

Technical Committee

Nice Meeting
December 1992
Report No.: 9

President: M.Bona (Italy)
Secretaries: T.Belleli (France)
G.Blankenburg (Germany)

LINEARITY AND FOCUS INDEPENDENCE OF THE OFDA

B.P.Baxter & M.A.Brimms

SGS Wool Testing Services (Australia), P.O.Box 279, Hamilton Hill 6163, West Australia

SUMMARY

Experimental work has been carried out with both wires and a graticule to determine whether the accuracy of focus of the OFDA produces a significant effect within the operating range of the instrument. As part of this work, the linearity of the instrument was investigated between fibre diameters of 5 and 125 micrometres. The results confirm that the OFDA is linear over this measuring range, and that it is not significantly affected by the focus setting as long as this is within the normal operating range accepted by the instrument, which is automatically checked during measurements.

INTRODUCTION

At the Punta del Este meeting of the technical committee of IWTO, a Test Method under Examination (TME) was proposed and subsequently accepted for the measurement of mean fibre diameter and distribution by image analysis¹. The TME was supported by a technical paper on the performance of the Optical Fibre Diameter Analyser (OFDA)², which followed up on previous work presented at the Nice 1991 meeting³. Two of the queries raised in Punta del Este were whether the OFDA was linear over its entire measuring range, and whether its performance was independent of focus over this range.

This paper addresses these two issues. Experimental work has been carried out in which precision wires have been measured on two OFDA instruments and on between two and four projection microscopes. Additionally a specially manufactured graticule has been measured on an OFDA instrument. Measurements on the wires and on the graticule were carried out at five focus positions.

PRINCIPLES OF MEASUREMENT AND THE EFFECTS OF FOCUS

The principles used in the OFDA to measure mean fibre diameter and distribution of diameter are described in the referenced papers. The instrument scans a slide, on which there are snippets of wool, by traversing it under the objective of a low powered microscope. At each stage position the instrument captures an image and then analyses the image to determine the width of a selection of fibre images. Because the apparent width of an image depends on its sharpness, focus is a relevant parameter.

In the OFDA, low power magnification is used to allow a practical depth of focus in the object plane. The algorithm measures the degree of out-of-focus of the image, and if this is likely to be such as to cause a significant bias, the instrument indicates a fault and requires the operator to either re-seat the slide, or to adjust the focus, before allowing the measurements to continue. Both referenced papers have described tests in which the focus effect has been investigated, but only over a limited range of fibre diameters.

¹IWTO(E) 22-92(E) Measurement of the mean and distribution of fibre diameter of wool using an image analyser

²Further studies on the performance of the OFDA, B.P.Baxter, M.A.Brimms & T.B.Taylor, IWTO Technical Committee report, Punta del Este, Apr. 1992

³Description and performance of the Optical Fibre Diameter Analyser (OFDA), B.P.Baxter, M.A.Brimms & T.B.Taylor, IWTO Technical Committee report 8, Nice, Dec. 1991

INVESTIGATION METHODS

Two instruments in two countries were used in this test program. Both were calibrated in accordance with the TME to measure wool snippets cut to a nominal length of 1.6 mm using parallel bladed instruments. For all the measurements, the wires and graticule lines were oriented at approximately 90° to the OFDA traverse direction.

Wires

In order to closely simulate measurements on fibres, 5 samples of precision wire were obtained. The wires were hard drawn from almost pure tungsten, which minimised corrosion or other deterioration problems. Samples of wire were drawn from each reel for despatch to a number of laboratories for projection microscope measurements, and additional samples were used to prepare slides suitable for measurement on the OFDA. The wires were of nominal diameters 10, 20, 25, 50 and 125 micrometres. In order to minimise the number of projection microscope measurements undertaken, samples of each diameter were sent to only 3 randomly selected laboratories out of a possible 5. However, one laboratory lost one of the samples but undertook measurements on the other 4, and all laboratories also weighed the samples, which were of pre-determined lengths. The laboratories were requested to measure the wires in accordance with IWTO-8. The results are detailed in Table 1.

The wire samples were prepared for measurement on the OFDA by wrapping them around slides at a spacing of about 1 to 2 mm; closing the slide pair, taping the edges; and then cutting off the wires on the outside of the sandwich. Whilst this was not the only method which could have been used, it was the most practical, since the thicker wires were very difficult to cut and manipulate, and this technique avoided possible interferences from damaged or distorted wires.

In one set of tests undertaken on OFDA 11, individual slides were prepared from each diameter and measurements were carried out by setting the instrument to scan and measure each slide 5 times. Another set of tests was conducted on another instrument (OFDA 27), in which samples of each wire were all taped to a single slide. In this latter case the full distribution data had to be analysed in order to separate the results for the five sizes of wire.

Each slide was mounted in the OFDA in the normal manner. In the first set of tests on OFDA 11, the instrument was set up with the position of best focus determined on the 25 micrometre slide. For the 4 smaller diameters the position of best focus was not altered from slide to slide, although with the 125 micrometre sample this proved necessary as the instrument refused to measure the slide with the initial setting. The position of best focus was noted as a null setting on a micrometer dial gauge. For each slide, measurements were carried out with the stage positioned at the null position, and at +/- 0.10 and +/- 0.20 mm. Table 2 shows the results of these measurements.

