

Investigation into the shape of diamond styli used for surface texture measurement as part of project LE9953, milestone 5.3.1.9.

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ABSTRACT

The stylus instrument is the most common form of instrument used in industry to measure surface texture. As the stylus is the only active component in contact with the surface being measured it is important that its dimensions and shape are accurately known. Measurements of the shape of four styli with differing radii were made using four different measurement techniques. Of the four techniques only the scanning electron microscope (SEM) provided an absolute measurement of radius. Use of a roughness artefact proved to be the most efficient method for checking stylus radius. A further seven styli were measured using only the SEM.

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1. INTRODUCTION

The most common form of instrument used in industry today to measure surface texture is the stylus instrument (see Whitehouse 1994 and Thomas 1999 for a description of stylus instruments). A typical stylus instrument consists of a stylus that physically contacts the surface being measured and a transducer to convert its vertical movement into an electrical signal. Other components include: a pickup, driven by a motor and gearbox, which draws the stylus over the surface at a constant speed; an electronic amplifier to boost the signal from the stylus transducer to a useful level; a device, also driven at a constant speed, for recording the amplified signal or a computer that automates the data collection.

The stylus is the only active component in contact with the surface being measured (possibly with the exception of those instruments with an additional skid). It is important that the dimensions and shape of the stylus are chosen appropriately - it is these features that will have an influence on the information gathered during measurement. The most common stylus shape is a cone with a spherical tip. The spherical type stylus usually has a cone angle of either 60° or 90° with a typical tip radius (r_{tip}) of 1 μm , 2 μm , 5 μm or 10 μm (truncated pyramidal, or chisel, shaped, 0.1 μm tips are available for specialised measurements).

The static measuring force at the mean position of the stylus is specified as 0.75 mN, in ISO 3274: 1996, and should not change during the measurement. In use the tip will be subject to wear. A damaged or worn stylus tip can lead to serious errors and the condition of the tip should be checked on a regular basis. Usually, the only information on the size and shape of a stylus is the manufacturers specification – it is extremely rare to see a stylus with a certified tip radius and cone angle.

The size and shape of the stylus can affect the accuracy of the traced profile in a number of ways:

(a) Penetration into valleys

On surfaces with deep, narrow valleys the stylus may not be able to penetrate to the bottom. The larger the tip radius the less the penetration, therefore the value of a roughness height parameter will be smaller than the true value.

(b) Distortion of the peak shape

When a spherical stylus passes over a peak the point of contact moves across the stylus. The effect on the stylus is to follow a path that is more rounded than the peak (see figure 1). However the stylus is raised to its full height when it makes contact with the crest, so that the true peak height is measured.

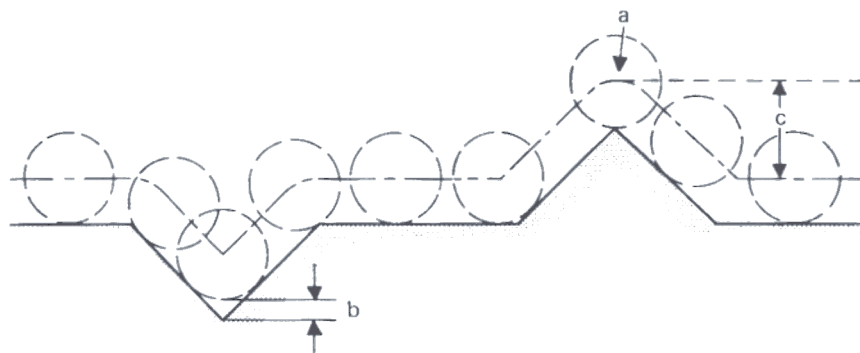


Figure 1 Effects of a finite stylus shape, courtesy of Taylor-Hobson Ltd

With reference to figure 1, the finite curvature and shape of the stylus has the following effects:

- a) it tends to round off peaks;
- b) it reduces the depths of valleys;

However the peak height remains unaffected.

