

ART. XXXIII.—*The Comparison of Two Screws*;* by CARL BARUS.

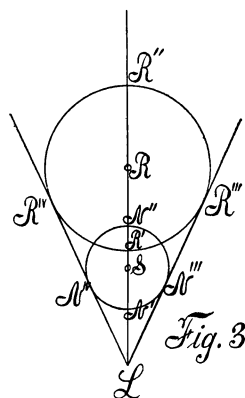
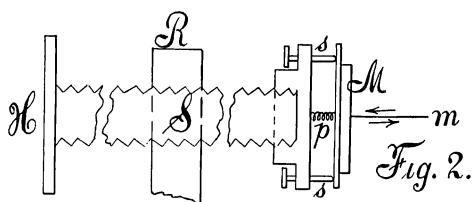
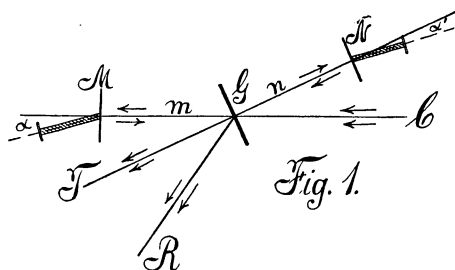
1. *Introductory*.—In work where two lengths are to be compared, a shift ΔN measured with one micrometer, for instance, and a thickness e with another (a caliper screw), it becomes of importance to coördinate these data directly. This may be done with facility by mounting the opaque mirrors M and N of an interferometer of the displacement type† on the two screws in question, shifting the ellipses away from the spectrum line with the first screw at N and returning them to the identical line with the other screw at M , through successive consecutive steps of their length. The screws must now be identically reversed in relation to the fixed beam of light and a similar series of complete data investigated. The true relation is the geometric mean of the two results, at each step.

2. *Method*.—In fig. 1 let M and N be the opaque mirrors, actuated by the micrometer screws at an angle α and α' respectively, to the beams of light m and n , *i. e.*, the normals of the mirrors. C is the collimator, G the grating, and T the telescope. Let the latter be clamped, so that the direction TG is fixed throughout the experiment, as is also CG . It must be possible to remove the mirrors M and N , together with their micrometer screws, without changing the angles α and α' in

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FIG. 1.



order that they may be identically reversed. Let S be the pitch of the screw at N , for instance, s the corresponding equivalent (often approximate pitch) at N . Then

$$(1) \quad S \cos a = s \cos a'$$

Now let the mirrors be reversed, the angles a and a' and the beams m and n being reproduced, in virtue of the fixed direction GT . In this case

$$(2) \quad S \cos a' = s \cos a$$

Hence

$$(3) \quad S^2 = ss' = s^2 (1 + k).$$

Since k is very small

$$(4) \quad S = s(1 + k/2) = \frac{1}{2}(s + s'), \text{ nearly.}$$

In order that the reversal may be properly made, the tablets carrying the micrometers M and N with the attached mirrors should be truly horizontal, so that merely an adjustment of each in azimuth is necessary. The sharp white line which is the direct reflection from the mirror N is first restored to the cross hairs of the fixed telescope, after which the reflection from M is restored to the same image, the two lines merging into a single vertical sharp line. The slit images should now

also coincide horizontally in the field, *i. e.*, the two images of any specks of dust or cross lines in the slit should cover each other. If this is not the case the tablets carrying M and N must be provided with three adjustment screws, so that the condition of mirror normal to the beams of light may be reestablished without changing a and a' . In other words, the adjustment screws of the mirrors on the micrometer must be left untouched.

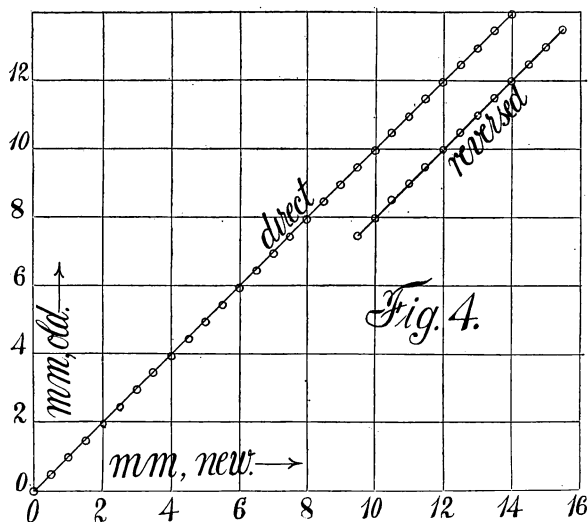
When this is done, the ellipses will be seen in the direction of the refracted rays R as soon as the proper distances m and n have also been reestablished, by moving either mirror alone. The arrangement of mirrors on the tablet should therefore be as nearly as possible symmetric, even when different forms of screws are compared.