The wire measurements on OFDA 27 were all carried out at the same focus position, and were intended to serve as a reference for the other measurements carried out on that instrument. The results are shown in Table 3.

Polyester fibres

In order to provide comparative data relating specifically to textile fibres, two slides of polyester fibre were also measured over the same focus range. The slides were prepared in the normal manner from 1.6 mm snippets. The results are shown in Table 4.

Graticule measurements

A graticule was specially manufactured as a pilot project to examine the feasibility of using graticules to calibrate OFDA instruments. The graticule was prepared by a photographic technique in which the final product was a glass slide with metallic lines produced by electrodeposition. The slide had 5 groups, each of 10 lines. Each group comprised a set of identical parallel lines. The groups had nominal widths of 5, 10, 20, 50, and 100 micrometres, and the lines were 15 mm long. The line spacing was 200 micrometres. The slide was calibrated by individual measurements of the width of each line at a randomly selected position along its length. The measurements were carried out in the manufacturer's own NAMAS-accredited laboratory, with traceability to UK national standards. The precision of calibration was stated as being 95 % confidence limits of +/- 0.5 micrometres.

The graticule was mounted on a standard OFDA slide, and the instrument set in each case to measure the slide twice. The slide was measured at optimum focus, and at stage displacements of +/- 0.10 and +/- 0.20 mm. The results are shown in Table 5.

ANALYSIS OF FOCUS EFFECTS

In the focus tests, for each wire or fibre diameter or line width, the measured mean diameter and standard deviation at best focus were used as datum results against which the out-of-focus results were compared. The effects of malfocus are theoretically asymmetric about the position of best focus. However, within the range of stage displacement tolerated by the instrument (ie. approximately +/- 0.2 mm), the majority of contributory effects are nearly linear. This was confirmed by carrying out one way analyses of variance with nominal diameter (or line width) as covariate, in which the 5 stage positions were each treated as independent. The results are shown in Table 6. Only in the case of the 125 micrometre wire was there a significant degree of asymmetry (see below).

Wires

It can be seen from table 6.1.1 that the changes observed in mean fibre diameter were not significantly affected in a systematic manner by the wire diameter. Figure 1 shows that there is slight asymmetric effect for all the wires, but the case of the broadest wire is exceptional. In table 6.1.3, the results from this wire have been removed, and it can be seen that there remains a small but significant effect - reference to Figure 1 shows that it is less than 0.1 micrometres. In the case of the 125 micrometre wire, the overall effect is approximately 0.3 micrometres, which is not considered to be of practical importance. It should also be noted that because of the large depth of field, it is difficult to determine the point of best focus with the larger diameters, and therefore some degree of asymmetry in the measurements is inevitable. The standard deviation changes, however, were not significantly affected by either wire diameter or stage position.

Graticule

The graticule results showed no detectable systematic effects on either mean line width or standard deviation.

Polyester

In the case of the polyester slides, there were no significant effects on standard deviation, but there was a detectable effect on the mean fibre diameter due to the stage position. Reference to Figure 2 shows that the effect is much less than 0.1 micrometres in magnitude and is only detectable because of the very low error variance.

ANALYSIS OF LINEARITY

Table 7 details the average mean fibre diameter and standard deviation values for the measurements at the positions of best focus for the wires and the graticule. In the former case table 7.1.1 also shows the average results obtained in the projection microscope trial. The results of relevant linear regressions are also shown.

Wires

It can be seen from table 7.1.2 that for both instruments the linear regressions between measured mean wire diameter and the mean projection microscope diameters give low standard errors of prediction. Figures 3 and 5 show these relationships. Figures 4 and 6 show the regression residuals - it can be seen from these that the residuals form no obvious pattern, and the linear regression model is quite adequate to describe the relationship. ANOVA's for these regressions are shown in table 7.3, and again there can be little doubt that the linear model fits the data quite satisfactorily.

It may be noted that there was an approximately 2 % difference between the mean wire diameter measured by projection microscope, and that calculated from the gravimetric measurements. This would equate to an error of 4 % in the assumed specific gravity for tungsten, which, since the wires were certified as being of high purity, seems unlikely.

In view of the fact that the two OFDA instruments were independently calibrated using the Interwoollabs IH tops, the degree of agreement between them is excellent; especially when it is considered that these tops cover only 16 % of the range of wire diameters, and the extrapolation is therefore large. There is a significant difference in calibration slope between the wires and wool. The reasons for this are being investigated.

The relationships are poor between the values of standard deviation obtained on the OFDA and the values obtained in the projection microscope measurements. The main reason for this concerns the method specified for carrying out the PM work, which was IWTO-8. The class interval in this test method is 2 micrometres, which is too

large for the small distributions observed for the wires. In retrospect it would have been wiser to request the laboratories to estimate the actual wire diameter for each reading. This is one case in which Sheppard's correction could usefully be applied, but since there is little correlation in this case the added complication does not seem to be warranted. (A similar problem of class size applies to the measurement on the OFDA of the 5 micrometre lines on the graticule - see below.) It will be noted that there is reasonable correlation between the two OFDA instruments on the standard deviation results. The differences, whilst significant, are probably not of practical importance in view of the class interval problem.

