A COMPARATIVESTUDY OF SURFACE TEXTURE MEASUREMENT USING WHITE LIGHT SCANNING INTERFEROMETRY AND CONTACT STYLUS TECHNIQUES

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1.0 INTRODUCTION

Surface texture generated by metal removal processes has been measured using stylus type instruments for well over half a century. In recent years, a number of optical techniques have been developed for measuring surface texture. Instruments based on these techniques were initially developed to measure optically smooth surfaces. These instruments overcame some of the disadvantages of stylus type techniques in that they are non-contact and can quickly provide three-dimensional assessment of surface texture. However, instruments based on phase measuring interferometry were limited to very smooth surfaces and small fields of view. Recently, the capability of these instruments has been extended to the measurement of rough surfaces or step heights using white light vertical scanning interferometry. This extension has been achieved through increases in the vertical range and field of view. Commercial instruments are currently available with a vertical range of 500μm and field of view up to 10 x 10mm. The enhanced range and improved field of view have now made this type of instrument very useful in the numerous industries.

The improved capabilities also make these instruments appropriate for characterizing surfaces produced by metal removal processes. The measurement of these surfaces has traditionally been the domain of stylus instruments. This paper presents the results from a comparative study of the profiles obtained from a scanning white light interferometer white the profiles obtained from a stylus instrument.

2.0 INSTRUMENT CHARACTERISTICS

The surface texture measurements in this study were performed using two different instruments. The optical instrument was a WYKO Roughness/Step Tester (RST) while the stylus instrument was a Form Talysurf (FTS). The characteristics of each instrument are described in the following sections.

WYKO Roughness/Step Tester (RST):

The RST is a vertically scanning interference microscope system that operates with one of several interchangeable magnification objectives. Each objective contains an interferometer, consisting of a reference mirror and beam splitter, that produces interference fringes when light reflected off the reference mirror recombines with light reflected off the sample. When short-coherence white light is used, these interference fringes are present only over a very shallow depth on the surface. The surface is profiled by scanning vertically so that each point on the surface produces an interference signal and then locating the exact vertical position where each signal reaches its maximum amplitude.

Form Talysurf S5:

The stylus instrument used in this study has a 4mm vertical range with 10nm resolution, and 120mm horizontal scan range. A conical stylus with a 1.5-2.5μm nose radius and 90° included angle was used. In general, the finite dimensions of the stylus mechanically filters very small surface wavelengths. The characteristics of this filtering depend on the radius and the included angle of the stylus. In addition, if a skid is used in the measurement it results in additional mechanical filtering of the longer wavelengths. The measured surface profile is then filtered to separate roughness and waviness.

3.0 RESULTS

The instruments described above were used to measure a number of different surfaces. The profiles from these measurements were analyzed in detail to understand the correlation between the two measurement techniques. The validity of this comparison requires careful consideration of the measurement procedure. The measurement procedure should ensure that the profiles are collected from the same location with similar ordinate spacing. This has been achieved by first physically profiling the same location using both instruments to obtain two profiles. The stylus profile ordinate spacing was then adjusted to be the same as the optical profile's using an iterative down sampling procedure. The resulting profiles were then quantitatively compared. The ensuing sections describe the measurement and analysis of these profiles.

Measurements were performed on a variety of surfaces. These surfaces ranged from reference specimen from NIST (sine wave) and PTB (repeatedly random ground surface), and manufactured surfaces (e.g. vertical milling and turning). These surfaces were chosen to cover a wide range of surface roughnesses and lay patterns. The results for the PTB specimen are discussed below.

Random Profile Calibration Standard:

Examination of random profile calibration standards allows for the evaluation of the measurement interaction over a wide range of wavelengths. The random profile calibration standards are a set of ground surfaces that have a random surface profile that repeats at regular intervals. The PTB reference surface used in this study had an average roughness (R_a) of 0.54μm, maximum peak-to-valley length (R_t) of 3.51μm and repeat interval of 2mm. The analysis results for this surface are given in figures 1 and 2. Figure 1 shows only minor differences between the down sampled stylus profile and the RST profile. The power spectrum plots show differences only in the short wavelength region which corresponds with the deviations observed in the profiles.

4.0 CONCLUSIONS

Surface texture measurements have been done using white light scanning interferometry and stylus profilometry on a variety of surfaces. In order to compare the profiles from the two instruments, measurements were carried out in the same region and then matched using correlation techniques. The results of the comparison have shown that white light scanning interferometry is capable of measuring machined surfaces.

Profile ID	R_a (μm)	R_q (μm)	R_t (μm)
FTS Original	0.5353	0.6709	3.6414
FTS Down Sampled	0.5290	0.6666	3.4128
RST	0.5008	0.6226	3.1548

Table 1 - Parameter values for PTB reference specimen.

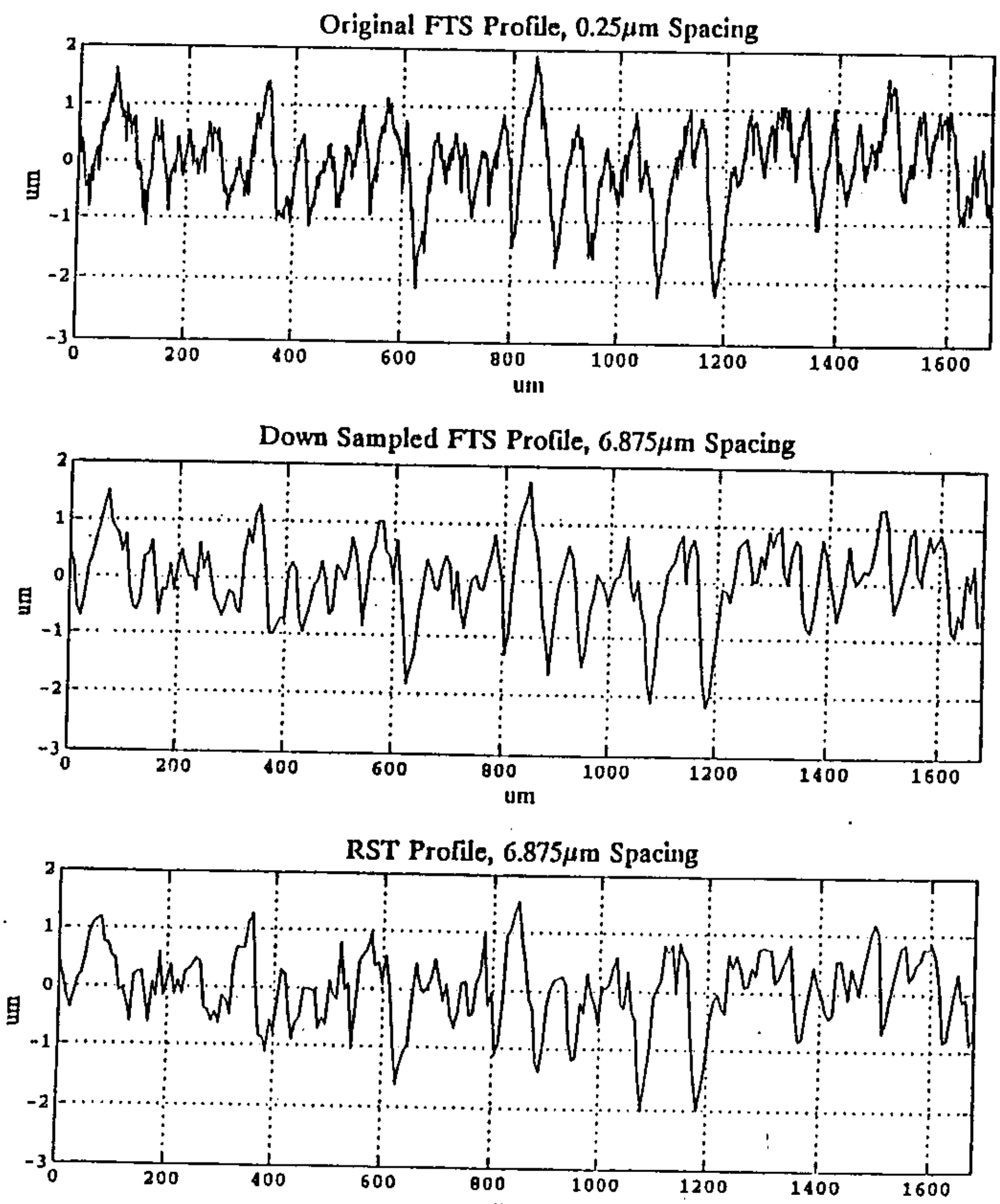

Figure 1. Unfiltered surface profiles from PTB roughness specimen

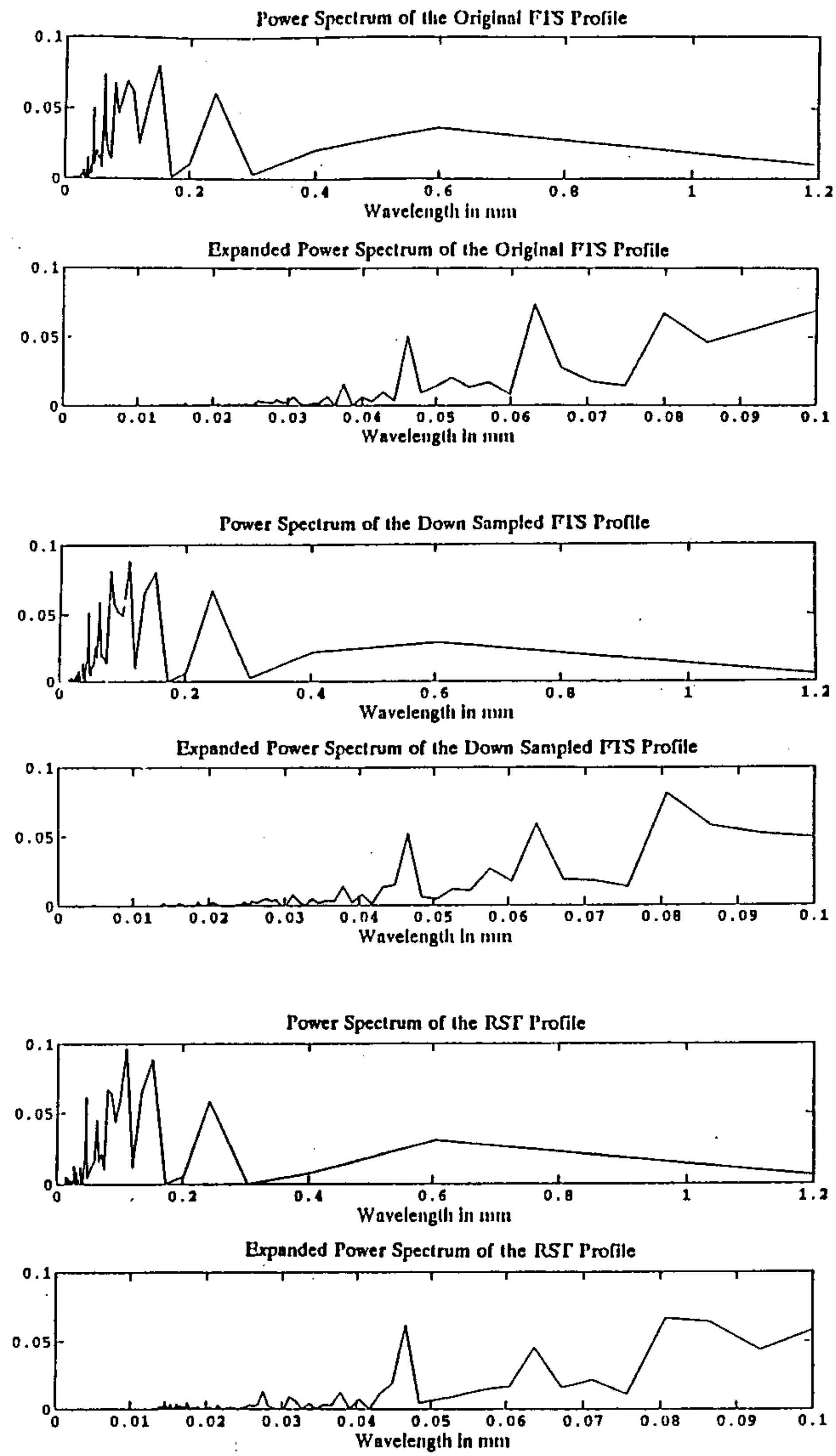

Figure 2. Power spectrum plots of profiles from PTB specimen

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A COMPARATIVE STUDY OF SURFACE TEXTURE USING WHITE LIGHT VERTICAL SCANNING INTERFEROMETRY AND CONTACT STYLUS TECHNIQUES

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ABSTRACT

The characterization of machined surfaces is becoming an increasingly important activity in todays quality minded business environment. Historically, these surfaces would have been evaluated using a stylus instrument but optical instruments are now becoming increasingly prevalent. One instrument, the white light vertical scanning interferometer, is even capable of performing a complete three-dimensional evaluation in a single scan. This paper examines the application of white light vertical scanning interferometry on machined surfaces. In addition, a quantitative comparison of the results from vertical scanning interferometry and stylus has been performed.