A simple type of micrometer screw or attachment suitable to any screw to be tested will also be used below and may be described here. S , fig. 2, is the micrometer screw in question, with its graduated head at H revolvable in the socket R , this being adjustable, with three screws as usual, on the tablet at either N or M , fig. 1. The mirror M , fig. 2, is separately adjustable with three screws (horizontal and vertical axes), s , s , and a strong spring suggested at p . The whole arrangement Mps is firmly fixed to the end of the screw S . In this case the mirror rotates with the screw as it advances and the latter is therefore necessarily normal to the component beam m , an adjustment secured by the set screws at s in the usual way, the effect of the operations being observed in the telescope T in fig. 1. The approximate adjustment is conveniently made with sunlight returned by reflection from the mirror to a screen 20 or 30 feet distant. Suppose, fig. 3, the mirror is nearly normal to the screw; let the intersection of the incident ray, the screw axis, the normals, and the reflected rays with the screen, all lines prolonged if necessary, be at L , S , N' and R , respectively. If the screw is rotated 360° , the normal will trace a circle N' to N^{IV} , the reflected ray a similar circle R' to R^{IV} . If the normal N' coincides with the axis of the screw S , the reflected ray will be at the center, R , of the circle $R'R''$. Hence the center is to be sought by rotating the screw. The mirror is now adjusted so that the reflected ray is at R . Then N is at S , as required. With successive trials this succeeds very well.

3. *Data*.—A trial comparison was made of the screws of two slide micrometers, one of them old but with an excellent slide, the other with a good new screw but an imperfect slide. As a result of this it was impossible to keep the ellipses adequately sharp throughout the whole motion of the screw. In fact, it was necessary to make a readjustment of mirrors M and N from

time to time, *i. e.*, to take a fresh start, so that the comparison proceeded rather in sections. Moreover, the motion of the slide not strictly parallel to itself appears in the data as an error of the screw and virtually it is so. The discrepancy may, however, be corrected without reëstablishing a fresh zero, by removing the effect of any slight rotation at one mirror, due to an imperfect slide or other causes, by adjustment screws at the tablet of the other mirror, until the sharp lines of the ellipses are quite restored. In fact, this is a method of compensation, by which excess of length due to incidental rotation at one mirror is manually imparted to the other. Care must be taken to keep the angles α and α' unchanged. In other respects the comparison so far as the experiment is concerned was satisfactory (see fig. 4), very little difficulty in adjusting

FIG. 4.



and reversing being encountered. With two good slides the work would have proceeded smoothly from end to end of the screws, which were several inches long.

The first screw had a pitch of $\cdot 05$ centimeter, the micrometer reading to $\cdot 00010$ centimeter; the second a pitch of $\cdot 025$ centimeter, the micrometer reading to $\cdot 00005$ centimeter. The former was turned in steps of a single pitch, and the value which brought the center of ellipses, originally coincident with the given Fraunhofer line, back to coincide with it was read off on the finer screw.

For the reasons stated it was necessary to coördinate the successive sections of the measurements made and a fresh fiducial mark was determined in terms of the preceding whenever the ellipses lost adequate clearness. To find the relation of the two screws, the mean of the initial and final halves of each series was computed by deducting the corresponding observations from each other and averaging the result. In this way the ratio r of the old appears in

Series I	$r' = .9962$
“ II (mirrors reversed).....	$r'' = .9997$

Thus the true relation is finally

$$r = (r' + r'') / 2 = .9980$$

Usually a large part of the difference of values of the two screws is to be ascribed to the angles of alignment a and a' , if no special means are taken to orientate them accurately. With the ratio $r = S/s$ given, the ratio of the alignment angles would follow, but this is of little value. In fact, if

$$a' = a + da \qquad da = (1 - r) \frac{2 - a^2}{2a}$$

where a^2 may be neglected in comparison with 2. Hence da increases as a decreases, numerically. The real problem of finding a for the measuring micrometer is naturally not touched by such a method, in case of two slide micrometers. It is given at once, however, when one of the micrometers is of the form of fig. 2, where a' (say) is necessarily zero. Hence if the screws are identical $\cos a = 1/r$. Virtually, however, $S \cos a = s$ is the effective absolute value of the micrometer screw calibrated in this way in terms of s . This is a particular reason for the development of such an apparatus, fig. 2, to serve the purposes of comparison and standardization.

4. *Conclusion.*—The advantage of the present method is that steps of any size, quite arbitrarily, are admissible and there is no danger of ever losing count. A rigorously linear slide is presupposed. If the slide is slightly circular, even with very large radius, the ellipses are soon blurred and lost. To restore the ellipses by rotation of mirror is possible, but in any case precarious.

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