Graticule

The linear regression results for the graticule are shown in table 7.2.2. The precision of estimation is not as good as for the wires, although the limited precision of the graticule calibration may be an obvious contributory factor. Figure 7 shows the plot of measured "diameter" against line width, and Figure 8 shows the residuals. It can be seen that there is a possible pattern in the residuals, and with this in mind, regressions were performed using 2 and 3 degree polynomial; square root; natural and base 10 logarithm; reciprocal and e^x transformations. None of these yielded significantly improved mean square errors. Whilst the result for the 5 micrometre lines cannot statistically be justified as an outlier under the normal standard error criteria, it can be seen from Figure 8 that its residual is much further away from the line than the others. Bearing in mind that the OFDA works on a class interval of 1 micrometre, and the precision of calibration of the graticule is of the order of 0.5 micrometres, it does not seem unreasonable to examine the possibility of this result having a significantly higher uncertainty than the others. With this in mind, the result was removed from the data set, and the resulting linear regression is shown in table 7.2.2. This regression has very significantly improved precision, and gives constants slightly closer to those obtained in the regressions for the wires. Figure 9 shows the residuals plot for this data set, and Table 7.3 shows the ANOVA's. It may be concluded that there is insufficient evidence to suggest anything other than a linear model.

Again, there is a significant difference between the calibrations for wool and for the graticule, and a small difference between the graticule and wire calibrations. These differences are being investigated, but have no practical consequences as far as the use of the OFDA for wool measurement is concerned.

CONCLUSIONS

The results obtained in this study confirm previous data which showed that the OFDA is not sensitive to focus. Within the normal operating focus range of the instrument (ie. between the limits at which the instrument itself detects significant malfocus, and halts the measurement process), changes in stage to objective distance of up to +/- 0.2 mm do not produce systematic errors in mean fibre diameter or standard deviation of practical importance.

Measurements on wires of nominal diameters from 10 to 125 micrometres, and on a graticule with line widths of between 5 and 101 micrometres confirm that the instrument is highly linear over these ranges. Comparisons between two instruments calibrated in accordance with the TME showed that linear extrapolation may be satisfactorily carried out to cover individual fibre diameters which lie outside the range of mean fibre diameters covered by the Interwoollabs IH tops.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the following institutions who carried out projection microscope and gravimetric determinations on samples of wires:

British Textile Technology Group (BTTG) - England
Lincoln University Department of Wool Science - New Zealand
SGS Wool Testing Services - New Zealand
SGS Wool Testing Services International - England
Secretariado Uruguayo de la Lana, Uruguay

