

AN ACOUSTIC EMISSION TECHNIQUE FOR MEASURING SURFACE ROUGHNESS

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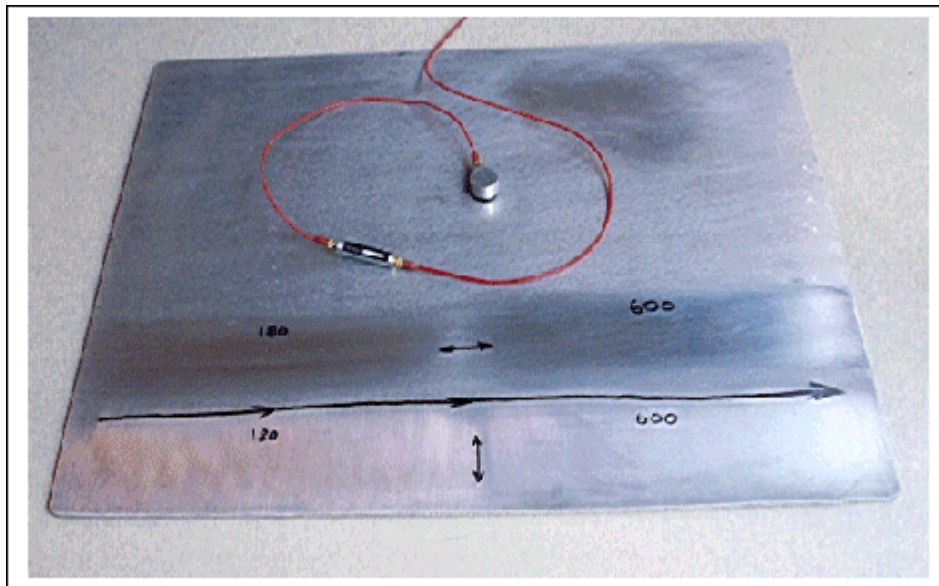
INTRODUCTION

It has been well established by anyone who has ever conducted an acoustic emission test on structures in the field, that contact and subsequent rubbing of two surfaces as a component is stressed will produce acoustic emission signals with a very broad range of frequencies. In addition there has been numerous publications dealing with head-disk-interference (HDI) for hard disk media in the study of the acoustic emission produced when a recording head comes in contact with a spinning disk. Other work relating to the contents of this report has dealt with the acoustic emission produced during metal cutting and grinding processes. One feature of all the above work is the use of a fairly broadband acoustic emission sensor and instrumentation operating in frequency range from 100Khz to 1Mhz. In the later two cases above it is usually the RMS or the average signal level (ASL) of the AE signal generated which is used in order to better understand the process. The problem encountered with present methods when trying to relate the AE data to the process under measurement is that the signal amplitude produced is influenced by the sensitivity of the transducer over a given frequency band, the gain of the instrumentation, the relative velocity between the two contacting surfaces, the surface roughness of the two surfaces, and the amount of material removed in cutting and grinding processes.

This report will concentrate on presenting results of a unique new method for the measurement of surface roughness using acoustic emission techniques. The conclusions reached could well apply to the cutting, grinding, and polishing of materials and will be reported at a later time.

BACKGROUND

A previous report (ref 1), has shown that the acoustic emission signals produced by the use of different sandpaper grit sizes rubbing against the surface of an aluminum plate could be used to correlate directly with the grit size used for abrading the surface. This was accomplished by recording the acoustic emission (AE) signals from a broadband transducer (SE900-MWB). The AE signal detected was split and electronically filtered through a 20-60Khz bandwidth, and a 100Khz-1Mhz bandwidth. Both filtered signals were then put through electronic circuitry that calculated the average signal level (ASL) of the two filtered signals. An A/D converter then sampled each signal at a selected sample rate of 10 milliseconds. The voltage of the high frequency channel was then divided by the voltage of the low frequency channel to produce a ratio designated as the HF/LF ratio in this report. As will be illustrated by the following experimental data, it is this ratio that is the unique parameter that will allow surface roughness to be determined, without being influenced by velocity or instrumentation amplification.



