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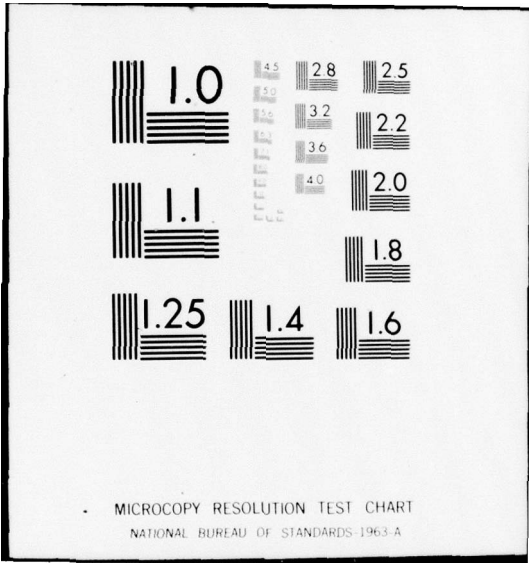
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MELBOURNE, VICTORIA

**TECHNICAL NOTE**

MRL-TN-394

CALIBRATION OF GRATICULES TO HIGH ACCURACY

D. B. Prowse



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### SUMMARY

A technique for calibrating graticles (or stage micrometers) to high accuracy ( $\pm 0.1 \mu\text{m}$ ) is described. The lines were sensed photo-electrically and the distance between lines was measured with a laser interferometer. The accuracy is limited mainly by the quality of the graticule lines but for a graticule with long well-defined lines the uncertainty of measurement was  $0.04 \mu\text{m}$ .

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## CALIBRATION OF GRATICULES TO HIGH ACCURACY

### INTRODUCTION

Graticules, or stage micrometers, are used in the calibration of a number of measuring instruments, such as measuring microscopes, hardness measuring instruments and accelerometers. Some instrument specifications require graticules to have a calibration accuracy of  $\pm 0.25 \mu\text{m}$  or better, and from experience it has been found that calibration with an optical microscope does not yield an accuracy of better than  $\pm 0.5 \mu\text{m}$ . A number of large and elaborate instruments have been developed for the calibration of line standards, for example by BIPM (1), (2) and NML (3). This note describes a relatively simple method developed for calibrating graticules or short scales (less than 10 mm long) to an accuracy of  $\pm 0.1 \mu\text{m}$ . Simplicity was possible because the scales were short and careful temperature control and measurement were not required. Although sophisticated equipment in the form of a laser interferometer and a photo-electric microscope were used, they were not permanently built into the apparatus and so can be used for other measurements.

### APPARATUS AND METHOD

The apparatus was assembled from existing metrology equipment and except for a small mounting bracket to hold the graticule and a corner cube no components were made for the apparatus. The apparatus was constructed as a temporary laboratory model and, after the required graticules had been calibrated, it was dismantled. It can easily be reassembled.

A schematic diagram of the apparatus is shown in Figure 1. It was mounted on a large granite surface plate (3.7 m x 1.5 m) with the main apparatus at one end and any heat-generating equipment, such as the laser and the quartz-iodine light source, at the other end.

A two-dimensional cross-slide table (1) (see Figure 1) was used for the coarse translation of the graticule. A fine adjustment was achieved by a gear mechanism (2) to position the table to a few tenths of a micrometre. A piezo-electric translator (3) was used for the fine

adjustment of the graticule position. This piezo-electric device had a range of 2  $\mu\text{m}$  and could be used to position the graticule to 0.01  $\mu\text{m}$ . A mounting bracket (4) was made to attach the graticule and a corner cube (5) to the piezo-electric translator. The corner cube (5) was used as a retro-reflector in the laser interferometer.

A photo-electric microscope (made by Hilger & Watts), with a nominal magnification of 50, was mounted by means of a stand clamped to the surface plate to view the horizontal graticule. In normal use this microscope has an overall resolution of approximately 0.1  $\mu\text{m}$ , although this can be improved by means of a brighter light source. A quartz-iodine lamp gave a resolution to within 0.01  $\mu\text{m}$ . This lamp was positioned at the far end of the surface plate and a beam of light, made approximately parallel by a lens, was focused on the graticule by lens (6).

The length measurement was made with a Hewlett-Packard laser interferometer which had a resolution of 0.01  $\mu\text{m}$ . The remote interferometer (8) was attached to the surface plate and as close to the piezo-electric translator as possible. The laser beam and cross-slide table movement were aligned to better than 3 minutes of arc with the aid of a quadrant detector. Thus, no cosine error greater than 1 part in  $10^6$  would have been introduced.

The graticule was mounted as close as possible to the axis of the corner-cube in accordance with Abbé's principle. The focal length of lens (6) was chosen to match the focal length of the objective lens of the photo-electric microscope so that the maximum amount of light was collected by the microscope. Because of different line widths in the various graticules, a high-power and a low-power objective were used as required, giving magnifications, as viewed through the microscope, of approximately 150 and 20 times respectively. The photo-electric microscope was used as a null-setting device and the position of the sensing mechanism was not altered during measurements. The optical components of the illuminating system were also kept fixed during measurements so that each line was sensed in exactly the same position and with the same illumination, hence any non-uniformity in the light source, or divergence of the light at the graticule, was the same for each line and did not affect the calibration.