Figure 1: 2-way interactions - mean fibre diameter of wires

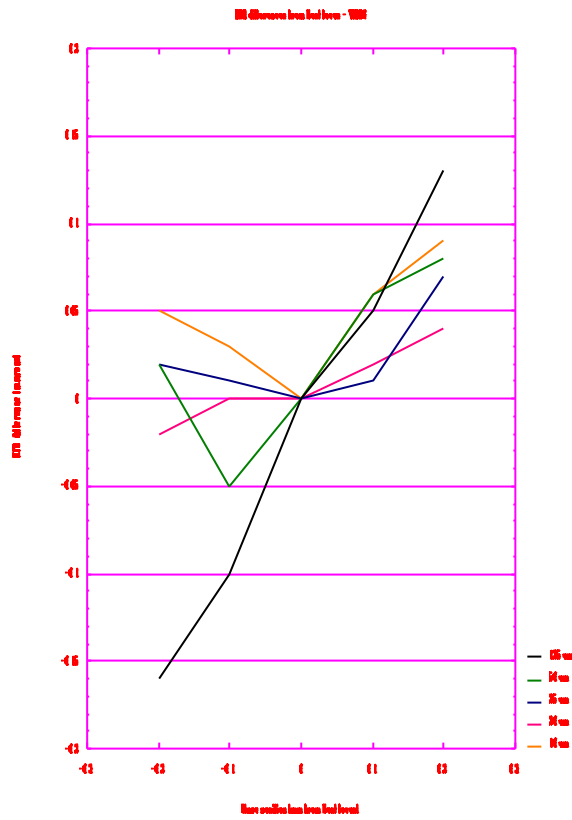


Figure 2: 2-way interactions - mean fibre diameter of polyester

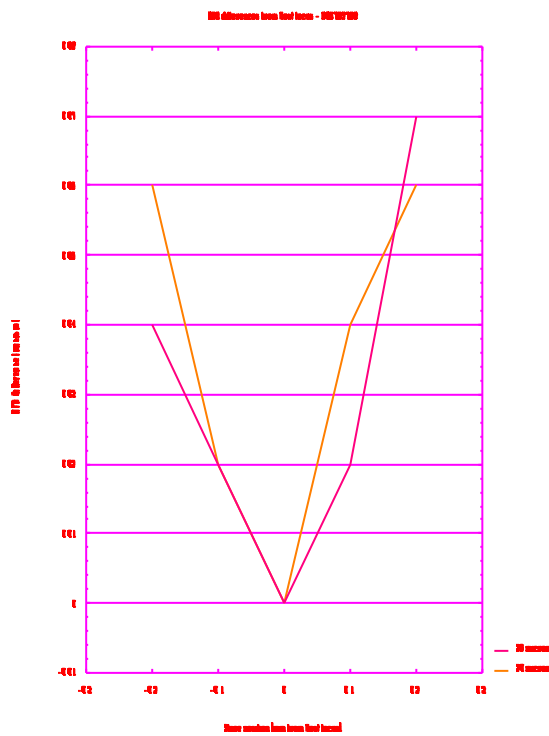


Figure 3: OFDA 11 mfd vs. mean projection microscope mfd

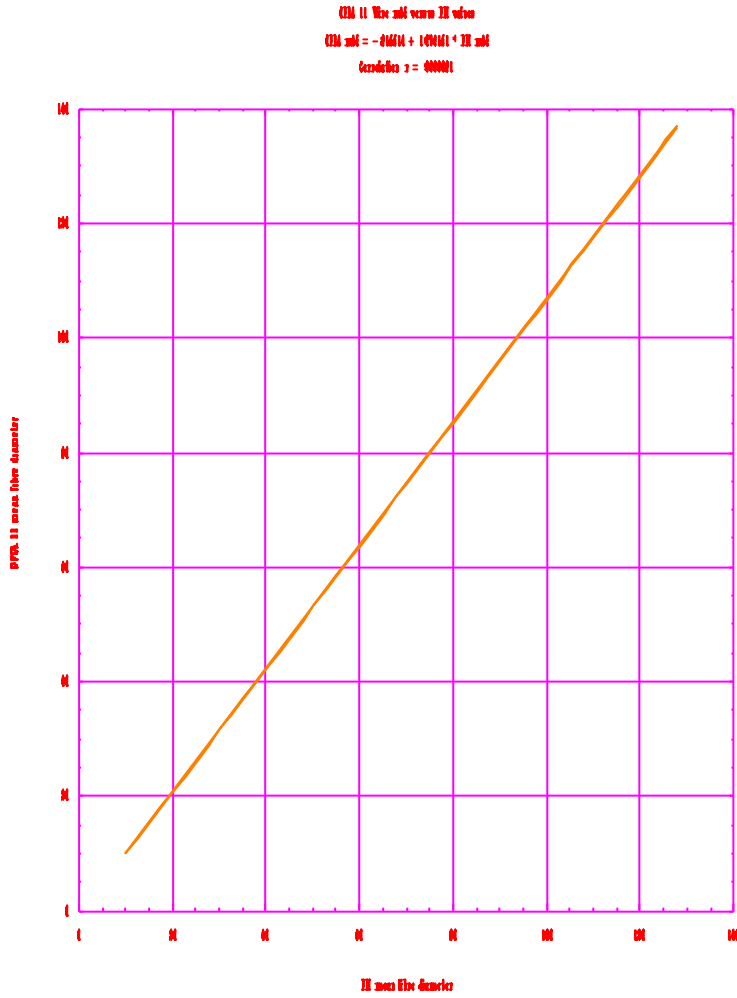


