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Government of Madras.

Public Works DEPARTMENT.

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*Proceedings of the Madras Government, Public Works Department,
4th September 1872.*

No. 44. Read the following despatch from the Right Honourable the Secretary of State for India, (Public Works,) to His Excellency the Right Honourable the Governor in Council, Fort St. George, dated India Office, London, 11th July 1872, No. 12:—

I HAVE forwarded per book-post ten copies of each of the under-mentioned publications, and I request that they may be circulated among the officers of the Public Works and Survey Departments of your Presidency, namely:—

Report by Major G. A. Laughton on the working of an instrument called the Omnimeter.

Memorandum on Eckhold's Omnimeter by Lieutenant-Colonel Strange, F.R.S.
Description of Eckhold's Omnimeter by the inventor.

2. The copies have been addressed to the Secretary, Public Works Department, Madras.

ECKHOLD'S OMNIMETER.

THIS instrument is intended, as its name denotes, to effect several operations, as measuring the bases of triangulation, measuring distances either inclined or horizontal, measuring altitudes, and measuring angles.

Description.

The instrument consists of the following parts:—

1. Of a graduated circle, to read off each ten seconds in the measurement of horizontal angles.
 2. Of a powerful telescope, revolving in a plane perpendicular to the graduated circle.
 3. Of a microscope, of high power, connected with the telescope and moving with it.
 4. Of a highly sensitive level lying upon —.
 5. Of a rule, or plane, having a fixed length (of 20 centimetres, for example).
 - *6. Of a scale fixed vertically at the extremity of the said rule, at a distance coincident with the optical axis of the microscope, which scale is divided into half millimetres (the millimetres are indicated by the numbers between 1 and 100).
 7. Of a micrometrical screw movement connected with the base of the scale and giving the $\frac{1}{1000}$ of a millimetre of the scale, legible on the graduated circle beneath.
 8. Of a second extremely sensitive level, capable of being applied to the telescope and determining, in case of need, its horizontality.
- Further, of all the necessary screws, keys, and other matters required to secure the efficient working of the instrument.

As the necessary complement of the omnimeter, there is a levelling staff (*see* fig. 2), not divided, but of an invariable length (as, for example, three metres), which length is defined by two white lines on a ground of black, one at the upper extremity and the other at the lower extremity of the staff, as *m*, *m'*.

Mode of Operation.

Before going into more ample details regarding the instrument, it may be as well, in order to show the way of working with it and the advantages to be obtained by its use, to take an example.

Supposing, then, that we require to ascertain the distance between any two points—

* This description refers to the original French form of the instrument; the straight graduated scale is now, in the English pattern, horizontal not vertical.

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The first thing is to place the levelling staff at one of the points (in this as in all geodesical operations, the staff must, of course, be held in a true vertical position).

We then take the omnimeter to the other point, and set it up. By means of the level (4), and its screw adjustment, we place the instrument in a horizontal plane.

Then directing the telescope upon the upper white line m of the staff, we fix the telescope (with the screw for that purpose).

We read off on the scale, by means of the microscope, the inclination of the telescope.

On account of the figures being magnified by the microscope, we shall be able to see only one number at a time of the 100 integrals of the scale; suppose we find the number 67 (millimetres) plus the unascertained fraction comprised between that number and the horizontal thread of the microscope. We will ascertain the fraction exactly, by means of the micrometer; say, in our example, that it reads as 2,035 on the circle of the micrometer.

This we note down in our book to the right of the number 67 already obtained,

thus 672035

We repeat this operation in every particular for the line m' (the lower one) of the staff, and we obtain, say 609400

The operation with the instrument is now complete, as we are in possession of the data required for calculating the distances. Let us take the difference between

these two quantities 62635

and divide 6000000, a constant number for all cases, by the difference we have thus obtained, and we shall have 95m.79 as the horizontal distance in question.

In fact, let us (fig. 1) suppose the levelling staff in position at mm' , let O be the point round which the telescope revolves, AB representing the difference as found — 62635.

From the point O let us draw a horizontal line; let us produce the line AB to H , and the line mm' to D . We have then AB and mm' perpendicular to OD .

In the similar triangles OAH and OmD we have the following proportion—

$$\frac{OH}{AB} = \frac{OD}{mm'}, \text{ therefore } OD = \frac{OH \times mm'}{AB};$$

But $OH = 0m.20$ (by the construction of the instrument).

$mm' = 3m.00$ (the invariable length of the staff).

$AB = 62635$ (the quantity obtained in our example by the scale).

The last quantity in fractions of the metre is 0m.0062635; if we substitute for the letters their respective values, we have:

$$OD = \frac{0m.20 \times 3}{0m.0062635} = \frac{0m.60}{0m.0062635} = \frac{6000000}{62635} = 95m.79.$$

In the preceding example, we have supposed the staff to be placed at one point and the omnimeter at the other. This manner of operating is not, however, the only one; there are two others, one by placing the omnimeter in line with the two points; the other, by fixing it at some point outside. In either case, a staff must be set up at each of the points. In the first instance, the total distance is obtained directly by adding together the back and foresights. In the second instance, we obtain the distance by measuring the horizontal angle, which we read off on the great circle, and by calculating the triangle (trigonometrically) by means of the angle thus obtained and the two sides.

For the establishment of a base of triangulation, the latter mode is that which we should recommend for adoption; for, if we proceed thus by small distances from 10 to 20 metres on each side, or thereabouts, we may easily measure a base line of 1,000 metres within an approximation of 0m.004—a result which is quite satisfactory.

In fact, if for a distance of 10 metres the scale gives us the difference 0m.06, it will give us for a distance equal to 9m.99996 the difference 0m.0600002, a quantity appreciable on the circle of the micrometer.

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The nature of this operation requiring extreme exactness, a staff of special construction should be employed. This staff would have the two faces similar to those already described, would be provided with supports to ensure its verticality, and, at its base, would be armed with a steel point and iron tressles.

As regards the measurement of the slope or the inclined distance, the operation requires, further, the reading off of the horizontal line on the scale.

We have, then (fig. 2), a new proportion:—

$$\frac{AB}{BH} = \frac{mm'}{m'D}, \text{ and } m'D = \frac{mm' \times BH}{AB},$$

$$\text{consequently } Om' = \sqrt{(m'D^2 + OD^2)}.$$

General Observation.—The practice of the omnimeter has proved to us that in the measurement of lengths requiring extreme accuracy, it is not prudent to make the points more than 200 metres apart. At that distance we are within an approximation of 0m.04; at 500 metres, by making use of a staff of four metres high, the approximation would be within 0m.17—a sufficiently satisfactory result, as, by one forward and one back sight, we can determine a kilometre within 0m.34. With the chain we know as a fact that it is hardly possible to come nearer than within a mean of $\frac{1}{700}$ of difference.

In levelling, the operation is identical with that we have described for the measurement of inclined distances. The quantity is given by the formula (see fig. 2) $m'D = \frac{mm' \times BH}{AB}$, that is, three (metres) multiplied by the difference of the sights, divided by the difference with the horizontal line.

The readings are obtained with the greatest precision. For distances not exceeding 100 metres, they are obtained within a fraction of a millimetre; and for greater distances (at which the instruments at present in use are inoperative) the measurement can be obtained within a millimetre.

This degree of precision is attained because—

1. In placing the instrument, we have not to pay attention to centralizing the optical axis.
2. Because the operator has always to point his telescope on the same lines of the staff, which lines denote an invariable length, namely, three metres.
3. Because there can be no hesitation in reading the staff as with the ordinary levelling staves, with which we have an element of guess-work not found here.

In difficult and hilly ground, levelling with the ordinary levels becomes a very long and expensive operation, because the sights are necessarily short, and because the number of them is multiplied in proportion to the rapidity of the incline. The omnimeter, as may be perceived at once from the nature of the instrument, allows of levelling points placed at great distances apart, and which make considerable angles with the horizon. Merely considered as a level, it offers a considerable advantage over the instruments hitherto in use.

The omnimeter is calculated, therefore, to effect an important improvement, combining as it does in one instrument the theodolite and the level, doing away with the necessity for tedious chain measurements, and requiring in its operation no complicated calculations.

Memorandum on ECKHOLD'S "Omnimeter" by Lieutenant-Colonel A. STRANGE, F.R.S.,
Inspector of Scientific Instruments, India Store Department.