EXPERIMENTAL PROCEDURE

In the previous report rubbing differing size grit sandpaper on the surface of an aluminum plate was the source of the AE signals recorded. In the present report the aluminum plate was abraded with two different roughness of grit (180 and 600) over an area of approximately 10 inches in length and 2 inches wide. A strip of this length was abraded with the 180 grit and immediately followed by a strip of 600 grit. In one case the surface was abraded with movement of the sandpaper along the length of the 10-inch strip with each grit size giving a 2-inch wide strip of abraded surface 20 inches long. Adjacent to this strip was an identical strip with the two grit sizes, only this time the movement of the sandpaper to form the abraded surface was 90 degrees to the movement producing the first strip. A photograph of the aluminum plate is shown in figure 1, showing the AE sensor (SE900-MWB) and MINI-P preamplifier in the center of the 500X500mm plate of aluminum 5mm thick. The small arrows show the direction of movement of the sandpaper used to create the two surfaces, while the large arrow shows the movement of the index finger of the author in contact with the abraded surfaces to produce the AE signals. Several different objects moving in contact with the abraded surfaces to produce AE signals were tried, but the best results were obtained by using the human finger.

VELOCITY EFFECTS

Figure 2 shows the effects of three different velocities for the two different surface roughnesses on the HF voltage channel. Note that the voltage is trending higher as the velocity increases for the 600 grit surface, but shows very little increase as the velocity increases for the 180 grit surface. The drop in voltage during the last second for the 600 grit surface is due to a combination of a decrease in velocity and contact pressure created by attempting to lift the finger to prevent artifacts created when the finger goes over the edge of the plate. These results show a very high dependence of the HF voltage on velocity for the 600 grit surface, and a lesser increase as a function of velocity on the rougher surface.

Figure 2-HF VOLTAGE FOR THREE VELOCITIES AND 2 SURFACE ROUGHNESS

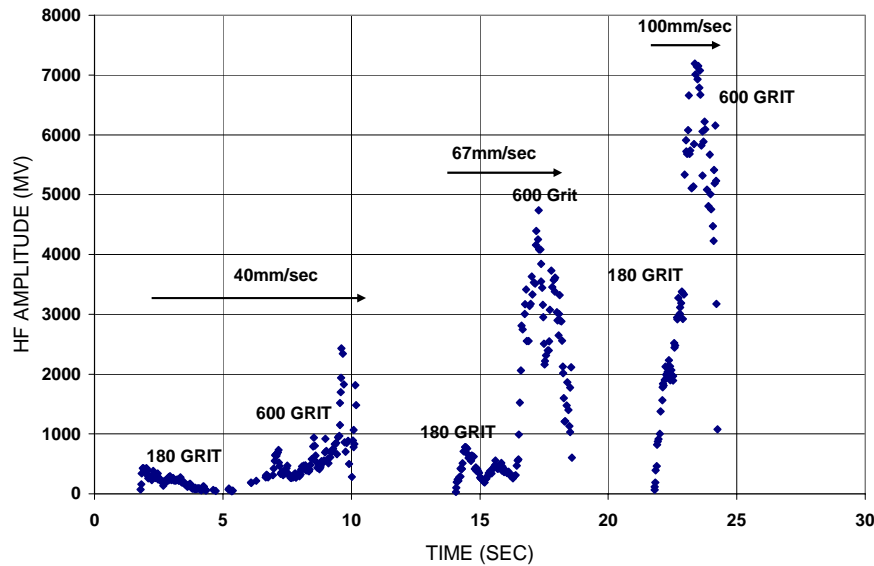


Figure 3 shows the LF voltage as a function of time for this same experiment. Note in this example just the opposite effect is present in the data. In this example a large increase in the low frequency voltage is observed as the velocity is increased for the 180 grit surface, and a lessor increase is seen in the voltage level for the 600 grit surface.