Figure 4: OFDA 11 linear regression residuals

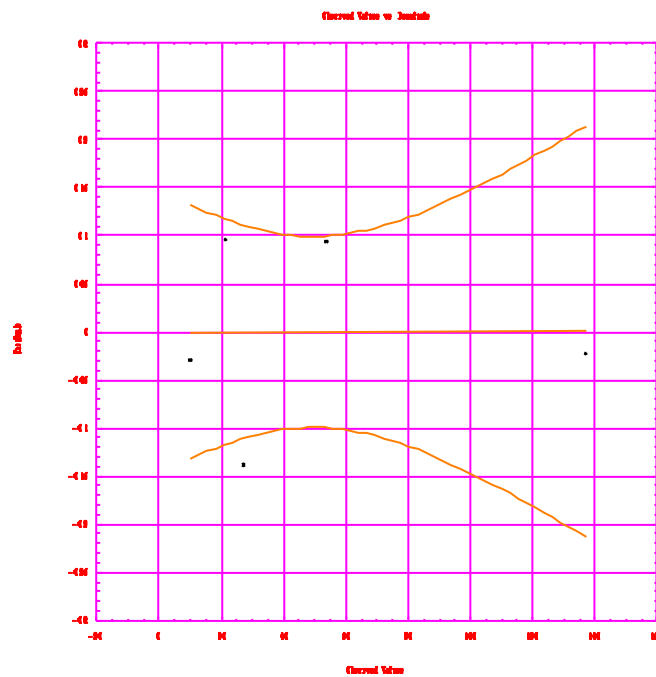
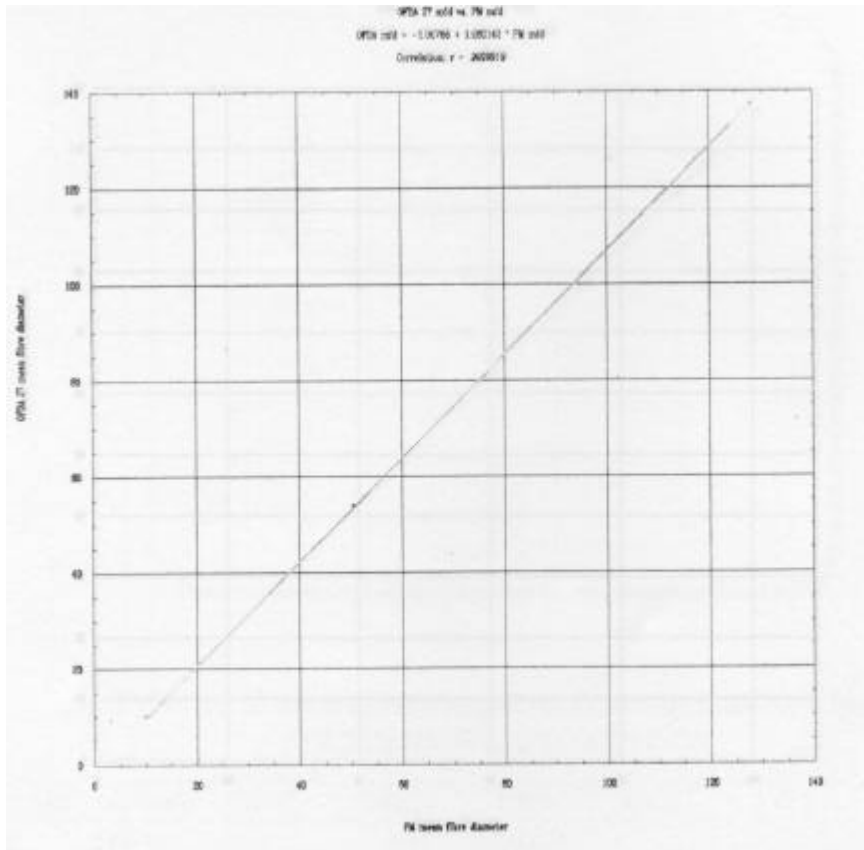


Figure 5: OFDA 27 mfd vs. mean projection microscope mfd



(note: original image lost in file conversion, this image scanned from hard copy)