As the new instrument named the "Omnimeter" has attracted some notice amongst Indian Surveyors, I think it desirable to state my opinions on certain points connected with it, with a view of ascertaining whether it still admits of improvement, and if so in what direction. With this view, I beg to recommend that this memorandum, Major Laughton's report, to which it will frequently refer, and the inventor, M. Eckhold's, description of the instrument (appended) be printed and circulated to the Public Works and Survey Departments in the three Presidencies.

2. The invention under notice was brought to me by its author, M. Eckhold, about three years ago. I made a very careful examination of it, and came to the conclusion that the principle was sound, and that, if properly applied, it was calculated to effect a considerable saving of both time and money in those surveys in which chain measurements have hitherto been employed, and in levelling operations.

3. But the individual instrument of French manufacture, submitted to me by M. Eckhold, was very badly designed. I need not here describe its defects, but they were such that I declined to recommend the trial in India of the principle in that shape. I had many conferences with M. Eckhold on the subject, and explained to him the modifications in the form of the instrument which would be necessary in order to give its principle fair play. After a good deal of delay and several alterations, Messrs. Elliott Brothers produced an instrument in which my instructions were to some extent carried out, and it was this instrument, modified under my advice, which Major Laughton saw when he was in England, and justly considered worthy of trial. He anticipated my intention of recommending that it should be tried, and some private correspondence on the subject passed between us. On only one point did I express a doubt regarding the practical efficiency of the instrument, namely, that, as its successful use depends mainly on the manipulation of a very delicate micrometer screw for determining exceedingly minute linear quantities, I did not feel sure that the persons ordinarily employed in the Public Works Department on levelling works and in the Revenue minor detail surveys would prove sufficiently trained to fastidious refinement of observation to do justice to such an appliance. I had no doubt that in Major Laughton's hands the instrument might succeed, but I very much feared it might fail in the hands of his less refined subordinates. It is true that the instrument is getting largely into use on the Continent, but it is notorious that subordinate surveyors are more highly educated abroad than with us.

4. Major Laughton's report on the instrument after trial is in some respects favourable. But he does not mention by whom it was used, and until more is known on that point I think it my duty to repeat the above caution.

5. The three principal operations for performing which this instrument professes to have advantages over the ordinary methods are (1) the measurement of heights; (2), levelling; (3), the measurement of linear distances.

6. Major Laughton states (paragraph 17) that for measuring heights the instrument is "exceedingly accurate," and (paragraph 19) that in levelling it is "wonderfully accurate." I shall therefore take those two points as settled, and confine my remarks to the third, namely, its accuracy as a distance measurer.

7. Many attempts to dispense with direct chain measurements by means of instrumental micrometers or scales of various kinds have been made at different times. The omnimeter is the best arrangement of this kind with which I have met; but it must not be forgotten what are the unavoidable mathematical conditions of the problem in question, namely, to employ an "ill-conditioned triangle" of a very extreme kind. No method of determining a distance is known in which a measured base line can be dispensed with (except the very uncertain one founded on the velocity of sound). In the omnimeter method this measured base is a staff of from 2 to 4 metres long, and is therefore very short compared with the distance to be measured. This unfavourable condition is sought to be counteracted by introducing a finely divided scale and delicate micrometer, which are the distinguishing features of the instrument, which is equivalent in point of fact to an instrument having a vertical circle of about 6 inches radius read off by one micrometer microscope in the usual way. The substitution of a straight scale for a circle, by introducing the principle of "similar triangles," simplifies the computation, but does not confer greater accuracy than that attainable with the circle; but it must never be lost sight of that the method, whether a circle or a straight scale be employed, is subject to the fundamental disadvantage above pointed out.

8. Major Laughton states (paragraph 31), "The difference between the observations of two persons amounted in some instances to .00005; but this is a most serious difference, for the difference of .00001 in 600 feet is equal to an error of 3 inches, at 1200 — to 1 foot; in other

words the error increases according to the square of the difference between the distances, consequently, should the difference between two observations amount to .00005, this would equal 5 feet at 1,200 yards—a most serious error."

9. The discrepancy between two persons here spoken of evidently means the discrepancy between their micrometer readings. Major Laughton describes this discrepancy (of .00005 in a single reading) to want of delicacy in the straight scale, and insufficiency of sub-division in the circular micrometer head, and he proposes modifications in these parts, by means of which he expects to render readings made by different observers more accordant.

10. In this expectation I fear he will be disappointed for the following reason:—The celebrated Troughton laid down the dictum that no smaller quantity can be measured by a given instrument than that which can be seen in its telescope. This, of course, applies equally to a microscope used for measurement. The dictum is based on sound sense, and has never been controverted. Numerous experiments which I have made on the subject satisfy me of its substantial correctness.

11. What, then, is the smallest quantity visible in the microscope of the omnimeter. I have, since the receipt of Major Laughton's Report, examined one now under construction by Messrs. Elliott. I placed before the microscope a set of "Nobert's Test Lines," which are remarkably fine lines, cut on glass made expressly to test microscopes. The coarsest set of lines were 12,000 per inch. The microscope was totally unable to show these as separate lines. I then tried a scale on glass (made for another purpose) which had 2,500 lines per inch. The microscope resolved these perfectly, and I estimated that it would have shown lines of twice that fineness, namely, 5,000 per inch. This, I think, is about the smallest quantity the microscope will show with certainty. Let us compare this with the scale and micrometer head. The scale is divided to half millimetres, and one division = 0.01969 inch, say, 0.02 inch, or $\frac{1}{50}$ th of an inch. To sub-divide this, the micrometer head has 500 divisions. A single division of the micrometer = $\frac{1}{500}$ th of $\frac{1}{50}$ th of an inch, which is equal to the $\frac{1}{25,000}$ th of an inch. This quantity being five times smaller than the smallest above found to be visible in the microscope, I foresee no advantage from increasing the delicacy of the indicating appliances, which already so much exceed that of the microscope.

12. Hence it would appear that the microscope itself needs greater optical power. And this can be done by diminishing the focal length of its object glass. But this will bring the object glass nearer the scale, and as this, being an opaque object, is viewed by direct, not transmitted, light, there is a limit to this source of power. The limit has been reached in the microscopes used for reading off large circles. Those of the great theodolite, designed by me for the Great Trigonometrical Survey of India, afford an example. They are brought as near to the circle as illuminating exigencies admit. They indicate, under average circumstances, with certainty about 0.5" (half a second of arc). This angular quantity on the circle in question (3 feet diameter) is = 0.0000436 in., or about $\frac{1}{22,900}$ (one twenty-five thousandth) of an inch. The present delicacy of the indicating appliances of the omnimeter is thus already equal to that of such microscopes as those of the large instrument referred to, which are four or five times more powerful than the microscopes of the omnimeter according to my experiments above mentioned. It would appear, therefore, that the power of the microscope should be increased rather than the power of the indicating appliances. But, before proposing to do that, we must ascertain what amount of increase in microscopic power would be really effective, and to do this we must take one step further and examine the telescope, for again applying Troughton's rule, it is of no use to make the microscope, with which the observation is only read off, much more powerful than the telescope with which the observation is taken.

13. I find, from very numerous experiments made for other purposes, that telescopes of about the size in question, if good, when directed to an opaque object at comparatively short distances and well illuminated, show no smaller angular quantity than about (7") seven seconds of arc. I say "about," because the quantity varies with the light and the quality of the telescope. I find, too, that an average spider's line in such telescopes subtends about the same angular quantity.

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14. It is easy to compute that seven seconds of arc on the straight scale, taken as part of a circle of say 6 inches radius, are equivalent to $\frac{1}{180}$ of an inch. Now this is exactly the quantity which, by direct experiment above referred to, I find to be the least that the microscope will show, and five times greater than the smallest quantity which the scale and micrometer head already indicate.

15. If the above reasoning is sound, it would therefore appear that the part of the instrument which requires strengthening is the telescope itself, not the indicating appliances, which are already so much in excess. What angular quantity, then, should the telescope be able to show in order to place it on a par with the indicating parts? These now show, as I have stated, the $\frac{1}{180}$ of an inch. This, on a circle of 6 inches radius, is equivalent to $(1.4'')$, less than one and a half second of arc. No telescope of less than 24 or 3 feet focal length would show such a quantity in an opaque object. To apply such a telescope to an omnimeter would so entirely alter the character of the instrument that I need not discuss the project.

16. The conclusions at which I arrive are as follow:—

1st.—That the telescope cannot be much increased in size without altering the whole design of the instrument, and that, as with it the observation is taken, it must be accepted as the basis.

2nd.—That the microscope is at present on a par with the telescope, but that, in order that no part of the accuracy of the original observation should be lost, the microscopic power should be increased, which can be done to a certain limited extent without inconvenience to the illumination of the straight scale.