Figure 3- LF VOLTAGE FOR THREE VELOCITIES AND 2 SURFACE ROUGHNESS

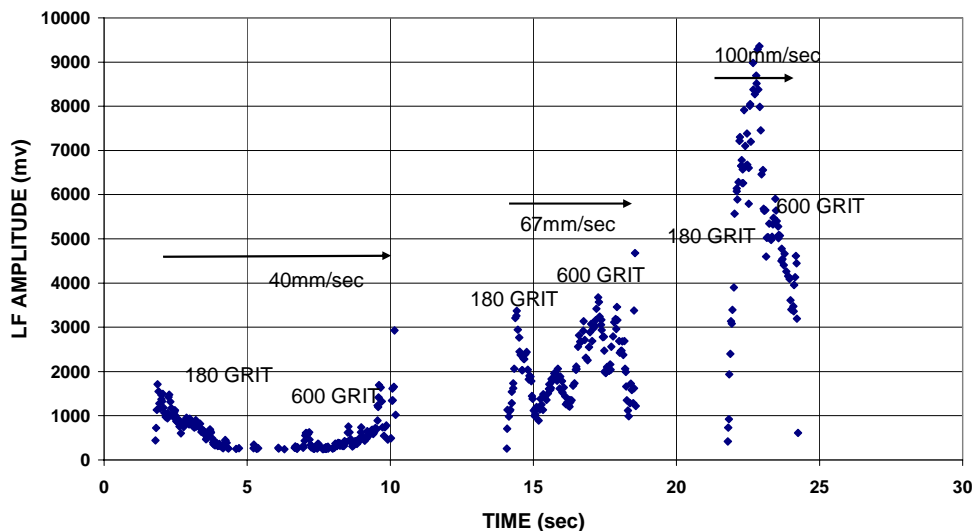
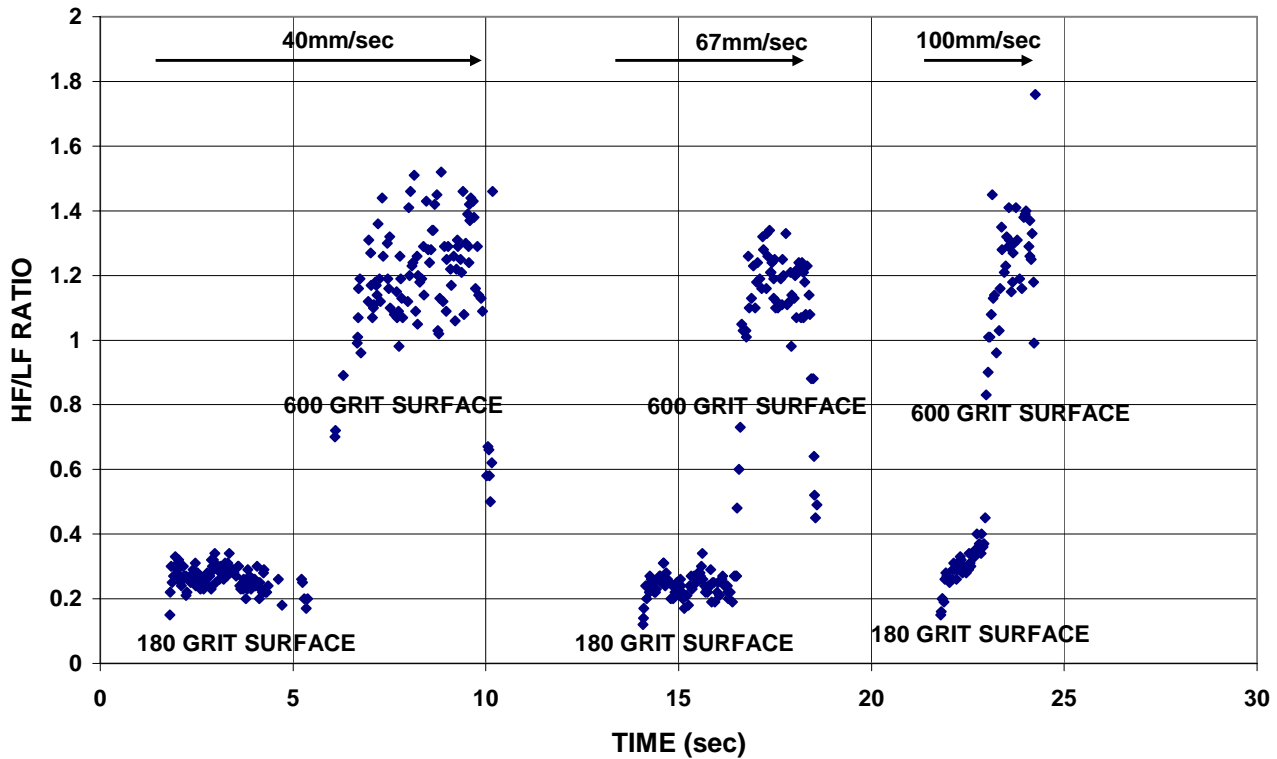


Figure 4 shows the Ratio of the HF/LF voltage for the three velocities. Note that a very large difference is observed in the ratio for the two different grit sizes with no apparent dependence on the velocity of movement across the different surfaces.

