AUTO-COLLIMATOR

Used for straightness and flatness.

1. Analyze the data recorded in the lab.

2. Research and describe how and where the auto-collimator method would be used to assess flatness, say of the granite table.

3. What other uses does the auto-collimator have?

6.23 Tests for Straightness and Flatness

It will be appreciated that for a carriage to move along a straight line in both vertical and horizontal planes, the controlling guide-ways must themselves be straight. Tests for this condition may be carried out in several ways, the most convenient of which are by precision level and by the auto-collimator. It is the latter method which will be discussed here, but the method of tabulating and using the results of individual measurements is similar in each method.

The principle of measurement by the auto-collimator has been dealt with in Chapter 4, but the method of determination of straightness and flatness is dealt with now.

Assume that the straightness of a lathe bed 2 m in length is to be measured.

The general arrangement of measurement would be as in Fig. 6.4, the auto-collimator being set up independently of the lathe bed, about ½ m from one end, the parallel beam from the instrument being projected along the length of the bed. A particularly rigid support, preferably of the tripod type, is required for this. Assuming the bed to have flat-ways, the plane reflector is set on to the end of the bed nearer the instrument and a reflection obtained from it such that the image of the cross-wires of the collimator appear nearer the centre of the field. The reflector is then moved to the other end of the bed, and provided the general line of movement of the reflector has been reasonably parallel to the optical axis of the instrument, then the image of the cross-wires will appear in the field of the eyepiece at this position of the reflector also. This procedure ensures that reflections at intermediate positions will be within the field, and is thus an approximate check on the level of the bed in the horizontal plane.

A straight-edge should now be set down on the bed, to ensure that the reflector is stepped along it in a straight line.

Assume that the distance between the support feet of the reflector is 103.5 mm, and that the interval length at which measurements are taken is also 103.5 mm.

Now, since 1 min of arc \( \frac{2\pi}{360 \times 60} = \frac{2\pi}{21600} \) radians

then, on a base length of 103.5 mm, 1 min of arc \( \frac{2\pi}{360 \times 60} \times 103.5 \text{ mm} = 0.03 \text{ mm} \)

That is, each tilt of 1 min of arc of the reflector as it is stepped along the bedway corresponds very closely to a rise or fall of the guide-way surface of 0.03 mm.

Having ensured that an image of the cross-wires will be received by the auto-collimator when the reflector is set at the end positions of the bed, the reflector is now set at the forward end of the bed, nearest the instrument, to begin the series of readings. This condition, and those for subsequent readings, is shown in Fig. 6.4 in which the rise and fall of the bed surface is greatly exaggerated.

With the reflector set at A–B, the setting wires in the auto-collimator eyepiece are moved to straddle symmetrically the image of the horizontal cross-wire, by the suitable rotation of the micrometer drum, and the micrometer reading is noted. The reflector is then moved 103.5 mm to the position B–C and a second reading is taken on the micrometer drum. Successive readings at C–D, D–E, E–F, etc., are taken until the length of the bed has been stepped along. A second set of readings should now be obtained by stepping the reflector in the reverse direction along the bed, to reveal any serious errors in the first set of readings. Assuming none have occurred, the mean values of each set of readings may now be recorded, and these represent the angular positions of the reflector, in seconds relative to the optical axis of the auto-collimator at each of its positions along the bed.

The method of tabulation of the results of measurement are shown on p. 121. Column 1 gives the position of the plane reflector at 103.5 mm intervals along the bed. Column 2 gives the mean reading of the auto-collimator to the nearest second. In practice it is possible to observe sub-divisions of seconds, and this should
be done. Column 3 gives the differences of each reading from the first. In column 4 these differences are converted to the corresponding linear rise or fall, on the basis of 1 sec of arc = 0.0005 mm per 102.5 mm. The second zero introduced at the head of column 4, when associated with the previous zero in this column, represents the heights of the two feet of the reflector support mounting when in its original position. Column 5 gives the heights of the support feet of the reflector above the datum line drawn through their first position. That is, the values in column 5 are obtained by successively adding, algebraically, the values in column 4. This is necessary because the individual heights obtained in column 4 are the heights of the back feet of the support relative to the front feet in a given position and not relative to the datum.

<table>
<thead>
<tr>
<th>Position on Surface</th>
<th>Reading</th>
<th>Difference from 1st Reading (sec)</th>
<th>Rise or Fall in Interval Length (0.001 mm)</th>
<th>Cumulative Rise or Fall (0.001 mm)</th>
<th>Adjustment to bring both ends to Zero (0.001 mm)</th>
<th>Errors from Straight Line (0.001 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2 10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2 10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2.0</td>
<td>−2</td>
</tr>
<tr>
<td>2</td>
<td>2 12</td>
<td>+2</td>
<td>+1.0</td>
<td>+1.0</td>
<td>−4.0</td>
<td>−3</td>
</tr>
<tr>
<td>3</td>
<td>2 15</td>
<td>+5</td>
<td>+2.5</td>
<td>+3.5</td>
<td>−6.0</td>
<td>−2.5</td>
</tr>
<tr>
<td>4</td>
<td>2 17</td>
<td>+7</td>
<td>+3.5</td>
<td>+7.0</td>
<td>−8.0</td>
<td>−1.0</td>
</tr>
<tr>
<td>5</td>
<td>2 18</td>
<td>+8</td>
<td>+4.0</td>
<td>+11.0</td>
<td>−10.0</td>
<td>+1.0</td>
</tr>
<tr>
<td>6</td>
<td>2 17</td>
<td>+7</td>
<td>+3.5</td>
<td>+14.5</td>
<td>−12.0</td>
<td>+2.5</td>
</tr>
<tr>
<td>7</td>
<td>2 15</td>
<td>+5</td>
<td>+2.5</td>
<td>+17.0</td>
<td>−14.0</td>
<td>+3.0</td>
</tr>
<tr>
<td>8</td>
<td>2 13</td>
<td>+3</td>
<td>+1.5</td>
<td>+18.5</td>
<td>−16.0</td>
<td>+2.5</td>
</tr>
<tr>
<td>9</td>
<td>2 9</td>
<td>−1</td>
<td>−0.5</td>
<td>+18.0</td>
<td>−18.0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>2 12</td>
<td>+2</td>
<td>+1.0</td>
<td>+19.0</td>
<td>−20.0</td>
<td>−1.0</td>
</tr>
<tr>
<td>11</td>
<td>2 14</td>
<td>+4</td>
<td>+2.0</td>
<td>+21.0</td>
<td>−22.0</td>
<td>−1.0</td>
</tr>
<tr>
<td>12</td>
<td>2 16</td>
<td>+6</td>
<td>+3.0</td>
<td>+24.0</td>
<td>−24.0</td>
<td>0</td>
</tr>
</tbody>
</table>

