Production and measurement of line standards in Eindhoven University of Technology

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PRODUCTION AND MEASUREMENT OF LINE STANDARDS IN EINDHOVEN UNIVERSITY OF TECHNOLOGY

by

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AIM

The object of the work described here was the production of line standards of reasonable quality, i.e. of 1 m length and errors within 1 μm.

PRINCIPLE

All dividing machines use some sort of standard which is copied into the object to be divided; in many machines this standard is a lead screw. Generally there is some correcting system to eliminate the errors of this standard. In view of the possibilities of the laboratory, combined with a personal dislike against the leadscrew - nut - combination, a line standard was chosen as the standard to be copied. Therefore the most conspicuous part of the dividing machine is a rather long carriage supporting the standard to be copied and the standard to be divided, arranged in line. A photoelectric microscope is used to observe the lines of the first standard and to control the position of the carriage. Corrections for the errors of the standard are entered into the system in digital form.

PREREQUISITES

Two essential starting points in building a machine of this kind are (1) a suitable line standard and (2) a measuring instrument of sufficient range and accuracy to determine the corrections to be applied to the standard and to measure the products. The first point will be dealt with later in this paper. For measuring line standards a universal length measuring machine (Carl Zeiss, Jena)of 3 m range was available; in this instrument the well known eppenstein compensation system is used to eliminate tilting errors. Thus, the instrument behaves as a longitudinal comparator. The accuracy of the instrument was not quite sufficient when the quality of the standards produced approached our aim. Moreover, the measurements took too much time. Therefore, at a later stage, a line standard interferometer was built for the purpose; a description of this instrument was presented at the CIRP meeting of September 1970.

CONSTRUCTION ELEMENTS COMMON TO DIVIDING MACHINES AND COMPARATORS

In both instruments a line standard has to be positioned according to the lines engraved. The lines are observed by a simple photo-electric microscope using a vibrating slit. The slit is moved sinusoidally by means of an electromechanical exciter, which resembles a small loudspeaker without a cone. The surface of the standard is imaged by the objective lens onto this slit; light passing through this slit is collected on a photosensitive transistor. The properties of a microscope of this kind are such that the position of the lines of the standard can be observed on an oscilloscope and that the output voltage can - after suitable amplification - control the position of the standard by means of a servo system. The net result is that the line is positioned on the axis of the microscope within a second and with an accuracy of better than 0.1 μm. In this context the axis of the microscope is defined as the line joining the centre of the objective lens and the central position of the slit.

As the mechanical construction of both instruments is similar, two identical beds were made with dimensions 4 x 0,4 x 0,5 m^3 and with a mass about 1000 kg. Because in that case only one standard has to be accomodated, the range of the interferometer is much greater than that of the dividing machine.

COARSE CONTROL SYSTEM

In both instruments the displacement of the carriage over long distances is done by means of a lead screw and a special kinematical nut. In the dividing machine the leadscrew is turned by a stepping motor; the motor can be switched off at mm intervals by means of a slotted disc and a photodiode. In the interferometer a d.c. motor is used which is switched off by means of an auxiliary counter counting an appropriate number of interference fringes. Thus there are no limitations set to the pitch of the standard to be measured.

CORRECTION SYSTEM

The corrections are punched in a tape using a BCD code. The tape is read by a conventional tape reader, the corrections are processed by a combined relay memory and digital-to-analog converter. Net result is a direct current proportional to the correction. This current is introduced into the moving coil of the exciter, causing this coil and the slit which is coupled to it to oscillate around a new central position. Therefore the axis of the microscope is shifted an amount proportional to the correction inserted, and the standard is displaced over a corresponding distance by the servo system.

SECONDARY QUALITY CONSIDERATIONS

The quality of a line standard - given an accurate division - is determined to a large extent by the state of the surface and of the lines engraved. At the moment we use steel standards of a conventional H-profile. The surface to be divided is lapped, nickel plated and fine lapped, successively.
A simple, yet adequate, lapping machine was built for the purpose. the tracing mechanism uses spring strip pivots throughout. Movement of the tool is governed by two adjustable eccentrics in such a way that the "free" path of the tool is a narrow ellipse. If the tracelet is lowered, the tool rests on the surface during part of the cycle; in that case the force can be adjusted by means of a counterpoise. Normally the force is around 0.9 N (90 gf) resulting in a line width of 3 μm.

The eccentrics mentioned are mounted on a shaft rotated by a small D.C. motor by means of a gear train. By changing the voltage on the motor the time cycle can be adjusted from a few seconds to more than a minute.

Just after the tool is lifted off the surface, a microswitch is actuated; this causes the coarse control, correction tape etc. to advance.

