Report on Optical Scans of Wax Cylinders from the Franz Boas "700" Series Recordings

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V1.0 July 20, 2010

In this report we present preliminary results from optical scans made of cylinders 707-718 from the Franz Boas 1930 Vancouver Island Kwakiutl recording sessions. These are wax cylinders provided by the Archive of Traditional Music (ATM) at Indiana University. ATM also provided stylus transfers of cylinders 708-718 from two sessions in 1957 and 1984 respectively.

The background to optical scanning with a 3D probe is discussed in the document "3D Scanning" posted on this project website [1]. A simple illustration is given in Figures 1 and 2. Figure 3 shows the full scale scanner configured for a wax cylinder. Figure 4 shows a sample being loaded on the scanner.

3D optical scanning is a method for extracting audio from historical grooved media with no mechanical contact to the surface. This protects delicate, damaged, or at risk samples from further degradation. It also permits damaged or broken samples to be played, in some cases, when a mechanical stylus would be unable to track or otherwise follow the surface. Optical data sets can be processed digitally to remove some of the effects of scratches and debris and are less susceptible to low frequency artifacts of mechanical playback such as "wow" and "rumble"

The data collected consists of an array of depth measurements on a grid oriented along the time direction and across the grooves. This is further defined in Figure 2. Each measurement has a depth resolution of about 90 nanometers, small compared to the depth variation due to recorded audio. The data array is stored in a file and then analyzed by a software package referred to as "PRISM". In the analysis, a virtual stylus trajectory is found along the groove, and at each time sample the groove depth is determined and compared with the next time sample. These comparisons, when appropriately filtered and averaged, yield a statistical estimation of the recorded sound. Examples of the PRISM data display and samples of the raw data are shown in Figure 5.

The optical scan is capable of measuring the audio information out to a very high frequency. For example the Boas cylinders were sampled at either 49.5 or 55.5 KHz, corresponding to a Nyquist frequency of 24.75 or 27.75 KHz. In practice, no audio is recorded with this early acoustic technology above about 5 KHz. Consequently we have applied a low pass digital filter at 4 or 7 KHz as noted in the filenames.

The optical scan data analysis includes a "blob removal" process which is designed to delete dust or other debris from the surface. This is illustrated in Figure 5. Additional "de-clicking" of the waveforms can also be applied to remove any residual pulses which remain (filenames which include this are appended with the designator "DC").

A list of the Boas cylinders with comments on condition is given in Table 1. All cylinders were scanned to the extent they contained reasonable data. Two scanning strategies were applied. In the first, called "one-pass" the cylinder was sampled at the native resolution of the probe, with 10 microns spacing between fibers. This is a fast scan, requiring about 20 minutes to cover a cylinder. The scan parameters and analysis parameters are given in Figure 5 and filenames. The second, called "four-pass" utilized a sub-sampling process whereby the probe was translated by 2.5 microns for a series of four scans and then moved the full 1.8 mm to the next group of four. This resulted in a quadrupling of the data set and scan time but typically will lower the white noise (broadband) by a factor of two. This note will focus on “one-pass” data. Later we will revise with a comparison with “four-pass” data.

The Boas cylinders were transferred to tape using stylus playback both in 1957 and 1984. Subsequently these tapes were digitized. ATM made these digital files available to the project and they have been very useful for comparison with the optical measurements. Generally speaking, the quality of the 1984 transfer far exceeds that of the 1957 one. The 1957 data is nearly useless due to high noise and distortion. The only counter example is for cylinder 716 for which the 1984 transfer failed, apparently due to poor tracking. The stylus seems to jump off the media once per revolution. No stylus version of cylinder 707 was provided, presumably due to the poor condition of the surface (see Table 1).

Generally speaking, most of the Boas cylinders were in good condition and yielded good audio from optical scans, particularly for one-off field recordings. There were a number of advantages found using the 3D optical scans.

- The most significant advantage of the optical approach is outlined in Figure 6. Some of the audio content is very loud and apparently resulted in an overdrive of the cutting tool. On the outward excursion the cutter is seen to leave the surface entirely. The stylus playback show more distortion than the optical playback in these cases.

- Some of the stylus files contain significant low frequency wow and rumble relative to the optical files. This could perhaps be mitigated by additional high pass filtering applied to the stylus data.

- The stylus playback apparently included some sort of applied equalization (frequency dependant bias). The causes a complicated roll of with frequency above about 4 KHz. The optical playback is manifestly flat up to the imposed Nyquist cutoff (here typically ~25 KHz). We instead apply a well controlled low pass digital filter above a chosen frequency (either 4 or 7 KHz).

- Cylinder 707, for which no stylus copy was provided, was found to scan optically, for at least part of the surface.

Here we will discuss and illustrate results on a selected subset of the cylinders.

- Cylinder 711: This was a best case example. Audio quality is good here and this cylinder provides an excellent illustration of the overdrive distortion effect discussed above and in Figure 6. Figure 7 illustrates some of the data from this cylinder. The effects of distortion and apparent frequency bias as clear here.

