Default Calibrations

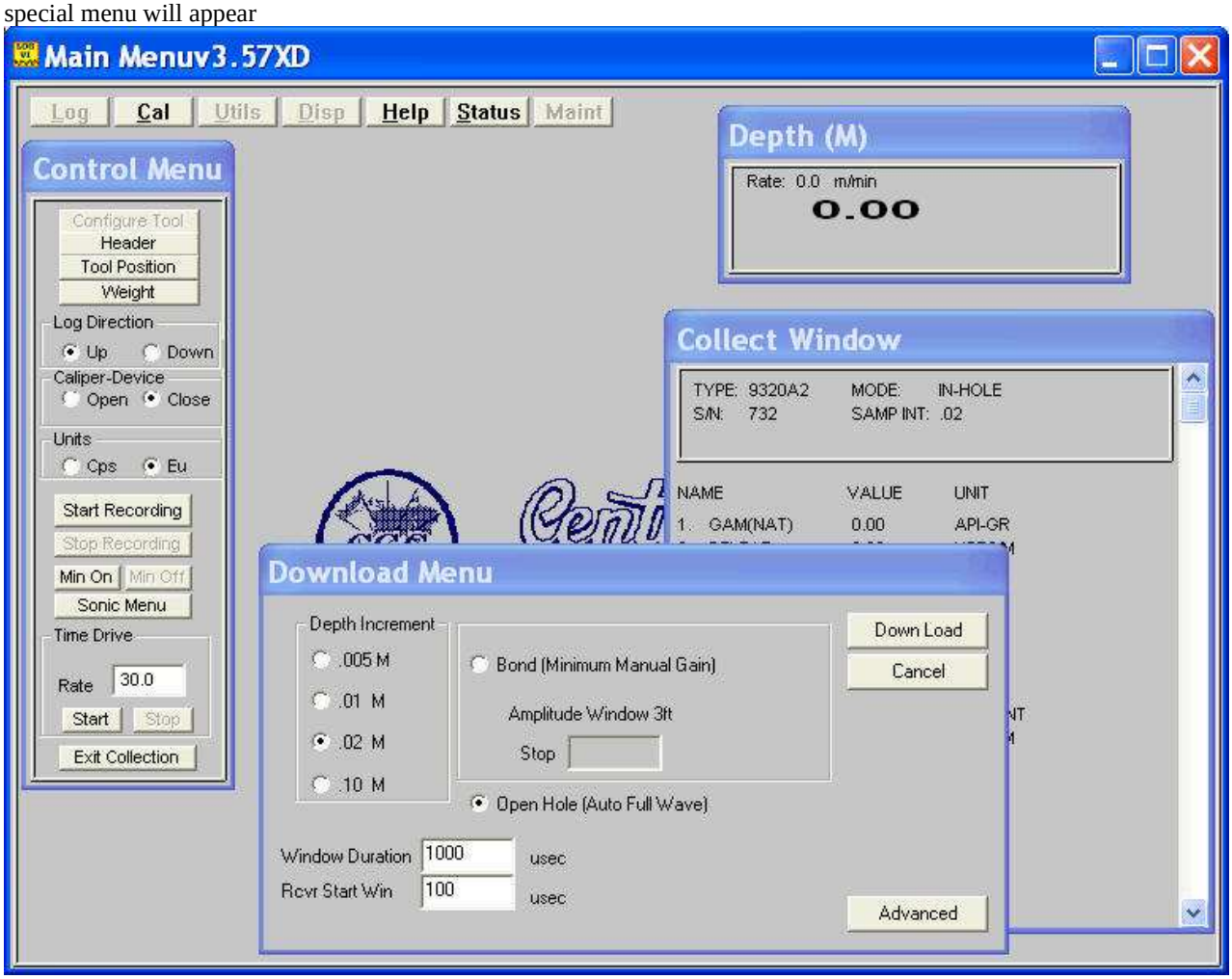
The following parameters are sensors and responses are set up to electronic bench testing specifications. Therefore, these "default" calibration numbers may be used to log the tool. The sensors are the following:

Sensor	Standard	Response
Natural Gamma	0 API units 200	0 cps 180 - 220 cps

API Conversion Factor: 1 cps = 1.04 API units In the calibration file, if the default values of 0 cps equals 0 engineering units is not changed, the tool will then automatically use the default values in the tool module for that tool.