3rd.—I consider, and here I come to a conclusion exactly the reverse of that arrived at by Major Laughton, that the indications of the micrometer are already, in a considerable degree, more delicate than they need be. I should be disposed to substitute a smaller circular head rather than a larger one, in order to diminish the weight on the screw, which is of very delicate structure, and to lessen the risks of accident to this very exposed part.

4th.—It should not be lost sight of that, after all, the accuracy of the result is dependent on the accuracy of the division of the straight scale. It is not probable that their errors are so small as $\frac{1}{180}$ of an inch, the present value of one division of the micrometer.

17. I may close this part of the subject with the general remark that the power of an instrument is, like that of a machine, equal to the power of its weakest part, and that in designing instruments harmony of proportion should be more studied than it is. The problem, in designing a portable instrument, I conceive to be this, "Given a certain size or mass, how can the utmost power be got into that?" It is evident that this can only be done by giving, as nearly as possible, equal power to all the different members of the instrument. It is difficult to arrive at these proportions rigorously, but I have endeavoured to show how, in a given instrument, some idea of the approach made to them can be gained.

18. I would now say a few words on the distances which Major Laughton proposes to measure with the omnimeter, and of the admissible errors which he contemplates.

19. In his paragraph 31, which I have already quoted, he speaks of measuring, as I understand him, by a single observation, "1,200 yards."

20. Referring to the printed description of the instrument furnished to me by the inventor himself, M. Eckhold, I find the following passage on this point:—

"General Observations.—The practice of the omnimeter has proved to us that, in the measurement of lengths requiring extreme accuracy, it is not prudent to make the points more than 200 metres [656 feet] apart. At that distance we are within an approximation of 0.34 metres [1.57 inches]; at 500 metres [1,640 feet, or 546 yards], by making use of a staff of 4 metres high, the approximation will be within 0.17 metres [6.7 inches], a sufficiently satisfactory

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result, as, by one forward and one back sight, we can determine a kilometre within 0.34 metres [about $\frac{1}{3}$ of an inch]. With the chain we know, as a fact, that it is hardly possible to come nearer than within a mean of $\frac{1}{10}$ of difference."

21. It will be seen from this that the inventor only contemplates measuring distances of 656 feet, or 219 yards, with the 2-metre staff, and not more than 546 yards even with a 4-metre staff, and that he does not speak of such distances as 1,200 yards, to which Major Laughton alludes. I have recently discussed the subject verbally with the inventor, who adheres to the above as what the instrument may be expected to do, repudiating any profession of measuring distances so great as 1,200 yards. Indeed, at that distance the staff would hardly be discernible at all. It is no less than 541 chains, whilst 10 or 12 chains is an extreme distance for reading staves in ordinary levelling work with a very similar telescope.

22. As to the average errors of chain measurements, Major Laughton's estimate (paragraph 34) is 1 foot in 1,000 or $\frac{1}{1000}$ th, whereas M. Eckhold, in the above extract, takes it at $\frac{1}{100}$ th. My own experience in chaining has been very limited, and I can therefore express no opinion on this point. Much, of course, depends on the character of the ground chained, and on the precautions taken in testing and stretching the chain, etc., and it is, of course, hardly to be expected that all observers will ensure the fulfilment of the same conditions, and a very small variation in method will lead to a very different result.

23. It is to be remarked, however, that the more uneven the ground the more probable will be the superiority of the omnimeter over the chain as a distance measurer.

24. But, on the whole, I am inclined to caution observers against expecting too much from the instrument for this particular purpose. No method of determining distances is so accurate of linear measurement. It would be invariably employed if the intervention of hills, rivers, undulations, and other accidents of ground, did not stand in the way of its economical use. The theodolite and triangulation secure much greater rapidity and cheapness, but not greater accuracy, than linear measurements. The omnimeter method is virtually a species of triangulation of an unfavourable kind, as I have already stated, owing to the shortness of the base. I do not say this in order to discourage the use of the instrument. Far from it. I think it should be thoroughly tested, as a most promising contrivance, but a word of caution against pushing its principle beyond what it is calculated for may not be amiss.

25. I will now refer to the only test given by Major Laughton of the instrument as a distance measurer, namely, the discordant results given by different observers in reading off the scale and micrometer. Such discordances are to be expected. They constantly occur in the reading off of astronomical instruments of the highest class, which is effected by means identical with those in question; they are due to physiological causes inherent in each individual, and, in regular observatories, are allowed for under the name of "personal equation."

26. I would beg to suggest to Major Laughton these further tests:—

1. Let each observer make a considerable number of settings of the micrometer, with the instrument securely clamped, a second observer reading off and recording the micrometer readings, of which the first observer should be ignorant until the series is completed, in order that he may have no bias. If several observers go through this process, we shall have data for ascertaining whether the discrepancies are due to different degrees of skill in different observers, shown by some obtaining a more accordant series than others; or whether there is a deficiency in the definition of the microscope, or in the clearness of the scale, or some other mechanical defect, which will be shown by all the different series exhibiting about equal discordances. If it is found that the differences of each observer with himself are about equal in all cases, but that the mean results (the instrument being of course unmoved) obtained by different observers are not alike, which I imagine is what Major Laughton has found, this will indicate the "personal equation" above alluded to as a phenomenon which may be expected to occur.

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2. Let now several distances be measured on level ground with great care, with the best means available. Let the different observers make each a number of determinations of each distance, the readings of the micrometer head being always taken by a second observer as before. This is the real practical test of the instrument as a whole. We shall learn from it several things, namely, whether all the observers are equally skillful, as shown by the accordance of the series taken by each; whether different observers, assumed of equal skill, obtain similar distances; and whether the omnimeter distances agree, within admissible limits, with the measured distances, and if not, whether the discordances follow some law, or are apparently accidental.
27. The observers selected to make these tests should be of the class who are to be employed in using the omnimeter in the field, not men selected for skill in the use of delicate instruments.
28. I should expect to find from these tests two things. First, that very different degrees of skill exist amongst the observers. This evil can, of course, be corrected only by training and practice. Second, that different observers, equal in skill, disagree in their determination of the same distance. If this is found to be the case, it will be probably a matter of personal equation, which will render it necessary that every observer, before working with a given omnimeter, should compare its determinations taken by himself with carefully measured test distances, and apply to all distances obtained by him with that individual instrument a correction previously so ascertained.
29. I trust that the tenor of these remarks may not be considered as opposed to the introduction of the omnimeter. I entertain, on the contrary, a high opinion of its merits. It promises to reduce very considerably the cost of levelling and chaining. But nothing is more calculated to bring a new invention into disrepute than to claim too much for it. The questions I have here discussed relate to its accuracy, which there is some danger may be over-rated. I have, therefore, endeavoured to show on what its accuracy depends, and what is the probable limit of accuracy attainable; my opinion, stated in general terms, being that it will most likely be found in practice rather to fall short of than exceed the ordinary methods in precision, though to an extent insufficient to forbid its substitution for them in the great majority of cases, but that some special training of those using the instrument will be found necessary in order fully to call forth its powers.

LAMBETH OBSERVATORY,
20th January 1872.

(Signed) A. STRANGE, Lieutenant-Colonel,
Inspector of Scientific Instruments.

No. 45.

ORDER THEREON, 4th September 1872, No. 2,102.

ESTABLISHMENT, No. 3.

ORDERED that the two last-named publications be re-printed for circulation to the officers of the Public Works and Survey Departments, Major Laughton's report having already been distributed.

(True Extract.)

Colonel, R.E.,

Secretary to Government.

To the Acting Chief Engineer for Irrigation.
" Superintending Engineers.
To Major R. B. Kennedy.
To the Superintendent of Revenue Survey.
Exd. F. R. Pantlema.

(A.)

No. 150 of 1871.

To Lieutenant-Colonel J. T. FRANCIS, Survey and Settlement Commissioner,
Northern Division.

Bombay,
22nd March 1871.

Sir,

I have the honour to enclose a copy of letter from the Secretary of State for India, sanctioning an application I made, while lately on furlough in England, to be allowed to bring out for trial a new instrument called the "Omnimeter," and requesting me to submit a report upon the working of the instrument to the Government of Bombay.

2. This instrument was not ready when I left England in the end of last August, but was subsequently forwarded to me and arrived in Bombay towards the end of January last.