1.0 INTRODUCTION

Surface texture generated by metal removal processes has been measured using stylus type instruments for well over half a century. In recent years, a number of optical techniques have been developed for measuring these surfaces. The non-contact nature of these instruments allows them to overcome the limitations of stylus techniques to quickly provide a complete three-dimensional assessment of surface texture. The initial optical instruments, based on phase measuring interferometry, were limited to very smooth surfaces and small fields of view. Recently, the capability of these instruments has been extended to the measurement of rough surfaces or step heights using white light vertical scanning interferometry. This extension has been accompanied by increases in the vertical range and field of view. Commercial instruments are currently available with a vertical range of 500μm and field of view up to 10 x 10mm. The enhanced range and improved field of view make this type of instrument very useful in a number of different industries.

The improved capabilities also make these instruments appropriate for characterizing surfaces produced by conventional metal removal processes. The measurement of these surfaces has traditionally been the domain of stylus instruments. All prior experience and knowledge concerning these surfaces is limited to stylus instruments. The interaction between the stylus and surface texture has been investigated in the past [1]. In the case of optical instruments the nature of this interaction on rough surfaces is not well understood. It is not known whether this interaction is significant enough to be detectable in analysis results. The objective of this study is to analyze the effects of these interactions by examining the correlation between stylus and white light vertical scanning interferometry based surface measurement techniques. This was accomplished through careful measurements of surfaces and quantitative analysis. The following sections describe the instruments, measurement and analysis procedures, and the results.

2.0 INSTRUMENT CHARACTERISTICS

The surface texture measurements in this study were performed using both a non-contact and contact based instrument. The non-contact instrument was a WYKO Roughness/Step Tester (RST) while the contact instrument was a Form Talysurf (FTS). The characteristics of each instrument are described in the following sections.

WYKO Roughness/Step Tester (RST):

The RST is a vertically scanning interference microscope system that operates with one of several interchangeable magnification objectives. Each objective contains an interferometer, consisting of a reference mirror and beam splitter, that produces interference fringes when light reflected off the reference mirror recombines with light reflected off the sample. When short-coherence white light is used, these interference fringes are present only over a very shallow depth on the surface. The surface is profiled by scanning vertically so that each point on the surface produces an interference signal and then locating the exact vertical position where each signal reaches its maximum amplitude. The RST starts the measurement sequence by focusing above the top of the surface being profiled and quickly scanning downward. At evenly spaced intervals during the scan, frames of interference data imaged by the video camera are captured and processed by high speed digital signal processing hardware. As the system scans downward, an interference signal for each point on the surface is formed. The system uses a series of advanced computer algorithms to precisely locate the peak of the interference signal for each point on the surface. Each point is thus processed in parallel, and at the end of the scan a three-dimensional surface map is obtained. The spatial dimensions of the scan are defined by the magnification factor. The 2.5X objective used in this study produced a 1.7 x 1.9mm field of view and a 6.85μm ordinate spacing.

Form Talysurf S5:

The stylus instrument used in this study has a 4mm vertical range with 10nm resolution, and 120mm horizontal scan range. A conical stylus with a 1.5-2.5μm nose radius and 90° included angle was used. In general, the finite dimensions of the stylus mechanically filters very small surface wavelengths. The characteristics of this filtering depend on the radius and the included angle of the stylus. In addition, if a skid is used in the measurement it results in additional mechanical filtering of the longer wavelengths. The measured surface profile is then filtered to separate roughness and waviness. This filtering is typically performed using the filter transmission characteristics specified in both national and international standards [2,3]. In this study only fixed datum measurements and linear trend removal were used to minimize the effect of this filtering. All original FTS profiles were digitized at 0.25μm intervals.

3.0 MEASUREMENT AND CHARACTERIZATION OF SURFACES

The instruments described above were used to measure a number of different surfaces. The profiles from these measurements were analyzed in detail to understand the correlation between the two measurement techniques. The validity of this comparison requires careful consideration of the measurement procedure. The measurement procedure should ensure that the profiles are collected from the same location with similar ordinate spacing. This has been achieved by first physically profiling the same location using both instruments to obtain two profiles. The stylus profile ordinate spacing was then adjusted to be the same as the optical profile's using an iterative down sampling procedure. The resulting profiles were then quantitatively compared. The ensuing sections describe the measurement and analysis of these profiles.

Profiling:

Of all the actions required in this study, profile measurement is the most important. This is important because the variability in the measured profiles may not only come from the instruments that are being compared but also from the surface being measured. One researcher has found up to 50 percent variation in parameter values on typical machined surfaces and even 15 percent on calibration samples [4]. Care must therefore be exercised to ensure that the two profiles are obtained from the same location and orientation on the surface. The relocation requirements however are quite stringent with values typically being within several microns. Kinematic mounting principles are usually used to obtain the required repositioning accuracy [5]. These studies however were only concerned with repositioning on a single measuring instrument. Accurate repositioning on two separate instruments is an extremely challenging undertaking. Fortunately, the repositioning requirement can be relaxed using surfaces with extremely strong surface lay (e.g. calibration samples). The strong lay ensures that the correlation length in the lay direction is quite long. In this way the relocatability requirements in the lay direction are reduced. The fact that the RST produces a three-dimensional data map was also used to simplify the profiling procedure.

The profiling procedure started with the collection of a three-dimensional data map with the RST. This map was collected in such a way that a significant feature of the surface was present in the topography map. The significant feature can either be an edge or scratch but its function is to serve as a reference point so that a two-dimensional profile can be collected across the area of interest. The position of the feature in the surface map can also be used to extract the appropriate profile.

Down Sampling:

The term down sampling has been used to describe the action of matching a single profile trace from the RST surface map to a segment of the much longer Form Talysurf profile. Down sampling is required because the surface profiles from the two instruments match in neither the number or spacing of the ordinates. The goal of down sampling is to obtain two nearly identical profiles, one from each of the instruments, that matched in both the number and spacing of the individual ordinate values. This procedure was automated through the use of the cross-correlation function. The cross-correlation function is a signal processing tool that can be used to quantify the degree of similarity between two series of data. The form of this function for discrete data can be given as [6]:

$$\rho_{XY}(j) = \frac{\sum_{n=0}^{N-1} X(n)\ Y(n+j)}{\left[\sum_{n=0}^{N-1} X(n)\ \sum_{n=0}^{N-1} Y(n)\right]^{\frac{1}{2}}}$$

where, ρ_{XY} varies between 1 and -1, X and Y each represent a series of data, and N is the number of values in each series. A value of 1 indicates that series X and Y are identical while a -1 indicates that they are inverses. While the cross-correlation function is uniquely suited to determining the similarity of two profiles, the calculation of the full function is computationally extensive. For that reason the procedure adopted in this study only requires that the correlation value at zero shift (j=0) be calculated.

The down sampling routine is actually implemented as an iterative search method. It first begins by setting the down sampling starting point the beginning of the stylus profile. The initial starting point and the respective ordinate spacings are then used to extract a trial reduced profile from the stylus data. The zero shift correlation between the trial and optical profiles is then calculated and retained for future reference. The starting point is then increased by a constant value, and the extraction and cross-correlation procedures are repeated. This process is continued until the entire stylus profile has been covered. The final reduced profile is obtained by using the starting point that gave the maximum correlation value for down sampling. By design this technique is always capable of finding a reduced profile, however, caution must always be observed. The user should always examine the maximum correlation value and the resulting profiles to ensure that meaningful data has been produced. Incrementing the starting point by less than half the ordinate spacing of the optical profile was optimal.

Characterization:

Comparison of the optical and stylus profiles was performed on two different levels. First, a visual comparison was performed to ensure that the results of the automated down sampling procedure were valid. This comparison was achieved by simultaneously plotting the original stylus profile, down sampled profile and optical profile all to the same scale. This form of comparison provides a simple way to observe both the effects of down sampling and the degree of correlation between the optical profile and the stylus profiles. Secondly, a quantitative analysis was performed by evaluating the auto- and cross-correlations, frequency spectrum and parameter values. The correlation analysis is another simple way to visually evaluate the degree of similarity between the stylus and optical profiles. If the two profiles are highly correlated (i.e. the same) then both the auto- and cross-correlation plots should be nearly identical. Furthermore, the cross-correlation function should also be symmetrical with no apparent shift. The frequency spectrums allows for an inspection of the wavelength content of the profiles produced by each instrument. A simple comparison of the two frequency spectrums quickly identifies the wavelength regions that are affected by the measurement characteristics of the two instruments. In this study the area under the spectral curve was normalized to allow for the comparison of spectral plots of profiles with different numbers of data points. Several parameter values were also calculated. The parameters considered in this study were average roughness (R_a), root-mean-square roughness (R_q) and maximum peak-to-valley height (R_t). These parameters were included to examine the overall similarity of the two profiles. All profiles were filtered using an ISO gaussian phase corrected filter (0.25mm cutoff) prior to parameter evaluation.

4.0 RESULTS

Measurements were performed on a variety of different surfaces. These surfaces ranged from reference specimen to manufactured surfaces. These surfaces were chosen to cover a wide range of surface roughnesses and lay patterns. The results from a repeatedly random reference specimen from PTB and a milled surface are presented here. The following sections provide a brief description of each specimen and the results of the correlation study.

Random Profile Calibration Standard:

Examination of random profile calibration standards allows for the evaluation of the measurement interaction over a wide range of wavelengths. The random profile calibration standards are a set of ground surfaces that have a random surface profile that repeats at regular intervals. The PTB reference surface used in this study had an average roughness (R_a) of 0.54μm, maximum peak-to-valley length (R_t) of 3.51μm and repeat interval of 2mm. The analysis results for

Profile ID	R_a (μm)	R_q (μm)	R_t (μm)
FTS Original	0.5353	0.6709	3.6414
FTS Down Sampled	0.5290	0.6666	3.4128
RST	0.5008	0.6226	3.1548

Table 1 - Parameter values for PTB reference specimen.

this surface are given in figures 1 to 2 and table 1. Figure 1 shows only minor differences between the down sampled stylus profile and the RST profile. The high degree of visual agreement of these profiles validates the analytical procedures used for down sampling. The power spectrum plots show differences only in the short wavelength region which corresponds with the deviations observed in the profiles.

Vertical Milling:

A vertical milled surface was included in this study to observe the measurement variation on a machined surface. This surface is part of an electro-formed surface roughness standard produced by Fowler (Set No. 52-720-000). The particular patch used in this study was produced with a surface roughness (R_a) of 0.8μm and maximum peak to valley length (R_t) of 4.0μm. Figures 3 to 4 and table 2 present the analysis results of this surface. A comparison of the profiles in figure 3 shows small variations in the representation of the surface structure. The high degree of similarity is again confirmed by the spectral plots shown in figure 4. This conclusion is also supported by the similarity of the parameter values in table 2.

5.0 CONCLUSIONS

Surface texture measurements have been done using white light scanning interferometry and stylus profilometry on a variety of surfaces. In order to compare the profiles from the two instruments, measurements were carried out in the same region and then matched using correlation techniques. The results of the comparison have shown that white light scanning interferometry is capable of measuring machined surfaces. The average parameters such as R_a and R_q are primarily determined by the longer wavelengths. The profile and power spectrum plots reveal that the long wavelength characteristics of the surface are resolved by the scanning interferometry technique. The shorter wavelengths are not fully resolved at the magnification used in this study. This magnification was used to facilitate the computation of parameters according to national standards which require a certain profile length. However, improved spatial resolution can be obtained using higher magnification objectives. In which case the length of the profile available for parameter computation is shorter. In summary, the white light scanning interferometry is a viable technique for measuring machine surfaces.

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Profile ID	R_a (µm)	R_q (µm)	R_t (µm)
FTS Original	0.9335	1.1487	4.8051
FTS Down Sampled	0.9299	1.1436	4.5371
RST	0.8816	1.1155	4.6442

Table 2 - Parameter values for milled surface.

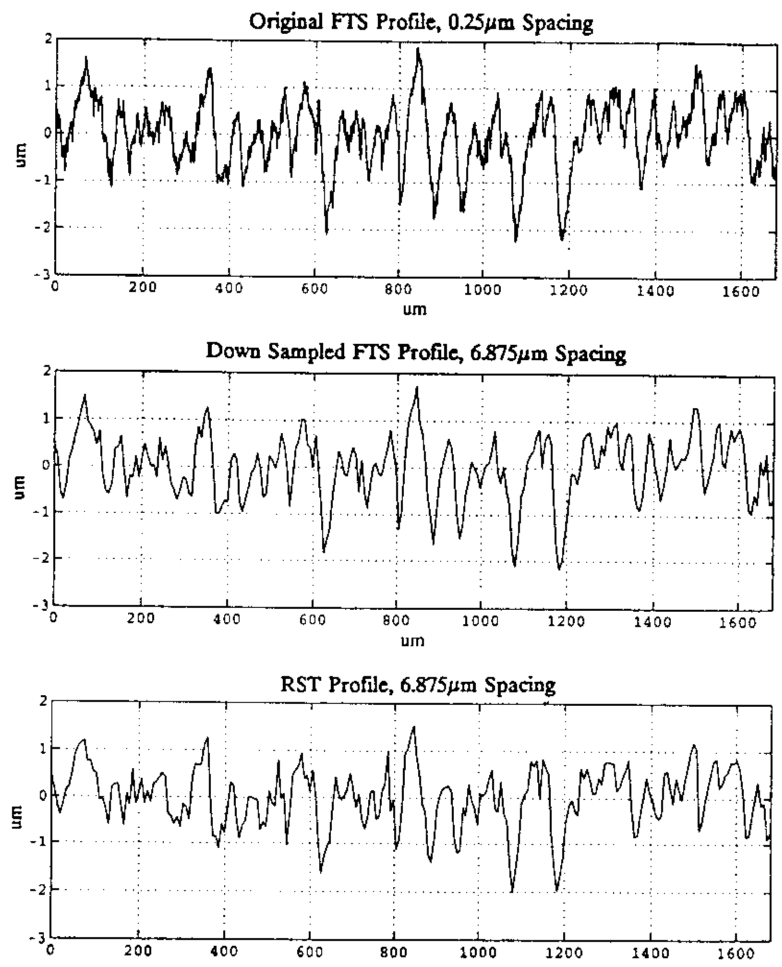

Figure 1 - Unfiltered surface profiles from PTB specimen.

