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CHALLENGES IN SURFACE METROLOGY

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Abstract: *In an area which has been explored and researched for many years, normally there may not be many challenges left. However, in surface metrology in which research started in a systematic fashion in the late thirties of the last centaury, there are still many challenges left and more are in the offing. The reasons for this can be seen in the development of technologies associated with this measurement and the demand from the user groups keen on getting worth while inputs for clear specification, product realization in practice and reliable applications in current and emerging areas. This paper addresses some of these challenges with specific reference to surface roughness and emerging technologies.*

1. INTRODUCTION

Surface metrology has been in vogue as a tool for achieving the required finish in manufactured parts, for over seven decades. While dimensional measurements were the focus of attention in the initial phase of manufacturing, currently surface is becoming a significant feature to be evaluated in practice. This arose from the linking of dimensional variations (tolerance) and the finish of the part manufactured, as the tolerance diminished substantially. As long as the tolerance on the part remained reasonably high the need for achieving good finish was of secondary consideration. No doubt even then strides were made to evaluate the achieved finish in manufacturing through different means and to assign a specific value for it for quantification. In the late thirties of the last centaury, efforts were on to develop suitable techniques which could provide a convenient procedure for the assessment of finish achieved in manufacturing. Initial surface studies were reported using optical microscopes of low magnification where in surface images were qualitatively assessed with reference to comparison standards. Different approaches based on mechanical, optical and electrical principles were soon developed both for a 2D visualization of the rough surface profile as well as to get a representative quantitative value for such profiles for convenient specification. Both tactile and non-tactile methods were adopted which could meet the requirements at that point of time. The first tactile device using mechanical amplification was developed at NPL, England around 1920. In about another decade one of the earliest books on the topic of surface and its evaluation was published in Germany by G. Schmaltz. It was basically on optical methods of surface measurement and comparison. Both the tactile and optical devices had limitations on amplification of the surface profile and in assigning a suitable parameter for its measurement. A practical approach for measurement and recording was possible with the advent of stylus instrument with electrical amplification, in the next few decades. In fact it was this instrument which allowed convenient measurement of the roughness as well as the recording of the profile. Parallel to this, other optical instruments were developed based on light sectioning and interference principles. Most of the early roughness parameters emerged from these instruments and were basically related to the geometry of the surface profile [1, 2].

2. EVALUATION OF ROUGHNESS

In the last sixties, advances in electronics permitted some flexibility in the parameters measured by tracing stylus instruments with different switching circuits for different measurements. Roughness parameters at this point of time were limited in number, mostly confined to those obtained through electronic stylus instruments. Another interesting development at that time was the concept of form, waviness and roughness. Basically this came from two angles - one from the application side and the other from the measurement side. Due to specific amplification needs, all the three could not be measured at the same time, leading to their separation in measurement. However the two paths never converged fully, resulting in difficulty in the procedure for separating them. On one side, the application needs prompted a mechanical concept to be developed for the separation of relatively long waves consisting of waviness and form. Concurrently the advancements in signal processing allowed the electronic tracing stylus instruments to separate these features using electrical filters. Due to this convenient procedure, electrical separation of waviness and form became a standard procedure in surface measurements. The other geometrical cum mechanical approach of filtering named as Envelope System, suffered a set back due to severe instrument limitations.

With hardware instrumentation there was not much to choose from among the roughness parameters in vogue at that time. They were simple enough to be accepted by the industry but were of limited advantage in various applications concerned with the functional behavior of surfaces. While application engineers religiously used the accepted parameters as there was not much choice for them, surface metrology researchers focused on the measurement approaches and roughness evaluation. However the fact remained that once a parameter is accepted and used, it is difficult to dispense with it unless there are compelling reasons to do so. It is a fact that we have not yet seen any urgent reason to change this.