3. Having given the instrument a thorough trial, I have now, in terms of the above letter, to submit for the information of Government the following report:—

4. The "omnimeter" is an instrument which effects several operations, viz., it measures vertical and horizontal angles; it determines altitudes, and can consequently be used as a level; and, lastly, it measures linear distances, whether inclined or horizontal. In fact, with this instrument, work combining the use of the chain, level, and theodolite, can be done more expeditiously than with the latter instruments at one and the same time, and consequently in a great measure supersedes the necessity of using them.

5. This instrument professes to measure—

Distances of 100 feet to within 0.001,
" 1,000 feet " 0.050.
" 1,000 yards " 1 foot.
Heights at a distance of 300 feet to within 0.0005 of a foot.
" " 1,000 feet " 0.0002.

6. The principal parts of the "omnimeter" are,—

- (1.) A powerful telescope.
- (2.) A powerful microscope.
- (3.) A scale fixed on the horizontal plate and divided into half millimetre.
- (4.) A micrometer screw, turning a circular disk, which is divided into 500 equal parts, one whole turn of which moves the above scale half a millimetre.
- (5.) A graduated circle for measuring horizontal angles.
- (6.) A level to adjust the horizontal plate.
- (7.) A second level placed upon the telescope.
- (8.) An arc for measuring vertical angles.

N.B.—The one on this instrument is not divided, and consequently is useless for the above purpose.

7. The instrument is formed by combining the powerful microscope with the telescope, and the micrometer, which gives measures on the scale fixed on the horizontal plate, and which is divided into half millimetres as fine as 0.0000002 of a metre, or 0.0002 of a millimetre. The microscope is perpendicular to the telescope, and both move on the same axis.

8. The perpendicular distance from the centre of the axis to the scale on the horizontal plate can be found to any required degree of accuracy; it is a constant quantity in each instrument.

9. The bases and the perpendicular of any number of triangles may be taken by use of the microscope, micrometer, and scale, with accuracy, which triangles will be similar to corresponding ones taken by the telescope. The most important triangle given by the telescope is that formed by supposing two lines to pass

(7757.)

10. Accompanying the instrument are two or more staves of an invariable length; those used with this instrument are about 11 feet long, having two white lines on a black ground exactly 10 feet apart, and as all the measurements are of a decimal character, this length is the best that could be adopted.

11. The above is the description of the instrument, and of what it professes to be able to perform. It is altogether as portable as any ordinary theodolite. I may here state that I am mainly indebted to "Spon's Dictionary of Engineering" for the description I have given of the "omnimeter."

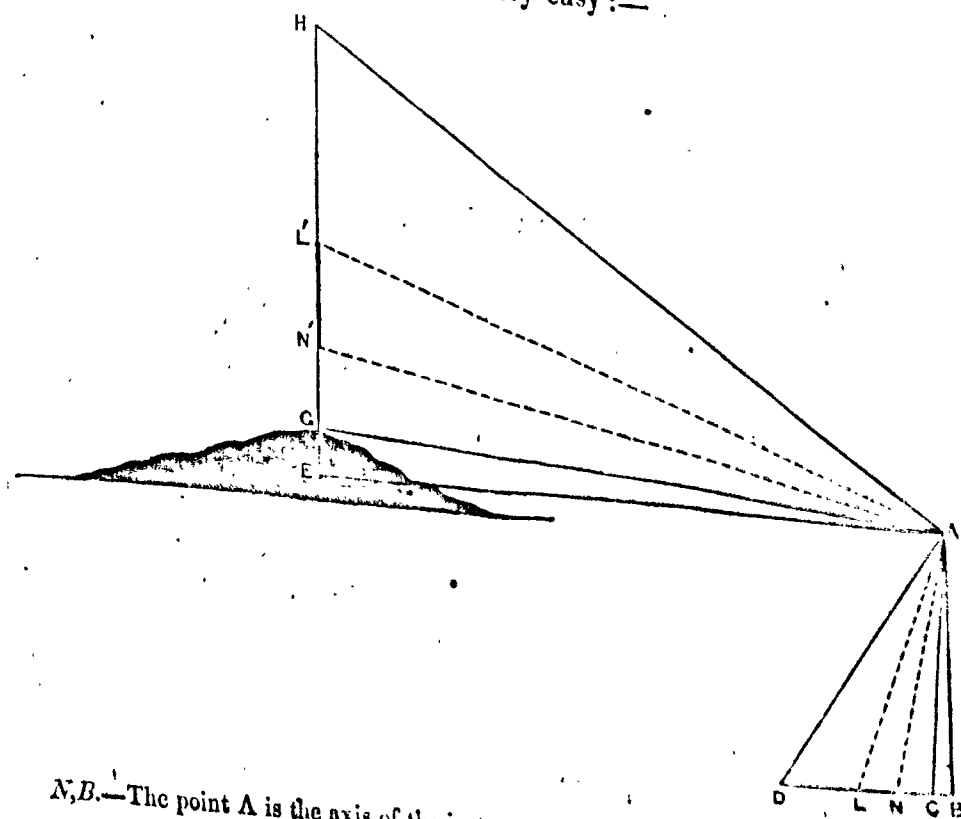
12. I now proceed to show to what degree of accuracy I have been able to work with the instrument.

13. As the omnimeter professes to perform five things, as stated in para. 4, I will take them in the order therein mentioned.

14. The arrangements for measuring vertical and horizontal angles are similar to those of an ordinary theodolite, and require no explanation; the horizontal plate in this instrument is 5½ inches in diameter, and is divided into divisions of 20'—the vernier reads to 30"—the vertical arc, and is divided into divisions of 20'—the vernier reads to 30"—the vertical arc, as stated before, is not divided, and thus one of the principal parts is wanting, for, without it, the finding of the distance from the axis to the surface of the scale fixed on the horizontal plate, as also the "stationary point" of the scale, required for levelling purposes, is a laborious operation.

15. To determine altitudes. The staff is placed in a vertical position alongside of the object the height of which is required. The instrument being placed at a short distance away from the object, duly adjusted, a reading is taken to the upper line of the staff, and then to the lower line, after which the telescope is directed to the top and bottom of the object the altitude of which is required.

16. The distance from the object being ascertained, as will be described hereafter. The height of the object is obtained by the proportion, thus: Let AB = the distance from the axis to the surface of the scale, CD = the difference of readings between top and bottom of object as read off the scale, AE = the linear distance between the instrument and object, LN = the difference of readings between top and bottom of staff, and GH = the required height of the object; then as $AB : CD :: AE : GH \therefore GH = \frac{CB \times AE}{AB}$; AE may be put = 1, 10, 100, 1,000, and so on, the calculation becomes extremely easy:—



N.B.—The point A is the axis of the instrument.

18. The manner of levelling consists in determining the lines LN and NB on the scale; the first is in proportion to the staff, and the other to the height over or under the level of the instrument. The first of these lines, LN, is found, as before described, by reading the top and bottom lines of the staff. The second, NB, by finding out the point B, called the stationary point of the scale, which is obtained by the optical axis-line of the microscope, when the telescope is brought horizontal by means of the level attached to it; the point B is constant, and serves for all calculations in levelling operations. The line NB is thus found to be the difference between the number N, obtained by sighting the staff and the number of the stationary point B. The proportion is then as follows:

(*Vide* the same figure.)

$$LN : NB :: \dot{L}\dot{N} : \dot{N}E \therefore \dot{N}E = \frac{\dot{N}\dot{L} \times NB}{LN}$$

19. In levelling, the "omnimeter" has been found to be wonderfully accurate, quite equal to what, as shown in para. 5, it professes to be able to do.

20. The principal tests I have put it to are as follows:—A series of points were fixed in a direct line, from 150 to 900 feet, at every 50 feet; the levels of these were accurately determined by an ordinary level twice over; this operation of course took considerable time. The omnimeter was then adjusted, and, without being moved from that spot, observations were taken to the top and bottom lines of the staff, at each point, a work which occupied only a very short time, for, as there are only two well-defined lines on the staff, there was not the same hesitation in reading as with an ordinary levelling staff, with which there is an element of guesswork not found in using the staff of the "omnimeter;" on the levels being calculated from the data thus obtained, the greatest difference between the results obtained by the two instruments, viz., ordinary level and omnimeter, was 0.01.

21. As the linear distance obtained by this instrument is the principal element in determining the level of any given point, for experiment it was supposed that a mistake of 3 feet existed in a distance of 900 feet; but on calculating the level with this error—that is, the distance being known to be 900 feet, the numbers 897 and 903 were taken in calculating the height of the point—in each instance the level thus obtained differed from the true level by ∓ 0.02 .

22. Again, in a distance of upwards of 6,000 feet, working through a crowded city, with constant interruption, the last reading on a bench-mark, from which the work was commenced, was found to differ from the first by only 0·22.