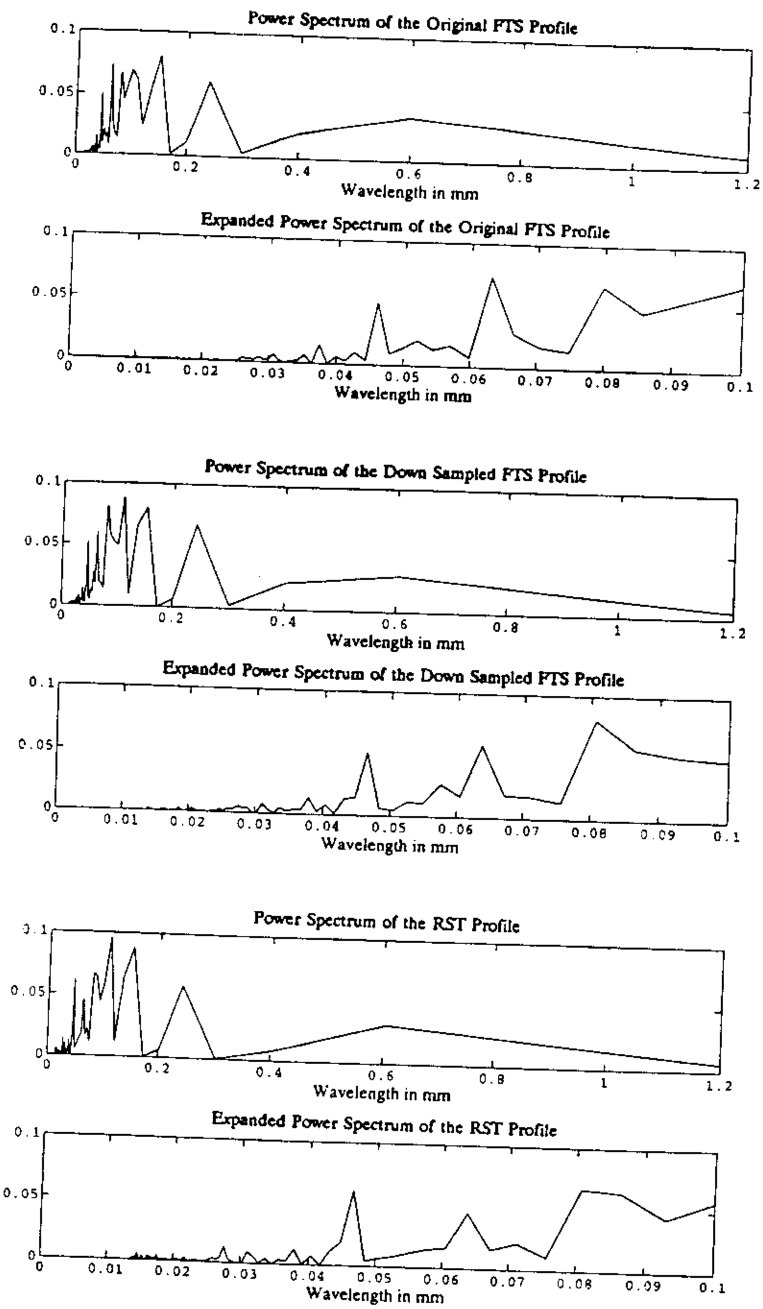

Figure 2 - Spectrum plots of the PTB surface profiles.

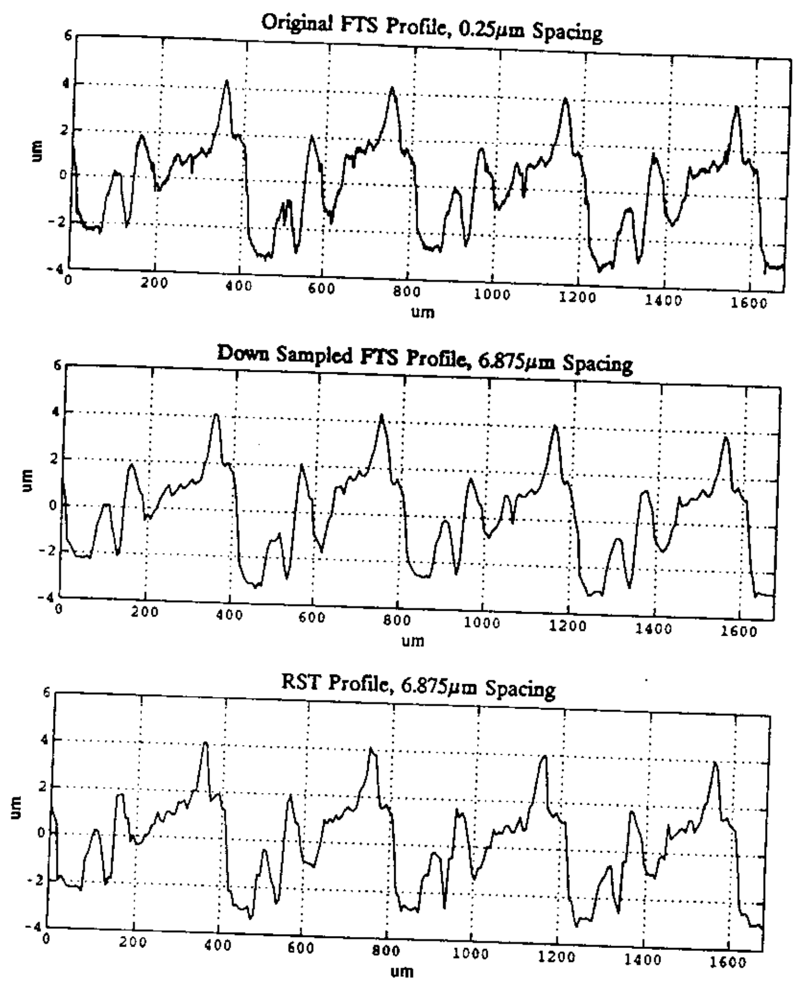

Figure 3 - Unfiltered surface profiles from the milled surface.

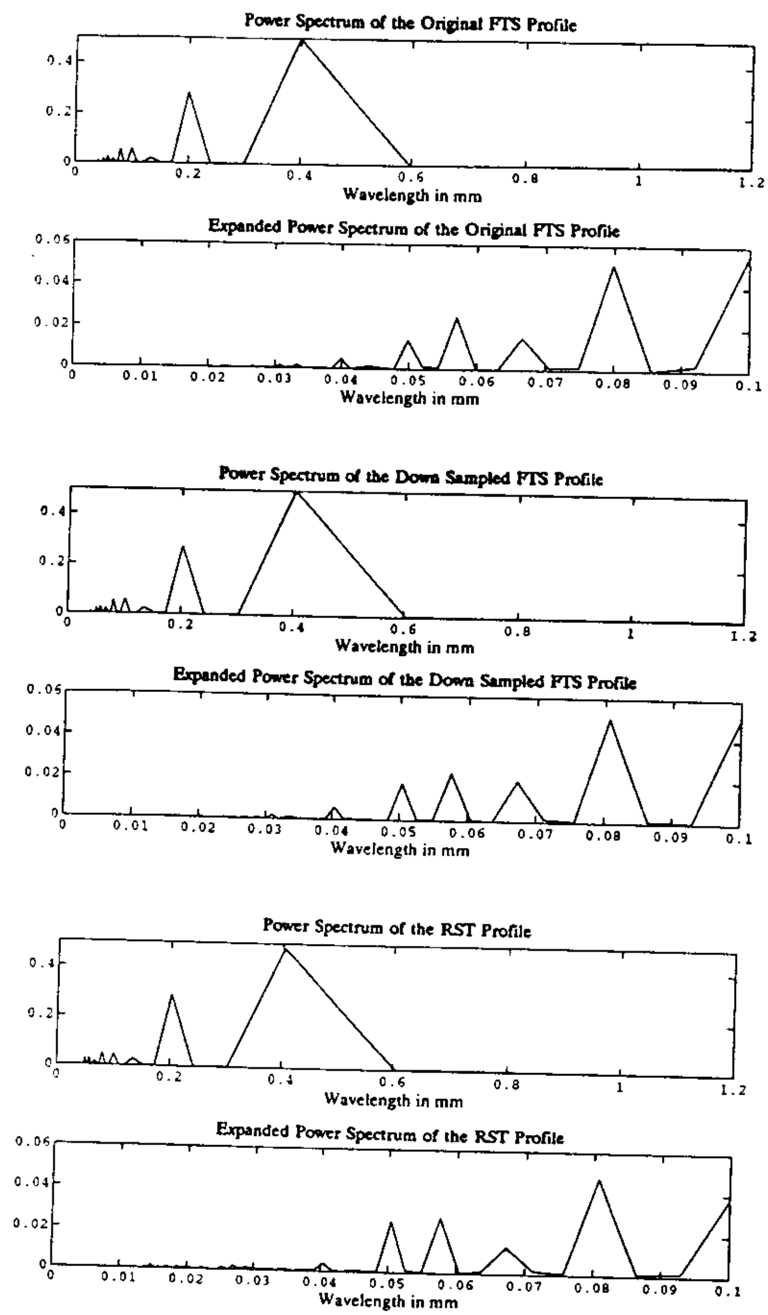

Figure 4 - Spectrum plots of the milled surface profiles.

MEASUREMENT OF SURFACE TEXTURE USING WHITE LIGHT VERTICAL SCANNING INTERFEROMETRY

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ABSTRACT

The use of optical instruments for surface characterization has significantly increased in recent years. The capabilities of some instruments have improved to the point where they can measure rough surfaces generated by traditional metal cutting processes. In general, stylus type instruments are used to measure machined surfaces. This paper presents the results of an investigation of the measurement of machined surfaces using white light vertical scanning interferometry. In addition, a quantitative comparison of the results from vertical scanning interferometry and stylus has been performed.

1.0 INTRODUCTION

Surface texture generated by metal removal processes has been measured using stylus type instruments for well over half a century. In recent years, a number of optical techniques have been developed for measuring surface texture. Instruments based on these techniques were initially developed to measure optically smooth surfaces. These instruments overcame some of the disadvantages of stylus type techniques in that they are non-contact and can quickly provide three-dimensional assessment of surface texture. However, instruments based on phase measuring interferometry were limited to very smooth surfaces and small fields of view. Recently, the capability of these instruments has been extended to the measurement of rough surfaces or step heights using white light vertical scanning interferometry. This extension has been achieved through increases in the vertical range and field of view. Commercial instruments are currently available with a vertical range of $500\mu m$ and field of view up to 10 x 10mm. The enhanced range and improved field of view have now made this type of instrument very useful in the numerous industries.

The improved capabilities also make these instruments appropriate for characterizing surfaces produced by metal removal processes. The measurement of these surfaces has traditionally been the domain of stylus instruments. All prior experience and knowledge concerning these surfaces is limited to stylus instruments. The interaction between the stylus and surface texture has been investigated in the past [1]. In the case of optical instruments the nature of this interaction for rough surfaces is not well understood. It is not known whether this interaction is significant enough to be detectable in analysis results. The objective of this study is to analyze the effects of these interactions by examining the correlation between stylus and white light vertical scanning interferometry based surface measurement techniques. This was accomplished through careful measurements of surfaces and quantitative analysis. The following sections describe the instruments, measurement and analysis procedures, and the results.

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Magnification	2.5X	10X	20X	40X
Field of View	1.7 x 1.9mm	422 x 468μm	211 x 234μm	105 x 117μm
Ordinate Spacing	6.85 x 7.95μm	1.70 x 1.96μm	0.851 x 0.979μm	0.423 x 0.490μm

Table 1 - Magnification objectives for WYKO RST used in the study. [2]

Form Talysurf S5:

The stylus instrument used in this study has a 4mm vertical range with 10nm resolution, and 120mm horizontal scan range. A conical stylus with a 1.5-2.5μm nose radius and 90° included angle was used. In general, the finite dimensions of the stylus mechanically filters very small surface wavelengths. The characteristics of this filtering depend on the radius and the included angle of the stylus. In addition, if a skid is used in the measurement it results in additional mechanical filtering of the longer wavelengths. The measured surface profile is then filtered to separate roughness and waviness. This filtering is typically performed using the filter transmission characteristics specified in both national and international standards [3,4]. In this study only fixed datum measurements and linear trend removal were used to minimize the effect of this filtering. All original FTS profiles were digitized at 0.25μm intervals.