Figure 6: OFDA 27 linear regression residuals

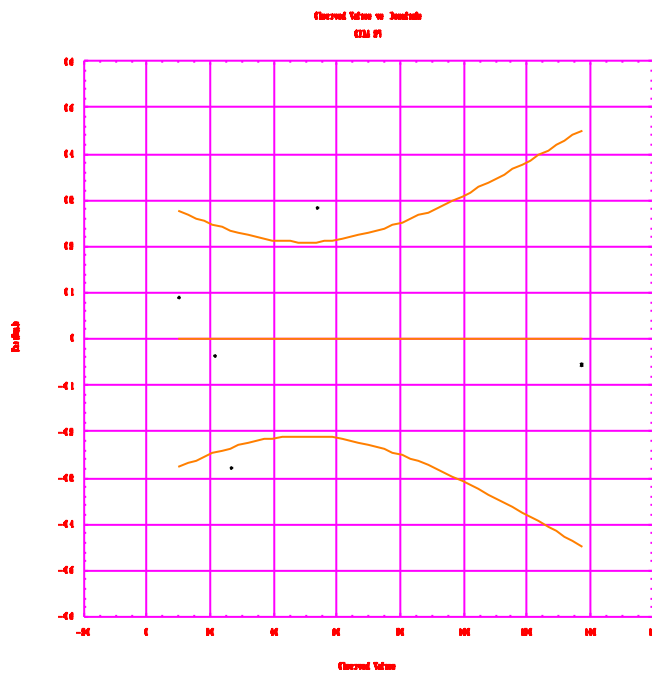


Figure 7: OFDA 27 mfd vs. graticule line width

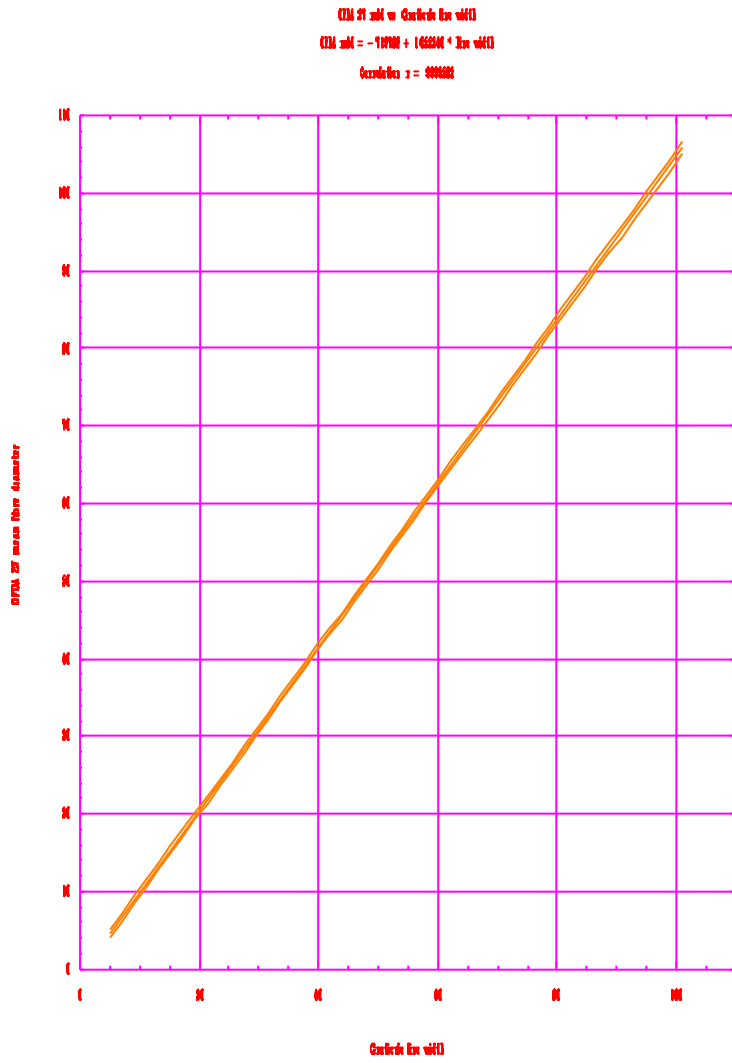


Figure 8: OFDA 27 linear regression residuals - graticule

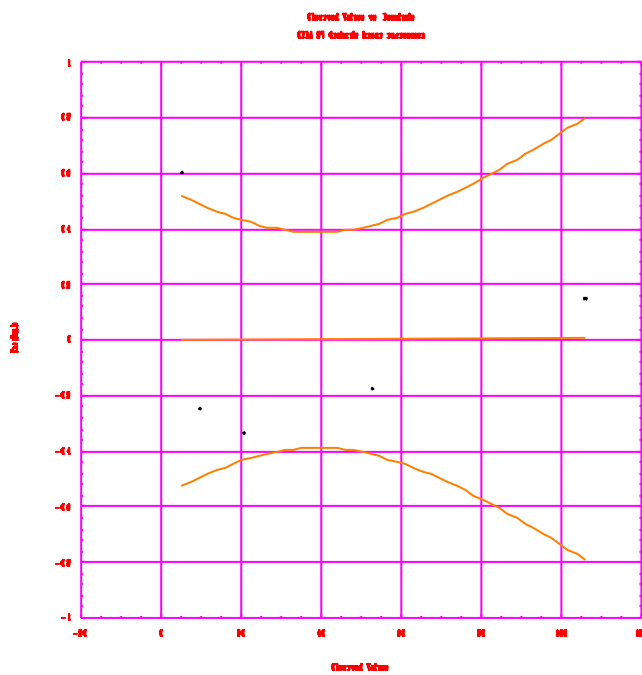


Figure 9: OFDA 27 linear regression residuals - graticule
(5 micrometre line width data removed)

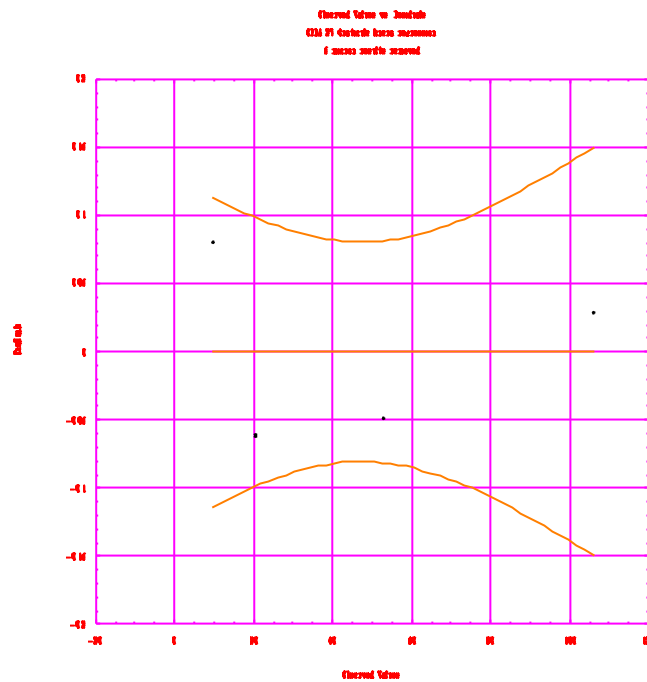


Table 1 - Wire measurements by projection microscope and gravimetric determination