- Cylinder 716: This cylinder has significant surface damage beginning about halfway through the track. In addition, the entire stylus playback is bad due to apparent skips, once per revolution. Figure 8 compares waveforms for the optical version, which is reasonable, the 1957 stylus (noisy) and the 1984 stylus. All this data comes from the early part of the playback mainly before the significant surface damage appears. Figure 9 address the latter part and illustrates the surface damage using the depth images first defined in Figure 5. In Figure 9 (top) a clean region (top) is compare with a damaged region (bottom).

- Cylinder 718: This cylinder provides another illustration of the high amplitude distortions and the effect of the apparent stylus frequency bias (Figure 10). Here also there is some pitch shift seen relative to the recommended playback speed of 165 RPM.

- Cylinder 707: This cylinder had no stylus version and was observed to have significant surface damage. None-the-less, optical scan yielded a playback albeit with some distortion similar to that which affects the second half of cylinder 716.

For the purpose of audio comparison we have posted some clips related to these examples at the project site [1].

References

[1] http://irene.lbl.gov/Boas_Examples.html

Figures

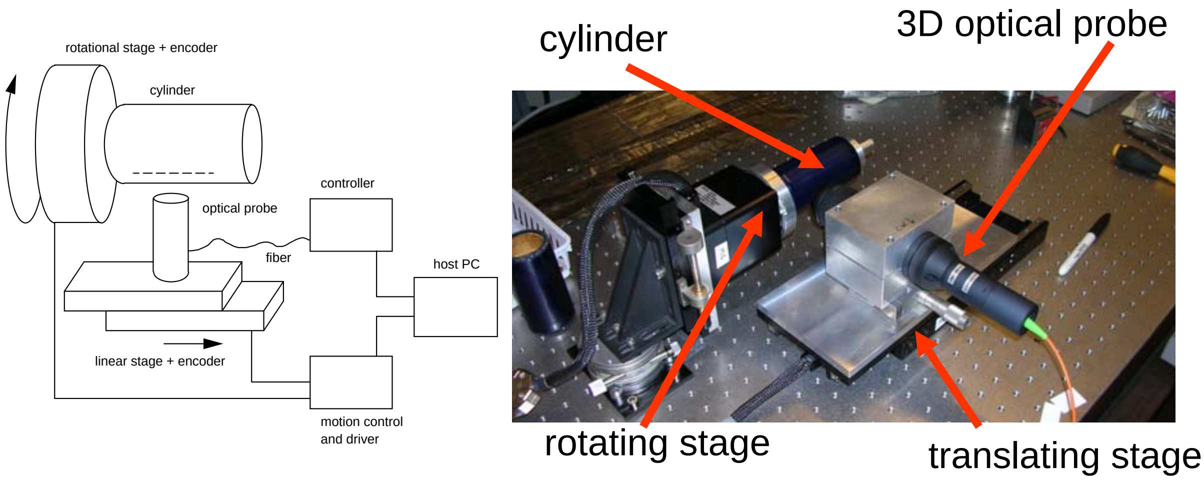


Figure 1: Basic scheme of the optical scanner. Probe is translated along cylinder axis. Cylinder is held on mandrel and rotated by during measurement.