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Profiling:

Of all the actions required in this study, profile measurement is the most important. This is important because the variability in the measured profiles may not only come from the instruments that are being compared but also from the surface being measured. One researcher has found up to 50 percent variation in parameter values on typical machined surfaces and even 15 percent on calibration samples [5]. Care must therefore be exercised to ensure that the two profiles are obtained from the same location and orientation on the surface. The relocation requirements however are quite stringent with values typically being within several microns. Kinematic mounting principles are usually used to obtain the required repositioning accuracy [6]. These studies however were only concerned with repositioning on a single measuring instrument. Accurate repositioning on two separate instruments is an extremely challenging undertaking. Fortunately, the repositioning requirement can be relaxed using surfaces with extremely strong surface lay (e.g. calibration samples). The strong lay ensures that the correlation length in the lay direction is quite long. In this way the relocatability requirements in the lay direction are reduced. The fact that the RST produces a three-dimensional data map was also used to simplify the profiling procedure.

The profiling procedure started with the collection of a three-dimensional data map with the RST. This map was collected in such a way that a significant feature of the surface was present in the topography map. The significant feature can either be an edge or scratch but its function is to serve as a reference point so that a two-dimensional profile can be collected across the area of interest. The position of the feature in the surface map can also be used to extract the appropriate profile.

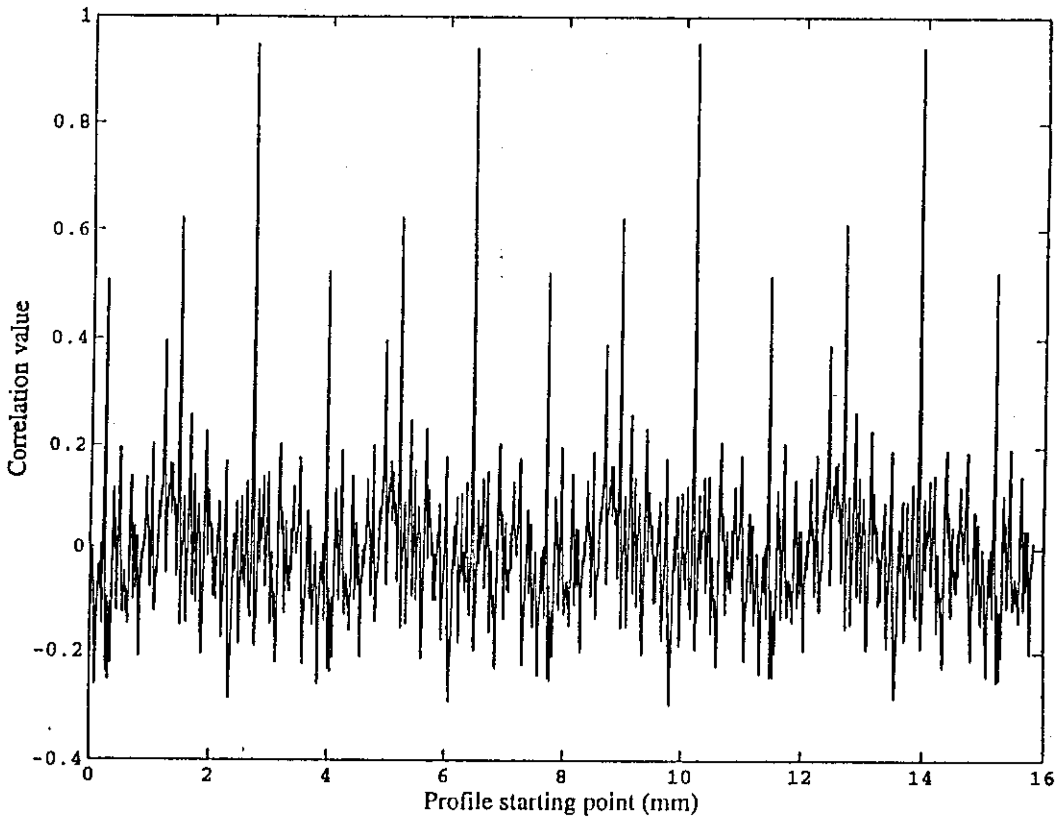

Figure 1 - The correlation values generated by the automated down sampling procedure (PTB specimen).

Down Sampling:

The term down sampling has been used to describe the action of matching a single profile trace from the RST surface map to a segment of the much longer Form Talysurf profile. Down sampling is required because the surface profiles from the two instruments match in neither the number or spacing of the ordinates. The goal of down sampling is to obtain two nearly identical profiles, one from each of the instruments, that matched in both the number and spacing of the individual ordinate values. This procedure was initially performed manually but was later automated through the use of the cross-correlation function.

Manual down sampling was a two step process: profile matching and data extraction. Profile matching was performed using a simple program that simultaneously displayed the optical profile and a segment of the stylus profile using equal scales. The operator then stepped through the data until the best match was found. After the best match was found, the reduced profile was obtained by using an initial starting point (from above) and then skipping a suitable number of ordinate values to obtain equal spacing in both profiles. This process was continued until the required number of ordinates were obtained. Usually several iterations were also required on the starting point to find the best match. This simple procedure proved to be capable of producing matching profiles but it was very time consuming and the results were often subjective.

Automated down sampling that uses the cross-correlation function was developed as a systematic search procedure to locate the segment of the stylus profile that most closely matches the optical profile. The cross-correlation function is a signal processing tool that can be used to quantify the degree of similarity between two series of data. The form of this function for discrete data can be given as [7]:

$$\rho_{XY}(j) = \frac{\sum_{n=0}^{N-1} X(n)\, Y(n+j)}{\left[\sum_{n=0}^{N-1} X(n) \sum_{n=0}^{N-1} Y(n) \right]^{\frac{1}{2}}}$$

where, ρ_{XY} varies between 1 and -1, X and Y each represent a series of data, and N is the number of values in each series. A value of 1 indicates that series X and Y are identical while a -1 indicates that they are inverses. While the cross-correlation function is uniquely suited to determining the similarity of two profiles, the calculation of the full function is computationally extensive. For that reason the procedure adopted in this study only requires that the correlation value at zero shift (j=0) be calculated.

The cross-correlation based automated down sampling method is actually implemented as an iterative search method. It first begins by setting the down sampling starting point at the beginning of the stylus profile. The initial starting point and the respective ordinate spacings are then used to extract a trial reduced profile from the stylus data. The zero shift correlation between the trial and optical profiles is then calculated and retained for future reference. The starting point is then increased by a constant value, and the extraction and cross-correlation procedures are repeated. This process is continued until the entire stylus profile has been covered. Typical correlation values produced by this process are shown in figure 1. The high correlation peaks, shown in this figure, are indicative of a repeating pattern in the surface lay structure. The final reduced profile is obtained by using the starting point that gave the maximum correlation value for down sampling. Figure 2 shows a down sampled profile and original profile over the same region. By design this technique is always capable of finding a reduced profile, however, caution must always be observed. The user should always examine the maximum correlation value and the resulting profiles to ensure that meaningful data has been produced. Incrementing the starting point by less than half the ordinate spacing of the optical profile was optimal.

During analysis it was observed that one profile was consistently longer than the other. After careful study it was determined that this extension was the result of slight variations in the specified ordinate spacings of the two instruments. Although troublesome, this effect was easily compensated for by using another iterative procedure. This second procedure is similar to the automated down sampling program except that it varies the assumed ordinate spacing of each trial reduced profile and evaluates the entire cross-correlation function for each profile. The maximum correlation and assumed ordinate spacing are saved for each trial. The assumed ordinate spacing that results in the maximum correlation value is used for the final down sampling. Figure 3 shows that an ordinate spacing of 6.875μm results in a maximum correlation of the optical and down sampled profiles. In this procedure, the maximum correlation value was used to accommodate for slight shifts between the two profiles. The results of this procedure were found to be consistent for a number of different measurements and samples. All subsequent data sets were down sampled using the improved ordinate spacing.

Characterization:

Comparison of the optical and stylus profiles was performed on two different levels. First, a visual comparison was performed to ensure that the results of the automated down sampling procedure were valid. This comparison was achieved by simultaneously plotting the original stylus profile, down sampled profile and optical profile all to the same scale. This form of comparison provides a simple way to observe both the effects of down sampling and the degree of correlation between the optical profile and the stylus profiles. Secondly, a quantitative analysis was performed by evaluating the auto- and cross-correlations, frequency spectrum and parameter values. The correlation analysis is another simple way to visually evaluate the degree of similarity between the stylus and optical profiles. If the two profiles are highly correlated (i.e. the same) then both the auto- and cross-correlation plots should be nearly identical. Furthermore, the cross-correlation function should also be symmetrical with no apparent shift. The frequency spectrums allows for an inspection of the wavelength content of the profiles produced by each instrument. A simple comparison of the two frequency spectrums quickly identifies the wavelength regions that are affected by the measurement characteristics of the two instruments. In this study the area under the spectral curve was normalized to allow for the comparison of spectral plots of profiles with different numbers of data points. Several parameter values were also calculated. The parameters considered in this study were average roughness (R_a), root-mean-square roughness (R_q) and maximum peak-to-valley height (R_t). These parameters were included to examine the overall similarity of the two profiles. All profiles were filtered using an ISO gaussian phase corrected filter (0.25mm cutoff) prior to parameter evaluation.

A)

B)

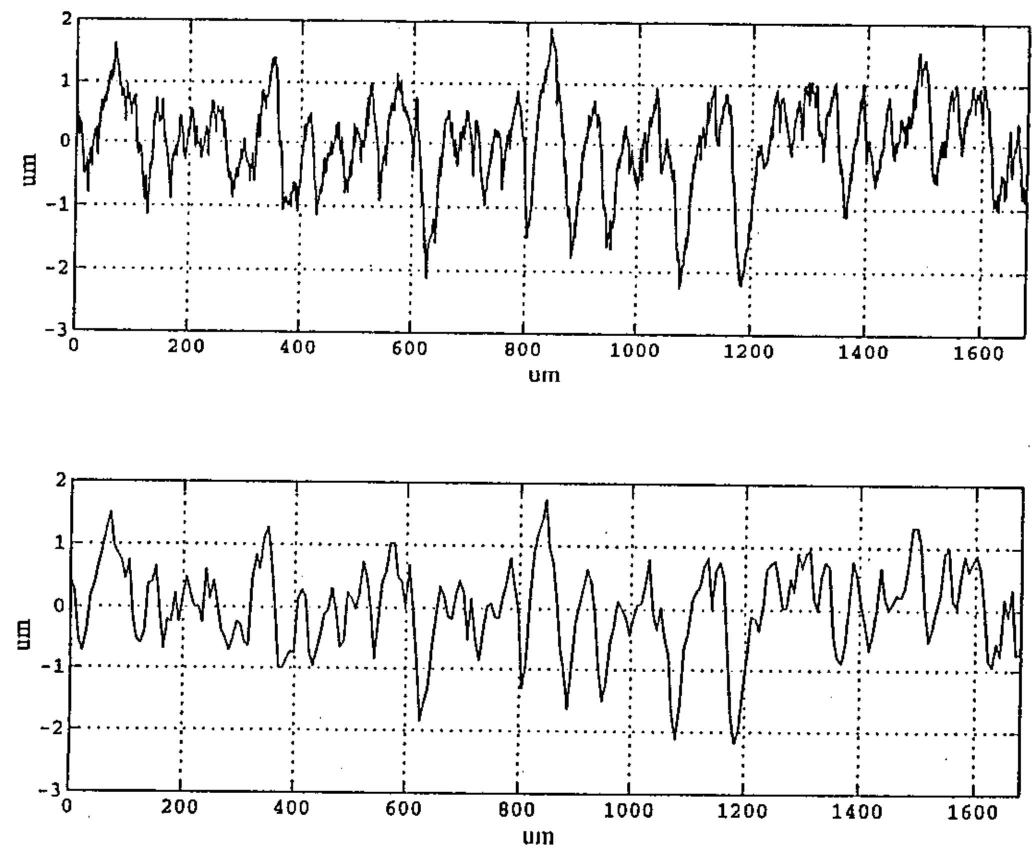

Figure 2 - Original (A) and down sampled (B) profiles at 0.25μm and 6.875μm ordinate spacings (PTB specimen).

4.0 RESULTS

Measurements were performed on a variety of surfaces. These surfaces ranged from reference specimen from NIST (sine wave) and PTB (repeatedly random ground surface), and manufactured surfaces (e.g. vertical milling and turning). These surfaces were chosen to cover a wide range of surface roughnesses and lay patterns. The results from three different surfaces are used to illustrate the correlation between stylus and white light scanning interferometry. The following sections provide a brief description of each specimen and the results of the correlation study.

Sinusoidal Standard Reference Materials:

The sinusoidal reference specimen (SRM 2072 and SRM 2074) allow for the examination of the measurement characteristics at a single wavelength. During manufacture the surface form of these standards is physically cut into the surface using a diamond turning process. Figures 4 through 6 and table 2 show the analysis results for SRM 2074. This specimen has a certified average roughness (R_a) of 0.974μm and spatial wavelength (D) of 40μm. An examination of figure 4 clearly shows the 40μm periodicity in this surface. However, it also shows that both the down sampled and RST profiles do not represent the peaks and valleys as accurately as the original FTS profile. Nevertheless, the correlation plots shown in figure 5 indicate a high degree of quantitative agreement between the profiles. An examination of the spectral plots, in figure 6, clearly shows the single wavelength nature of this specimen. The broadening of the dominant peaks in the down sampled FTS and RST spectrums is probably a result of the peak and valley conditions.