Nom.diam	Parameter	Lab.1	Lab.2	Lab.3	Lab.4	Lab.5	Average
10	MFD		9.92	10.24			10.08
	SD		1.00	1.07			1.03
	Grav.diam		10.49	9.95			10.22
20	MFD	21.00		20.54	20.15	21.00	20.67
	SD	n/a		1.03	0.99	n/a	1.01
	Grav.diam	18.39		20.51	19.33	20.20	19.61
25	MFD		26.76		25.53	25.75	26.01
	SD		1.48		0.89	1.90	1.42
	Grav.diam		24.02		25.36	25.18	24.85
50	MFD	51.47		49.80	50.12	50.85	50.56
	SD	0.85		1.28	1.00	0.71	0.96
	Grav.diam	(47.24)*		49.49	49.68	49.67	49.61
125	MFD	130.60	126.10		127.49		128.06
	SD	1.22	(4.31)*		1.27		1.24
	Grav.diam	124.64	124.94		125.47		125.02

Note - gravimetric diameter was determined by each laboratory weighing the supplied sample, which had been cut to a predetermined length of 1.2 or 2.4 metres. The diameter was calculated using an assumed specific gravity for the wire of 19.3.

Where n/a appears against s.d. above, the results all fell into the same class interval.

Results identified with an asterisk are excluded as outliers according to Dixon at the 0.05 level.

Table 2 - Wire measurement results on OFDA 11

Nom.diam. (μ)	Stage (mm)	Focus no.	M.F.D. (μ)	S.D. (μ)
10	-0.20	12.7	10.05	0.84
10	-0.10	11.3	10.03	0.93
10	0.00	11.0	10.00	0.80
10	+0.10	11.9	10.06	0.86
10	+0.20	13.6	10.09	0.83
20	-0.20	13.1	21.50	0.87
20	-0.10	11.8	21.52	0.84
20	0.00	11.0	21.52	0.82
20	+0.10	11.4	21.54	0.87
20	+0.20	12.9	21.56	0.85
25	-0.20	12.6	27.06	0.88
25	-0.10	11.5	27.05	0.92
25	0.00	11.2	27.04	0.92
25	+0.10	11.9	27.05	0.97
25	+0.20	13.2	27.11	0.90
50	-0.20	13.4	53.71	1.02
50	-0.10	12.1	53.64	1.12
50	0.00	11.1	53.69	0.99
50	+0.10	11.1	53.75	1.09
50	+0.20	12.0	53.77	1.08
125	-0.20	11.2	136.81	1.45
125	-0.10	10.3	136.87	1.48
125	0.00	10.0	136.97	1.47
125	+0.10	11.0	137.02	1.47
125	+0.20	12.6	137.10	1.45

Note that the focus number is reported by the instrument - it is an arbitrary measure of the average degree of focus of the image.

Table 3 - Wire measurement results on OFDA 27

Nom.diam. (μ)	M.F.D. (μ)	Average (μ)	s.e. (μ)
10	9.94	9.98	0.06
10	10.05		
10	9.96		
20	21.25	21.28	0.03
20	21.31		
20	21.29		
25	26.83	26.81	0.05
25	26.75		
25	26.85		
50	53.99	53.89	0.23
50	54.06		
50	53.63		
125	137.63	137.25	0.33
125	137.07		
125	137.06		

Table 4 - Polyester fibre measurement results on OFDA 27

Nom.mfd. (μ)	Stage (mm)	Focus no.	M.F.D. (μ)	S.D. (μ)
20.2	-0.20	11.9	20.30	3.40
20.2	-0.10	10.6	20.26	3.42
20.2	0.00	10.1	20.24	3.42
20.2	+0.10	10.6	20.28	3.47
20.2	+0.20	12.1	20.30	3.44
29.2	-0.20	12.0	29.24	3.92
29.2	-0.10	10.6	29.22	3.80
29.2	0.00	10.0	29.20	3.85
29.2	+0.10	10.4	29.22	3.70
29.2	+0.20	11.9	29.27	3.80

Table 5 - Graticule measurement results on OFDA 27

Nom.width (μ)	Stage (mm)	Focus no.	M.F.D. (μ)	S.D. (μ)
5.0	-0.20	12.9	5.28	0.9
5.0	-0.10	10.8	5.22	0.9
5.0	0.00	10.1	5.12	0.8
5.0	+0.10	10.9	5.21	0.9
5.0	+0.20	12.7	5.18	0.9
10.0	-0.20	11.3	9.77	0.9
10.0	-0.10	9.8	9.63	1.0
10.0	0.00	9.3	9.59	1.0
10.0	+0.10	10.2	9.71	1.1
10.0	+0.20	11.7	9.71	0.8
20.5	-0.20	11.2	20.73	0.8
20.5	-0.10	10.1	20.57	0.8
20.5	0.00	9.6	20.62	0.7
20.5	+0.10	10.6	20.57	0.8
20.5	+0.20	11.8	20.55	0.7
51.0	-0.20	11.0	53.00	0.8
51.0	-0.10	9.8	52.96	0.9
51.0	0.00	9.5	52.92	1.0
51.0	+0.10	10.4	52.96	0.9
51.0	+0.20	11.9	52.82	0.8
101.0	-0.20	10.8	106.18	1.1
101.0	-0.10	9.7	106.18	1.2
101.0	0.00	9.3	106.02	1.1
101.0	+0.10	10.6	106.20	1.2
101.0	+0.20	11.8	106.14	1.2

Table 6 - Analyses of variance - Focus effects

Significant effects are highlighted in bold italic.