Figure 4-HF/LF RATIO FOR 3 VELOCITIES AND 2 SURFACE ROUGHNESS

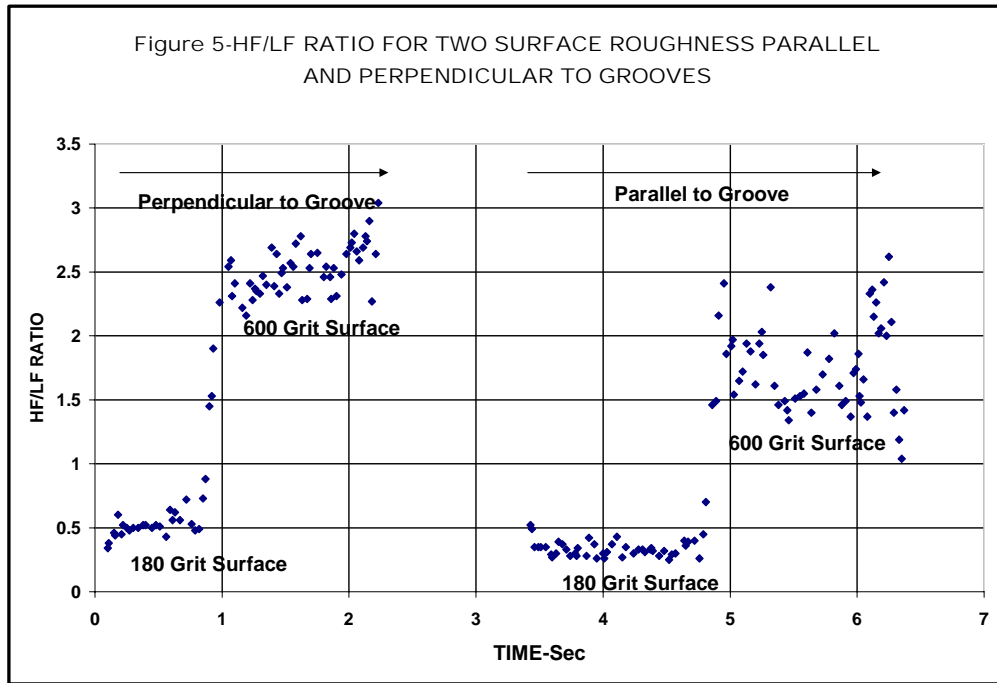


ORIENTATION EFFECTS

An experiment was conducted to study the effects of moving the finger over the different roughness of the plate, parallel and perpendicular to the grooves created by the sandpaper.

Figure 5 shows these results. An attempt was made to maintain the same velocity of movement for each of these conditions, but as can be observed by the length of time required to cover the full 20 inches of the plate, the velocity for the movement parallel to the grooves in the plate was slower.

If one assumes that velocity is not a factor, as was shown in the previous figure, the data shows that orientation effects are very minimal on the rougher surface, but do appear to have an effect on the smoother surface.



INSTRUMENTATION GAIN EFFECTS

This experiment was designed to study the effects of instrumentation gain settings on the ability of the HF/LF ratio to measure the difference between two surface roughness. Figure 6 shows the HF voltage as a function of time for two roughnesses at 50 and 60 dB of instrumentation gain. Note the large difference in voltage level for the two gain settings. The drop in voltage for the 600 grit situation after reaching its peak value is due to a decrease in velocity near the edge of the plate. Although differences are observed in the HF voltage level from the two different surfaces it would be difficult to base a quantitative measure of surface roughness on such data.