Both reflecting and transmission-type graticules were measured by use of this system. For reflecting-type graticules, the light from the quartz-iodine lamp was directed into an attachment supplied with the microscope. This has a beam splitter positioned above the objective to reflect light through the objective and on to the graticule; lens (6) was then not required, its function being taken over by the microscope objective. For transmission-type graticules, the apparatus was as shown in Figure 1.

The photo-electric detector has maximum sensitivity when the lines sensed are of sufficient length to fill the field of view; for shorter lines more light can reach the photo-detector in the null position and the sensitivity is consequently lower. Unfortunately some graticules tend to have relatively short lines, that is, lines that are only about 5 times the minimum graticule spacing (typically 10  $\mu\text{m}$ ). This problem was overcome

in two ways. First, if the lines were sufficiently fine and well defined then the optical magnification was increased. Secondly, if this was not adequate then the unused field of view was masked off by the use of knife-edges (7) placed on top of the graticule. These masks also had the advantage of masking out any line numbers and blemishes that may have been in the field of view and which consequently would have influenced the photo-electric setting. Where some lines were longer than others (e.g., every fifth or tenth line), a different null, which was obviously displaced relative to other lines, was obtained under certain conditions. This was thought to be due to uneven illumination, such that the sensitivity varied across the field of view in the direction of the graticule lines. Hence the portion of the line in the more sensitive section of the field of view would have greater influence on the position sensed for the line. Thus, if the image is slightly distorted, due to the objective lens, then a slightly different line position could be sensed for the longer lines. Masking to the shortest line length overcame this problem. As the distortion mentioned above was small, and because the photo-electric microscope is a null-setting device, the masks on the top and bottom of the lines did not have to be set precisely parallel, lining up by eye through the microscope being quite adequate. Resetting the masks between runs made no difference to the measurements of the line spacings.

The graticule was positioned so that the ends of the graticule lines were parallel to the direction of movement. This was accomplished visually, and it was found to be relatively easy to reduce the cosine error to less than  $0.01 \mu\text{m}$  (corresponding to 1 part in  $10^5$ ). The photo-electric microscope sensor was then set parallel to the graticule lines.

Temperature measurements were made with thermocouples appropriately placed on the apparatus. However, as the apparatus was in an air-conditioned room controlled to  $\pm 0.5^\circ\text{C}$ , temperature effects were found to be negligible.

The laser interferometer has a facility for setting the pressure, temperature and relative humidity, so that the resultant length displayed requires no further corrections. Since the total distance being measured was small, 1 mm for most graticules, the small departures observed from the assumed standard conditions (101 kPa,  $20^\circ\text{C}$ , 50% R.H.) did not significantly influence the setting on the laser interferometer.

## RESULTS

For fine uniform lines with clean edges the reproducibility from one run to the next was found to be within  $0.04 \mu\text{m}$ . A graph of the errors obtained for a typical graticule is shown in Figure 2.

For lines that were too thick for the photo-electric sensor it was found possible to detect each edge of the line and thus calculate the position of the midpoint, although with a greater uncertainty ( $0.3 \mu\text{m}$ ) than in the previous case. However, this method is susceptible to drifts in the electronics, and it is believed that better accuracy would be obtained by reducing the magnification of the microscope to bring the line width within the range of the sensor.

### ACKNOWLEDGEMENT

The assistance of Miss L.M. Ramsay with the measurements and calculations is much appreciated.

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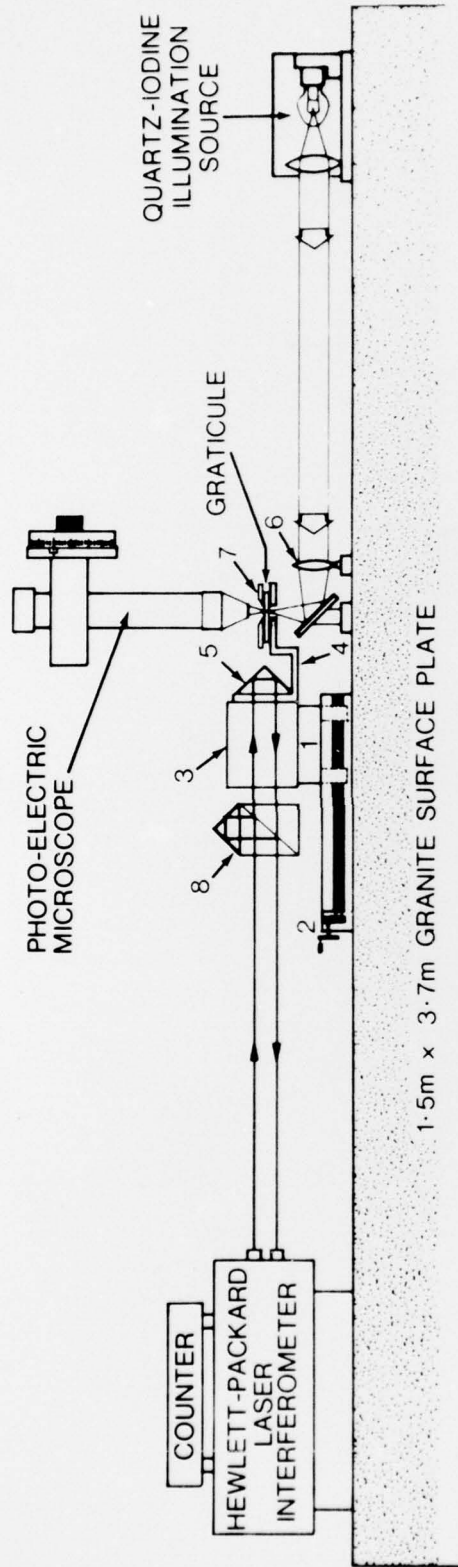