23. Another test was as follows:—The height of a hill of about 90 feet was determined by carefully levelling both up and down with an ordinary level, a work which occupied us nearly two hours; the same height within 0.29 was obtained within five minutes after adjusting the "omnimeter," by observing the staff at the bottom of the hill, in the manner before described, and another at the top of the hill. This was done without moving the instrument.

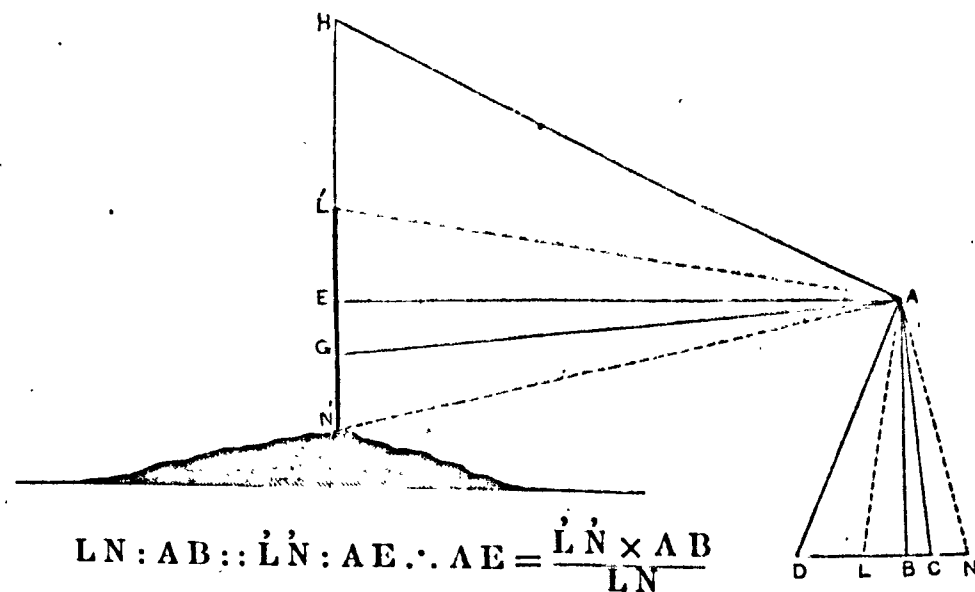
24. I now come to the last operation performed by this instrument, namely, that of measuring linear distances, and I would be glad indeed were I able to report as favourably on this as on the others.

25. The operation in determining the distance from the instrument to the staff is similar to the others, that is, the staff is held vertically on the point, and the top and bottom lines are observed as before; the proportion is as follows, *vide* last diagram:—

$$LN : AB :: \dot{L}\dot{N} : AE \therefore AE = \frac{\dot{L}\dot{N} \times AB}{LN} = \text{the required distance.}$$

26. Another case can be taken where LN is placed partly below the horizontal line AE, as is seen in the following diagram; a little study will show that the

triangles are similar to those in the foregoing diagram, consequently the proportions and calculations are similar.



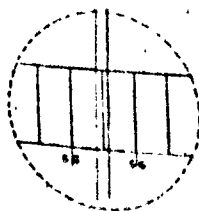
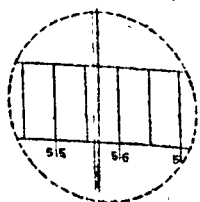
27. Distances up to 1,000 feet have been taken with this instrument, but in its present state it is not to be depended upon over 600 feet, and even at this distance errors amounting to a foot are not unfrequent.

28. The causes of error are as follows:—

- 1st. The telescope not being powerful enough.
- 2nd. The arrangement for reading the scale being faulty.
- 3rd. The scale itself, though apparently to the naked eye very finely divided, when under the microscope appears exceedingly coarse.
- 4th. The diameter of the disk is too small, and the divisions not sufficiently minutely divided.

29. The first element of error is easily rectified.

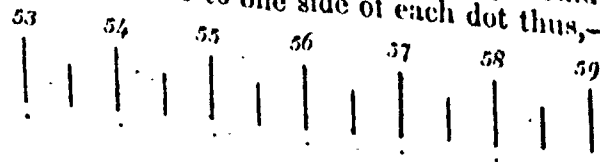
30. The manner of reading the scale is as follows:—On looking through the microscope two parallel hairs are seen, the micrometer being set to zero on the disk; it is necessary to find out how much beyond the nearest line on the scale the hairs denote the distance to the right; to do this, the micrometer is turned around, which action draws the scale to the right, until the hairs are placed (as it were) one on each side of the line. *Vide diagram.*



this is a matter of individual judgment, no two reading it alike, or placing the hairs in the same position.

31. The differences between the observations of two persons amounting in some instances to .00005, but this is a most serious difference, for the difference of .00001 in 600 feet is equal to an error of 3 inches—at 1,200—to 1 foot; in other words the error increases according to the square of the difference between the distances, consequently, should the difference between two observations amount to .00005, this would equal 5 feet at 1,200 yards, a most serious error.

32. The manner of rectifying this error would be as follows,—instead of having two hairs in the eye piece of the microscope there should be only one, the divisions, instead of being engraved as continuous lines, should be shown by the minutest possible dot, with a line to one side of each dot thus,—



the one hair would then be brought so as to cover the required dot, and the figures over the adjoining line would show its value.

33. The diameter of the disk is 3 inches, and it is divided into 500 divisions—one whole turn moves the scale (on the horizontal plate) half a millimetre. I would propose to increase the diameter of the disk and divide it, and the scale, more minutely, so that in observing the difference, if any, should not be in the first five figures, that is, if carefully observed, the first five figures should always be the same.

34. With these improvements I am of opinion that the "omnimeter" will be a most admirable instrument for city surveys—it will then, without doubt, determine distances up to 1,000 feet within 1 foot, which is the amount of allowable error in our present work with theodolite and chain, and as, besides the linear distances, levels and horizontal angles are obtained at one single and "unique" operation, the saving of time and expense will be immense.

35. The present instrument, even with only the improvements suggested in para. 32, without increasing the power of the telescope, the size of the disk, and the fineness of the scale, will be most useful in the hilly and jungly districts of the Concan, where, at times, it is impossible to drive a chain without cutting a path through the brushwood, and I would respectfully beg to suggest that as many instruments as are immediately required for the survey of that part of the country should be ordered without delay.

36. Instruments for city survey work should have the following:—

- (1.) Lower plate seven inches in diameter.
- (2.) Vernier of horizontal plate and that of arc for measuring vertical angles to be divided to 10".
- (3.) The telescope to be very powerful, so as to distinguish a white line $\frac{1}{20}$ of an inch wide distinctly at 1,200 feet.
- (4.) The scale on the horizontal plate to read 100,000, or to six places of figures, and the divisions to be shown by dots and lines, as described in paragraph 32.
- (5.) The microscope to have only one hair.
- (6.) Circular disk to be larger, and more finely divided in the same proportion as the scale.
- (7.) The level on horizontal plate to be longer and more sensitive.
- (8.) The level attached to telescope to have divisions on it the same as on ordinary level tubes.
- (9.) The base line of the instrument, viz., the distance from the axis to the surface of the scale, should be found out before the instrument is sent to this country, in order to see if any change arises from difference of climate, and in the same way the "zero," or the point on the scale, which is given by the optical axis line of the microscope when the telescope is brought horizontal by means of the level attached to it, should be noted; with all these improvements the instrument will still remain exceedingly portable.

37. There is one more improvement I would beg to propose, and it is one that not only applies to this instrument but also to all theodolites, and this is, instead of employing spider's webs for the hairs in the eye piece of the telescope and microscope, fine lines photographed on glass should be inserted. These lines can be made finer than any hair; also the glass can be taken out and cleaned, and the risk of breaking the hairs, and the trouble required to re-insert them, be entirely done away with; in like manner, the division on the scale of the omnimeter should be photographed instead of being engraved.

38. I ought to apologize for this long report, but when I came to think what a vast amount of trouble and expense can be saved by universally employing such an admirable instrument as the "omnimeter," I feel I cannot say too much.

39. For city surveying, in laying down transverse lines, all chaining is done away with, horizontal angles are taken at one and the same operation.

40. For surveying and levelling in rough, hilly, and thickly wooded country, only those who have been obliged to use theodolites and chains in such places can understand what a boon this instrument will be to others similarly employed.

41. For railways and irrigation purposes it is equally, if not more useful.

42. In conclusion, I would beg to propose that my report upon the omnimeter be printed, in order that not only Government engineers and surveyors in this and in other Presidencies, but the public in general, may have an opportunity of discussing the merits of this instrument.