Figure 6- HF VOLTAGE(mv) FOR TWO SURFACE ROUGHNESS AT TWO GAIN LEVELS

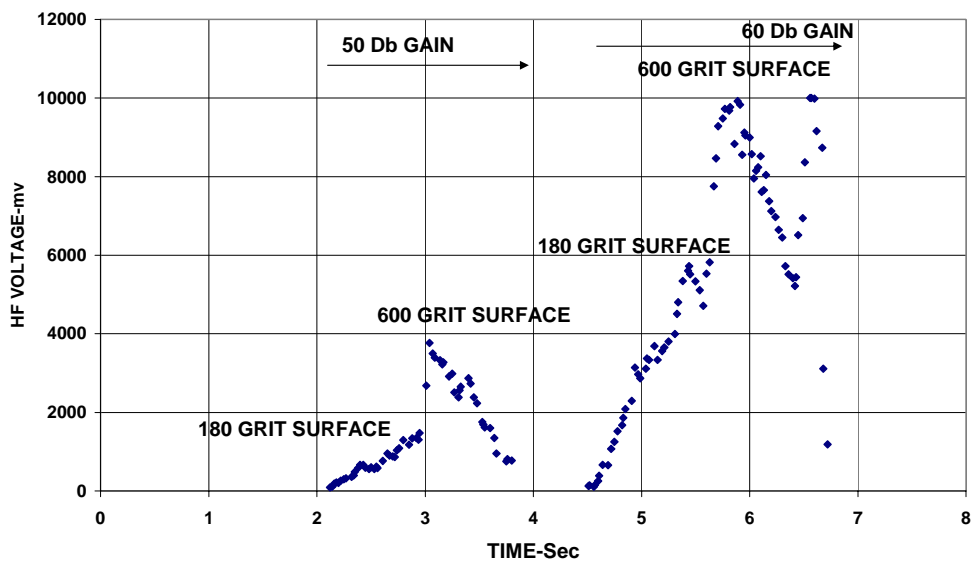


Figure 7 shows the LF voltage data from the same experiment. Here again we observe a large difference in the voltage level due to the 10dB difference in instrumentation gain. The same drop off in voltage observed in figure 6 is also present in this data. Note the difference in vertical scale between figure 6 and figure 7. Some of the signals in the HF data of figure 6 were approaching the saturation voltage of 10 volts for the 600 grit surface.

Figure 7-LF VOLTAGE(mv) FOR TWO GRIT SURFACE ROUGHNESS AT TWO GAIN LEVELS

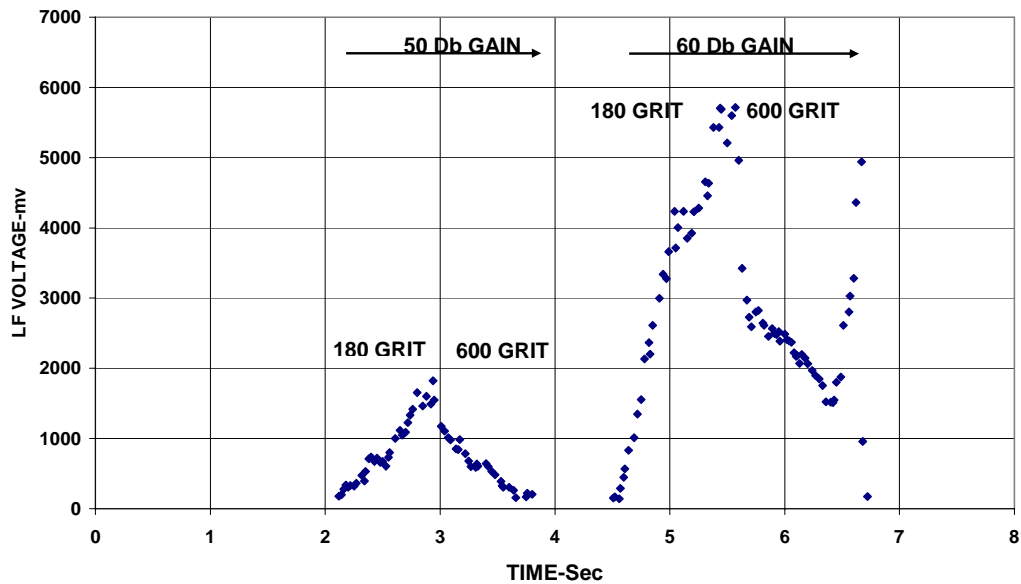
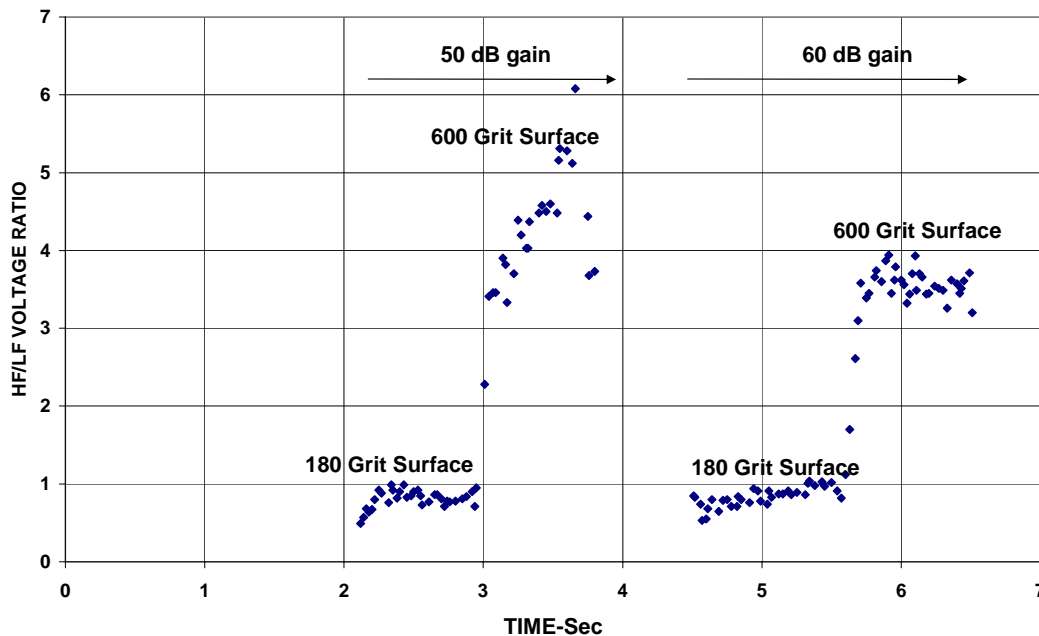