2. EXPERIMENTAL WORK

Four styli with nominal radii of $1\ \mu\text{m}$, $2\ \mu\text{m}$, $5\ \mu\text{m}$ and $10\ \mu\text{m}$ were measured using four different techniques. The styli were examined and measured using a scanning electron microscope (SEM) before and after all the experiments were carried out. All measurements of surface profile were carried out using the NPL NanoSurf IV instrument. The NanoSurf IV is an instrument that uses optical interferometry to measure the position of a stylus tip as it traces over the surface topography (Leach 2000). The uncertainty analysis of NanoSurf IV has been calculated according to the PD 6461 Part 3 (1995) (GUM) and is presented elsewhere (Leach 1999). The combined standard uncertainty of measurements in the x and z axes at 95% confidence is $\pm 1.3\ \text{nm}$. NanoSurf IV is linked to the realisation of the metre via the calibrated frequency of its laser source

A further seven styli, three with a nominal radius of $1\ \mu\text{m}$, three with a nominal radius of $2\ \mu\text{m}$ and one with a nominal radius of $0.1\ \mu\text{m}$, were measured using only the SEM.

2.1 SEM MEASUREMENTS OF STYLUS PARAMETERS

The SEM used for these measurements was a Cambridge Stereoscan 250 that uses NPL-developed laser interferometers to provide traceable displacement measurements in the x and y axes (*i.e.* the plane normal to the direction of incidence of the electron beam). For the initial measurements each stylus was mounted in turn in the SEM and a video print was taken. Each stylus was rotated by 90° and a second video print was taken at the same magnification setting. This procedure was repeated once for each

stylus. The radius of the stylus tip was determined by drawing a circle on the image, making sure that its circumference followed as exactly as possible the curvature of the stylus tip, and measuring its radius with a steel rule.

A final series of SEM images was taken on the styli after all other measurements had been completed to check if any damage had occurred to the styli during the experiments.

Measurements were made on the $0.1\ \mu\text{m}$ stylus in two orientations as above. Two sets of measurements were made initially. The stylus was subsequently used to measure surface roughness of a number of polished silicon wafers before a further two sets of measurements were carried out using the SEM. The remaining six styli were measured twice in two orientations in the SEM.

2.2 RAZOR BLADE METHOD

A razor blade tip was mounted vertically between two glass plates in order to produce a Type B3 artefact as defined in ISO 5436-1: 2000. The artefact was prepared using a trimmed-down razor blade and two 6 mm thick plates of microtome glass. The edges of the plates were ground to a shallow angle to ensure that they butted against the razor blade and to minimise the risk of the adhesive migrating to the razor blade tip. Adhesive tape with a consistent thickness of $30\ \mu\text{m}$ was applied to one surface of each plate, and the assembly of blade and blocks was clamped together and down onto a flat glass plate. The fillet between the blocks and the razor blade was filled with fast cure adhesive. The system was rigidly fixed together by gluing a third glass plate to the back of the system. After curing the assembly was unclamped and any adhesive tape removed (Morrell 2001). Figure 3 shows the assembly technique.

Each stylus traversed the protruding edge of the razor blade in turn and the resulting profile was recorded. Each stylus traversed the razor blade five times at each of three different positions, making fifteen measurements in total. For all the measurements a nominal stylus force of $98\ \mu\text{N}$ and a sampling rate of 100 Hz was used. A traversing speed of $0.05\ \text{mm min}^{-1}$ was used for the $1\ \mu\text{m}$ and $2\ \mu\text{m}$ styli and a traversing speed of $0.02\ \text{mm min}^{-1}$ was used for the $5\ \mu\text{m}$ and $10\ \mu\text{m}$ styli. The profiles for each set of five repetitions were superimposed to check visually for repeatability and were found to repeat well in all cases. One profile of each set of five was chosen at random and a circle was drawn on the profile ensuring that its circumference followed as exactly as possible the curvature of the reconstructed profile of the stylus tip. The radius of the circle, which equated to the radius of the stylus tip, was measured.