I have, &c.,
(Signed) G. A. LAUGHTON, Major,
Superintendent Bombay Revenue Survey.

(B.)

MEMORANDUM ON ECKHOLD'S "OMNIMETER," by Lieut.-Colonel A. STRANGE, F.R.S.,
Inspector of Scientific Instruments, India Store Department.

As the new instrument named the "Omnimeter" has attracted some notice amongst Indian Surveyors, I think it desirable to state my opinions on certain points connected with it, with a view of ascertaining whether it still admits of improvement, and if so in what direction. With this view I beg to recommend this memorandum, Major Laughton's report, to which it will frequently refer, and the inventor, M. Eckhold's, description of the instrument (appended) be printed and circulated to the Public Works and Survey Departments in the three presidencies.

2. The invention under notice was brought to me by its author, M. Eckhold, about three years ago. I made a very careful examination of it, and came to the conclusion that the principle was sound, and that, if properly applied, it was calculated to effect a considerable saving of both time and money in those Surveys in which chain measurements have hitherto been employed, and in levelling operations.

3. But the individual instrument, of French manufacture, submitted to me by M. Eckhold, was very badly designed. I need not here describe its defects, but they were such that I declined to recommend the trial in India of the principle in that shape. I had many conferences with M. Eckhold on the subject, and explained to him the modifications in the form of the instrument which would be necessary in order to give its principle fair play. After a good deal of delay and several alterations, Messrs. Elliott, Brothers, produced an instrument in which my instructions were to some extent carried out, and it was this instrument, modified under my advice, which Major Laughton saw when he was in England, and justly considered worthy of trial. He anticipated my intention of recommending that it should be tried, and some private correspondence on the subject passed between us. On only one point did I express a doubt regarding the practical efficiency of the instrument, namely, that as its successful use depends mainly on the manipulation of a very delicate micrometer screw for determining exceedingly minute linear quantities, I did not feel sure that the persons ordinarily employed in the Public Works Department on levelling works and in the Revenue minor detail surveys would prove sufficiently trained to fastidious refinement of observation to do justice to such an appliance. I had no doubt that in Major Laughton's hands the instrument might succeed, but I very much feared it might fail in the hands of his less refined subordinates. It is true that the instrument is getting largely into use on the Continent, but it is notorious that subordinate Surveyors are more highly educated abroad than with us.

4. Major Laughton's report on the instrument after trial is in some respects favourable. But he does not mention by whom it was used, and until more is known on that point I think it my duty to repeat the above caution.

5. The three principal operations for performing which this instrument professes to have advantages over the ordinary methods are (1) the measurement of heights; (2) levelling; (3) the measurement of linear distances.

6. Major Laughton states (para. 17) that for measuring heights the instrument is "exceedingly accurate," and (para. 19) that in levelling it is "wonderfully accurate." I shall therefore take those two points as settled, and confine my remarks to the third, viz., its accuracy as a distance measurer.

7. Many attempts to dispense with direct chain measurements by means of instrumental micrometers or scales of various kinds have been made at different times. The omnimeter is the best arrangement of this kind with which I have

met; but it must not be forgotten what are the unavoidable mathematical conditions of the problem in question, namely, to employ an "ill-conditioned triangle" of a very extreme kind. No method of determining a distance is known in which a measured base line can be dispensed with (except the very uncertain one founded on the velocity of sound). In the omnimeter method this measured base is a staff of from 2 to 4 metres long, and is therefore very short compared with the distance to be measured. This unfavourable condition is sought to be counteracted by introducing a finely divided scale and delicate micrometer, which are the distinguishing features of the instrument, which is equivalent in point of fact to an instrument having a vertical circle of about 6 inches radius read off by one micrometer microscope in the usual way. The substitution of a straight scale for a circle, by introducing the principle of "similar triangles," simplifies the computation, but does not confer greater accuracy than that attainable with the circle; but it must never be lost sight of that the method, whether a circle or a straight scale be employed, is subject to the fundamental disadvantage above pointed out.

8. Major Laughton states (para. 31), "The difference between the observations of two persons amounted in some instances to .00005; but this is a most serious difference, for the difference of .00001 in 600 feet is equal to an error of 3 inches, at 1200 = to 1 foot; in other words the error increases according to the square of the difference between the distances, consequently, should the difference between two observations amount to .00005, this would equal 5 feet at 1,200 yards,—a most serious error."

9. The discrepancy between two persons here spoken of evidently means the discrepancy between their micrometer readings. Major Laughton describes this discrepancy (of .00005 in a single reading) to want of delicacy in the straight scale, and insufficiency of subdivision in the circular micrometer head, and he proposes modifications in these parts, by means of which he expects to render readings made by different observers more accordant.

10. In this expectation I fear he will be disappointed for the following reason. The celebrated Troughton laid down the dictum that no smaller quantity can be measured by a given instrument than that which can be seen in its telescope. This, of course, applies equally to a microscope used for measurement. The dictum is based on sound sense, and has never been controverted. Numerous experiments which I have made on the subject satisfy me of its substantial correctness.

11. What, then, is the smallest quantity visible in the microscope of the omnimeter. I have, since the receipt of Major Laughton's Report, examined one now under construction by Messrs. Elliott. I placed before the microscope a set of "Nobert's Test Lines," which are remarkably fine lines, cut on glass made expressly to test microscopes. The coarsest set of lines were 12,000 per inch. The microscope was totally unable to show these as separate lines. I then tried a scale on glass (made for another purpose) which had 2,500 lines per inch. The microscope resolved these perfectly, and I estimated that it would have shown lines of twice that fineness, viz., 5,000 per inch. This, I think, is about the smallest quantity the microscope will show with certainty. Let us compare this with the scale and micrometer head. The scale is divided to half millimetres, and one division = 0.01969 inch, say, 0.02 inch, or $\frac{1}{50}$ th of an inch. To subdivide this, the micrometer head has 500 divisions. A single division of the micrometer = $\frac{1}{500}$ th of $\frac{1}{50}$ th of an inch, which is equal to the $\frac{1}{25,000}$ th of an inch. This quantity being five times smaller than the smallest above found to be visible in the microscope, I foresee no advantage from increasing the delicacy of the indicating appliances, which already so much exceed that of the microscope.

12. Hence it would appear that the microscope itself needs greater optical power. And this can be done by diminishing the focal length of its object glass. But this will bring the object glass nearer the scale, and as this, being an opaque object, is viewed by direct, not transmitted, light, there is a limit to this source of power. The limit has been reached in the microscopes used for reading off large circles. Those of the great theodolite, designed by me for the Great Trigonometrical Survey of India, afford an example. They are brought as near to the circle as illuminating exigencies admit. They indicate, under average circum-

stances, with certainty about 0.5" (half a second of arc). This angular quantity on the circle in question (3 feet diameter) is = 0.0000436 in., or about $\frac{1}{23,000}$ (one twenty-five thousandth) of an inch. The present delicacy of the indicating appliances of the omnimeter is thus already equal to that of such microscopes as those of the large instrument referred to, which are four or five times more powerful than the microscopes of the omnimeter according to my experiments above mentioned. It would appear, therefore, that the power of the microscope should be increased, rather than the power of the indicating appliances. But, before proposing to do that, we must ascertain what amount of increase in microscopic power would be really effective, and to do this we must take one step further and examine the telescope, for, again applying Troughton's rule, it is of no use to make the microscope, with which the observation is only read off, much more powerful than the telescope with which the observation is taken.

13. I find, from very numerous experiments made for other purposes, that telescopes of about the size in question, if good, when directed to an opaque object at comparatively short distances and well illuminated, show no smaller angular quantity than about (7") seven seconds of arc. I say "about," because the quantity varies with the light and the quality of the telescope. I find, too, that an average spider's line in such telescopes subtends about the same angular quantity.

14. It is easy to compute that seven seconds of arc on the straight scale, taken as part of a circle of say 6 inches radius, are equivalent to $\frac{1}{30,000}$ of an inch. Now this is exactly the quantity which, by direct experiment above referred to, I find to be the least that the microscope will show, and five times greater than the smallest quantity which the scale and micrometer head already indicate.

15. If the above reasoning is sound, it would therefore appear that the part of the instrument which requires strengthening is the telescope itself, not the indicating appliances, which are already so much in excess. What angular quantity, then, should the telescope be able to show in order to place it on a par with the indicating parts? These now show, as I have stated, the $\frac{1}{23,000}$ of an inch. This, on a circle of 6 inches radius, is equivalent to (1.4"), less than one and a half second of arc. No telescope of less than 2½ or 3 feet focal length would show such a quantity in an opaque object. To apply such a telescope to an omnimeter would so entirely alter the character of the instrument that I need not discuss the project.