Detailed Logging Instructions

1. Connect the sonic tool to the logging cable and turn on the downhole power supply. When the tool has been identified, a special menu will appear



2. Use the mouse and keyboard to enter available options. **See Recommend Settings** .
3. Once all parameters are set, **Download to Tool**. Standard logging procedures may be used to start and stop logging. Failure to download will result in complete tool and computer failure, sometimes locking up the system.
4. While traveling downward with the sonic tool, no updates will be seen in the collect window and all tool parameters will read O. Tool updates will only occur while logging or in timedrive mode.

Notes On Logging The Sonic Tool

In general, the travel time of a formation depends on the elastic properties of the formation, which are related to porosity and lithology. The harder the material, then the faster the travel time of the formation. Increasing porosity would therefore increase the travel time. Standard velocities and delta travel times for various materials are given below:

Material	Velocity (ft/sec)	Avg matrix travel times (usec/ft)
Water	4,800-5,500	189 to 210 (salt water to fresh water)
Shale	5,800-16,600	60 to 170
Coal	6,200 -8,300	100 to 180
Sandstone	18,000-19,500	54
Limestone	21,000-23,000	49
Dolomite	23,000	44
Steel Casing	17,500	57
PVC Casing	8,300	120

The sonic tool is also used to calculate porosity. It is most valuable where a neutron or density source tool cannot be utilized, and formation porosity data is required. The standard method (Wyllie Time Average) of calculating porosity is similar to the density porosity calculation where:

Sonic Porosity = tLog - tMatrix / tFluid - t Matrix

tLog = is the reading on the sonic log in usec/ft.
tMatrix = is the transit time of the formation matrix in usec/ft.
tFluid = is the transit time of the fluid (usually 210 for freshwater).

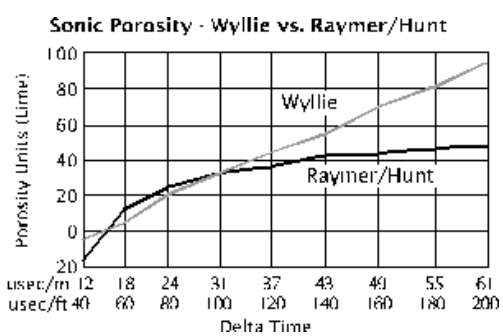
The above method works quite well in formation with travel times less than 330 usec/m (100 usec/ft). In slower formations, the Wyllie formula gives an optimistic porosity reading.

In shallow sedimentary formations, quite often the formations are not compacted and the travel times are relatively slow. A general rule of thumb for using the Wyllie formula is a nearby shale needs to be less than 330 usec/m (100 usec/ft), if it is not, a compaction factor needs to be calculated and applied.

With the limiting factors above in many formations, Century has chosen a more accurate formula based on empirical data, namely the Raymer-Hunt Formula for porosity calculations. Where:

Sonic Porosity = 63 x [1 - (tMatrix/tLog)]

The **following graph** depicts the difference between the two methods.



Century uses a "depth-derived" borehole compensated sonic log by saving the near and far travel times in a computer array and then calculating in a similar method as the dual transmitter/dual receiver tool. In Figures 10 and 11 at the end of this document, it can be seen that the travel time between a single transmitter T1 and second receiver is equivalent to the travel time from the second transmitter and first receiver in the two transmitter tool and the first transmitter to first receiver time is equivalent to the second transmitter to second receiver time.

The borehole compensation, although more accurate in the calculation of travel time, is more affected by cycle skips. A single

cycle skip will cause two invalid values on the BHC delta time, since each near and far travel time is used in the calculation twice.

Century Recommended Settings

The below parameters are set in the **SONIC MENU.** The recommended settings below should properly recorded and sample the full wave data in most normal field applications. Please refer to the Logging Instructions for full details of these settings.

1. **Depth Increment = 0.02 meters (0.1 ft)**
2. **Mode = Open Hole or Bond Mode**
3. **Gain Mode = Auto or Fixed by operator selection**
4. **Window Duration = 1000**
5. **Receiver Start Windows = 100**

Sample Interval: Allow user to select the sampling interval.
Options are: meters (.005, .01, .0.2, .10) and ft (0.02, 0.1, 0.25, 0.5).

Operation: This option sets the mode of the full wave data collection. Bond Mode records the data in a full wave, and uses the minimum gains. Open Hole Mode automatically sets the gains to receive the best signal.

Open Hole Mode: When in Full Wave mode, and the gains are adjusted automatically as described on page 4, "Operation Modes".

