

II.—*On the Measurement of Grayson's Ten-band Plate.*

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(Read December 15, 1909.)

SOME years ago I undertook the laborious work of carefully measuring all the spacings of my Grayson's ten-band stage micrometer. As such a task has probably not been undertaken by many, I venture to communicate the results obtained in case they may prove of interest to some Fellows of the Society.

Two conditions appear to me of paramount importance in all delicate micrometrical work where the most accurate results are aimed at:—

1. An objective of comparatively very high initial magnifying power should be employed.
2. The micrometer eye-piece should be of moderate power, so as not to unduly magnify errors which must always exist in even the best screws.

Under such circumstances, care being taken that the same portion of the screw is utilised so far as possible, highly accurate measurements may be effected.

For spanning the rulings of the Grayson plate it was decided to employ a nominal $\frac{1}{16}$ Powell dry objective. This lens is really 0.054 in. focus, has an initial magnifying power of a fraction over 185 on 10-in. tube, and its N.A. is 0.906. The optical index is thus extremely low (4.9), but, nevertheless, used under strictly critical conditions in conjunction with the 6 eye-piece of Powell's micrometer, the ruled lines appeared sharp, it being therefore possible to adjust the "wires" very precisely against the diffraction edges of the rulings. Although the optical arrangement, specified above, was selected at the time as the most suitable then available for the purpose in view, it is by no means maintained that the combination in question is the best possible, or the most desirable, and since that time I usually employ an amplifier, kindly specially computed by Mr. E. M. Nelson,* used in conjunction with a Powell $\frac{1}{2}$ oil-immersion objective of N.A. 1.27, and thus augmenting its initial magnifying power about 2.5 times. In order to obtain clear definition with the amplifier inserted between the objective and ocular, it is necessary that the former be provided with a correction collar, by means of which the

* See this Journal, 1904, p. 396.

First Band, 1000ths in.	Second Band, 2000ths in.	Third Band, 3000ths in.	Fourth Band, 4000ths in.	Fifth Band, 5000ths in.	Sixth Band, 6000ths in.	Seventh Band, 7000ths in.	Eighth Band, 8000ths in.	Ninth Band, 9000ths in.	Tenth Band, 10,000ths in.
Drum Divisions	Drum Divisions	Drum Divisions	Drum Divisions	Drum Divisions	Drum Divisions	Drum Divisions	Drum Divisions	Drum Divisions	Drum Divisions
764.1	383.9	254.4	194.6	153.7	126.9	108.0	93.7	85.3	76.9
762.5	381.5	253.1	192.1	152.8	127.2	108.1	94.2	85.5	77.0
762.3	383.3	254.8	191.0	152.0	123.3	108.9	94.0	85.4	76.9
762.0	380.9	256.0	192.1	150.9	122.0	109.0	93.5	85.2	77.0
765.9	380.5	252.7	191.0	152.7	124.5	109.2	94.5	85.4	76.9
765.1	381.3	255.7	190.9	153.6	123.1	109.4	93.3	84.9	77.5
759.0	382.5	253.2	192.7	153.2	123.4	107.4	94.4	84.5	77.2
765.0	380.8	253.9	190.9	155.0	124.8	109.1	93.2	85.5	77.9
762.9	382.1	252.4	190.7	155.4	123.0	108.2	93.7	84.7	77.9
765.1	384.4	254.3	192.0	153.5	122.7	108.0	94.1	85.3	76.6
..	..	255.3	192.5	151.9	123.8	109.1	94.0	85.6	77.4
..	..	256.9	192.0	153.9	123.3	108.4	95.2	84.5	77.2
..	..	255.5	191.0	154.3	122.4	107.0	95.2	85.1	77.5
..	..	254.7	190.9	154.4	123.4	107.3	94.1	84.5	77.7
..	..	257.8	190.9	152.3	122.4	107.8	94.3	84.7	75.6
..	..	..	191.8	150.9	124.5	107.0	94.0	85.3	75.9
..	..	..	191.4	151.5	124.1	106.2	94.2	84.9	77.4
..	..	..	190.0	152.3	125.1	106.6	93.9	85.1	76.5
..	..	..	189.7	152.7	124.5	109.3	93.5	85.6	77.2
..	..	..	194.0	152.6	125.8	107.7	94.0	85.3	76.7
..	..	..	..	153.4	124.9	107.1	94.5	85.8	77.6
..	..	..	..	152.8	126.4	107.0	94.3	84.3	77.2
..	..	..	..	153.6	124.5	107.3	94.9	85.5	77.6
..	..	..	..	153.4	125.8	106.7	93.8	84.7	77.2
..	..	..	..	154.0	125.2	106.9	93.7	86.5	76.8
..	..	..	..	..	126.1	107.3	94.3	84.8	77.0
..	..	..	..	..	125.9	106.9	94.6	84.6	77.3
..	..	..	..	..	124.5	108.4	94.1	85.1	77.1
..	..	..	..	..	125.9	106.2	94.8	85.9	77.7
..	..	..	..	..	126.3	108.4	93.5	85.1	77.2
..	..	..	..	..	..	108.5	95.1	84.0	77.4
..	..	..	..	..	..	107.9	94.8	84.9	77.7
..	..	..	..	..	..	109.6	94.0	86.0	77.5
..	..	..	..	..	..	109.0	94.0	85.4	77.3
..	..	..	..	..	..	109.4	94.2	86.2	76.9
..	..	..	..	..	..	..	94.0	86.2	77.1
..	..	..	..	..	..	..	94.0	86.1	77.5
..	..	..	..	..	..	..	94.3	86.2	77.4
..	..	..	..	..	..	..	94.8	85.9	77.1
..	..	..	..	..	..	..	95.1	85.5	77.5
..	..	..	..	..	..	..	..	85.9	77.1
..	..	..	..	..	..	..	..	85.9	77.0
..	..	..	..	..	..	..	..	85.5	77.5
..	..	..	..	..	..	..	..	86.5	77.0
..	..	..	..	..	..	..	..	86.0	77.1
..	..	..	..	..	..	..	..	..	76.9
..	..	..	..	..	..	..	..	..	77.7
..	..	..	..	..	..	..	..	..	77.0
..	..	..	..	..	..	..	..	..	77.9
..	..	..	..	..	..	..	..	..	77.0
Mean. 763.4	Mean in 1000ths 764.2	Mean in 1000ths 764.1	Mean in 1000ths 766.4	Mean in 1000ths 765.3	Mean in 1000ths 747.1	Mean in 1000ths 755.7	Mean in 1000ths 753.6	Mean in 1000ths 768.2	Mean in 1000ths 771.8

