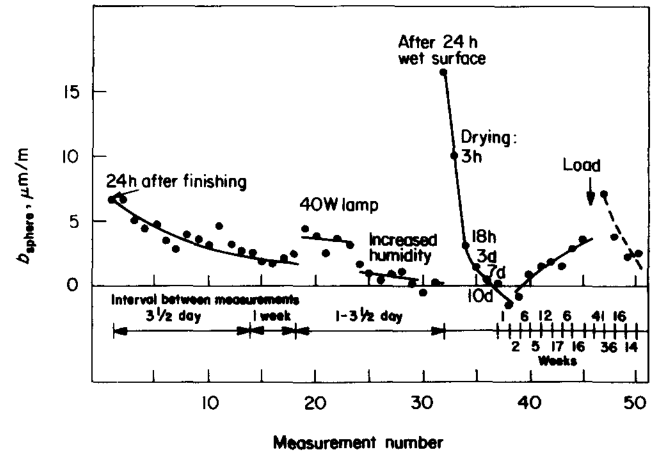

Fig 3 Changes in the b_s-parameter with time

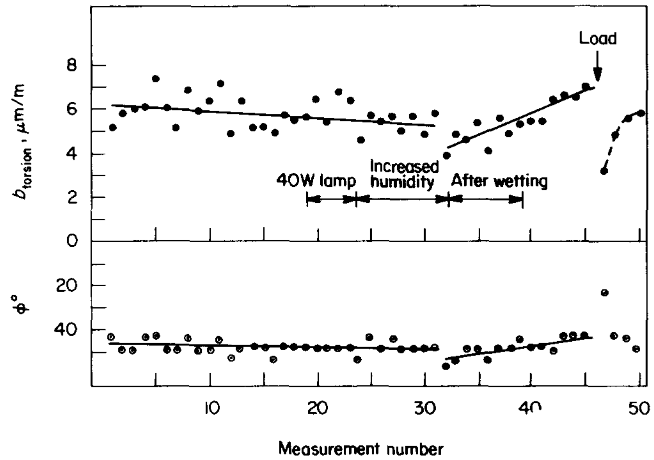

Fig 4 Changes in the b_t-parameter with time

Second drying period

Measurement Nos. 34 to 43 belong to another drying period in which the shape alterations were followed at increasing time-intervals. After measurement No. 43 it was believed that the original, more or less characteristic contour map had been reached again and the intervals between measurements were increased by several weeks.

Today, with the new facilities, it is clear that better attention should have been paid to questions such as: at what level and why the b_s-parameter passed through a minimum, why the original trend of the b_t-parameter significantly changed, and why the nearly stable level of 47° ± 4° of the angle ϕ of the torsion vector τ significantly changed to a decreasing trend (correlation coefficient 0.8).

First loadings on the plate

In July 1978, the deformation of the plate due to a weight of 18.2 kg was measured. Measurement No. 45 was carried out just before loading and No. 46 when the weight was in the centre of the plate. The maximum deviation of about 2.1 μm agreed with the calculated value for such a plate.

At the beginning of 1979, a weight of the same order of magnitude (about 20 kg) was kept on the plate for a couple of weeks. More than 4½ months after removing the weight, measurement No. 47 showed quite a strange contour map (Fig 7) for the unloaded plate. Both curvature due to real sphericity b_s and due to real torsion b_t give unusual values and the angle ϕ changed too. However, some additional measurements (Nos. 48 - 50) (Fig 8) tend to demonstrate a memory effect in the material of its direction of deformation before the sudden change of mechanical strain condition, judging by the values of b_s, b_t and ϕ in Figs 3 and 4.

Remaining parameters characterizing the flatness measurement

The remaining rms-value R has been introduced[1] as a fourth parameter for characterizing flatness and has been plotted also as a function of the sequence of measurements (Fig 9). Up to and including measurement No. 37, this value is surprisingly constant at R = 0.55 ± 0.03 μm. However, with the start of the concave deformation (No. 38) there is more scatter in the R-values, for which there is no ready explanation.