3. COMPUTING ROUGHNESS

By late sixties computers could be used for processing the data obtained from simple stylus instruments and the surface metrologist started breathing some fresh research air. They got too much of oxygen and there was the proliferation of profile analysis using newly developed algorithms. Sad to say, that they were again confined to the narrow areas of profile evaluation and characterization. There were only limited forays into genuine application areas to understand the advantage of any specific analysis or parameters got there of. This was the time of intense publication in the area and the development of “Parameter Rash” [3]

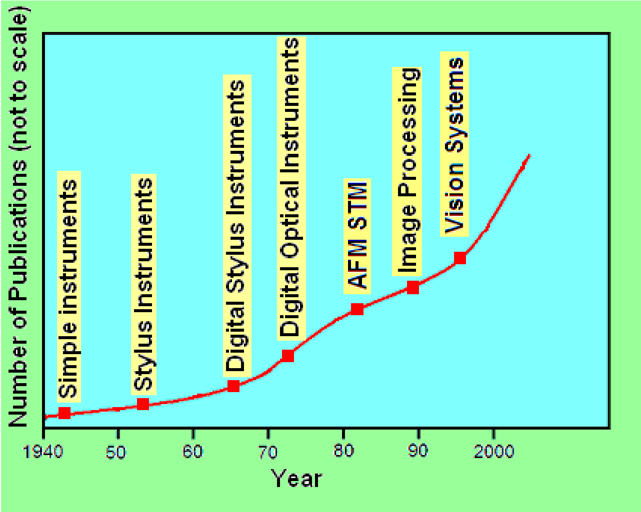


Fig.1 Trend in research publications in surface metrology

Fig.1 gives an approximate trend in the number of publications on surface metrology research and applications, over the years [4]. Reasons for specific increase in the numbers are due to paradigm shifts in the approaches in the measurement and analysis of surfaces in specific time intervals, as indicated in the figure. The first major shift was the digital analysis of surface data, in the late sixties. With developments in microelectronics came a set of optical measurement tools for surface measurements. These permitted areal (3D) measurement and analysis of surfaces. Instruments working on interference principles, confocal microscopes, fringe projection systems and white light speckle are the ones which were developed to meet this requirement. These instruments were ideally suited for the semiconductor industries and gradually emerged as the right ones for ultra high to medium finished surfaces. They could also cover micro machined components for topography measurement. Combined with excellent graphics software the data could be presented with stunning reality. Parallel to this, scanning electron microscopy was also used for certain specific observations on surfaces.

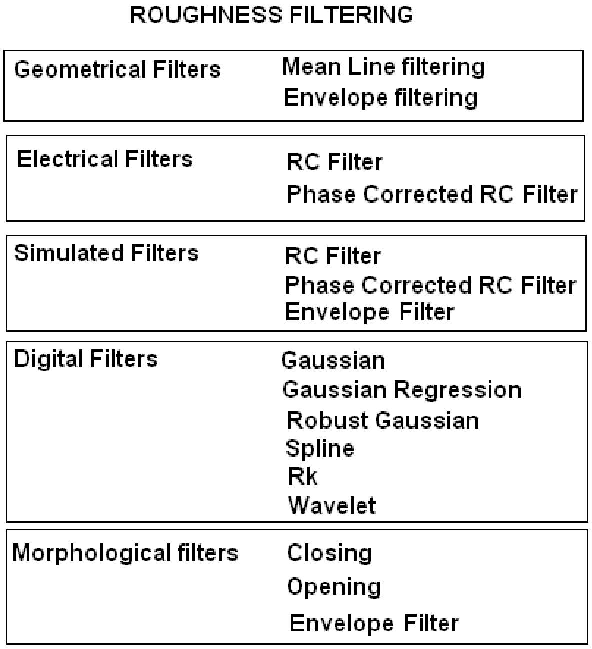
The major advantage of stylus and the optical approaches mentioned earlier is the ease with which these instruments could provide digital data which could be conveniently processed using a microprocessor or a full fledged computer. It allowed the researcher to try various alternative routes for the separation of waviness as well as for specific roughness value extraction. The number of parameters suggested presently for roughness evaluation is sometimes mind bogging as there are no clear recommendations on the applicability of a specific parameter for an intended application. Added to this, there came the possibility for deriving 3D roughness values, both geometrical and statistical, of surfaces. Search for the ever evading parameter which could answer many questions still being faced by the application engineer is continuing and the chance for finding such a unique one in the near future is almost remote. It will be a great relief if few selected surface parameters are identified which are attuned for specific practical applications. That will be a challenge to be taken jointly by the metrologist as well as the application engineer.