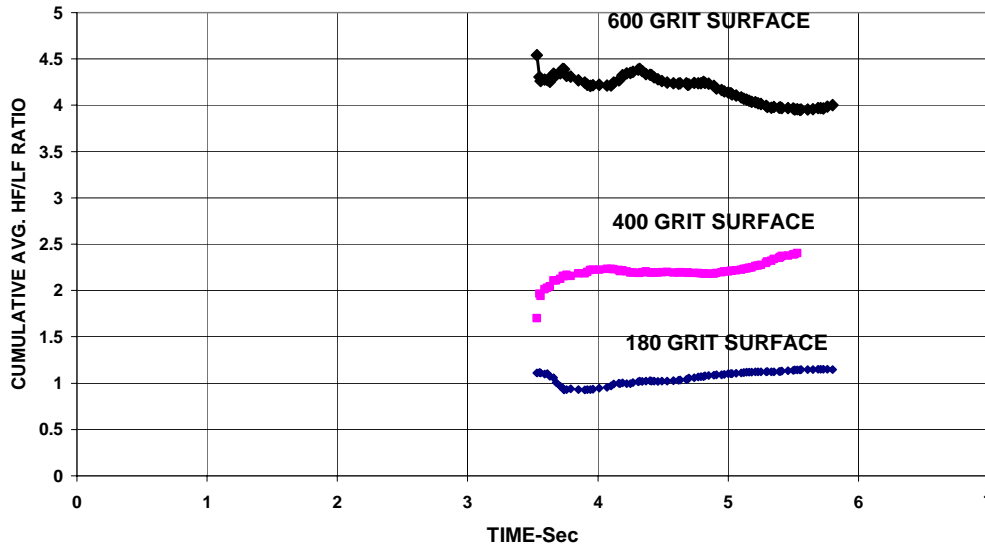
Figure 8 shows the HF/LF ratio of the data shown in figure 6 and figure 7. Here again we observe that taking the ratio of the high frequency to low frequency components of an AE signal provides a quantitative measure of the two surface conditions even though the instrumentation gain level was changed by a factor of 10dB.