Profile ID	R_a (μm)	R_q (μm)	R_t (μm)
FTS Original	0.9916	1.0980	3.2045
FTS Down Sampled	0.9925	1.0950	3.1043
RST	1.1607	1.2697	3.2827

Table 2 - Parameter values for SRM 2074 reference specimen.

Random Profile Calibration Standard:

Examination of random profile calibration standards allows for the evaluation of the measurement interaction over a wide range of wavelengths. The random profile calibration standards are a set of ground surfaces that have a random surface profile that repeats at regular intervals. The PTB reference surface used in this study had an average roughness (R_a) of 0.54μm, maximum peak-to-valley length (R_t) of 3.51μm and repeat interval of 2mm. The 2mm repeating pattern is clearly visible in the example down sampling correlation plot, figure 1. The analysis results for this surface are given in figures 7 through 9 and table 3. Figure 7 shows only minor differences between the down sampled stylus profile and the RST profile. The high degree of visual agreement of these profiles validates the analytical procedures used for down sampling. The high degree of similarity of the cross- and auto-correlation plots shown in figure

8 quantitatively confirms the visual similarity of the profiles. The power spectrum plots show differences only in the short wavelength region which corresponds with the deviations observed in the profiles.

Profile ID	R_a (μm)	R_q (μm)	R_t (μm)
FTS Original	0.5353	0.6709	3.6414
FTS Down Sampled	0.5290	0.6666	3.4128
RST	0.5008	0.6226	3.1548

Table 3 - Parameter values for PTB reference specimen.

Vertical Milling:

A vertical milled surface was included in this study to observe the measurement variation on a machined surface. This surface is part of an electro-formed surface roughness standard produced by Fowler (Set No. 52-720-000). The particular patch used in this study was produced with a surface roughness (R_a) of 0.8μm and maximum peak to valley length (R_t) of 4.0μm. Figures 10 to 12 and table 4 present the analysis results of this surface. A comparison of the profiles in figure 10 shows small variations in the representation of the surface structure. The high degree of similarity is again confirmed by the correlation and spectral plots shown in figures 11 and 12. This conclusion is also supported by the similarity of the parameter values in table 4.

Profile ID	R_a (μm)	R_q (μm)	R_t (μm)
FTS Original	0.9335	1.1487	4.8051
FTS Down Sampled	0.9299	1.1436	4.5371
RST	0.8816	1.1155	4.6442

Table 4 - Parameter values for milled surface.

5.0 CONCLUSIONS

Surface texture measurements have been done using white light scanning interferometry and stylus profilometry on a variety of surfaces. In order to compare the profiles from the two instruments, measurements were carried out in the same region and then matched using correlation techniques. The results of the comparison have shown that white light scanning interferometry is capable of measuring machined surfaces. The average parameters such as R_a

and R_q are primarily determined by the longer wavelengths. The profile and power spectrum plots reveal that the long wavelength characteristics of the surface are resolved by the scanning interferometry technique. The shorter wavelengths are not fully resolved at the magnification used in this study. This magnification was used to facilitate the computation of parameters according to national standards which require a certain profile length. However, improved spatial resolution can be obtained using higher magnification objectives. In which case the length of the profile available for parameter computation is shorter. In summary, the white light scanning interferometry is a viable technique for measuring machine surfaces.

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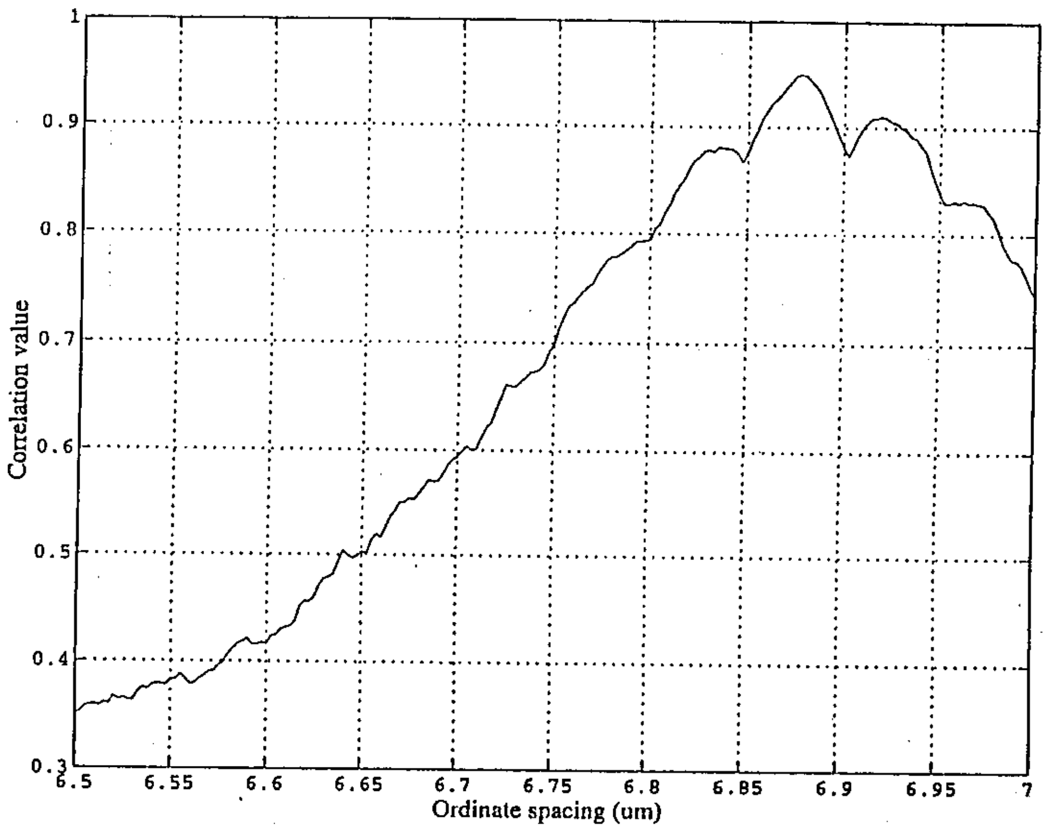

Figure 3 - Maximum cross-correlation value as a function of down sample spacing (PTB specimen).

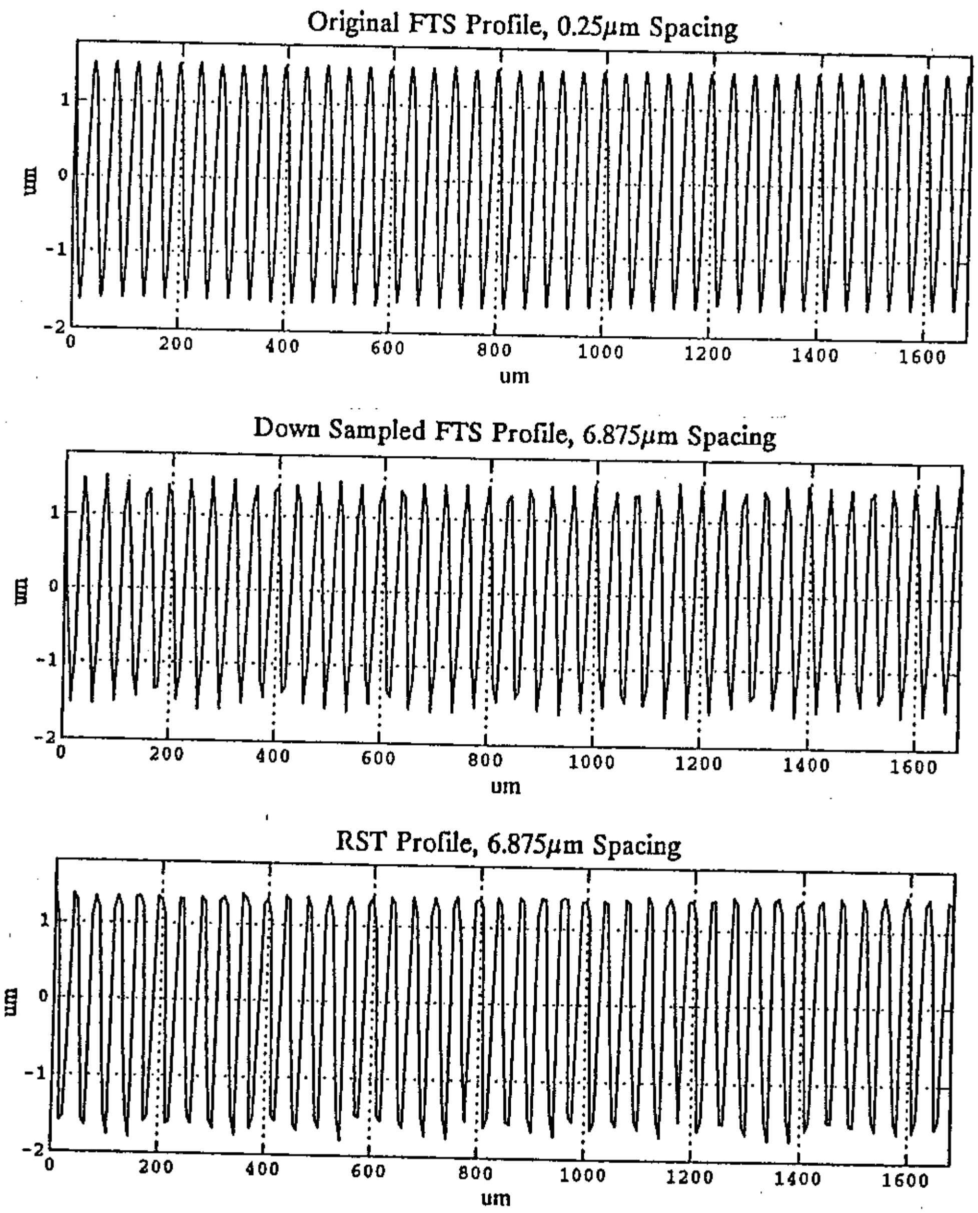

Figure 4 - Unfiltered surface profiles from SRM 2074.

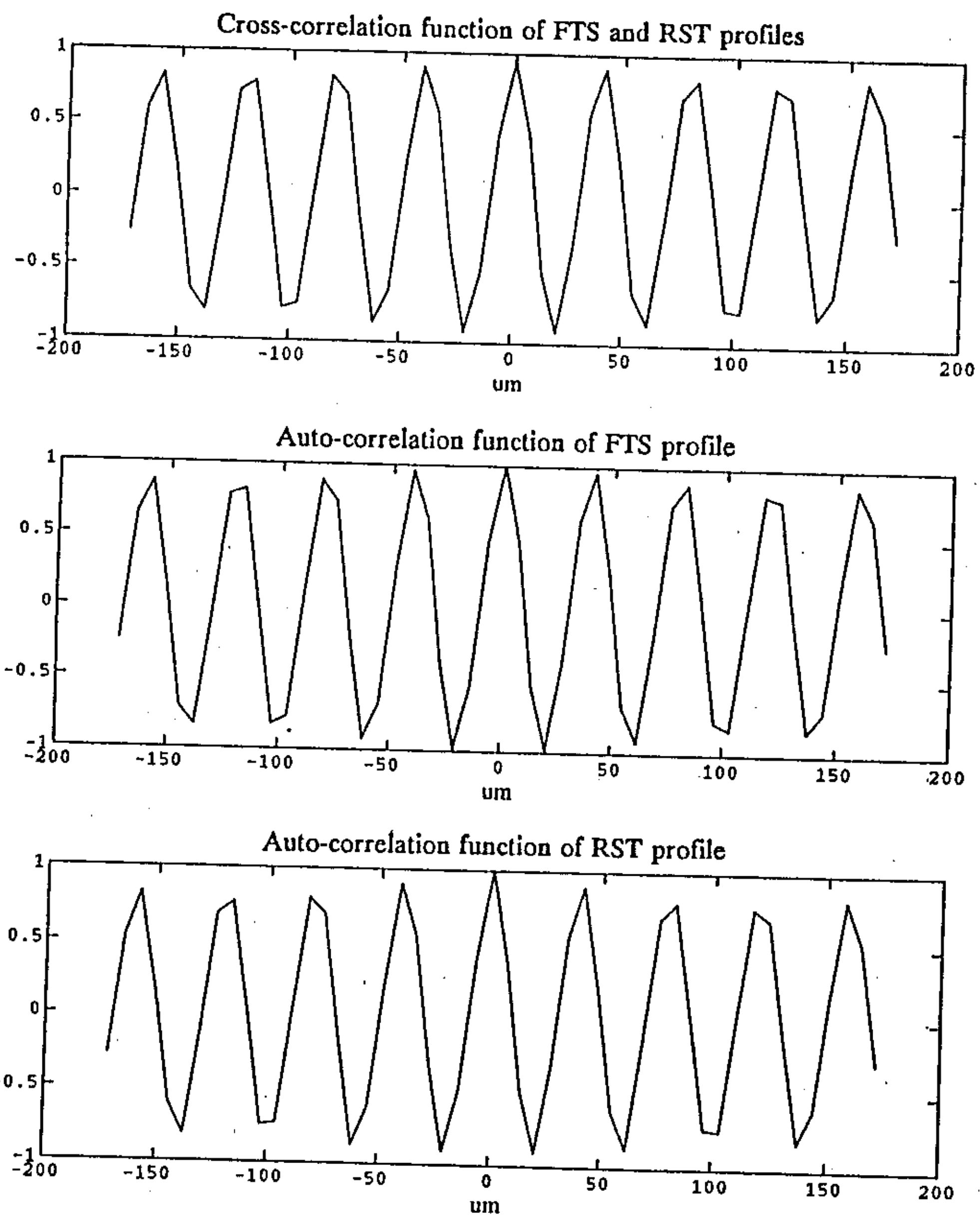

Figure 5 - Cross- and auto-correlation plots of the SRM 2074 profiles.