Bond Mode: When in Manual Mode Only, the gain adjustments are fixed by operator selection.

Preamp Gain: Sets tool preamplifier gains: LOW, MEDIUM, or HIGH. This is the gain closest to the receiver amplifier, which is less likely to cause increased noise by changing this adjustment. Recommended first gain adjustment: If additional gain is necessary, this preamp gain should be increased to its maximum before increasing the ADC PGA gain.

ADC PGA Gain: Stands for Analog Digitizer Converter, Programmable Gain Amplifier. Sets tool secondary gain, x1, x2, x4, x8, or x16. This is the gain at the digitizer. Recommend adjusting secondly.

Window Duration: Sets how long the tool will collect data for each channel separately. The valid range is 4 to 7000 usec, in 4 usec increments. The first arrival, which is used to compute travel time, is picked from the digitized full wave. Therefore, the window duration must be long enough to include the first arrival.

Rcvr 1 Start Window: Sets the start window or start delay for the near receiver. The valid range is 2 to 512 usec, 200 in most applications. Must be set in 2 usec intervals; otherwise the electronics will round to 2 usec travel times.

Rcvr 2 Start Window: Sets the start window or start delay for the far receiver. The valid range is 2 to 512 usec, 200 in most applications. Must be set in 2 usec intervals; otherwise the electronics will round to 2 usec travel times.

DOWNLOAD TO TOOL: Transmits the above parameters to the tool and exits the Sonic Tool Parameters Menu. This **MUST** be done **EVERY** time a parameter is changed or the tool has been turned off.

CANCEL; This simply exits the menu, WITHOUT transmitting the setting to the tool

Logging Messages

Successful Download: Tool parameters were successfully transferred to the tool electronics.

Missing Shot: The tool passed a sample interval without transferring the sample data.

Missing Trace No XX: The software received the sample data with a full wave trace missing.

Short Trace: The software received a trace with incomplete full wave trace data.

Bad Toolcard Numsamp: The software received a bad sample.

HDLC Data Collision: The toolcard has issued a warning to the operator that it is ready to send a message to the tool, but the

tool is still transmitting. But the collision was detected and avoided. This is most often caused by excessive logging speed.

First Arrival Identification and Delta T Accuracy

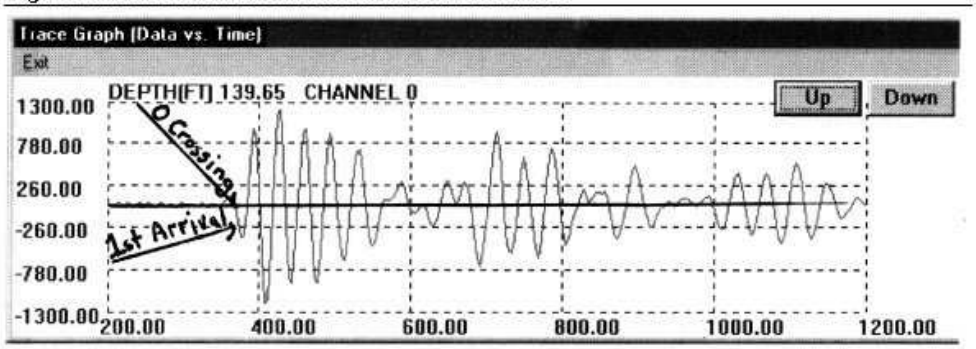
The sonic tool performs a full analog to digital conversion of the receiver signals. The sampling clock is derived from a 32 MHz crystal oscillator, which is accurate and stable to 100 PPM. The tool samples the full wave data at 4 usec samples, which results in a sample rate error of +/- 0.0002 usec. The processor then scans the sampled data for the first negative arrival below a preset threshold of -260. Then the amplitudes and locations of last sample above and below the zero crossing are noted. These two points are used in a linear interpolation routine to determine the zero crossing location within one microsecond, with an error on +/-one half microsecond. Given that the receiver spacing is 0.3 m (1 ft.), the delta-t becomes the difference between the near receiver zero crossing and the far receiver zero crossing. Since both crossing have an error of +/- one half microsecond, the subtraction results in a total delta-t accuracy of +/- one microsecond. Examples are given below:

Example 1: Delta T of shale runs approximately 394 usec/m (120 usec/ft.), given an accuracy of +/1 usec, results in a maximum error of 1.7%.

Example 2: Delta T of steel runs approximately 187 usec/m (57 usec/ft.), given an accuracy of +/- 1 usec, results in a maximum error of 3.5%.