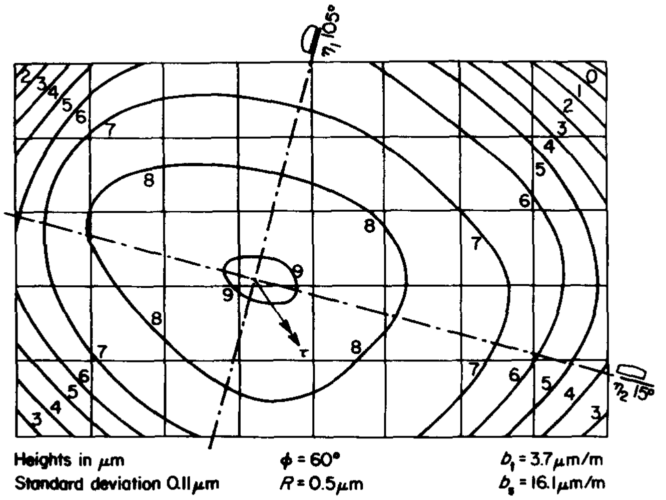

Fig 5 Shape of the surface plate after wetting No. 32

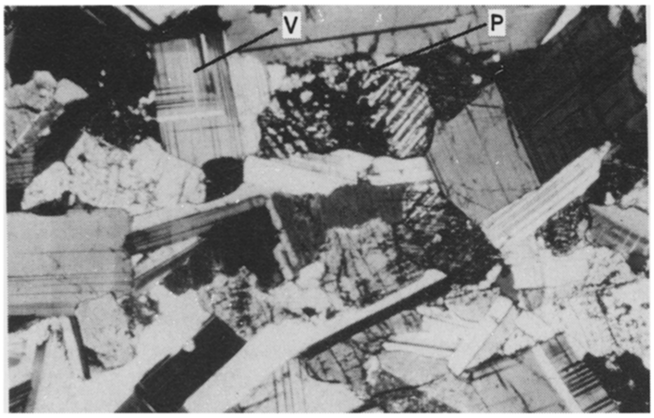

Fig 6 Crystalline structure of the granite concerned. V = Labrador feldspar; P = Plagioclase. Spectro-chemical analysis of material (weight-percent) from the same quarry resulted in 1976 in:

Silicon oxide	SiO_2	*56.1%*
Aluminium oxide	Al_2O_3	*19.1%*
Calcium oxide	*CaO*	*12.0%*
Iron oxide	Fe_2O_3	*6.5%*
Magnesium oxide	*MgO*	*3.0%*
Sodium oxide	Na_2O_5	*1.5%*
Potassium oxide	K_2O	*1.2%*
Other		*0.6%*

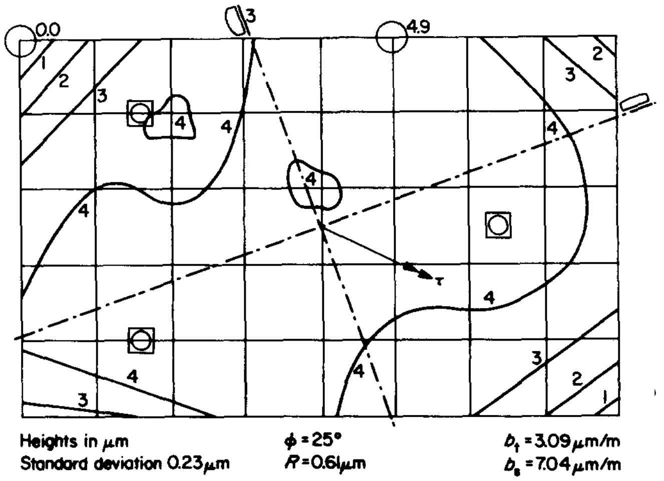

Fig 7 Contour map of measurement No. 47 forty-one weeks after No. 46

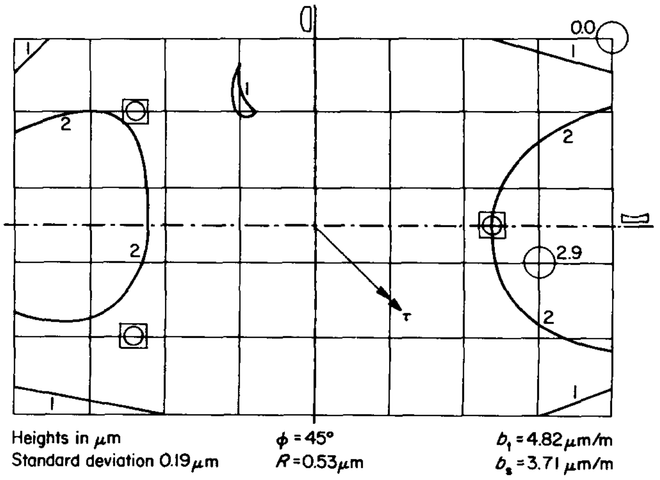

Fig 8 Contour map of measurement No. 48 thirty-six weeks after No. 47

Finally, the standard deviation σ_r based on the mean value of flatness deviations of all grid points is a measure of the accuracy of each flatness measurement. Up to and including measurement No. 42 σ_r is surprisingly constant at 0.12 ± 0.02 μm. Before measurement No. 43, a pair of permanent magnets was placed alongside the Talyvel-unit of the measuring system and only for half an hour. Since then, it has not been possible to regain the original accuracy.