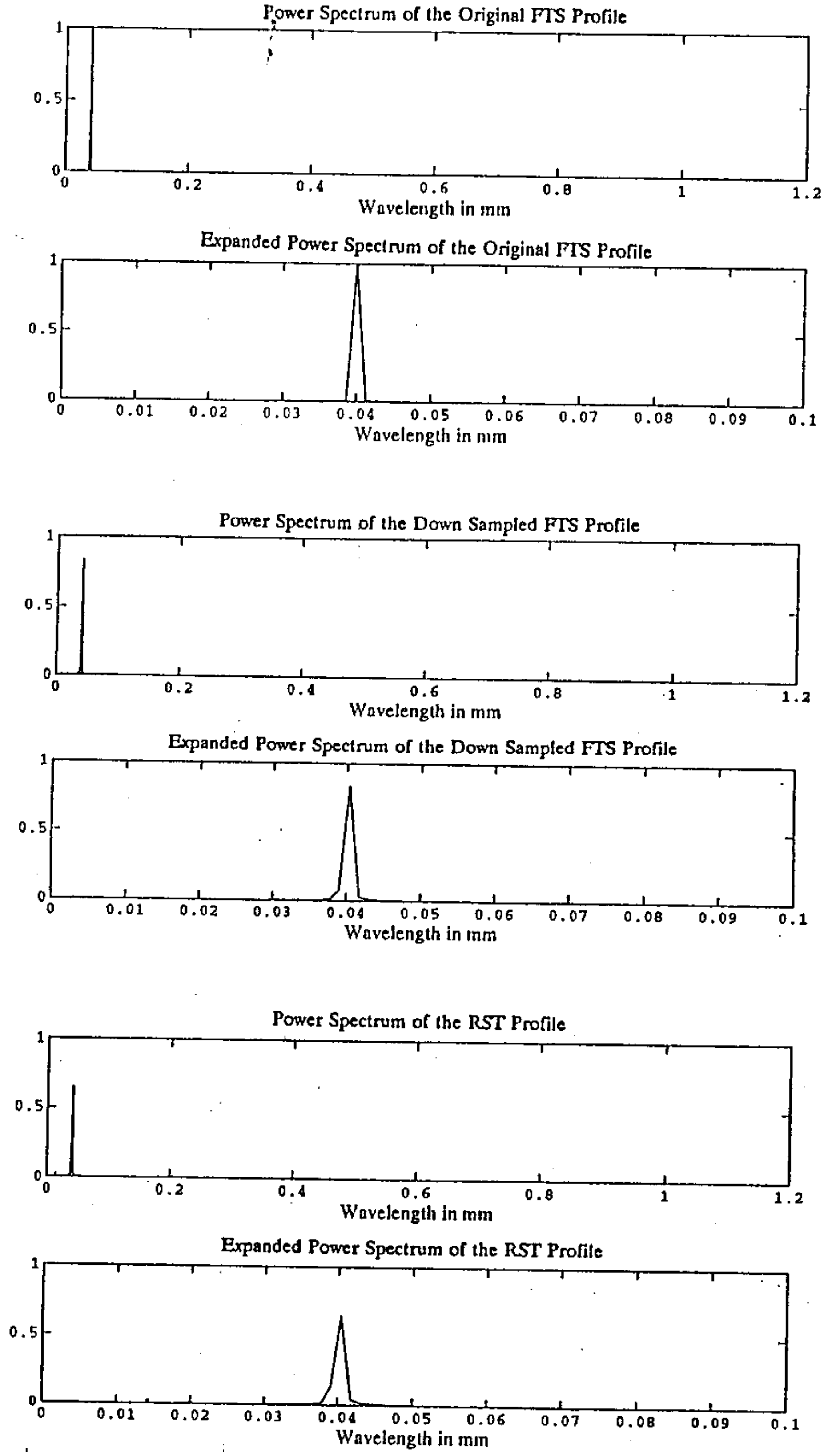

Figure 6 - Power spectrum plots of the SRM 2074 surface profiles.

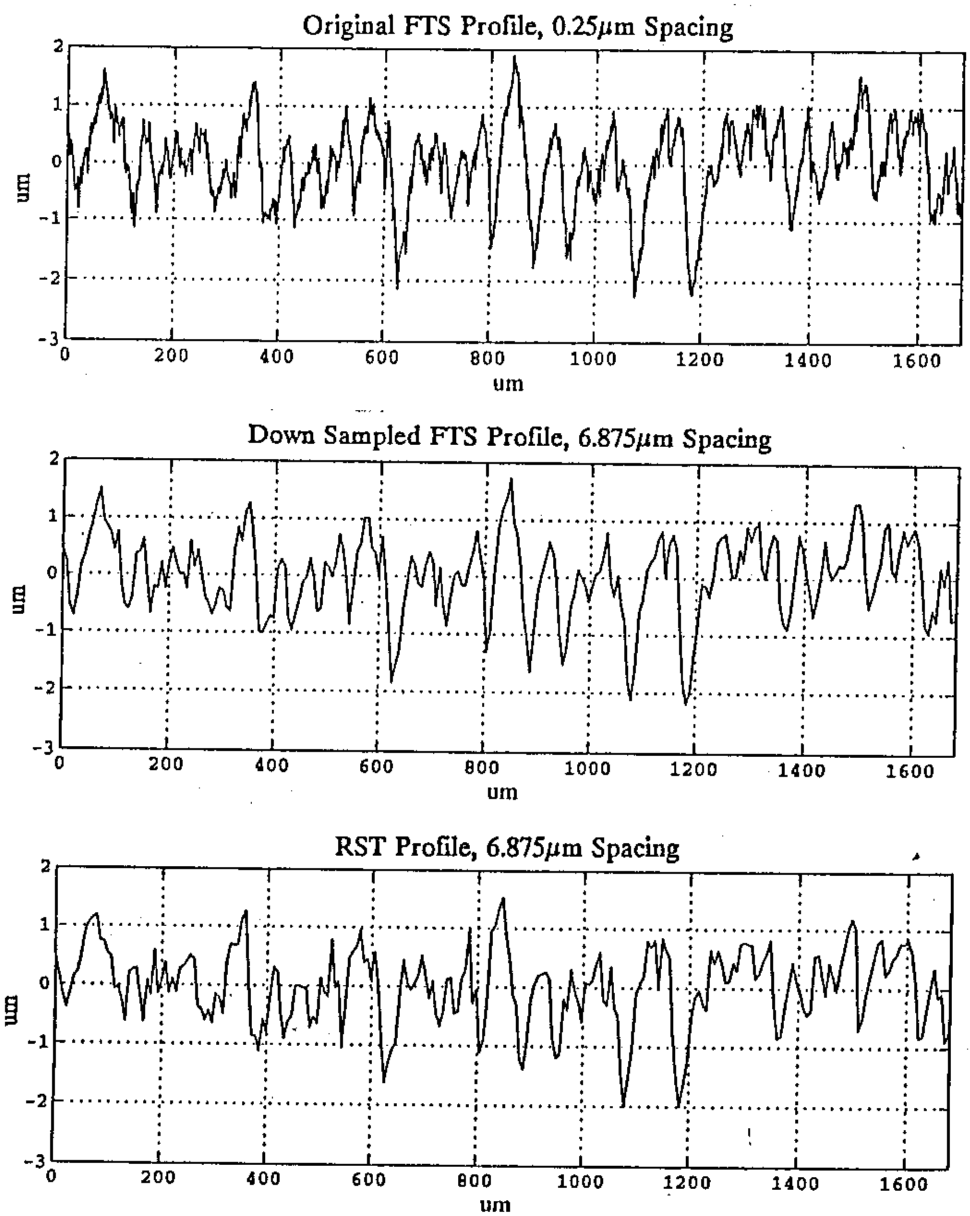

Figure 7 - Unfiltered surface profiles from PTB specimen.

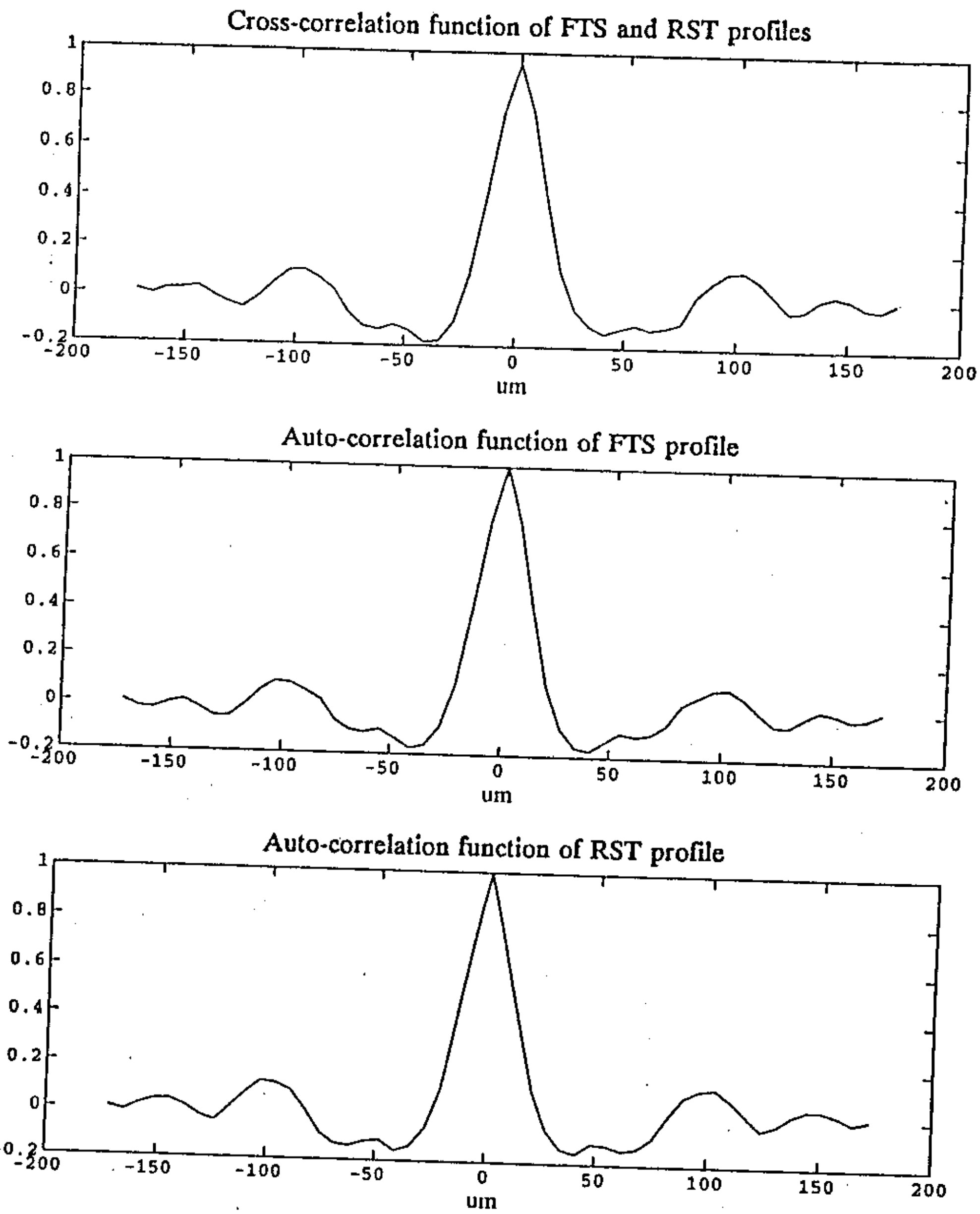

Figure 8 - Cross- and auto-correlation plots of the PTB profiles.