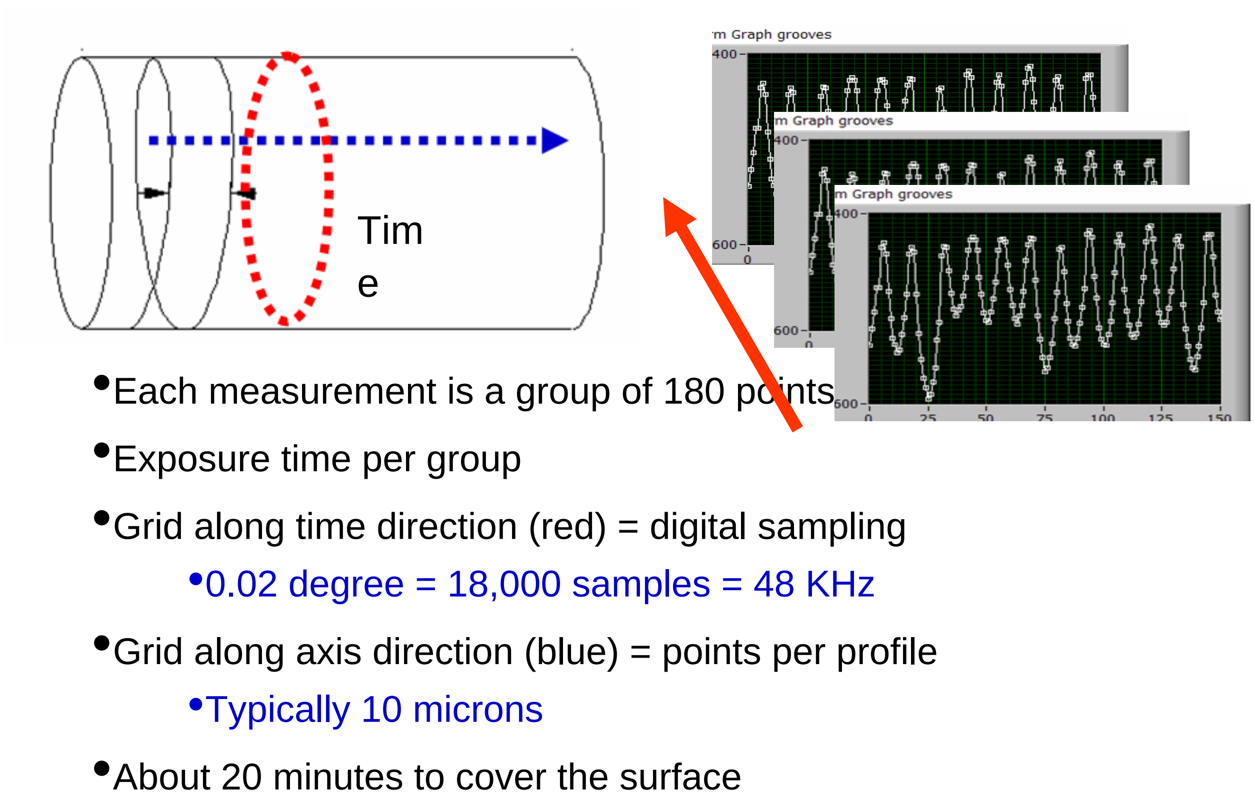


Figure 2: Principle of the 3D depth scan. The red circle represents a scan around the circumference which is executed first. After the circumferential scan, the probe is translated along the axis of the cylinder and the process is repeated. With the multipoint probe (MPLS180), each circumferential scan covers 180 points separated by 10 microns parallel to the cylinder axis. A few of these are represented by the images at upper right in the figure. The probe is then translated, typically, by 1.8 mm (180 points x 10 microns). The probe may be translated by smaller increments in order to cover the surface with a finer spacing than 10 microns. During the circumferential scan, the exposure time of the probe and the rotational speed of the cylinder determine the angular spacing between measurements. This then determines the digital time sampling of the measured audio waveform.

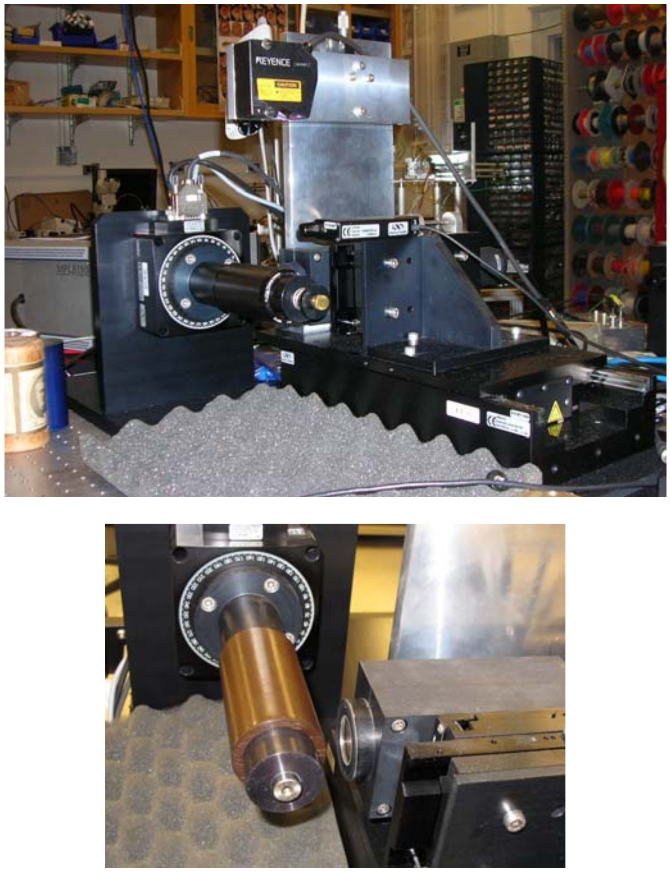


Figure 3: Overall view of the present full scale 3D cylinder scanner. Cylinder, in foreground, is held on mandrel and rotated by stage (marked with circular scale). Probe enters from right and is held on linear translation stage (lower right). Laser displacement sensor scans cylinder from above (marked with yellow safety tag).

Figure 4: UC Berkeley undergraduate physics major Maryrose Barrios is seen installing a cylinder from the collection on the scanner.