MEASURING SYSTEM OF THE INTERFEROMETER

The interferometer was described earlier (loc cit.). Therefore it may be sufficient to mention here that a single mode, frequency stabilised

laser is used, that the electronic system registers a pulse for a displacement of $\lambda/8 \approx 0.08$ μm and that, consequently, displacements of the carriage are punched in tape in units of ≈0.08 μm. Measurements are performed at a rate of between 2 and 3 seconds per line, somewhat dependent on the line quality of the standard.
Recently a quartz thermometer (Hewlett Packard model 2801 A) was added to the instrument to measure the temperature of the standard and of the air path in the interferometer. By means of a separate interface temperatures can be punched into the output tape at time intervals chosen according to the rate of change of the temperature.
The computer programme used to evaluate the measurements causes a new value of $\lambda/8$ to be calculated every time a new value of a temperature is offered.

GENERATION OF STANDARDS

We do not think it acceptable to make copies of commercially available high quality line standards. It is not necessary either, because in principle every standard can be used, provided its errors are within the range of the correcting system. Therefore we proceeded as follows.

1) a brass bar of 250 mm length was divided using a small shaper. The feed of the table could be adjusted to 1 mm, and a crude tracing mechanism was mounted on the ram. The line quality was rather bad.

2) a brass bar of 250 mm length was copied from (1).

3) a steel strip of 550 mm length was divided. It was necessary to displace bar (2) two times over 200 mm, using gauge blocks. Next a copy of (3) was made and mounted end to end with (3).

4) the combination was used to make a steel standard of 1100 mm length, of H-profile, and divided over a length of 1030 mm. The error curves of these form standards are represented in Fig. 1.

Some more blanks were divided to gain insight into the properties of the machine. The standard denoted (5) in Fig. 1. is the last one made to date (March 10, '71). The accuracy of this standard is 1.5 μm, that is: the error of the distance of any pair of lines is within that value. This accuracy is still somewhat outside our aim. We have reason to assume that it is not an optimal result, and that the machine can produce standards of slightly better quality with only minor readjustments.

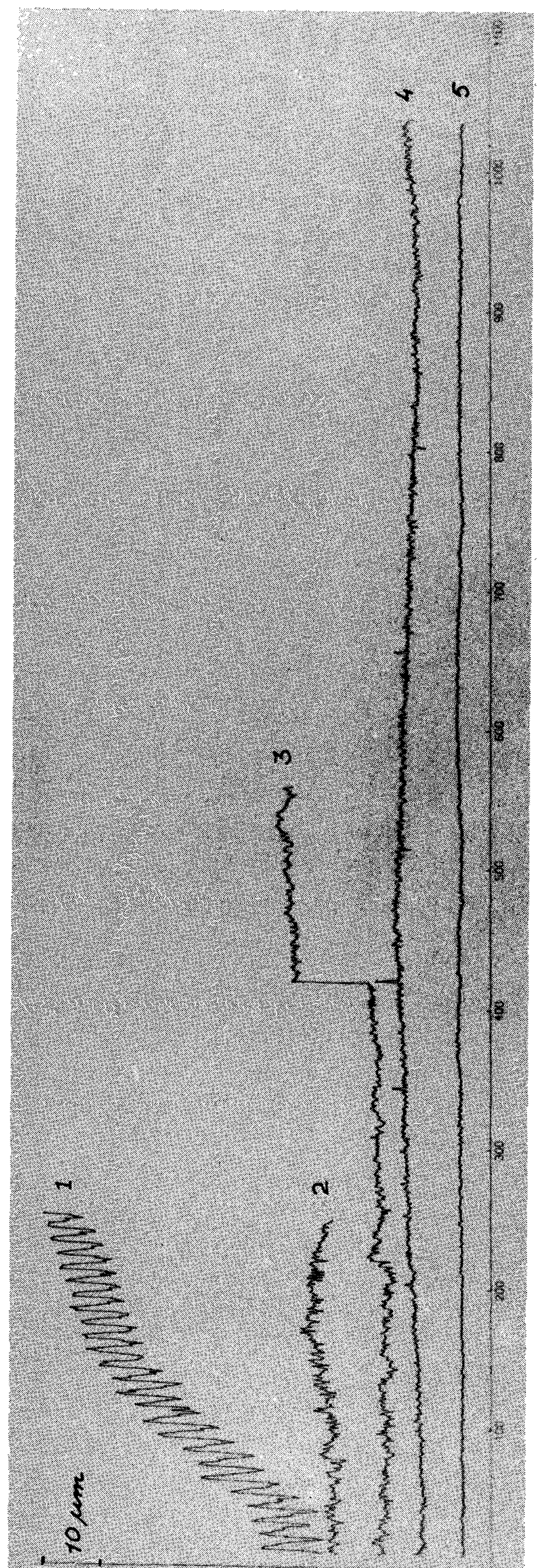

Fig. 1.