FIG. 1 - Schematic diagram of the apparatus.

1. Cross-slide table.
2. Fine-adjustment gear-mechanism for the cross-slide table.
3. Piezo-electric translator.
4. Mounting bracket.
5. Corner cube.
6. Lens.
7. Knife-edge type masks.
8. Remote interferometer.

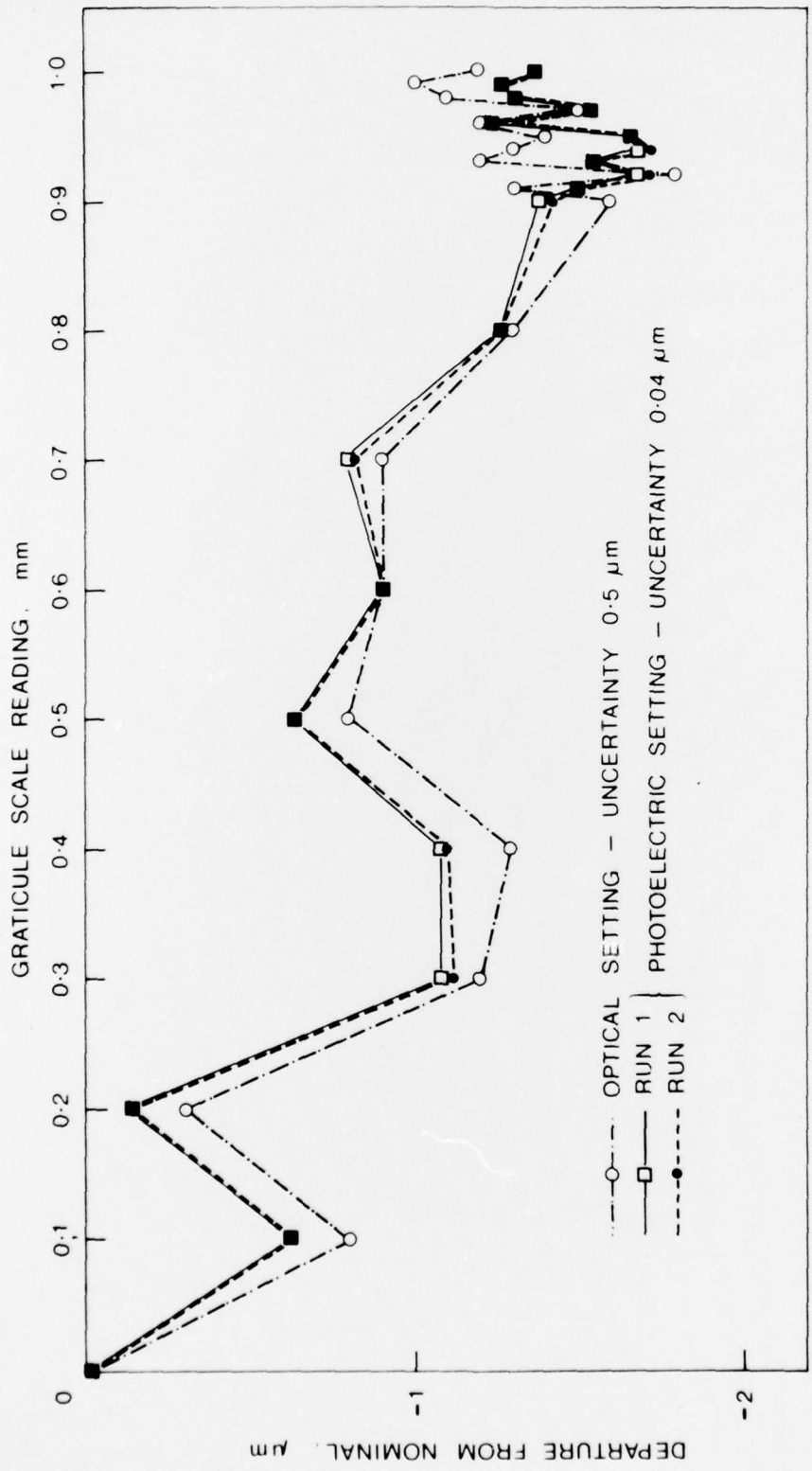


FIG. 2 - Errors obtained for a typical graticule. Also shown is a previous calibration obtained by visual setting of the lines.

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