Figure 8- HF/LF RATIO FOR TWO GRIT SIZES AT TWO DIFFERENT GAIN LEVELS



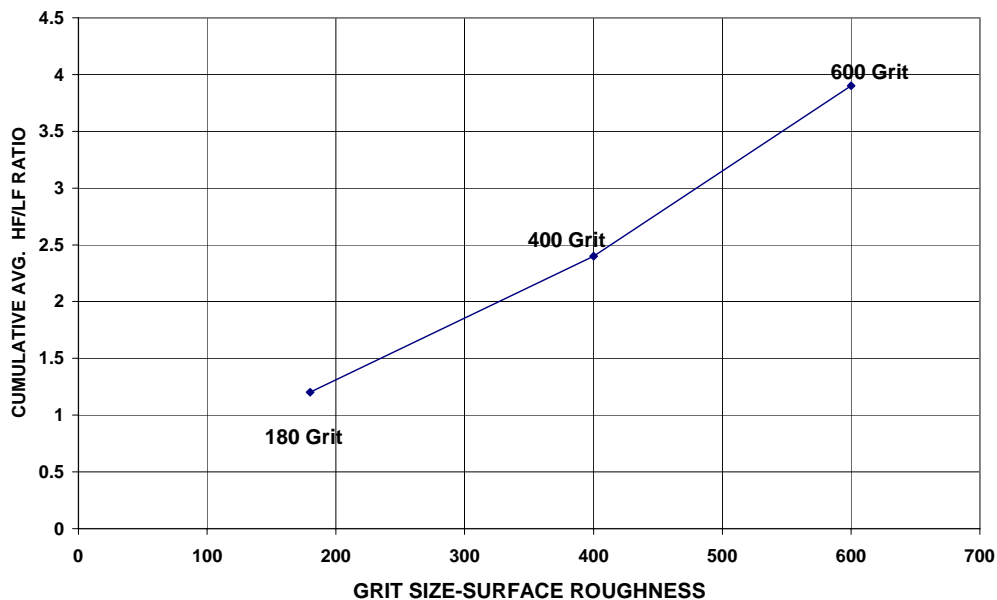
There is a great deal of scatter in the voltage data but considerably less scatter in the HF/LF ratio data. It appears that taking a cumulative average of the ratio data for a particular grit surface might be a better way of displaying the data. Also since only two grit surfaces were used it was decided to include a third grit surface intermediate between the 180 and 600 grit surfaces. Therefore 400 grit sandpaper was used to prepare another 10-inch strip on the aluminum plate. A run was made on each of the three surfaces and a cumulative average of the HF/LF data was calculated. This data is shown by figure 9.

Figure 9-CUMULATIVE AVERAGE HF/LF RATIO FOR THREE DIFFERENT SURFACE ROUGHNESS



The data presentation shown by figure 9 appears to be the best way of displaying the HF/LF ratio for measuring surface roughness. The software in the AESMART 302A is designed to show the cumulative average of the ratio data shown in figure 9 in real time, and a numerical value of the average of all data points for a particular run is displayed on the screen.

Figure 10-CUMULATIVE AVERAGE HF/LF RATIO VS SURFACE ROUGHNESS



From this value one can determine the surface roughness from the graphic in figure 10.

Another feature of the software in the Model 302A is a ratio filter. A value of the ratio corresponding to a desired surface roughness can be preset. This preset ratio has to be exceeded in order for any data recorded to be considered valid. In this manner the progress of metal machining, grinding, or polishing operations can be monitored until the desired surface finish is achieved. This of course assumes that the method used in this report to measure the surface roughness can be directly translated to the above processes.

DISCUSSION OF EXPERIMENTAL RESULTS

As stated previously the use of a single RMS or ASL value of the AE signal, and subsequent analysis of the data using pattern recognition techniques or neural networks, must take into account the velocity dependence of the process and the gain of the instrumentation. Figures 2 and 3 show the large differences in signal amplitude produced by varying the velocity of the contact area over the surface of the part to be measured. It is obvious from figure 3, that the low frequency components of the signal show a higher velocity dependence from the rougher surface and a lesser velocity dependence for the smoother surface. The opposite effect is shown from figure 2 for the high frequency data. There appears to be very little velocity dependence for the high frequency data from the rougher surface, but a large dependence on velocity for the smoother surface is observed. When the high frequency data in figure 2 is divided by the low frequency data of figure 3, the HF/LF ratio is calculated. This ratio data is shown by figure 4 and it is observed that there is no velocity dependence on this ratio and most of the scatter in the data disappears. The opposite effects produced on the different frequency components of the signal appear to amplify the difference seen in the ratios from the two different surface roughness and eliminate the velocity dependence.

Figure 5 shows that there are differences observed due to orientation of the grooves in the surface. When contact movement is made perpendicular to the grooves the best separation between rough and smooth surface is observed. Contact parallel to the grooves produces a considerable amount of scatter in the high frequency data and a lower overall ratio for both surfaces.

Figure 6 shows the dependence of the voltage from the high frequency channel for a change in instrumentation gain of 10dB. Figure 7 shows the change in the low frequency voltage for the same change in gain. The ratio of the HF/LF voltage shown by figure 8 shows that the gain dependence has no effect on the value of the ratio. This is an important feature in setting up a test method, since the measuring parameter is independent of the absolute amplitude of the signal. This again shows the value of taking the ratio of two frequency components of a signal rather than attempting to use the amplitude of the signal itself as a measuring parameter.