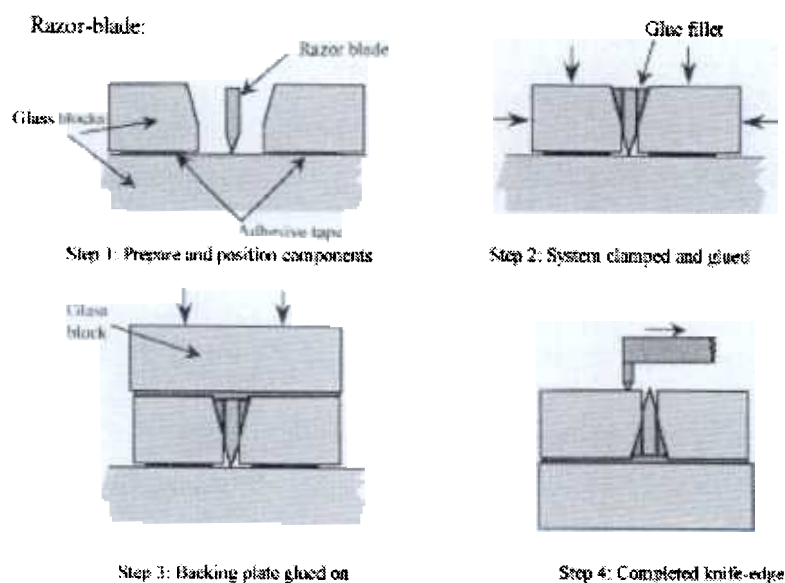


Figure 2 Assembly of the razor blade artefact

2.3 WEAR GAUGE

A Taylor Hobson stylus wear gauge was used to assess the nominal size of each stylus. This corresponded to a Type B1 tip measurement artefact as defined in ISO 5436-1: 2000, and consisted of four pairs of slits of consistent widths etched into a slice of silicon. The nominal widths of each pair of slits were $20\ \mu\text{m}$, $10\ \mu\text{m}$, $5\ \mu\text{m}$ and $2.5\ \mu\text{m}$. Each stylus was traversed across the pairs of slits at a speed of $5\ \text{mm min}^{-1}$ with a nominal stylus force of $98\ \mu\text{N}$ and a sampling rate of 100 Hz. By noting the number of slits shown on the trace for a given stylus a nominal value for that stylus was found. The measurement on the $10\ \mu\text{m}$ stylus was repeated as the first measurement indicated a stylus radius of less than $5\ \mu\text{m}$.

2.4 ROUGHNESS STANDARD

A Rubert + Co. roughness artefact (ISO 5436-1: 2000 Type B2) made from nickel and mounted on a flat aluminium base plate was chosen for this experiment. The artefact had a regular saw tooth wave profile with a nominal Ra ¹ of $0.4\ \mu\text{m}$ and a period of $15\ \mu\text{m}$. The artefact was measured using NanoSurf IV by each stylus in turn at ten random positions across the surface. Each measurement consisted of ten peaks and ten valleys. A speed of $0.2\ \text{mm min}^{-1}$, a sampling rate of 100 Hz and a nominal stylus force of $98\ \mu\text{N}$ were used throughout the measurements.

¹ Ra is the arithmetic mean of the absolute ordinate values within a sampling length (ISO 4287: 1997)

3. RESULTS

The results obtained by each experimental method are presented in table 1. The results obtained using the wear gauge and roughness artefact are purely comparative. Examples of the SEM images are shown in figure 4.

	Measured radius (μm)			
	Nominal 1 μm stylus	Nominal 2 μm stylus	Nominal 5 μm stylus	Nominal 10 μm stylus
SEM (before experiments)	8.7 10.3	2.7 3.9	4.8 7.0	9.5 10.6
Mean	9.5	3.3	5.9	10.1
SEM (after experiments)				
Mean	6.9	1.7	6.5	11.5
Razor blade method	2.2 2.2 2.1	0.8 1.3 1.0	1.7 1.3 1.3	2.9 3.4 3.1
Mean	2.2	1.0	1.4	3.1
Wear gauge	stylus radius < 2.5 μm	stylus radius < 2.5 μm	stylus radius between 2.5 μm and 5 μm	stylus radius < 2.5 μm
Roughness artefact	stylus radius < 10 μm and > 2 μm and 5 μm styli	stylus radius < 5 μm , 10 μm and 1 μm styli	stylus radius < 10 μm and 1 μm and > 2 μm styli	stylus radius > 5 μm , 2 μm and 1 μm styli

Table 1 Measured radii of 1 μm , 2 μm , 5 μm and 10 μm diamond styli using four different methods

