

A case of shape control by a temperature gradient

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Tijdens het bewerken van een groot bed voor één meetmachine werd de invloed van de temperatuur op de resulterende vorm bestudeerd. Het blijkt mogelijk de vorm gunstig te beïnvloeden door het aanbrengen van een verticale temperatuursgradient van bepaalde grootte.

prognose

Hoewel het onderwerp onze interesse heeft en zeker niet zonder belang is, moet voortzetting van het onderzoek uitgesloten geacht worden op grond van de ontoereikende personeelsformatie van het laboratorium voor lengtemeting.

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A case of shape control by a temperature gradient

J. Koning, P.H.J. Schellekens and J.P. Kroot.

The following note describes some incomplete experiments on the influence of temperature on the shape of a long workpiece. Shape can be controlled to some extent by a vertical temperature gradient, applied during the machining operation.

Some time ago two large instrumentbeds were needed in the metrology department of Eindhoven University, respectively for a dividing machine and for an interferometer. (length 4 m, width 0,3 m, mass ca. 1 ton). As can be seen from the sketch, there are 5 plane surfaces which determine the position of carriages, etc. Both instruments were designed following Abbe's principle, so tolerances were not too severe. As, however, the beds might well be used for different purposes at a later time, it was decided to make them as good as possible with a reasonable expenditure of time. The machine tool available is a planer of 4 meter travel, which can be used with an auxiliary grinding head. There are no facilities for cooling. The shop has no temperature control, the daily temperature cycle covers a range of 5°C.

The first bed was planed and ground in a normal way. Next the ways were fine-ground. After some experimenting, best results were obtained if the grinding was done with a very light cut, such that the surface was finished around 16 o'clock. Next morning the shape was measured by an autocollimator. Only one surface was ground each day. The finished bed was transferred to a temperature controlled room and measured. If the ends of the bed are disregarded, the ways are straight within $\pm 5 \mu\text{m}$ over 3 meter length, that is 75% of the total length.

The second bed was machined in the same way. However, during the last stage some experiments were performed.

- 1) a provisional cooling system was installed. This resulted in a somewhat better surface quality.
- 2) a few surfaces were machined in the early morning hours (5-7 o'clock), so the surfaces were finished before normal work in the shop started. Results, although good, were certainly not better than had been obtained before.

3) temperature of the workpiece was measured at two positions, respectively at the top and bottom, by means of a quartz thermometer (Hewlett-Packard model 2801-A). This instrument has a facility for direct reading of temperature difference. Further, ^{more} a thermostat was included in the cooling system. By these means a vertical temperature gradient can be introduced as required. The thermometer probes were considered too delicate to measure temperature during the actual machining.

In graph II some results are represented. Curve A gives the shape of the workpiece, ground and measured at zero temperature difference (zero to be understood as $< 0,01 \text{ K} = 0,01 \text{ }^\circ\text{C}$). Thus, the shape is determined by the shape of the machine tool. Curve B gives the shape of the same surface, measured at a temperature difference of 0,9 K. As can be expected, the surface is more ~~concave~~ ^{convex}. If the workpiece is ground in this condition, metal is removed in the middle, so it will be less ~~concave~~ ^{convex} after cooling down. As the temperature during machining is not the same as measured before the machining operation, some experimenting is necessary. Curve C gives the shape of the surface, when a temperature difference of 0,5 K was introduced during grinding; the measurement was done at zero temperature difference. It is seen that the surface is straight within $\pm 3 \text{ } \mu\text{m}$ over 90% of its length.

It is now clear what has happened during the machining of the first bed. It is well known that in a "uncontrolled" shop the temperature rises during the day, causing a vertical temperature gradient in metal structures. Evidently; the operators have selected such machining conditions that a temperature difference of ca. 0,5 K was present during the finishing cuts. It is a good example of a procedural solution (Mc Clure, p. 9). It must be emphasized again, that the systematic solution described above is very incomplete, e.g. no attempt has been made to measure temperature gradients in the machine tool structure.

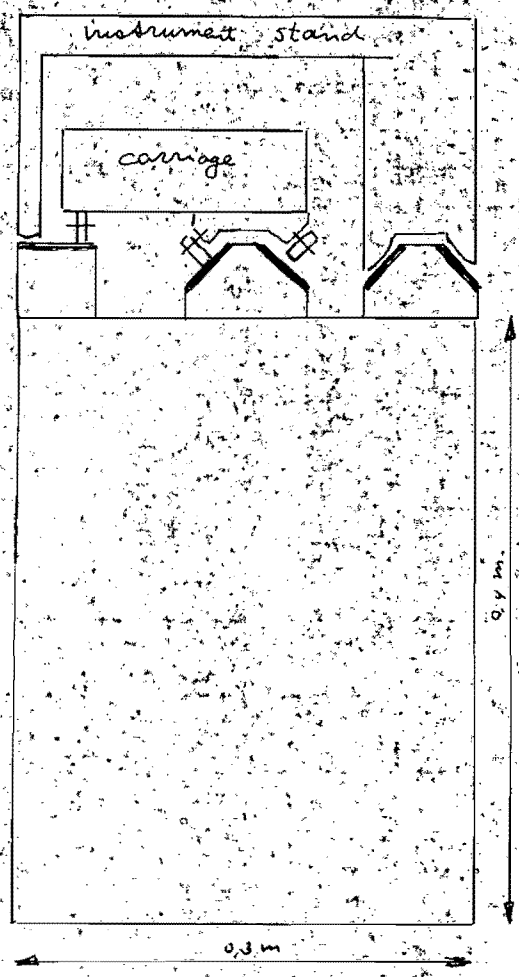
The temperature measuring instrument was replaced later by a different setup. It uses two platinum resistance thermometers in a bridge circuit. If the thermometers are reasonable equal, such a bridge circuit responds only to temperature difference. The properties of the circuit can be predicted from the properties of the thermometers. In our case the thermometers (specified according to DIN 43760) have $R_0 = 100 \text{ Ohm}$. If the current of the thermometers is 5,13 mA, a temperature difference of 1K