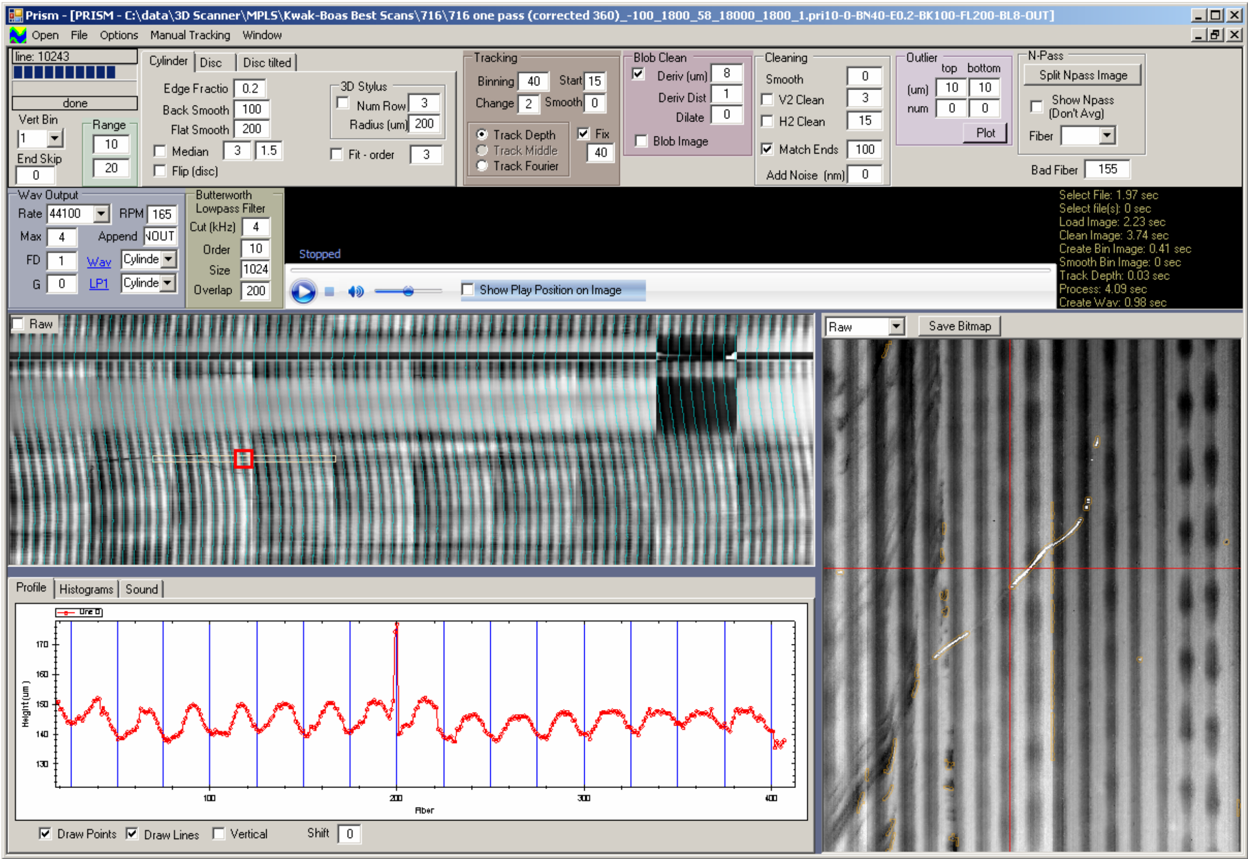


Figure 5: Example of the PRISM software interface and data display. Full width panel at top is used to control various analysis parameters which effect sampling, image processing, noise reduction, filtering, and reconstruction. Image panel at middle left is a view of the cylinder unrolled, grooves are vertical lines in this image, grayscale is depth, black being the deepest points. The region within the white rectangle, centered on a red square, is zoomed at right. Visible there is a dust particle (white structure) and a scratch (black "wispy" lines). The dust is typically subtracted from the image by the "blob clean" code. A horizontal red line indicates the position of the profile slice displayed at lower left. The scale is in micrometers. Each dot is a probe measurement. The narrow spike near the center of the trace is due the crossing of the dust particle.