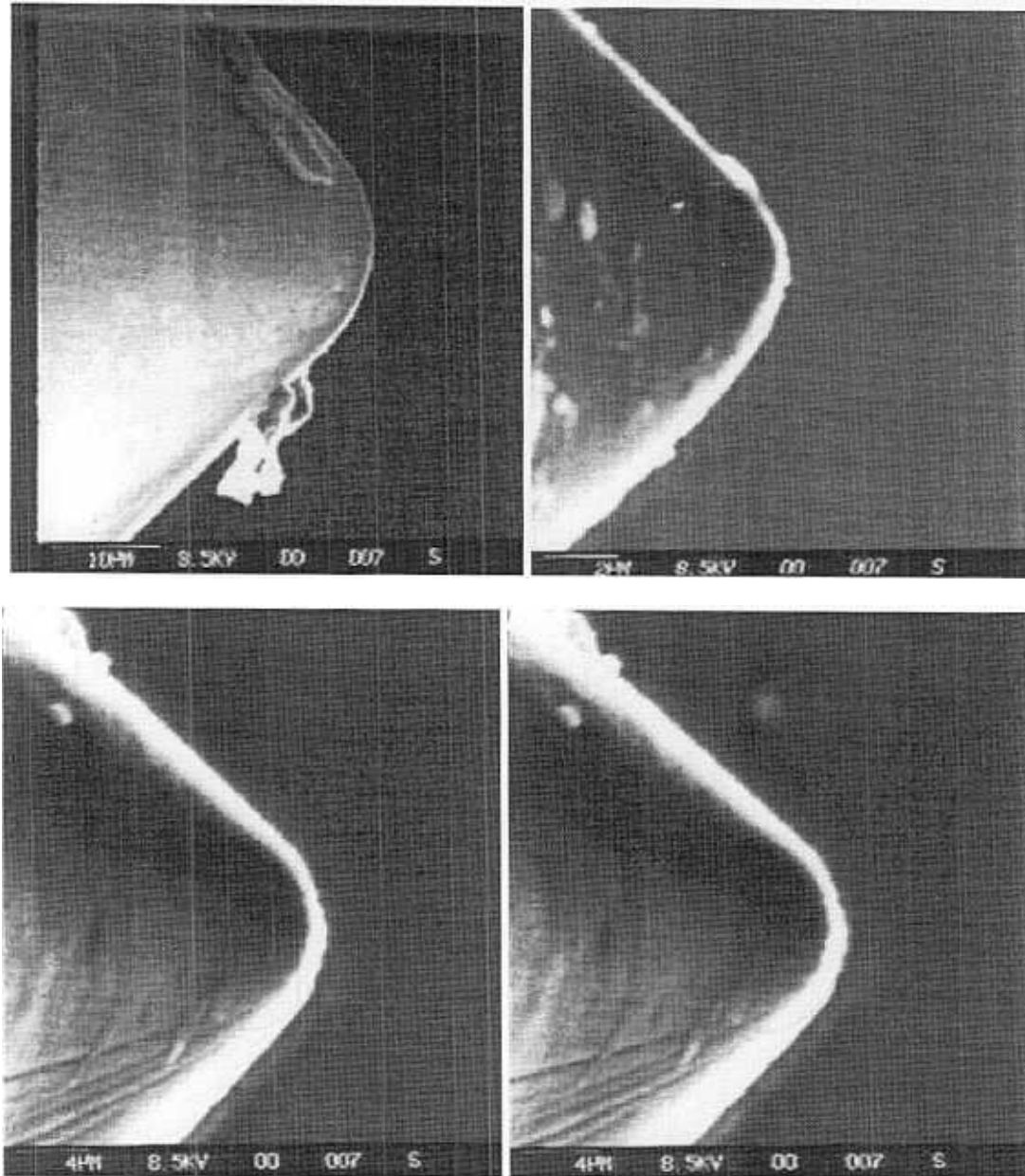


Figure 3 SEM images of $1\text{ }\mu\text{m}$ (top left), $2\text{ }\mu\text{m}$ (top right), $5\text{ }\mu\text{m}$ (bottom left) and $10\text{ }\mu\text{m}$ (bottom right) styli after the experiments

The results for the $0.1\text{ }\mu\text{m}$ stylus are given in table 2. Due to the chisel shape of the tip this stylus was measured in one orientation *i.e.* at its minimum radius. It should be noted that when all the styli were examined in the SEM after having been used there was contamination present on them in varying degrees. This is clearly demonstrated in figure 5.