Conclusions

This paper has tried to demonstrate that the four independent parameters characterizing the flatness of a workpiece, as previously advocated[1], are useful. Without these parameters it is very difficult to compare quantitatively the changes in flatness measuring results.

The long-term investigation of granite has shown that this naturally aged material is not necessarily stable. Changes of form of several microns on a (small) surface plate, as described, may occur under normal conditions in a metrology room. With the constant value of the measuring accuracy σ_r (related to the standard deviation of measurements σ_m) and the constant shape of the grid pattern and measuring procedure (related to the number of degrees of freedom F) it is very simple to estimate the value of the standard deviation of the dimensionless bow-rise parameters b_s and b_t. Finding these values of σ_b at 0.03 μm/m and 0.06 μm/m it is obvious that most of the deviations of the parameters with time have been significant.

The user of such granite plates for flat reference purposes should therefore

- in case of a new plate, wait for some weeks after production to achieve a steady state of flatness,
- keep the temperature gradient over the thickness of the plate constant (illumination always on, even during the night),

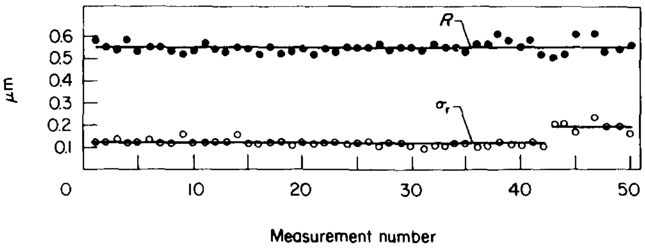

Fig 9 Remaining rms-parameter R *and standard deviation of flatness measurement* σ_r *with time*

- keep the room temperature constant to within one degree Celsius,
- keep the relative humidity in the room within an acceptable range,
- if using water for cleaning the surface, use as small a quantity for as short a time as possible and treat the under surface in the same way.

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Book reviews

Optical Instruments and Their Applications

D. F. Horne

This book will not only be of interest to practising and student engineers but also to a wider readership owing to the broad coverage of the subject. It embraces the following disciplines: ophthalmic, analytical, metrological, surveying and military instruments, process equipment for the printing trade, xerography, photography, astronomical telescopes, microscopes, together with a brief history of the British optical industry, with some extra items of general interest, sometimes out of context with the subject under discussion.

Each of the ten chapters can be read in isolation and stands in its own right. In general, the subjects are not dealt with in depth and the serious student or reader would need to delve more deeply into a suitable technical reference book to acquire a working knowledge of a chosen subject. In addition to the bibliography, it would have been helpful to have a list of standard works of reference for each subject included in the appendices.

There would appear to be one or two notable omissions from the history of the British Optical Industry 1920-1970. For example, neither Aldis Bros. Ltd nor Ross Ltd are included, although they have made significant contributions to the industry.

In general, the illustrations, numbering nearly 300, are clear and enhance the easily read and interesting text. Unfortunately, however, a few of the illustrations appear to have been erroneously used and are misleading. For example, a diagrammatic view which is stated to be of an "Automatic Position Sensing Autocollimator" does in fact show a simple photo-electric autocollimator as is described in the text, Fig. 8.5.8.

Apart from these few variances, the book offers technical descriptions of a wide range of optical systems which will enable technical management, within the scientific instrument industry, to have a valuable reference covering the spectrum of optical techniques currently available.

In conclusion: at £38, this book will no doubt be purchased mainly by industry and colleges for their technical libraries, where it should prove to be a practical guide to the general availability of optical instruments.

S.C. Bottomley
Manager, Special Products Division,
Rank Taylor Hobson,
Leicester Street, Leicester
LE5 3RG, UK

Published by Adam Hilger Ltd, Techno House, Redcliffe Way, Bristol BS1 6NX, UK