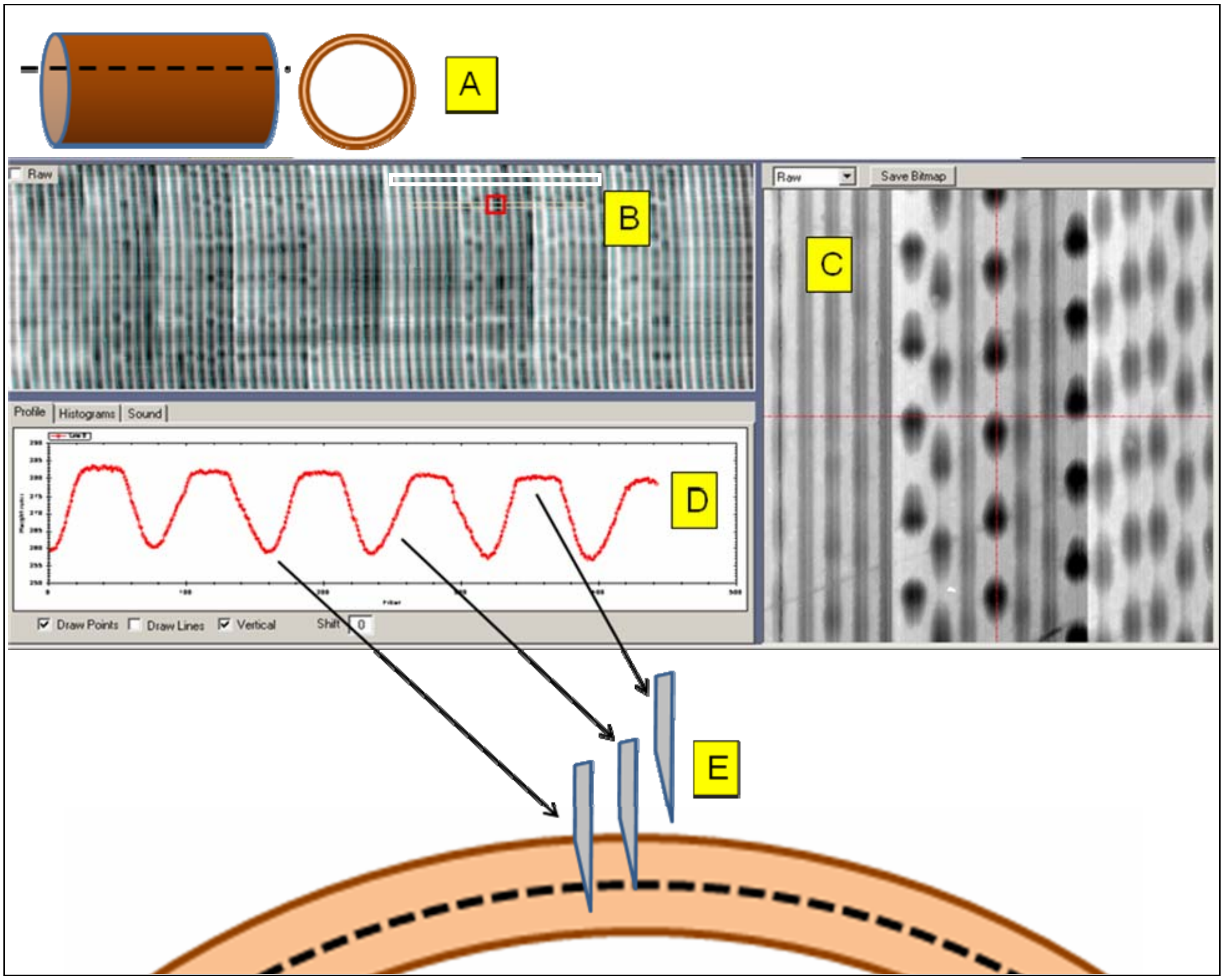


Figure 6: Description of over-cutting effect seen on the cylinders. Part A above is a cartoon of the cylinder. The dashed line is an imaginary cut along the axis. Part B is a grayscale image generated from the optical scan data. In this image the cylinder is cut along the indicated line and opened flat and depth is indicated with increasing darkness. Audio tracks are visible as the near vertical lines in section B. During the playback the stylus (needle) would ride up a track and begin again from the bottom, repetitively. Part C is a detail of a region located near the letter "B" and within the white outlined box centered on the small red cursor. In section C a vertical red line is visible. The surface depth variation along that red line is indicated by the left to right trace in section D. Part E is a cartoon indicating the action of the stylus or cutting tool during playback or recording. The brown structure indicates a section of the wax cylinder. The black dashed line is the "at-rest" position of the tool, corresponding to quiet. Sound amplitude would drive the tool further in or out of the wax. In the case of a large outward excursion, the tool would leave the surface, resulting in the flat sections of seen in the surface profile trace (D) at the rightmost arrow. In an optical playback of the cylinder, the precise shape of the surface is recorded. In a stylus playback additional mechanical dynamics may occur due to the response in this region, resulting in increased audio distortion as heard in the actual audio clips. In any case, such a surface structure will lead to some non-linearity in the audio waveform due to the apparent clipping which occurs.