	Measured radius (μm)	
	Initial measurements	Final measurements
	0.8 0.7	0.6 1.1
Mean	0.8	0.9

Table 2 Results for the 0.1 μm stylus, measured using the SEM.

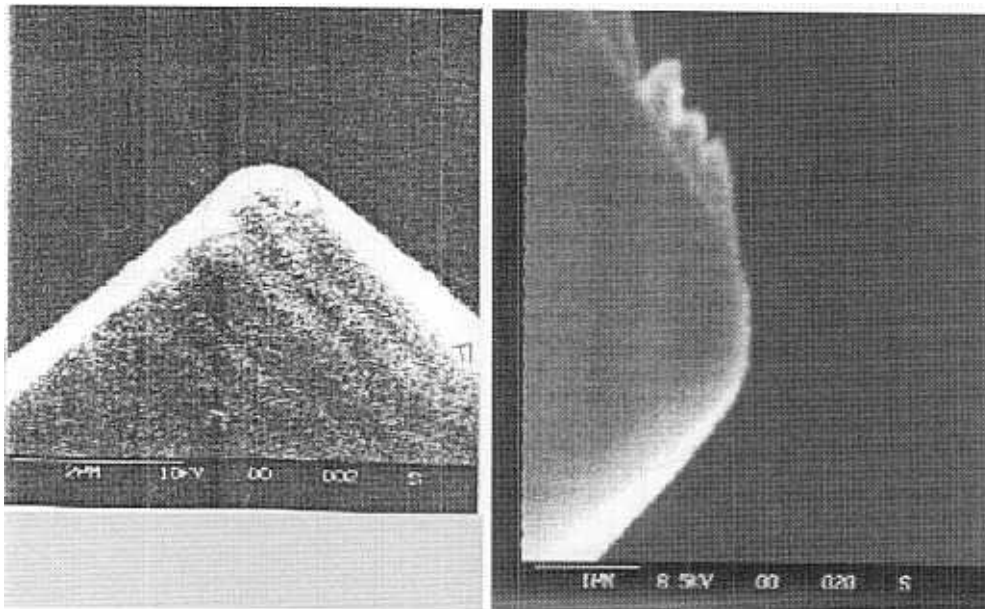


Figure 4 Stylus tip of 0.1 μm stylus before (left) and after (right) use.

Table 3 gives the results for the remaining six styli which were measured using the SEM.

Stylus ID	Nominal radius (μm)	Measured radius (μm)
1A	1	1.4
1B	1	0.9
1C	1	1.1
2A	2	3.0
2B	2	2.9
2C	2	2.4

Table 3 Results for the six styli measured using the SEM.

Figure 6 gives examples of the traces obtained using the wear gauge, and illustrates the problems in interpreting the results. Four pairs of slits are clearly visible on both traces, indicating that both styli have a radius of less than $2.5\ \mu\text{m}$.

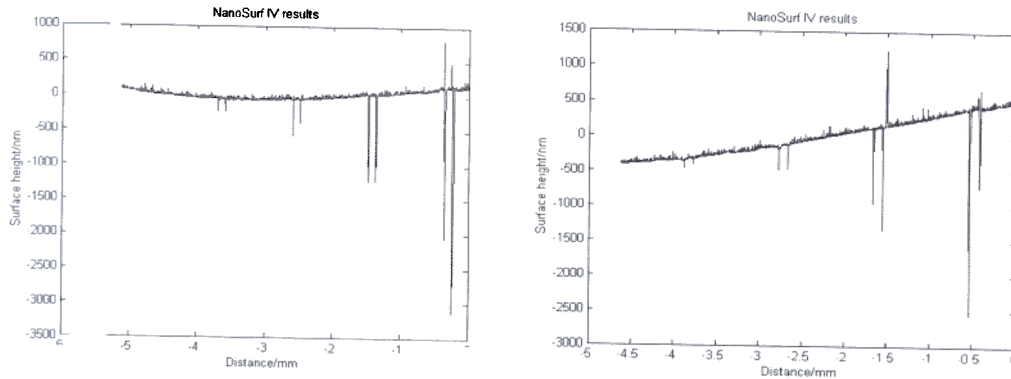


Figure 5 Wear gauge traces for $1\ \mu\text{m}$ (left) and $10\ \mu\text{m}$ styli (right)

Table 4 gives the mean and standard deviation of ten sets of results for R_a , R_p ² and R_v ³ using each of the four styli to measure the roughness artefact.