16. The conclusions at which I arrive are as follows:—

- 1st. That the telescope cannot be much increased in size without altering the whole design of the instrument, and that, as with it the observation is taken, it must be accepted as the basis.
- 2nd. That the microscope is at present on a par with the telescope, but that, in order that no part of the accuracy of the original observation should be lost, the microscopic power should be increased, which can be done to a certain limited extent without inconvenience to the illumination of the straight scale.
- 3rd. I consider, and here I come to a conclusion exactly the reverse of that arrived at by Major Laughton, that the indications of the micrometer are already, in a considerable degree, more delicate than they need be. I should be disposed to substitute a smaller circular head rather than a larger one, in order to diminish the weight on the screw, which is of very delicate structure, and to lessen the risks of accident to this very exposed part.
- 4th. It should not be lost sight of that, after all, the accuracy of the result is dependent on the accuracy of the division of the straight scale. It is not probable that their errors are so small as $\frac{1}{23,000}$ of an inch, the present value of one division of the micrometer.

17. I may close this part of the subject with the general remark that the power of an instrument is, like that of a machine, equal to the power of its weakest part, and that in designing instruments harmony of proportion should be more studied than it is. The problem, in designing a portable instrument, I conceive to be this, "Given a certain size or mass, how can the utmost power be got into that?"

It is evident that this can only be done by giving, as nearly as possible, equal power to all the different members of the instrument. It is difficult to arrive at these proportions rigorously, but I have endeavoured to show how, in a given instrument, some idea of the approach made to them can be gained.

18. I would now say a few words on the distances which Major Laughton proposes to measure with the omnimeter, and of the admissible errors which he contemplates.

19. In his para. 31, which I have already quoted, he speaks of measuring, as I understand him, by a single observation, "1,200 yards."

20. Referring to the printed description of the instrument furnished to me by the inventor himself, M. Eckhold, I find the following passage on this point,—
"General Observations.—The practice of the omnimeter has proved to us that, in the measurement of lengths requiring extreme accuracy, it is not prudent to make the points more than 200 metres [656 feet] apart. At that distance we are within an approximation of 0.04 metres [1.57 inches]; at 500 metres [1,640 feet, or 546 yards], by making use of a staff of 4 metres high, the approximation will be within 0.17 metres [6.7 inches], a sufficiently satisfactory result, as, by one forward and one back sight, we can determine a kilometre within 0.34 metres [about $\frac{1}{3000}$ th]. With the chain we know, as a fact, that it is hardly possible to come nearer than within a mean of $\frac{1}{700}$ of difference."

21. It will be seen from this that the inventor only contemplates measuring distances of 656 feet, or 219 yards, with the 2-metre staff, and not more than 546 yards even with a 4-metre staff, and that he does not speak of such distances as 1,200 yards, to which Major Laughton alludes. I have recently discussed the subject verbally with the inventor, who adheres to the above as what the instrument may be expected to do, repudiating any profession of measuring distances so great as 1,200 yards. Indeed, at that distance the staff would hardly be discernible at all. It is no less than 54 chains, whilst 10 or 12 chains is an extreme distance for reading staves in ordinary levelling work with a very similar telescope.

22. As to the average errors of chain measurements, Major Laughton's estimate (para. 34) is 1 foot in 1,000 or $\frac{1}{1000}$ th; whereas Mr. Eckhold, in the above extract, takes it at $\frac{1}{700}$ th. My own experience in chaining has been very limited, and I can therefore express no opinion on this point. Much, of course, depends on the character of the ground chained, and on the precautions taken in testing and stretching the chain, &c., and it is, of course, hardly to be expected that all observers will ensure the fulfilment of the same conditions, and a very small variation in method will lead to a very different result.

23. It is to be remarked, however, that the more uneven the ground, the more probable will be the superiority of the omnimeter over the chain as a distance measurer.

24. But, on the whole, I am inclined to caution observers against expecting too much from the instrument for this particular purpose. No method of determining distances is so accurate of linear measurement. It would be invariably employed if the intervention of hills, rivers, undulations, and other accidents of ground, did not stand in the way of its economical use. The neodolite and triangulation secure much greater rapidity and cheapness, but not greater accuracy, than linear measurements. The omnimeter method is virtually a species of triangulation, of an unfavourable kind, as I have already stated, owing to the shortness of the base. I do not say this in order to discourage the use of the instrument. Far from it. I think it should be thoroughly tested, as a most promising contrivance, but a word of caution against pushing its principle beyond what it is calculated for may not be amiss.

25. I will now refer to the only test given by Major Laughton of the instrument as a distance measurer, namely, the discordant results given by different observers in reading off the scale and micrometer. Such discordances are to be expected. They constantly occur in the reading off of astronomical instruments of the highest class, which is effected by means identical with those in question; they are due to physiological causes inherent in each individual, and, in regular observatories, are allowed for under the name of "personal equation."

26. I would beg to suggest to Major Laughton these further tests:—

1. Let each observer make a considerable number of settings of the micrometer, with the instrument securely clamped, a second observer reading off and recording the micrometer readings, of which the first observer should be ignorant until the series is completed, in order that he may have no bias. If several observers go through this process, we shall have data for ascertaining whether the discrepancies are due to different degrees of skill in different observers, shown by some obtaining a more accordant series than others; or whether there is a deficiency in the definition of the microscope, or in the clearness of the scale, or some other mechanical defect, which will be shown by all the different series exhibiting about equal discordances. If it is found that the differences of each observer with himself are about equal in all cases, but that the mean results (the instrument being of course unmoved) obtained by different observers are not alike, which I imagine is what Major Laughton has found, this will indicate the "personal equation" above alluded to as a phenomenon which may be expected to occur.

2. Let now several distances be measured on level ground with great care, with the best means available. Let the different observers make each a number of determinations of each distance, the readings of the micrometer head being always taken by a second observer as before. This is the real practical test of the instrument as a whole. We shall learn from it several things,—namely, whether all the observers are equally skilful, as shown by the accordance of the series taken by each,—whether different observers, assumed of equal skill, obtain similar distances,—and whether the omnimeter distances agree, within admissible limits, with the measured distances, and if not, whether the discordances follow some law, or are apparently accidental.

27. The observers selected to make these tests should be of the class who are to be employed in using the omnimeter in the field, not men selected for skill in the use of delicate instruments.

28. I should expect to find from these tests two things. First, that very different degrees of skill exist amongst the observers. This evil can of course be corrected only by training and practice. Second, that different observers, equal in skill, disagree in their determination of the same distance. If this is found to be the case, it will be probably a matter of personal equation, which will render it necessary that every observer, before working with a given omnimeter, should compare its determinations taken by himself with carefully measured test distances, and apply to all distances obtained by him with that individual instrument a correction previously so ascertained.

29. I trust that the tenor of these remarks may not be considered as opposed to the introduction of the omnimeter. I entertain, on the contrary, a high opinion of its merits. It promises to reduce very considerably the cost of levelling and chaining. But nothing is more calculated to bring a new invention into disrepute than to claim too much for it. The questions I have here discussed relate to its accuracy, which there is some danger may be overrated. I have therefore endeavoured to show on what its accuracy depends, and what is the probable limit of accuracy attainable, my opinion, stated in general terms, being, that it will most likely be found in practice rather to fall short of than exceed the ordinary methods in precision, though to an extent insufficient to forbid its substitution for them in the great majority of cases, but that some special training of those using the instrument will be found necessary in order fully to call forth its powers.

A. STRANGE, Lieutenant-Colonel,
Inspector of Scientific Instruments.

Lambeth Observatory,
29th January 1872.

(C.)

ECKHOLD'S OMNIMETER.

This instrument is intended, as its name denotes, to effect several operations, as measuring the bases of triangulation, measuring distances either inclined or horizontal, measuring altitudes, and measuring angles.

Description.

The instrument consists of the following parts:—

1. Of a graduated circle, to read off each ten seconds in the measurement of horizontal angles.
2. Of a powerful telescope, revolving in a plane perpendicular to the graduated circle.
3. Of a microscope, of high power, connected with the telescope and moving with it.
4. Of a highly sensitive level lying upon —.
5. Of a rule, or plane, having a fixed length (of 20 centimetres, for example).
6. Of a scale fixed vertically at the extremity of the said rule, at a distance coincident with the optical axis of the microscope, which scale is divided into half millimetres (the millimetres are indicated by the numbers between 1 and 100).
7. Of a micrometrical screw movement connected with the base of the scale, and giving the $\frac{1}{1000}$ of a millimetre of the scale, legible on the graduated circle beneath.
8. Of a second extremely sensitive level, capable of being applied to the telescope and determining, in case of need, its horizontality.