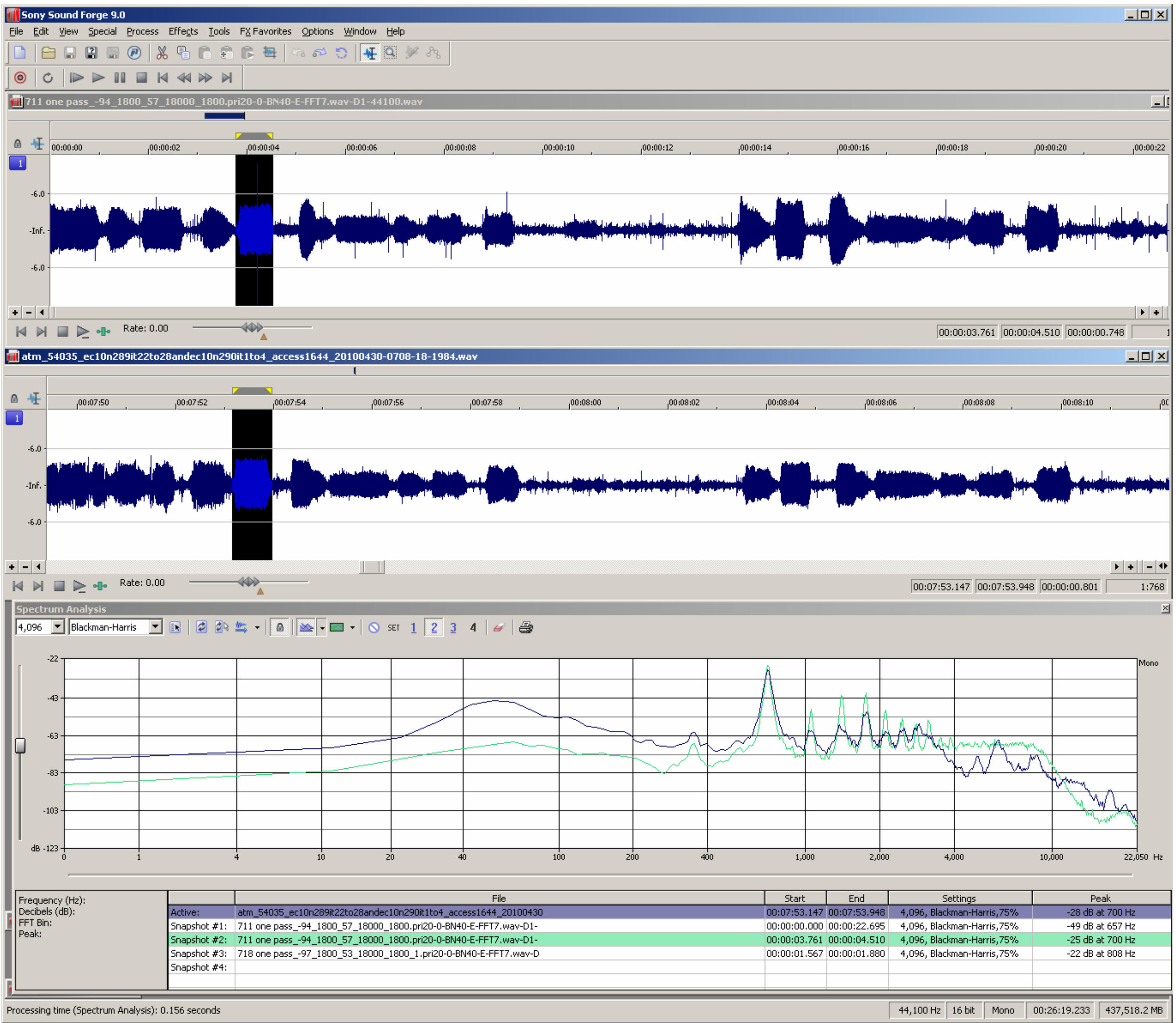


Figure 7: Comparison of waveforms and spectra for cylinder 711, between optical (top waveform, and green spectra) and 1984 stylus transfer (lower waveform and black spectra). The illustrated spectra refers to the common highlighted regions of the waveform where the "clipping" distortion discussed in Figure 6 is present and significant. The optical data was analyzed assuming a speed of 185 RPM and the spectra are observed to be well aligned. The non-linearity of the response results in a series of overtones above the primary peak near 800 Hz). The overtones are narrower and more clearly resolved in the optical data which also resolves some high frequency structure which is lost in the complicated bias structure seen above about 3000 Hz in the stylus data (see discussion of equalization in the text). The stylus data also shows extra power at low frequency due to mechanical rumble or "wow".

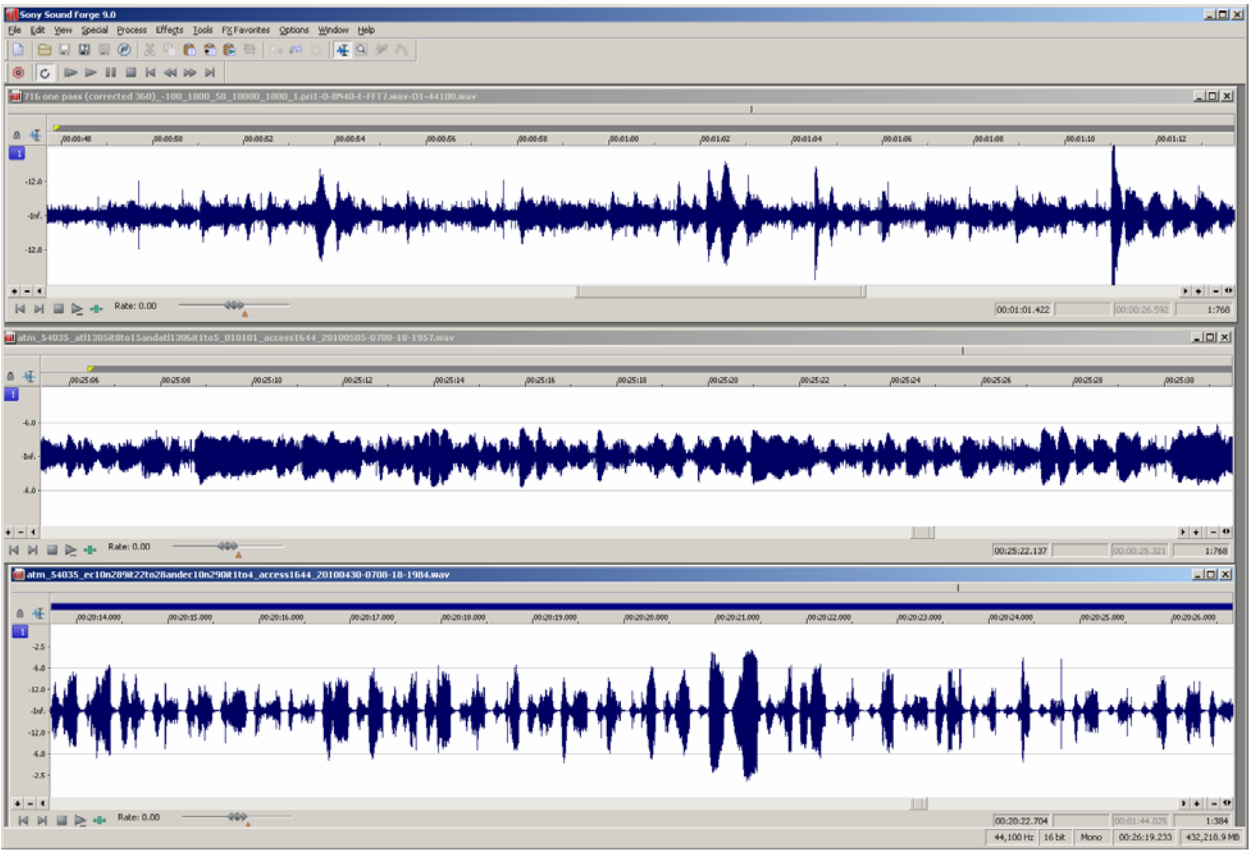


Figure 8: A comparison of the audio waveforms for cylinder 716, top is optical version, middle is 1957 stylus version, bottom is 1984 stylus version. Numerous gaps are seen in the 1984 version which are actually spaced one revolution apart. These are due to the stylus regularly jumping out of the groove due to some mechanical disturbance.