Nominal stylus radius (nm)	1	2	5	10
Mean measured stylus radius (nm)	8.2	2.5	6.2	10.8
R_a (nm)	406.97	415.93	413.08	390.98
Std. devn. (nm)	8.87	5.22	7.20	5.6
R_p (nm)	762.03	889.43	859.88	655.19
Std. devn (nm)	22.10	20.53	28.73	18.63
R_v (nm)	-850.55	-801.64	-802.99	-828.80
Std. devn.(nm)	16.55	25.15	13.58	27.96

Table 4 Results with the roughness artefact

² R_p is the largest profile peak height within a sampling length (ISO 4287: 1997)

³ R_v is the largest profile valley depth within a sampling length (ISO 4287: 1997)

4. DISCUSSION

The SEM results in table 1 show that the radii of the 2 μm , 5 μm and 10 μm styli were close to the nominal values stated by the manufacturer. However the radius of the 1 μm stylus was between 6.9 μm and 9.5 μm , which is more than six times greater than its nominal value. The small differences in the initial and final measurements were most likely due to a change in the exact position of the styli between the two series of measurements. The results for the 0.1 μm stylus (table 2) showed the greatest difference from the nominal with a maximum measured radius of 0.9 μm .

The measured radii of the further three 1 μm styli (1A, 1B and 1C in table 3) were around their nominal values, with a spread of 0.5 μm between the three results. The three 2 μm styli (2A, 2B and 2C in table 3) were all greater than their nominal values with a spread of 0.6 μm between the results.

The results using the razor blade method showed the radii of the styli to be similar to each other and all to be less than 3.1 μm . This did not reflect the nominal values supplied by the manufacturer. When examined comparatively the results did however indicate that the radius of the 1 μm stylus was greater than that of the 5 μm stylus and less than the radius of the 10 μm stylus. This confirmed the SEM results.

Using the wear gauge to verify stylus radius proved to be unreliable and imprecise, with the results indicating that the 10 μm stylus had a radius of less than 2.5 μm .

The R_a , R_p and R_v for the roughness artefact varied with the radius of the stylus used for the measurements (table 4). It was expected that R_a , R_p and R_v values would decrease as the radius of the stylus increased. Inspection of the results showed this was not the case and that therefore the radius of the 1 μm stylus was somewhere between 5 μm and 10 μm . This pattern reinforced the results of the SEM and razor blade methods.

5. CONCLUSIONS

In order to obtain meaningful results from measurements of surface texture using a stylus instrument the geometry of the stylus tip should be accurately known. From the results of the experiments carried out in this study, it is clear that it is not always possible to rely on the specified values that are supplied by a stylus manufacturer or distributor. In the case of the nominally 1 μm radius stylus that was measured to have a radius of nearer 10 μm , the distributor advised the authors that the stylus had been incorrectly packed. This confirms the need for an easy, quick and cost effective method for checking styli used routinely in industry.

Whilst the razor blade method and the use of a roughness artefact (advocated in ISO 5436-1: 2000) were useful in making comparative measurements on different styli, only the SEM provided an absolute measurement of radius. However, many companies could not afford the high cost of an SEM. The razor blade method proved useful but had a number of drawbacks. The construction of the artefact was difficult

and time consuming, it was awkward to set up and the fine edge of the blade was easily damaged with the diamond styli. The most efficient method for comparatively checking the radius of a stylus was found to be the roughness artefact.

The problems of the styli picking up dust, *etc.* from the surface during measurement were highlighted, showing the need for regular inspection and cleaning. Ideally styli should be inspected, and cleaned where necessary, using a proprietary cleaner suitable for styli used for commercial HiFi systems or some other means, before making any measurements.

6. ACKNOWLEDGEMENTS

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