4. UNDERSTANDING THE ROLE OF SURFACE ERRORS

Most of the research on surface metrology is done by people who are pretty well connected with measurements and analysis. While this brought new approaches for surface evaluation, absence of user interaction made the procedures limited in their applications. Right from the steps taken on waviness separation for roughness evaluation, this focus towards measurement approaches can be seen. Even today there are only vague explanations on the role played by waviness in surface applications. As the applications and the requirements are expanding, there is the need for some clarity on waviness separation in specific applications. Presently there are a number of different filters used for waviness separation with standard cut-off values [5]. Fig.2 gives the details of different filtering methods employed in surface evaluation. Note that the Envelope system has emerged again as a viable approach under morphological filtering.

It is quite possible that no application engineer has worked out the role of these cut-offs or specific waviness separation approaches, in any specific application area. One mistake the metrologist has done is to view the application requirements from the measurement angle. In some cases the user industries have found certain advantages with new parameters which were not developed originally from the measurement angle. Examples are in motif combinations and Rk value which are considered to be suited for automotive parts. As the application range is ever increasing it will be a challenge to arrive at the right procedure on waviness separation and to understand the role of cut-offs in specific applications.

Roughness evaluation for specific applications are on the increase as our basic knowledge on the interaction of surfaces with the environment improves. Whether this is to be the job of the metrologist devoid of application expertise or that of an application researcher with limited measurement knowledge is always a question. The ideal solution is to think of metrology for solving an application problem. If one is not prepared to look at this seriously, soon some of the application areas will come out with approaches which may not be easily correlated with standard measurements and analysis but good for the shop for control and for specific applications. We have already some things of this type where the values given by different instruments for the same surface may not have much correlation.



ROUGHNESS FILTERING

Geometrical Filters	Mean Line filtering Envelope filtering
Electrical Filters	RC Filter Phase Corrected RC Filter
Simulated Filters	RC Filter Phase Corrected RC Filter Envelope Filter
Digital Filters	Gaussian Gaussian Regression Robust Gaussian Spline Rk Wavelet
Morphological filters	Closing Opening Envelope Filter

Fig.2 Some of the filtering methods adopted in surface metrology

5. AREAL OR 3D SURFACE EVALUATION

One of the advantages of using digital measurement techniques in surface metrology is its ability to deal with areal (3D) surface data. Most of the optical instruments working on interference principle give excellent 3D rendering of the surface irregularities. They can conveniently give any profile of the measured surface, in any direction, with ease. That does not mean that these instruments are able to give a good idea of the 3D roughness involved. Though standard values for 3D roughness can be extracted from this data they are not yet in great demand. It is mainly because of the fact that the information content of a real 3D surface is far more than that is extracted as per the proposed standards. A picture is worth a thousand parameter is true here. This aspect of looking for surface topography details, which has been used in practice over the years, is a clear indication as to what is needed in this direction. Often complex measurement or sensing need parallel assessment of the entity through different means. Multi sensing enhances the measurement reliability as well as information content. Can we use areal information together with profile values to arrive at an acceptable solution? The challenge lies in bringing the right information contents of the roughness values and that of the areal features together for specific applications.

To the practicing engineer information on the process used to produce the surface is of great interest. The topography generated by the process is of specific interest to the function. The value of the finish to be controlled is to be taken together with the needed topography. Honing process is needed in engine cylinder production and that cannot be replaced by grinding or any other process even if they give the same 2D or 3D roughness values. Most of the advanced 3D measuring devices provide this visual information on the topography which has great significance. It is interesting to note that there are presently some attempts to capture this aspect of the topography through analytical means. Image processing techniques have been used in this direction. Areal filtering of surfaces is now possible through morphological filters and some of the approaches are those which were conceived in the early times of surface measurements. The E-system approach of measurement is that of a morphological filter which today can be done with ease. So some of the old concepts are now back in reckoning.