disturbance caused by the intervening negative lens can be compensated. With the $\frac{1}{12}$ objective, amplifier and 6-micrometer eye-piece, 1318 divisions of the drum equal $\frac{1}{1000}$ in.; thus the movement of the "wire" through one drum division represents an interval amounting to $\frac{1}{1318000}$ in. This may seem a practically unattainable degree of accuracy, but it must be borne in mind that separating power is not here in question, and, to myself at least, the wonderfully close agreement of the means of the first five columns of measurements annexed hereto are sufficiently significant, considering that they were effected with an objective, the utmost separating limit of which could not exceed $\frac{1}{94000}$ in.

With reference to the annexed results, taking 763·4, the mean of the first band, as a standard (the mean of nine out of ten divisions of another equally spaced Grayson plate in my possession is 763·6, the first space of the band being rejected as obviously faulty, it measuring only 752·5 divisions), we find that the second column, expressed in similar parts of an inch, varies from it by just under one drum division, or $\frac{1}{763400}$ in., the means of the second and third columns agreeing within the surprising amount of $\frac{1}{10}$ of a division, or $\frac{1}{7633000}$ in.! The mean of column four exceeds the standard by three divisions, while column five shows an excess of nearly two. It will be noticed that fairly considerable differences exist in the spacing of the individual lines in all the bands, but I venture to submit that the accuracy of the measurements is proved by the remarkably close agreement of the means of the various columns, expressed, for convenience of comparison, in similar and equal terms. So far as I can judge, the theory of probabilities renders it practically certain that such a close agreement of five means can be due to no fortuitous coincidence.

The sixth column exhibits the greatest variation from the standard, falling short by the very considerable amount of 16·3 divisions, representing a difference of about $\frac{1}{46834}$ in. The seventh column falls short of the standard by 7·7 divisions, and the eighth by 9·8. Columns nine and ten show that the two finest bands are wonderfully evenly ruled, their means being, respectively, 4·8 and 8·4 divisions more than the standard.

Since writing the foregoing, it has been thought desirable that measured readings of two lines together throughout the second band, three lines together throughout the third band, four through the fourth, and so on up to ten through the tenth, should be effected with the exact optical arrangement and magnification employed for the original measurements. In this manner the value of the whole ten bands is indicated in terms of the first, and exactly the same portion of the screw is utilised for all, thus error from differences in varying parts of the screw is eliminated, and consequently the means of the five necessary readings in each of

the last nine bands will show the extent of that factor in the original measures.

This idea has been carried out, with the following results, which indicate the high accuracy of Mr. Grayson's rulings. The mean of the first band re-measured equals 762·9 divisions.

			Drum Divisions
2nd band	($\frac{1}{2000}$ in.).	Mean of five $\frac{1}{1000}$ in. readings	763·1
3rd	" ($\frac{1}{3000}$ in.).	" "	762·4
4th	" ($\frac{1}{4000}$ in.).	" "	764·1
5th	" ($\frac{1}{5000}$ in.).	" "	758·8
6th	" ($\frac{1}{6000}$ in.).	" "	760·6
7th	" ($\frac{1}{7000}$ in.).	" "	758·4
8th	" ($\frac{1}{8000}$ in.).	" "	758·6
9th	" ($\frac{1}{9000}$ in.).	" "	758·9
10th	" ($\frac{1}{10000}$ in.).	" "	758·6

It will be noted that screw errors are thus revealed and differentiated. Another remarkable circumstance is the startling agreement of the last four means, an exactness which perhaps suggests some little coincidence, especially as the fractional division readings, from which the means are obtained, are necessarily only estimated tenth parts. Be this as it may, it is obvious that the probable error is exceedingly small.