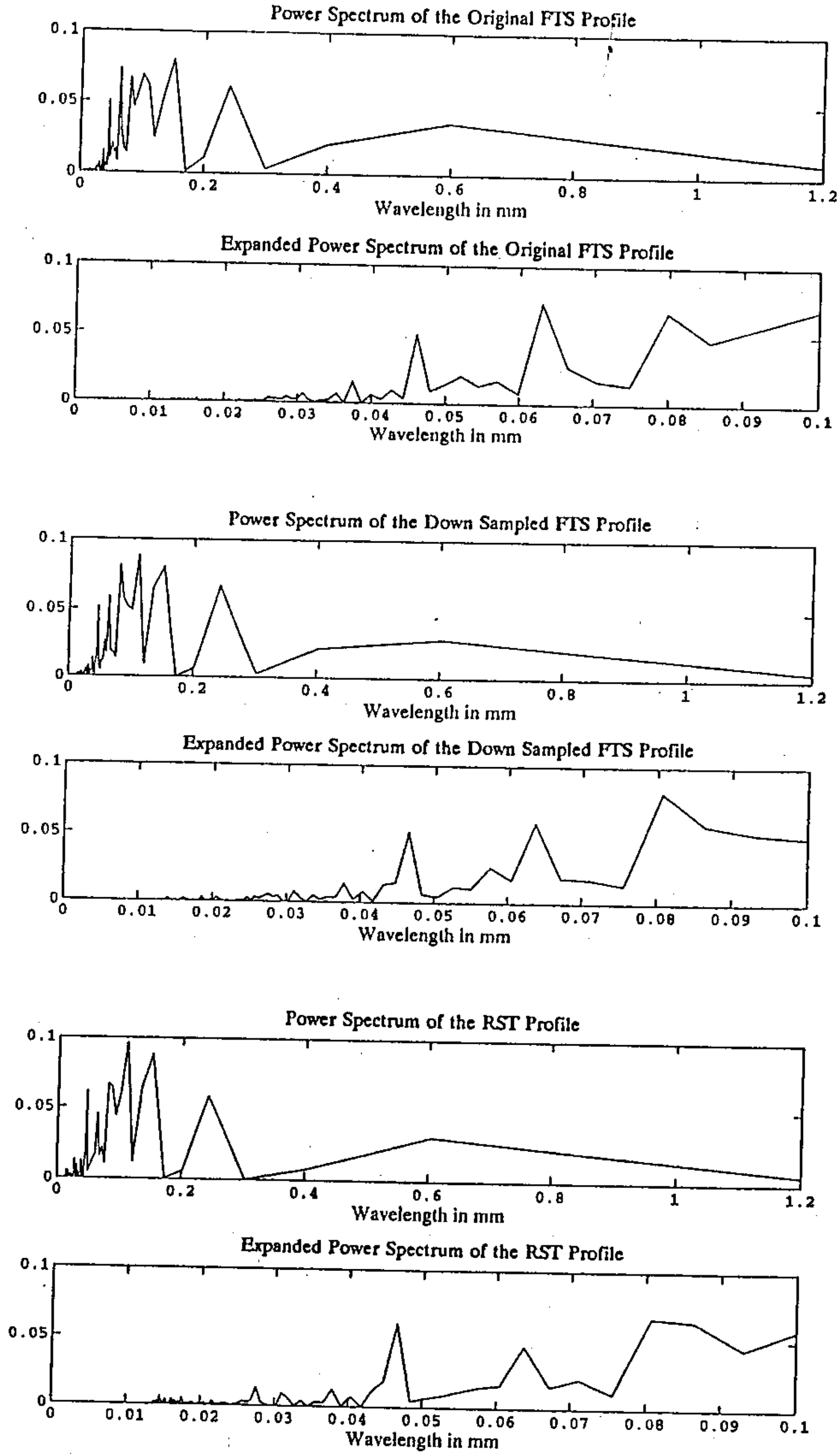

Figure 9 - Power spectrum plots of the PTB surface profiles.

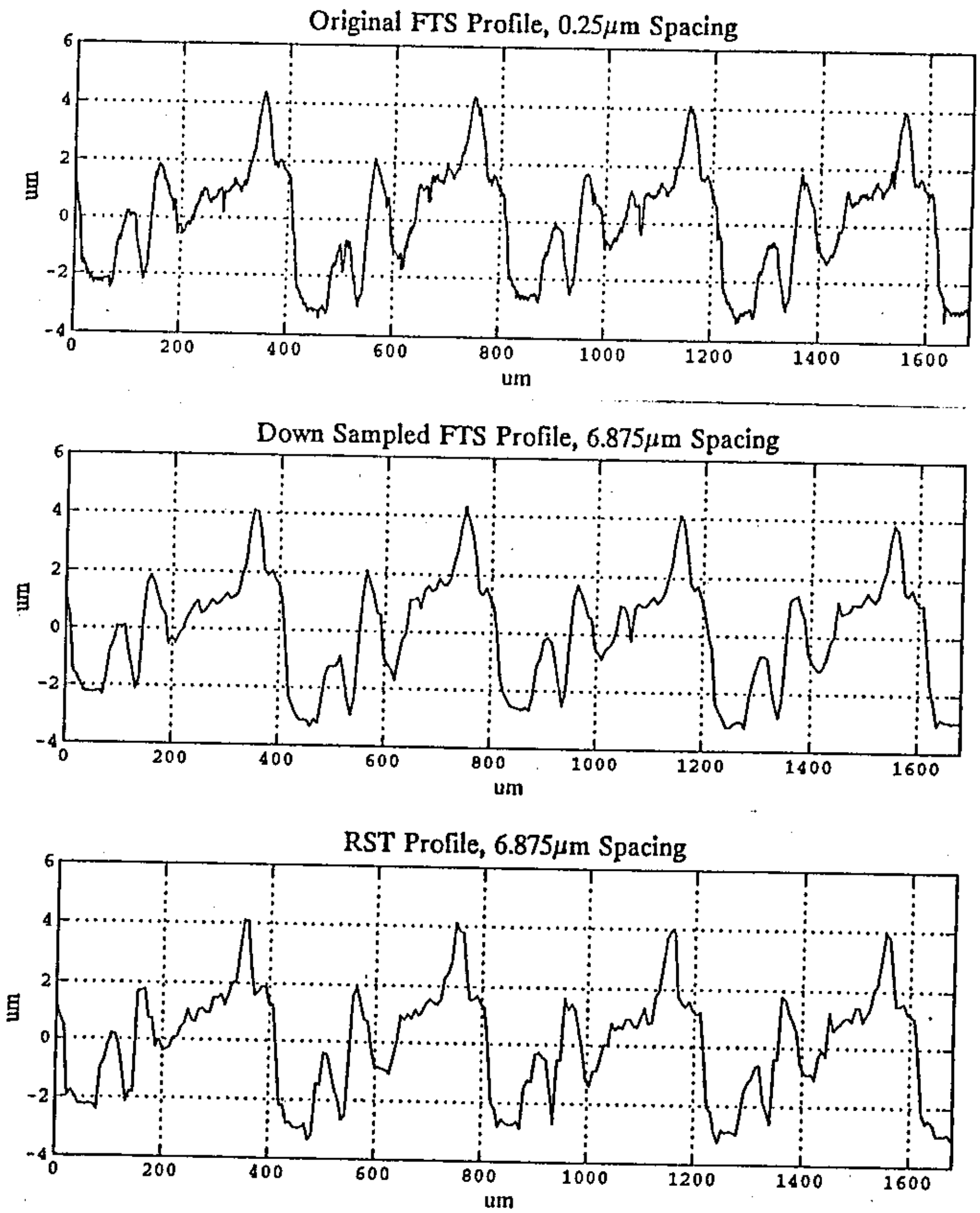

Figure 10 - Unfiltered surface profiles from the milled surface.

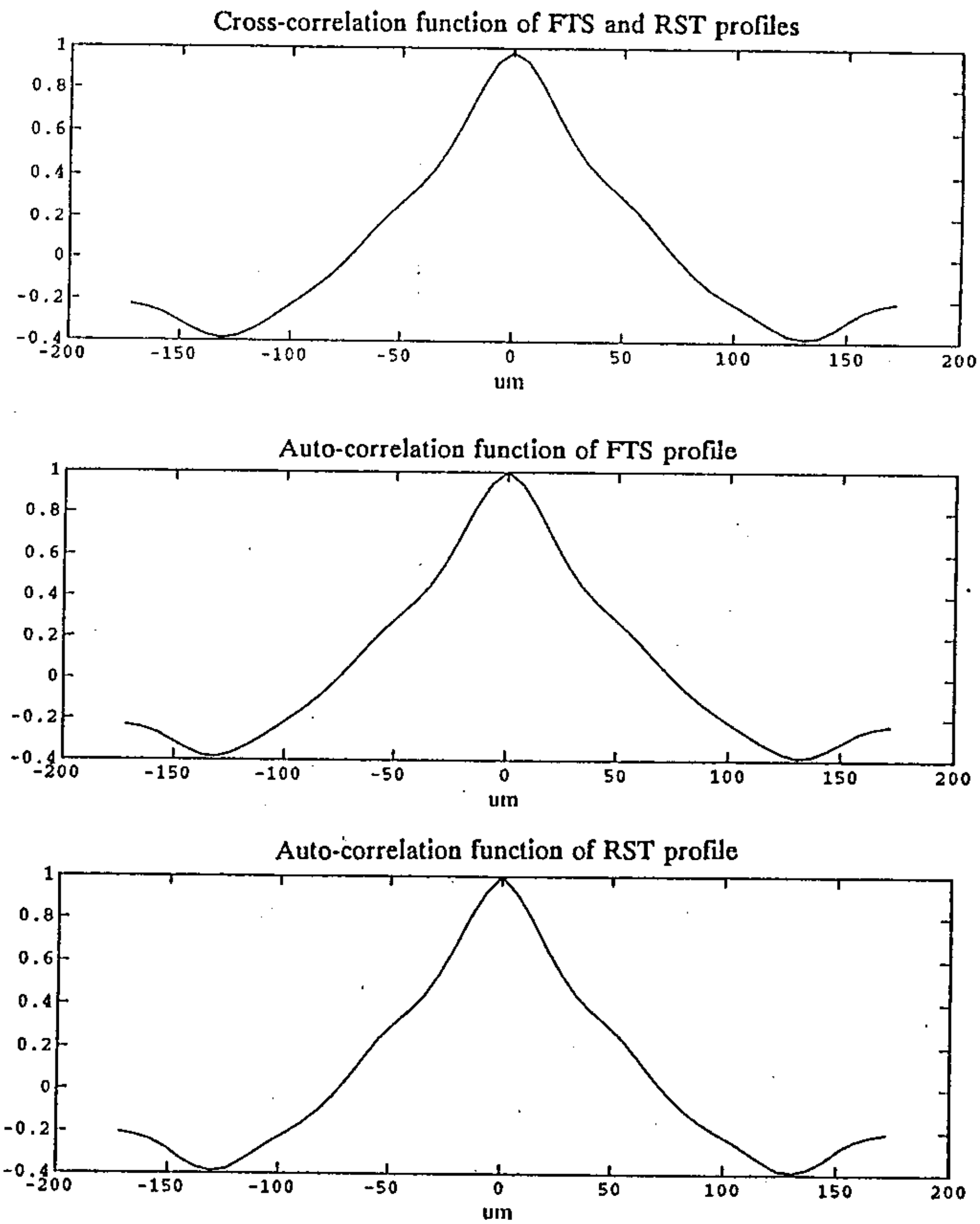

Figure 11 - Cross- and auto-correlation plots of the milled profiles.

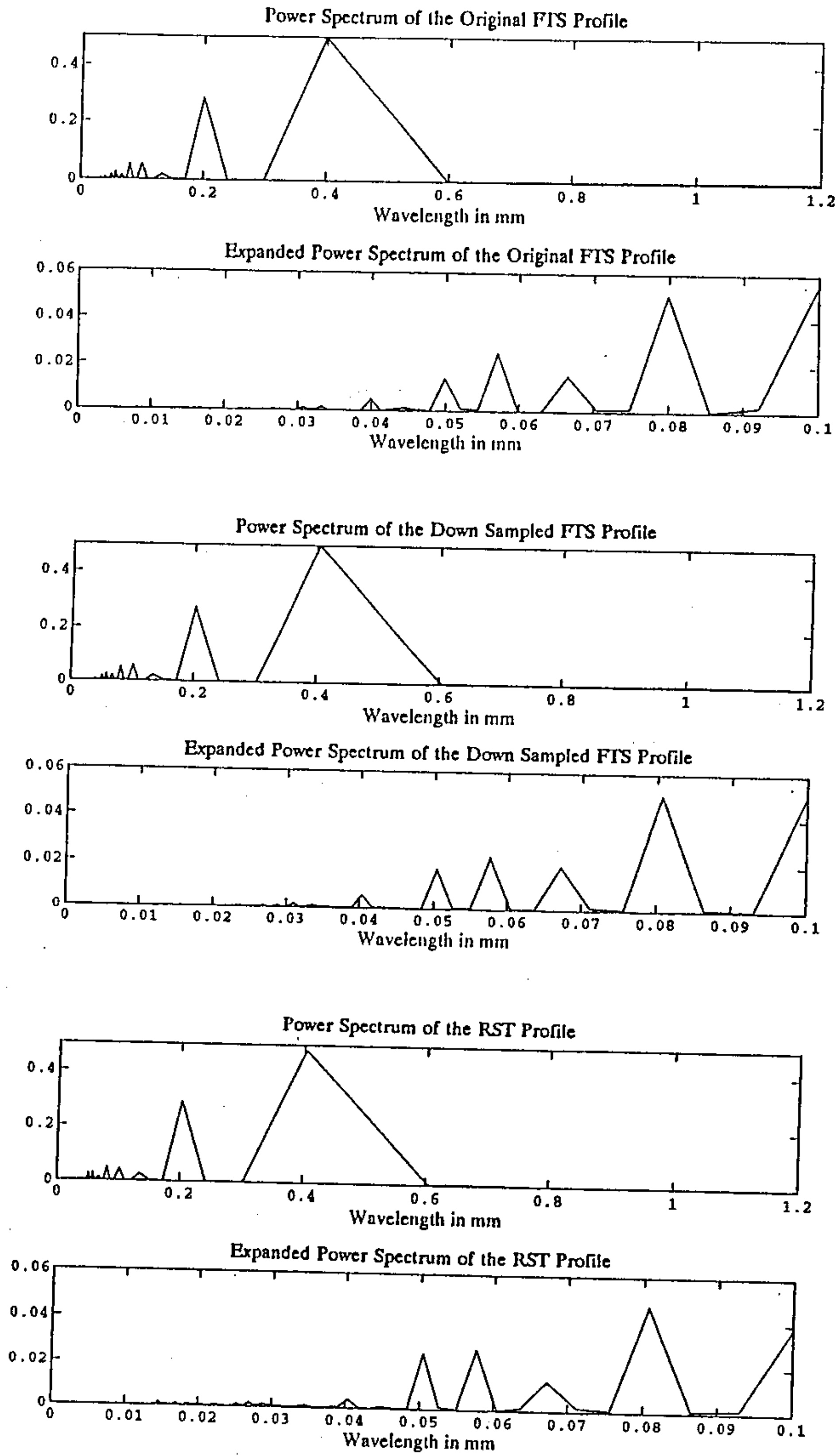

Figure 12 - Power spectrum plots of the milled surface profiles.