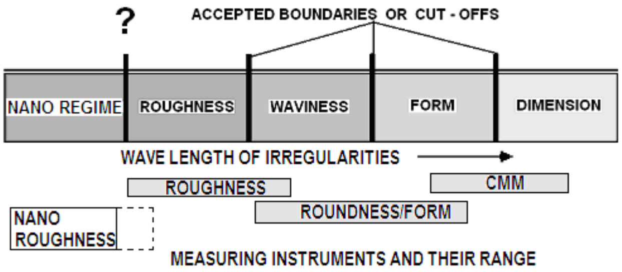


Fig. 3 Classification of surface errors

Fundamentally surface errors based on the wavelength criteria of the irregularities present allowed the formulations of form, waviness and roughness [6]. That was when we were not able to penetrate any further into finer details of the surface beyond roughness. With nano level engineering, there comes a group of surface irregularities with lower wave lengths which could form a different grouping. There is no terminology for it yet other than perhaps nano roughness. Will we be separating that from the rest using standard approaches hitherto used (Fig.3)? As we understand the role of these irregularities at the nano level, we may have to recon with this aspect soon. There are again the limitations on the instruments. Presently no instrument measuring the surface at the nano level has got the capability to include the roughness or waviness in the measurement. Tracing lengths as well as their vertical resolutions are different for these different instruments used for nano roughness, roughness, waviness and form. However one can develop hybrid instruments (CMM and AFM) and scan and stitch the images to get reasonable coverage of the area/length [7].

With the introduction of bottom-up approach of manufacturing, producing a surface of any specific topography is possible. Today structured as well as engineered surfaces can be produced with ease. Structured surfaces are geometrically defined and deterministic [3, 7]. Engineered surfaces are those which have been produced by processes that have been controlled to achieve the required function and surface properties. Production of structured surface was a tough proposition in the top down approach and masked etching is a method of manufacture which could give reasonably good results (Fig.4). Micro forming is another approach for replicating the structured surface.

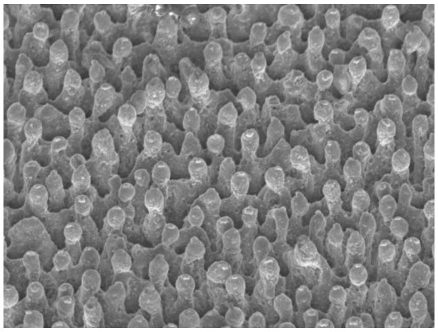


Fig. 4. Laser etched surface

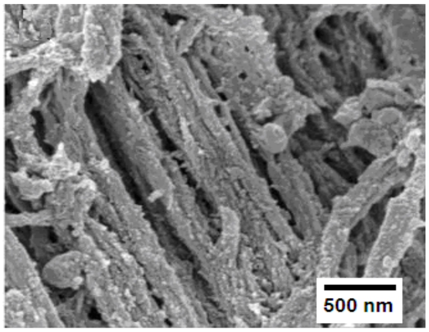


Fig. 5. Fractured bone surface

With the bottom–up approach, surfaces of deterministic nature rather than stochastic ones are easy to produce. Additionally surfaces with the required features covering dents, projections and pores can be fabricated at the nano scale. Such surfaces are to be evaluated for its function and the parameters needed for them could be different from the existing ones. Many naturally occurring surfaces like fractured bone surface exhibit these features (Fig.5).

In micro channels systematic variation of surface roughness has been employed for droplets propelled by vibration. Microfabricated silicon pillars have been developed to get the roughness which determines the contact angle for non wetting of the droplets [8]. Fig.6 shows the Fakir effect permitting the drop to move without wetting the surface.