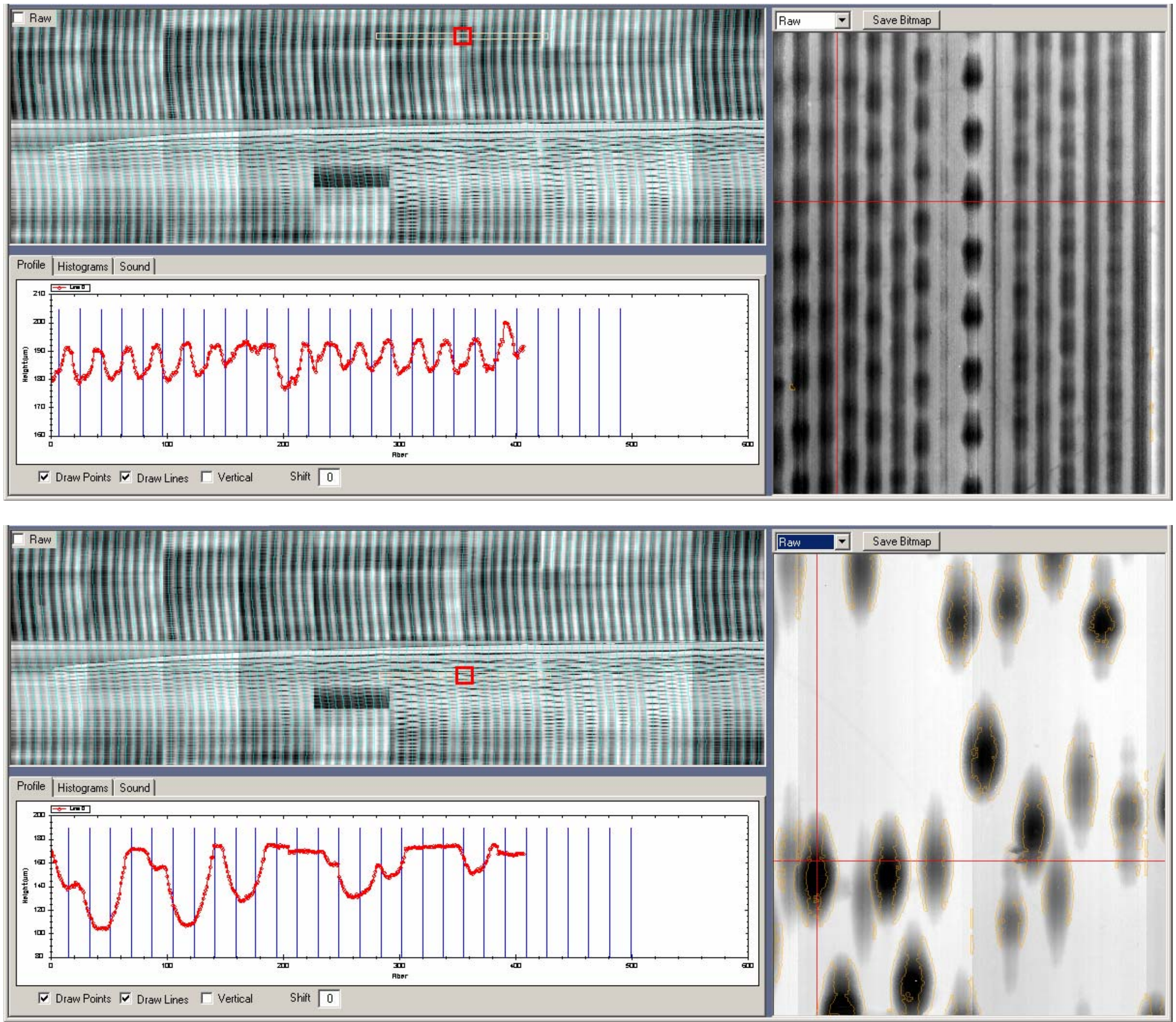


Figure 9: Two views of cylinder 716. This scan is on the second half which shows considerable surface damage (See Table 1). In the upper part of the figure we have selected a region with no significant damage (small red square). The line profile, across the grooves, is normal and is well tracked by the software (blue lines). In the lower part we select a damaged region (small red square) where much larger "pock" marks are seen and also not tracked either.