Further, of all the necessary screws, keys, and other matters required to secure the efficient working of the instrument.

As the necessary complement of the omnimeter, there is a levelling staff (see fig. 2), not divided, but of an invariable length (as, for example, three metres), which length is defined by two white lines on a ground of black, one at the upper extremity, and the other at the lower extremity of the staff, as *m*, *m'*.

Mode of Operation.

Before going into more ample details regarding the instrument, it may be as well, in order to show the way of working with it and the advantages to be obtained by its use, to take an example.

Supposing, then, that we require to ascertain the distance between any two points,—

The first thing is to place the levelling staff at one of the points (in this as in all geodesical operations, the staff must, of course, be held in a true vertical position).

We then take the omnimeter to the other point, and set it up. By means of the level (4), and its screw adjustment, we place the instrument in a horizontal plane.

Then directing the telescope upon the upper white line *m* of the staff, we fix the telescope (with the screw for that purpose).

We read off on the scale, by means of the microscope, the inclination of the telescope.

* This description refers to the original French form of the instrument; the straight graduated scale is now, in the English pattern, horizontal, not vertical.

On account of the figures being magnified by the microscope, we shall be able to see only one number at a time of the 100 integrals of the scale; suppose we find the number 67 (millimetres) plus the unascertained fraction comprised between that number and the horizontal thread of the microscope. We will ascertain the fraction exactly, by means of the micrometer; say, in our example, that it reads as 2,035 on the circle of the micrometer.

This we note down in our book to the right of the number 67 already obtained, thus

We repeat this operation in every particular for the line m' (the lower one) of the staff, and we obtain, say

The operation with the instrument is now complete, as we are in possession of the data required for calculating the distances. Let us take the difference between these two quantities

and divide 6000000, a constant number for all cases, by the difference we have thus obtained, and we shall have 95^m.79 as the horizontal distance in question.

In fact, let us (fig. 1) suppose the levelling staff in position at mm' , let O be the point round which the telescope revolves, AB representing the difference as found = 62635.

From the point O let us draw a horizontal line; let us produce the line AB to H, and the line mm' to D. We have then AB and mm' perpendicular to OD.

In the similar triangles OAH and Omd we have the following proportion—

$$\frac{OH}{AB} = \frac{OD}{mm'}$$

But $OH = 0^m.20$ (by the construction of the instrument).

$mm' = 3^m.00$ (the invariable length of the staff).

$AB = 62635$ (the quantity obtained in our example by the scale).

The last quantity in fractions of the metre is 0^m.0062635: if we substitute for the letters their respective values, we have:

$$OD = \frac{0^m.20 \times 3}{0^m.0062635} = \frac{0^m.60}{0^m.0062635} = \frac{6000000}{62635} = 95^m.79.$$

In the preceding example, we have supposed the staff to be placed at one point and the omnimeter at the other. This manner of operating is not, however, the only one; there are two others, one by placing the omnimeter in line with the two points; the other, by fixing it at some point outside. In either case, a staff must be set up at each of the points. In the first instance, the total distance is obtained directly by adding together the back and fore sights. In the second instance, we obtain the distance by measuring the horizontal angle, which we read off on the great circle, and by calculating the triangle (trigonometrically) by means of the angle thus obtained and the two sides.

For the establishment of a base of triangulation, the latter mode is that which we should recommend for adoption; for, if we proceed thus by small distances from 10 to 20 metres on each side, or thereabouts, we may easily measure a base line of 1,000 metres within an approximation of 0^m.001; a result which is quite satisfactory.

In fact, if for a distance of 10 metres the scale gives us the difference 0^m.06, it will give us for a distance equal to 9^m.99999 the difference 0^m.0600002, a quantity appreciable on the circle of the micrometer.

The nature of this operation requiring extreme exactness, a staff of special construction should be employed. This staff would have the two faces similar to those already described, would be provided with supports to ensure its verticality, and, at its base, would be armed with a steel point and iron tressles.

As regards the measurement of the slope or the inclined distance, the operation requires, further, the reading off of the horizontal line on the scale.

We have, then (fig. 2), a new proportion:—

$$\frac{AB}{BH} = \frac{mm'}{m'D}, \text{ and } m'D = \frac{mm' \times BH}{AB}$$

consequently

$$Om' = \sqrt{(m'D^2 + OD^2)}.$$

General Observation.—The practice of the omnimeter has proved to us that in the measurement of lengths requiring extreme accuracy, it is not prudent to make the points more than 200 metres apart. At that distance we are within an approximation of 0^m.04; at 500 metres, by making use of a staff of four metres high, the approximation would be within 0^m.17,—a sufficiently satisfactory result, as, by one forward and one back sight, we can determine a kilometre within 0^m.34. With the chain we know as a fact that it is hardly possible to come nearer than within a mean of $\frac{1}{700}$ of difference.

In levelling, the operation is identical with that we have described for the measurement of inclined distances. The quantity is given by the formula

(see fig. 2) $m'D = \frac{mm' \times BH}{AB}$ that is, three (metres) multiplied by the difference of the sights, divided by the difference with the horizontal line.

The readings are obtained with the greatest precision. For distances not exceeding 100 metres, they are obtained within a fraction of a millimetre; and for greater distances (at which the instruments at present in use are inoperative) the measurement can be obtained within a millimetre.

This degree of precision is attained because,—

1. In placing the instrument, we have not to pay attention to centralizing the optical axis.
2. Because the operator has always to point his telescope on the same lines of the staff, which lines denote an invariable length, viz., three metres.
3. Because there can be no hesitation in reading the staff as with the ordinary levelling staves, with which we have an element of guess-work not found here.

In difficult and hilly ground, levelling with the ordinary levels becomes a very long and expensive operation, because the sights are necessarily short, and because the number of them is multiplied in proportion to the rapidity of the incline. The omnimeter, as may be perceived at once from the nature of the instrument, allows of levelling points placed at great distances apart, and which make considerable angles with the horizon. Merely considered as a level, it offers a considerable advantage over the instruments hitherto in use.

The omnimeter is calculated, therefore, to effect an important improvement, combining as it does in one instrument the theodolite and the level, doing away with the necessity for tedious chain measurements, and requiring in its operation no complicated calculations.

No 4.

Public Works.
No. 12.

India Office,
London, 11th July 1872.

My Lord,

I have forwarded per
book-post 10 copies of each
of the undermentioned
publications and I request
that they may be circulated
among the officers of
the Public Works and
Survey departments of
your Presidency, viz.,

Report by Major G. A.
Laughton on the working
of an Instrument called
the Omnimeter.

Memorandum on Eckholdt's

Omnimeter by Lieutenant

His Excellency,
The Right Honorable
The Governor in Council
Port of Call for 1872.

Colonel

Colonel Strange. F. R. S.
Description of Eckhold's
Ommimeter by the Inventor

2. The copies have been addressed to the Secretary, Public Works Department, Madras.



1. The first part of the paper is devoted to a discussion of the general principles of the theory of the structure of the atom. It is shown that the structure of the atom is determined by the laws of quantum mechanics, which are based on the principle of the uncertainty of the position and momentum of the particles.

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No. 4.

Public Works

11th July 1872

Recd 13th Aug 72.

No.

Letter = Ant. & Eng.

No. 12.

3 Encls.

No 2102 - 4: Sept 72

Advising the
transmission of copies
of publications on an
instrument called the
transimeter, & requesting
their circulation among
the officers of the P. W.
Survey Department -
With a Circular

No 2102.

Ordered that the two last named publications be printed for
circulation to the Officers of the Public Works and Survey Department & for
Sergeants' reports having already been distributed

W. H. W.

Recd 11th 7/72

To Mr. W. H. W. 11th 7/72
Major R. B. Kennedy
Major R. B. Kennedy
Major R. B. Kennedy

sent to Mr. W. H. W. 11th 7/72

N. 8. 224.

Govt. of (1872) Madras.

PUBLIC WORKS.

To
The Acting Chief Engineer
for Irrigation

Date

Recd.

Page 3

6. 11. September 72. No. 2102

Nos. 1114 & 1115

Maximeter. Copies of
Publications, furnished
by the same party, & sent to
~~the printer~~ & circulated
to the Officers of the P.W.
& Survey Dept.