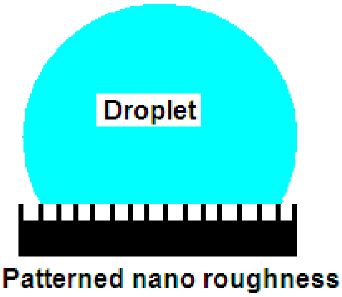


Fig.6 Fakir Effect due to patterned nano pillars in micro fluidics [8]

With expanded research on biological systems, there is the need to address many of these issues that are related with nano scale irregularities and arrive at possible solutions. Here again one sees the merit of the 3D surface topography and the challenges ahead.

Another interesting group of surfaces which can align easily with relatively longer wave lengths of the mating surface irregularities is seen in biological systems. These are soft surfaces that are able to get into compliance easily. This permits them to be in close contact at the nano level and exhibit strong bonding. Will it be possible to ascertain this ability of the surface to align with the finest and discreet irregularities of the mating surface? Many new surface interaction properties are derived at this level of operation affecting the functional performance of micro and nano systems. These include micro fluidics, IC line resistance, adhesion etc.

6. UNOBSERVED SURFACES

Almost all the instrumentation available for surface metrology has one defect. They are not capable of detecting undercuts and cavities. In fact even in ordinary machining,

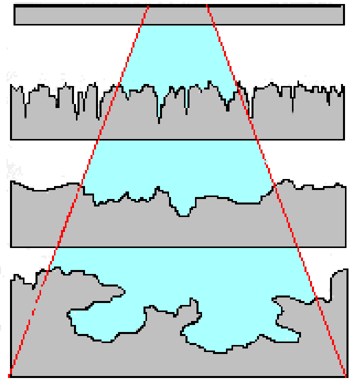


Fig. 7. True nature of a surface

material deformation leads to surface undercuts. Stylus and optical instruments have limitations on revealing the true nature of this irregularity. (Fig.7, 8)

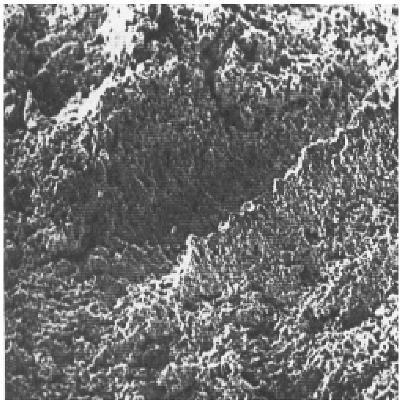


Fig.8 Deformed surface in machining

As many of the surfaces seen in nature have this feature, it will be a challenge to develop a non-destructive technique for their assessment. With that comes the assessment needs. Of late surface area measurement is gaining some significance, especially at the nano scale. Another challenge in surface metrology is the measurement of free form surface and that too at the micro level [9].

7. ON SHOP FLOOR REALITIES

Ultimate aim of any measurement is to control some action to achieve the required result. Surface metrology is not an exception to this. Presently there are limitations in this. Today surface metrology is often a post process action [10].

However with close tolerances and greater demand for surface finish control there is the need to develop a process monitoring strategy through dimension, form and finish