(= 1°C) results in a potential of 1 mV, giving full scale deflection of a conventional potentiometric recorder. Tolerances of the thermometers are such, that no calibration is necessary for 0,01K accuracy, if the bridge is balanced for $\Delta t = 0$.

The platinum wire is sealed in glass by the manufacturer; the glass tube was mounted in a brass block of dimensions 60 x 8 x 10 mm³.

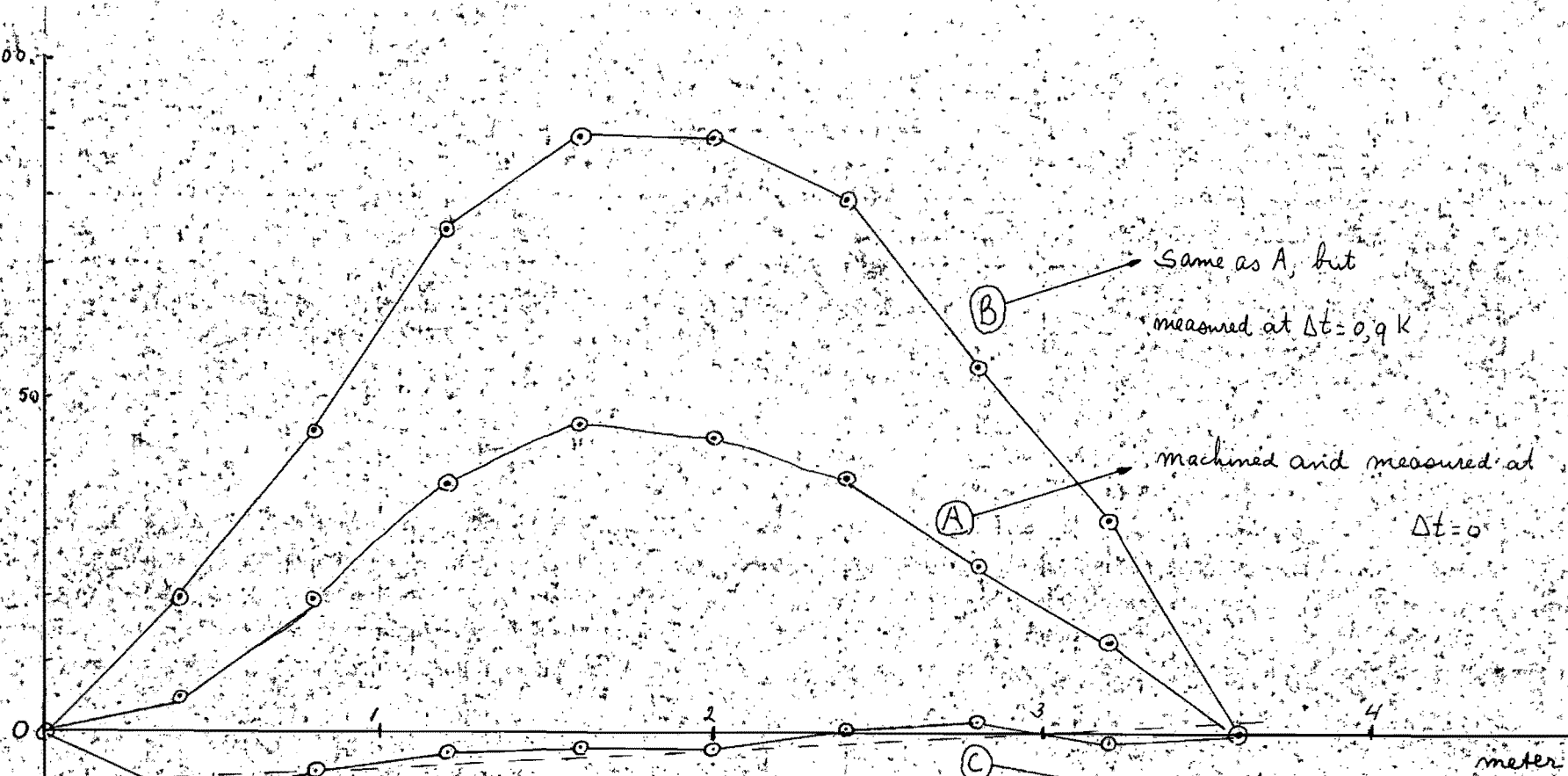
The brass block is fixed to the workpiece with a classical wax-and-rosin mixture. Although only limited experience has been gathered at the moment, the circuit performs well and can be used during machining without trouble.

Eindhoven, August 26, 1970.



sketch of cross section

mm. 100.



Same as A, but
measured at $\Delta t = 0,9 K$

machined and measured at
 $\Delta t = 0$

machined at $\Delta t = 0,5 K$
measured at $\Delta t = 0$

autocollimator
mirror base 0,4 m.