A COMPARATIVESTUDY OF SURFACE TEXTURE MEASUREMENT USING WHITE LIGHT SCANNING INTERFEROMETRY AND CONTACT STYLUS TECHNIQUES

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1.0 INTRODUCTION

Surface texture generated by metal removal processes has been measured using stylus type instruments for well over half a century. In recent years, a number of optical techniques have been developed for measuring surface texture. Instruments based on these techniques were initially developed to measure optically smooth surfaces. These instruments overcame some of the disadvantages of stylus type techniques in that they are non-contact and can quickly provide three-dimensional assessment of surface texture. However, instruments based on phase measuring interferometry were limited to very smooth surfaces and small fields of view. Recently, the capability of these instruments has been extended to the measurement of rough surfaces or step heights using white light vertical scanning interferometry. This extension has been achieved through increases in the vertical range and field of view. Commercial instruments are currently available with a vertical range of 500μm and field of view up to 10 x 10mm. The enhanced range and improved field of view have now made this type of instrument very useful in the numerous industries.

The improved capabilities also make these instruments appropriate for characterizing surfaces produced by metal removal processes. The measurement of these surfaces has traditionally been the domain of stylus instruments. This paper presents the results from a comparative study of the profiles obtained from a scanning white light interferometer white the profiles obtained from a stylus instrument.

2.0 INSTRUMENT CHARACTERISTICS

The surface texture measurements in this study were performed using two different instruments. The optical instrument was a WYKO Roughness/Step Tester (RST) while the stylus instrument was a Form Talysurf (FTS). The characteristics of each instrument are described in the following sections.

WYKO Roughness/Step Tester (RST):

The RST is a vertically scanning interference microscope system that operates with one of several interchangeable magnification objectives. Each objective contains an interferometer, consisting of a reference mirror and beam splitter, that produces interference fringes when light reflected off the reference mirror recombines with light reflected off the sample. When short-coherence white light is used, these interference fringes are present only over a very shallow depth on the surface. The surface is profiled by scanning vertically so that each point on the surface produces an interference signal and then locating the exact vertical position where each signal reaches its maximum amplitude.

Form Talysurf S5:

The stylus instrument used in this study has a 4mm vertical range with 10nm resolution, and 120mm horizontal scan range. A conical stylus with a 1.5-2.5μm nose radius and 90° included angle was used. In general, the finite dimensions of the stylus mechanically filters very small surface wavelengths. The characteristics of this filtering depend on the radius and the included angle of the stylus. In addition, if a skid is used in the measurement it results in additional mechanical filtering of the longer wavelengths. The measured surface profile is then filtered to separate roughness and waviness.

3.0 RESULTS

The instruments described above were used to measure a number of different surfaces. The profiles from these measurements were analyzed in detail to understand the correlation between the two measurement techniques. The validity of this comparison requires careful consideration of the measurement procedure. The measurement procedure should ensure that the profiles are collected from the same location with similar ordinate spacing. This has been achieved by first physically profiling the same location using both instruments to obtain two profiles. The stylus profile ordinate spacing was then adjusted to be the same as the optical profile's using an iterative down sampling procedure. The resulting profiles were then quantitatively compared. The ensuing sections describe the measurement and analysis of these profiles.

Measurements were performed on a variety of surfaces. These surfaces ranged from reference specimen from NIST (sine wave) and PTB (repeatedly random ground surface), and manufactured surfaces (e.g. vertical milling and turning). These surfaces were chosen to cover a wide range of surface roughnesses and lay patterns. The results for the PTB specimen are discussed below.

Random Profile Calibration Standard:

Examination of random profile calibration standards allows for the evaluation of the measurement interaction over a wide range of wavelengths. The random profile calibration standards are a set of ground surfaces that have a random surface profile that repeats at regular intervals. The PTB reference surface used in this study had an average roughness (R_a) of 0.54μm, maximum peak-to-valley length (R_t) of 3.51μm and repeat interval of 2mm. The analysis results for this surface are given in figures 1 and 2. Figure 1 shows only minor differences between the down sampled stylus profile and the RST profile. The power spectrum plots show differences only in the short wavelength region which corresponds with the deviations observed in the profiles.

4.0 CONCLUSIONS

Surface texture measurements have been done using white light scanning interferometry and stylus profilometry on a variety of surfaces. In order to compare the profiles from the two instruments, measurements were carried out in the same region and then matched using correlation techniques. The results of the comparison have shown that white light scanning interferometry is capable of measuring machined surfaces.

Profile ID	R_a (μm)	R_q (μm)	R_t (μm)
FTS Original	0.5353	0.6709	3.6414
FTS Down Sampled	0.5290	0.6666	3.4128
RST	0.5008	0.6226	3.1548

Table 1 - Parameter values for PTB reference specimen.

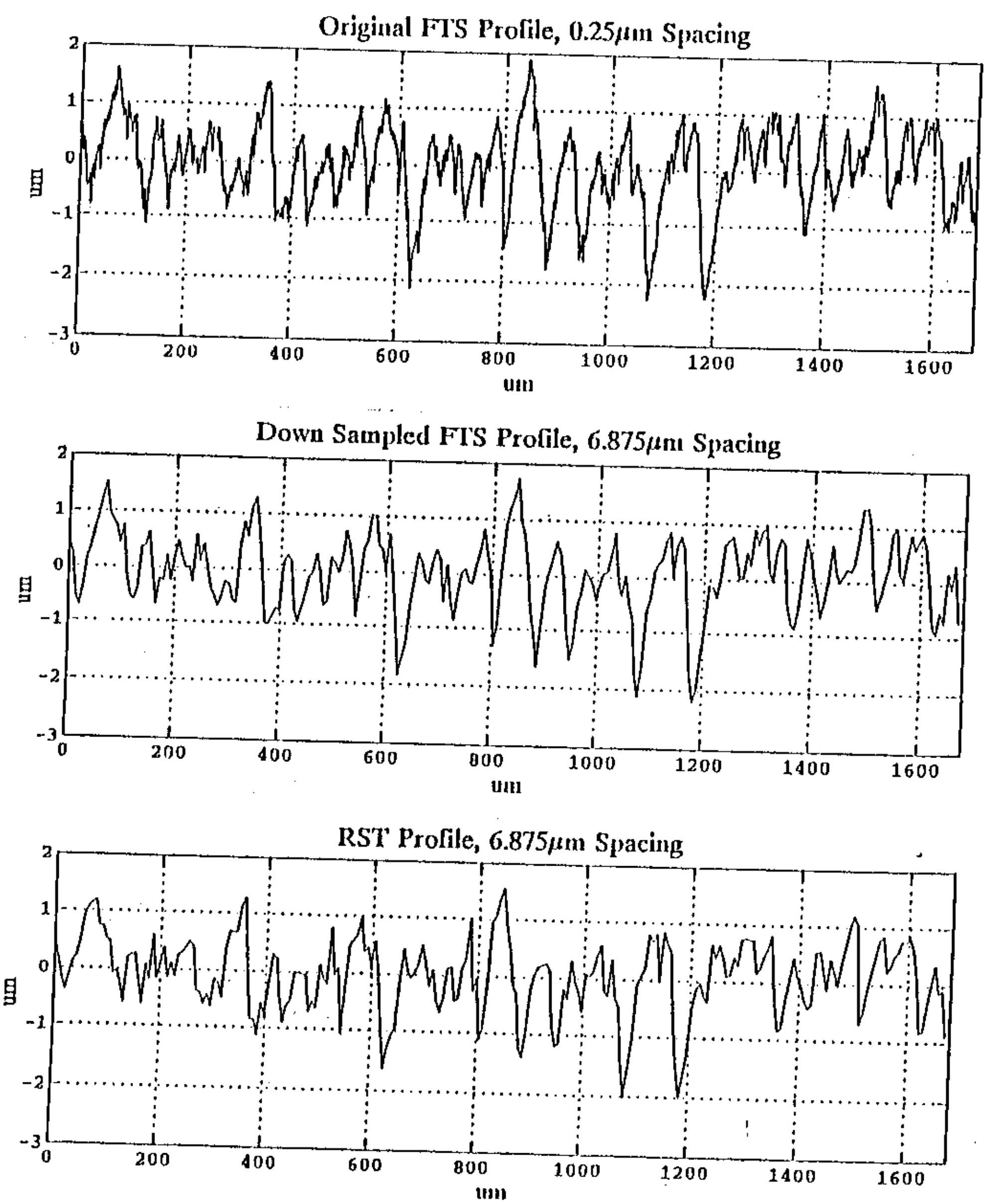

Figure 1. Unfiltered surface profiles from PTB roughness specimen

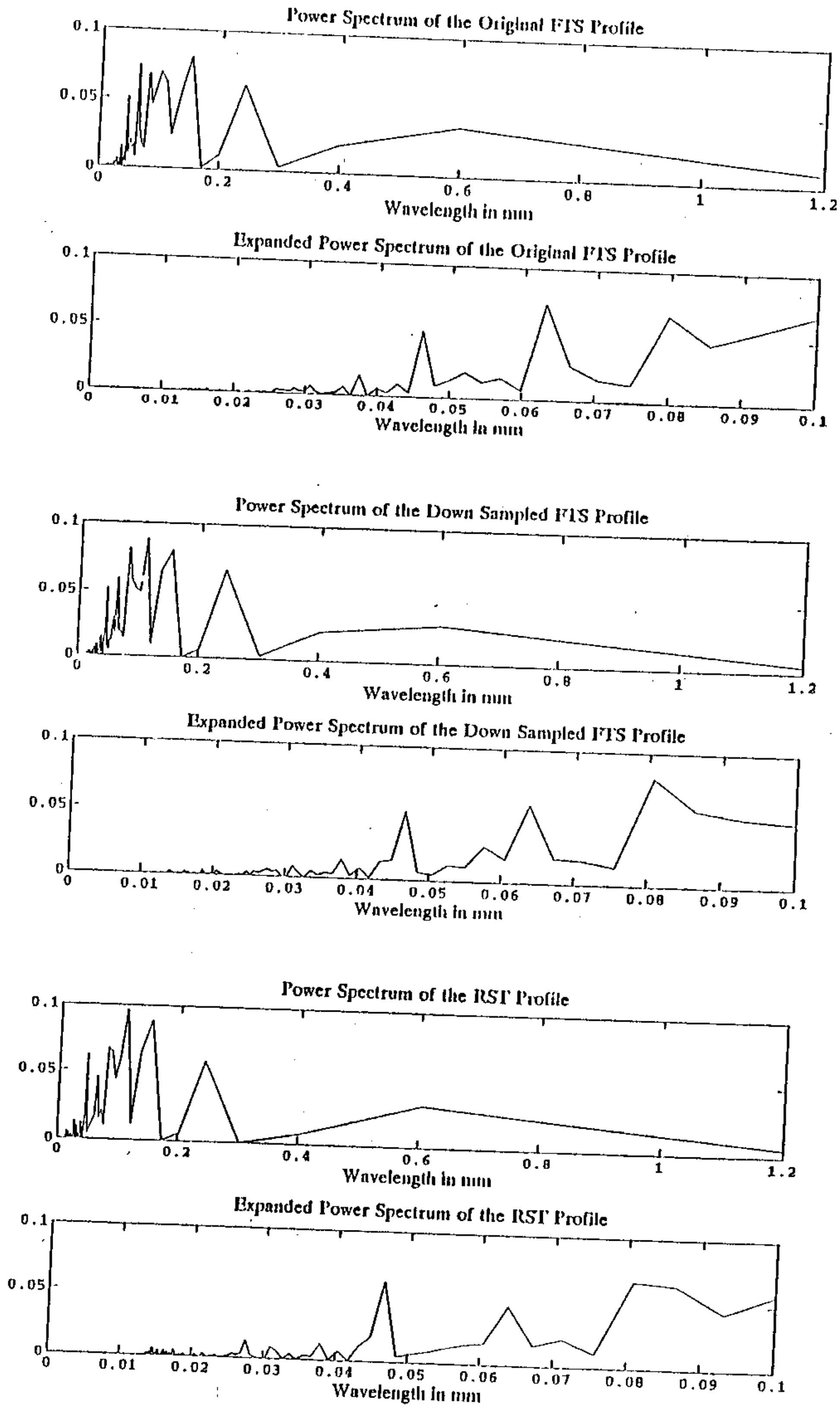

Figure 2. Power spectrum plots of profiles from PTB specimen