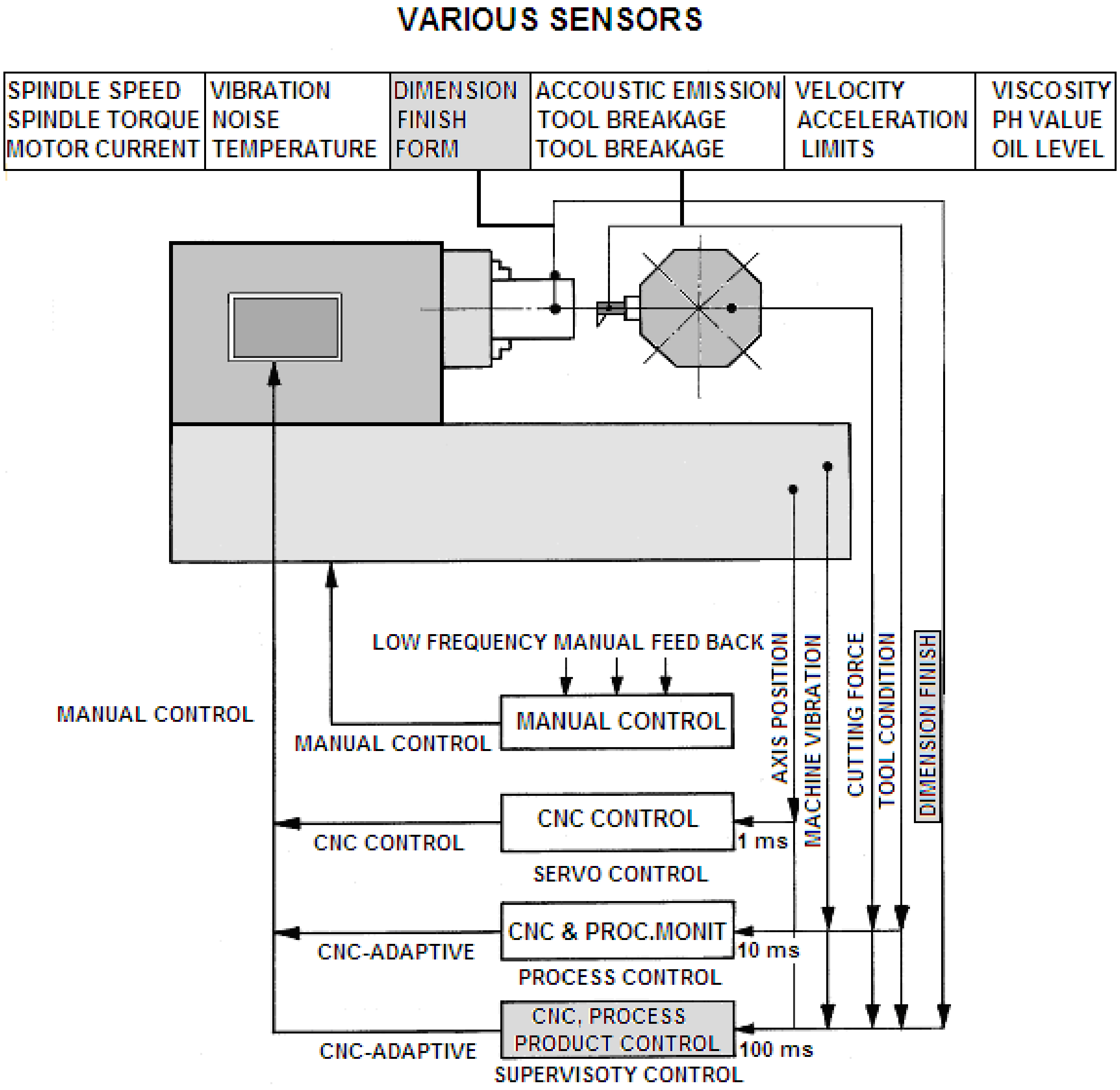


Fig.7 Intelligent Machining System

monitoring (Fig.7). This, when happens, should be in tune with those standards formulated over years on surface metrology. Further such systems should encompass monitoring of surface features of different types and scales which are needed currently. No doubt it will be a challenge worth taking by the practical engineer and the metrologist.

8. CONCLUSIONS

Over seventy years of surface metrology has revealed that we are yet solve some of the existing difficulties in this filed. In spite of this, an impressive array of procedures and protocols has been developed to address many of these difficulties. On the instrumentation front there has been a paradigm shift towards areal measurements. Micro and nano technologies are providing opportunities to generate structured surfaces which were hitherto difficult to achieve. Measurement of form, finish and other topographical feature of these surfaces at the micro and nano level will pose many challenges to the surface metrologists. However the bottom line is about providing the right information to the people who need them for specific applications. No doubt the applications are on the rise as we explore more and more at the bottom where there is plenty of room. For the metrologist the twin tasks will be on measurements focused towards understanding surface behavior in the new regimen and to provide the right measuring parameters for product realization.

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