A considerable amount of scatter is observed in the voltage amplitude of the data. Much of this scatter is due to the difficulty in producing a consistent surface of a specific roughness, and maintaining a constant velocity over the 20 inches of surface tested by simple movement of the index finger on the surface. The averaging method shown by the data from three different surfaces in figure 9 appears to provide a solution to this problem.

THEORETICAL CONSIDERATIONS

To the author's knowledge there has been no published theory that would explain the results given in this report. A possible explanation for the results observed are as follows: When the finger is rubbed over the surface both Sv and Sh shear waves are created. It has been shown in a previous report (ref 2) that Sv waves mode convert into a low frequency flexure wave in plates, while Sh waves maintain their high frequency content without mode conversion. A properly designed transducer coupled to the surface with petroleum jelly is capable of detecting both types of shear waves which are inherently high frequency in nature, and the low frequency

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flexure wave. The HF/LF ratio calculated is therefore the voltage due to the high frequency shear wave divided by the voltage due to the low frequency flexure wave. It is apparent from the data in figure 3 that the 180 grit surface produces higher voltages from the low frequency channel indicating that a higher percentage of Sv and subsequently low frequency flexure waves are produced by the rougher surface. This is supported by the drop off in voltage for the low frequency channel for signals from the smoother surface. It is postulated that the smoother surface produces a higher percentage of Sh waves that maintain their high frequency nature without mode conversion. This is supported by the higher amplitudes observed from the high frequency channel in figure 2 for the 600 grit surface.

POTENTIAL APPLICATIONS

MEASUREMENT OF SURFACE ROUGHNESS

The data in this report shows that surface roughness measurements can be made in a limited range of surface roughness with good accuracy. The data in figure 10 needs to be expanded to determine the limits if any on range of surface roughness that can be measured. In addition a better method of producing the signal needs to be explored. Rubbing the finger over a surface is not a desired method. Experiments are in progress using a thin high-pressure stream of helium gas to determine if this approach will work.

METAL CUTTING

The tool used on a lathe in a metal cutting process is a transducer of sorts. A sharp tool, optimum depth of cut and optimum speed of travel should produce primarily high frequency shear waves in the tool. If the tool encounters a hard inclusion, a crack is initiated, or the tool becomes dull micro-impacts will occur which will produce low frequency flexure waves in the tool. If a AE transducer is properly attached to the tool and instrumentation and data analysis similar to that performed in this report is utilized, the HF/LF ratio of the AE data should be able to determine optimum conditions for the cutting process and alarm if conditions outside the preset ratio filter are exceeded.

POLISHING

It is anticipated that results similar to the data presented in this report will result from polishing operations. As the surface becomes smoother higher ratios will result. Since only a limited range of surface roughness has been covered in this report, additional experimental data must be obtained to see if the trend in figure 10 continues in a reasonable fashion to much smoother surfaces.

GRINDING

We have reported (ref 1) that rubbing a surface with different size grit sandpaper to create different surface conditions can be properly qualified. It is anticipated that the same correlation can be obtained with surfaces created with a grinding wheel as opposed to sandpaper.

HEAD DISK INTERFERENCE (HDI)

Present HDI researchers using AE techniques utilize a very small transducer and monitoring frequencies in the 500Khz range. The low frequencies are rejected by hi-pass filtering of the AE data. Data in this report shows that utilizing the amplitude of a single high frequency signal can result in vastly different results, depending on velocity effects and instrument gain (fig.2, fig.6). It is anticipated that much better information can be obtained in HDI studies by utilizing the HF/LF ratio which is not affected by these parameters.

CONCLUSIONS

The data in this report shows that acoustic emission techniques can be used for the quantitative measurement of surface roughness produced on an aluminum plate by using different grit size sandpaper. A transducer attached to the plate detects the signals created by moving contact of the human finger along the desired surface. It is shown that splitting the received signal into two frequency bands and taking the ratio of the high frequency to low frequency components of the voltage amplitude (HF/LF ratio) can result in a parameter that can be quantitatively related to the surface roughness independent of the relative velocity between the finger and plate, and the instrumentation amplification. Variations of velocity, instrument gain, transducer placement and orientation of the grooves produced in the plate were studied. Of these four parameters studied only orientation of the grooves seemed to have a measurable effect on the HF/LF ratio data. Continued studies will be directed toward determining the effects produced by varying the geometry and thickness of the plate.

REFERENCES

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2. Dunegan H.L. "Modal Analysis of Acoustic Emission Signals" Journal of Acoustic Emission
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