6.1.1 - WIRES - Mean fibre diameter results

Effect	d.f. effect	MS effect	d.f. error	MS error	F-value	p-level
Stage pos'n	4	0.0097	19	0.0020	4.846	0.007
Covariat e - diameter	1	0.0071	19	0.0020	3.521	0.076

6.1.2 - WIRES - Standard deviation results

Effect	d.f. effect	MS effect	d.f. error	MS error	F-value	p-level
Stage pos'n	4	0.0003	19	0.0017	1.858	0.160
Covariate - diameter	8	0.0045	19	0.0017	2.644	0.120

6.1.3 - WIRES - Mean fibre diameter results (125 wire removed)

Effect	d.f. effect	MS effect	d.f. error	MS error	F-value	p-level
Stage pos'n	4	0.0036	14	0.0006	5.692	0.006
Covariate - diameter	1	0.0005	14	0.0006	0.828	0.378

6.2.1 - GRATICULE - Mean fibre diameter results

Effect	d.f. effect	MS effect	d.f. error	MS error	F-value	p-level
Stage pos'n	4	0.0139	19	0.0052	2.688	0.063
Covariate - diameter	1	0.0073	19	0.0052	1.422	0.248

6.2.2 - GRATICULE - Standard deviation results

Effect	d.f. effect	MS effect	d.f. error	MS error	F-value	p-level
Stage pos'n	4	0.0086	19	0.0114	0.754	0.568
Covariate - diameter	1	0.0072	19	0.0114	0.631	0.437

6.3.1 - POLYESTER - Mean fibre diameter results

Effect	d.f. effect	MS effect	d.f. error	MS error	F-value	p-level
Stage pos'n	4	0.0013	4	0.0001	14.333	0.012
Covariate - diameter	1	0.0001	4	0.0001	0.993	0.375

6.3.2 - POLYESTER - Standard deviation results

Effect	d.f. effect	MS effect	d.f. error	MS error	F-value	p-level
Stage pos'n	4	0.0009	4	0.0039	0.226	0.910
Covariate - diameter	1	0.0032	4	0.0039	0.823	0.415

Table 7 - Linearity data

7.1.1 - WIRES - Average values

Gravimetric m.f.d.	P.M. m.f.d.	OFDA 11m.f.d.	OFDA 27m.f.d.	P.M. s.d.	OFDA 11s.d.	OFDA 27s.d.
10.22	10.08	10.00	9.98	1.03	0.80	0.82
19.61	20.67	21.52	21.28	1.01	0.82	0.86
24.85	26.01	27.04	26.81	1.42	0.92	0.66
49.61	50.56	53.69	53.89	0.96	0.99	0.95
125.02	128.06	136.97	137.25	1.24	1.47	1.86

7.1.2 - WIRES - Linear regression data

Dependent variable	s.e. of prediction	Constant	s.e. of constant	Independent variable	Gradient	s.e. of gradient
PM mfd	0.51	0.17	0.34	Grav. mfd	1.023	0.006
OFDA 11 mfd	0.11	-0.82	0.08	PM mfd	1.076	0.001
OFDA 27 mfd	0.24	-1.01	0.16	PM mfd	1.080	0.003
OFDA 27 mfd	0.17	-0.19	0.11	OFDA 11 mfd	1.004	0.002
OFDA 11 sd	0.31	0.46 ns	0.88	PM sd	0.480 ns	0.771
OFDA 27 sd	0.55	0.73 ns	1.62	PM sd	0.268 ns	1.415
OFDA 27 sd	0.17	-0.62	0.32	OFDA 11 sd	1.652	0.310

Note: ns indicates that the coefficients are not significant at the 0.05 level

7.2.1 - GRATICULE - Average values

Line width	m.f.d.	s.d.
5.0	5.16	0.73
10.0	9.59	0.76
20.5	20.58	0.79
51.0	52.92	0.89
101.0	106.01	1.12

7.2.2 - GRATICULE - Linear regression data

Dependent variable	s.e. of prediction	Constant	s.e. of constant	Independent variable	Gradient	s.e. of gradient
OFDA 27 mfd With 5 micrometre results removed:	0.44	-0.72	0.29	Line width	1.055	0.006
OFDA 27 mfd	0.08	-1.09	0.07	Line width	1.060	0.001

7.3 - Linear regression - analyses of variance

Regression	d.f. regress.	MS regress.	d.f. error	MS error	F-value	p-level
OFDA 11 wire mfd/PM	1	10515.91	3	0.01	818187.9	0.000000
OFDA 27 wire mfd/PM	1	10594.06	3	0.06	185711.5	0.000000
OFDA 27 graticule mfd	1	7033.069	3	0.196	35900.54	0.000000
ditto, 5 um data removed	1	5614.662	2	0.007	834387.4	0.000001