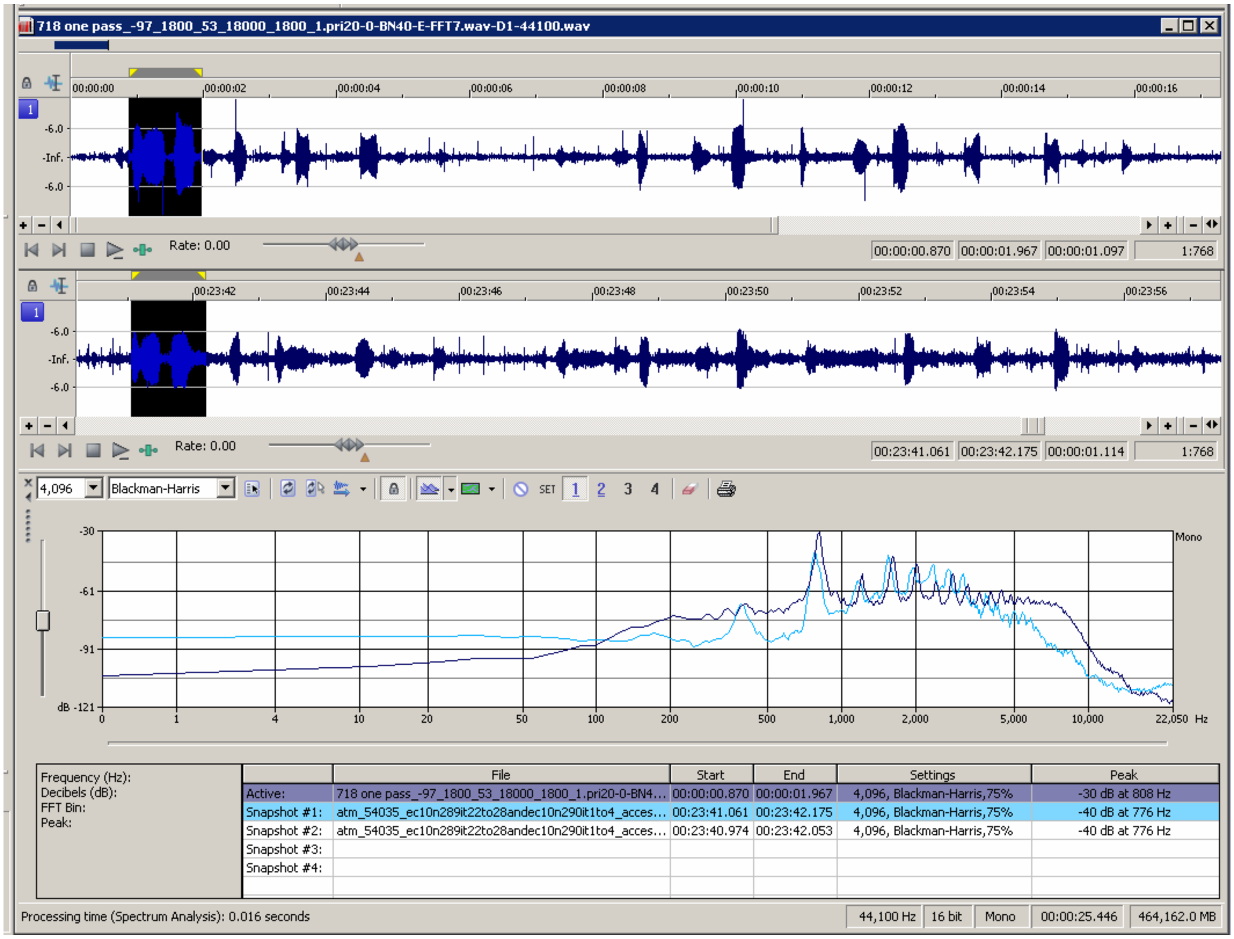
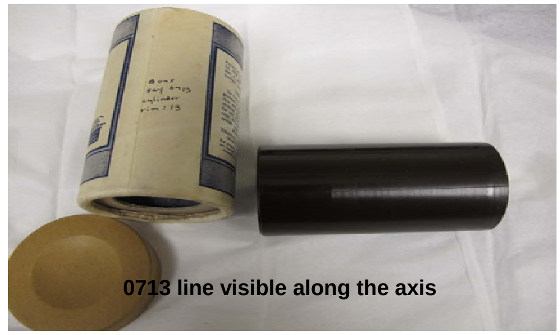


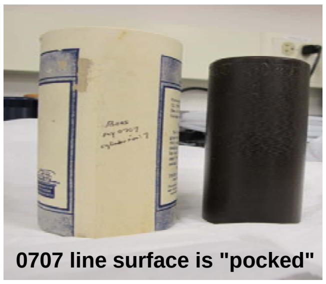
Figure 10: Comparison of optical (top waveform and black spectra) and 1984 stylus playback (lower waveform and blue spectra) for cylinder 718. Again the effects of distortion and the apparent equalization curve on the stylus version can be seen clearly.

Table 1

Inspection of ATM Boas cylinders, April 5, 2010, Carl Haber

cylinder number	
0707	heavily "pocked" or cratered on second half
0708	OK, one small white blemish
0709	OK
0710	white surface bloom, some smearing ?
0711	OK
0712	some small vertical scratches
0713	sractch or crack parallel to the axis, along the entire length
0714	OK
0715	OK
0716	partly smeared, probably half good
0717	partial crack or scratch near the end, mount carefully
0718	OK


0713 line visible along the axis


0707 line surface is "pocked"


0716 "smeared" region at right