The total rise in the surface of the bed over a 1½ m length from a datum along the line of the first reading is 24 μm. In column 5 this total rise is proportioned over the twelve readings taken, i.e. in increments of 24/12 = 2 μm. These values (column 6) are subtracted from the values in column 5 to give the errors (column 7) in the bed from a straight line joining the end points and within which the series of readings were obtained (i.e. it is as though a straight edge were laid along the bed profile and touching the end points of the test surface when they are in a horizontal plane). The rise and fall of the surface relative to the straight edge would be the values given in column 7.

A graphical representation of this is shown in Fig. 6.5 in which the values given in columns 5, 6, and 7 are plotted. In the graph of cumulative errors a straight line has been passed through the end points, and represents the straight line connecting the ends of the bed. In the graph of straightness errors, this line has been used as the axis, and thus the values plotted in the previous graph have the same relationship to it.

It is important to note that the increasing values for the readings given in column 2 of the table indicate the increasing angle of tilt of the top of the reflector towards the optical axis of the auto-collimator. Increasing readings have therefore indicated positive (+) values for the linear rise and fall, and vice versa. The lathe bed is thus both concave and convex along its length relative to the datum line joining its end points.

![Graph of cumulative error and actual error in a machine bed, determined using an auto-collimator.](image-url)
The test described relates to a flat-bed lathe, but the method applies also to a bed with vee guide-ways. In this case, however, the plane reflector mount must be supported on a carriage having a vee accurately ground in its base, to suit the vee of the bed. The apex of the carriage vee should be relieved so that contact is made only at the sides of the vee. With this arrangement, the straightness of the bed in the horizontal plane can be determined, as well as in the vertical (i.e., the tilt about the vertical axis indicates changes in the angle of the reflector in the horizontal plane).

As in the previous test, the reflector is stepped along the bed in intervals of 103.5 mm but in this case the auto-collimator tube is rotated 90° in its housing, to a pre-set step, so that the pair of setting wires in the eyepiece are vertical. Changes of position of the image of the vertical member of the cross-wires are then read on the micrometer drum, and would be recorded in column 2.

Associated with the error in the straightness of a lathe bed may be any crosswind which exists due to each way of the bed having different errors in straightness, or, if straight, lying in non-parallel planes. This condition cannot be detected with an auto-collimator, since the reflector would be merely rotating in its own plane as it was stepped along the bed. The most practical and convenient method of test is to step a precision level, laid transversely across the bed, along its length. If necessary, a bridge piece should be used as the level carriage, both to span the width of the bed, and to accommodate the vee guideways.

A computer program for handling this type of calculation is shown in Chapter 11, section 11.211.

### 6.3 Tests for Squareness

In many machine tools, for example, drilling machines and vertical milling machines, an essential accuracy lies in the squareness of the spindle axis with the plane of the table. Fig. 6.6 illustrates the principle, in which a test bar supports a dial test indicator at a suitable radius, say 150 mm.

With the measuring plunger bearing directly but lightly on the machine table, the spindle is rotated slowly by hand through 360°, dial indicator readings being taken at 180° in planes perpendicular to each other. In the case of drilling machines, the permitted error is of the order of 0.05 mm/300 mm, and in direction such that the front edge of the table is inclined upwards. That is, the force due to the downward traverse of the drill tends to correct the error.

In the case of vertical milling machines, the full test would apply only to fixed cutting head machines. A test in a direction perpendicular to the longitudinal table axis only is applicable to swivelling head machines, and an error of 0.02 mm/300 mm is applicable, the front edge of the table inclining upwards.

A test of this nature is known as the 'turn round method', and proves to be a very sensitive one.

In some classes of machine tools, the accuracy of construction called for requires optical methods for its testing. This applies especially to jig-boring machines, but is also applicable to milling machines of both vertical and horizontal types.

Fig. 6.7 illustrates the conditions of test for the squareness of the transverse table ways with the face of the column.

When using an optical method for such a test, and bearing in mind that the axis of the incident beam from the auto-collimator forms the measuring datum, it is clear that this must be turned accurately through 90°. It is done by means of an optical square. This is a special case of a prism, such that, regardless of the angle at which the incident beam strikes the face of the prism, then by internal reflection the beam is turned through 90°.

---

Fig. 6.6. Testing a drilling-machine spindle for squareness with the table.

Fig. 6.7. Auto-collimator and optical square being used to test the squareness of machine slides.