Figure 1 indicates how the screen will display the first negative lobe detection and zero crossing.

Figure 1: First Arrival Pick from Full Wave Mode



Operation Modes

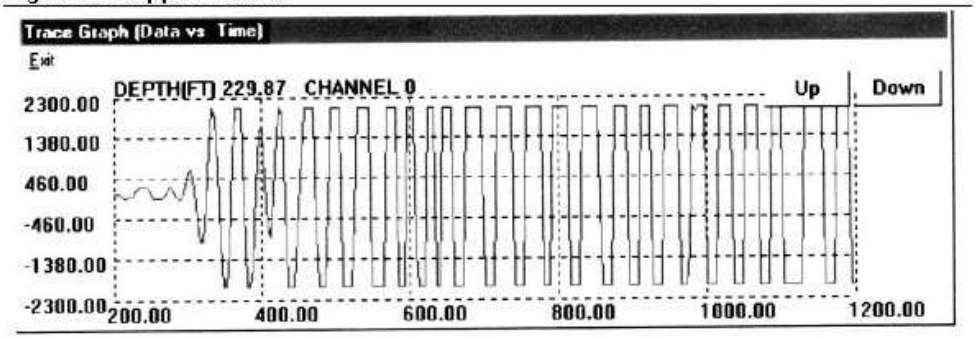
The tool operates in three different modes of operation as previously indicated.

A more detail description of these modes is as follows:

Clipped Mode: The transmitter is fired and a full wave trace is collected. The data is then scanned for the first arrival and the first arrival peak amplitude is measured. If the peak amplitude is less than 700 or greater than 2000, the gains are adjusted and a new data set is collected. The new data set is then used to calculate arrival time and peak amplitude. The gain level for this channel is saved to be used in the next sample. In the worst case, where the gains must be adjusted and refired, this process will take 75 millisec.

This mode of detection is best for picking the first arrival and matching the analog travel time to the full wave travel time. The full wave form that is recorded is the same as the one used by the tool electronics to pick the first arrival. Best used in open holes for travel times only or cased holes for cement quality. The "wave form trace" in **Figure 2** is of this mode.

Figure 2: Clipped Mode:



Full Wave Mode: The transmitter is fired and a full wave trace is collected. The data is then scanned for the first arrival and the first arrival peak amplitude is measured. If the peak amplitude is less than 700 or greater than 2000, the gains are adjusted and a new data set is collected. The new data set then is used to calculate arrival time and peak amplitude. The gain level for this channel is then used for the next shot. The gains are then adjusted to the previous "full wave gain" and the transmitter is fired and the data is collected. The data is scanned for the largest peak. If the peak is less than 700 or greater than 2000, the gains are adjusted and the full wave is recollected. The full wave gain level for this channel is saved to be used in the next sample. In the worst case, where the gains must be adjusted and refired, this process will take 177 millisec.

Manual Mode: In the manual mode the gain level is set by the operator and down loaded from the computer to the tool. The specified level is set for each receiver and the transmitter is fired. The data is collected and processed for the first arrival and first arrival peak amplitude. No attempt is made to alter the specified gains by the system hardware. This technique is used where a preset gain may be of some advantage, such as in steel pipe or open holes which maybe noisy or exhibiting cycle skips. Unless the logging engineer is highly experienced and knowledgeable in full wave sonic logging, this mode is not recommended.

Sonic Logging Speed

The logging speed is limited by the combination of the computer platform, telemetry system, and the data recording parameters (i.e., sample interval, start delay, and window). The following charts should be used to establish your maximum logging speed based on sampling rate. Increased speed over the values in the following tables can result in missing full wave data traces and depth recording problems.

S. I. (Metric)	Maximum Speed
0.005 m	1.15 m/min
0.01 m	2.25 m/min
0.02 m	4.5 m/min
0.1 m	22 m/min
S. I. (English)	**Maximum Speed**
0.02 ft	4 ft/min
0.1 ft	20 ft/min
0.25 ft	40 ft/min
0.5 ft	80 ft/min

Table based on delay of 200, and window of 1000.

Sonic File Size

The sonic tool records both the near and the far full wave form traces, along with standard digital data such as gamma ray, near and far travel times, amplitudes, delta time and BHC delta t. The file size of the data can be quite large, requiring multiple floppies to backup the logs. For example, a 76.2 m (250 ft.) hole, recorded at 0.06 m (0.2 ft.) samples, and a window of 1000, results in about 3 megabytes of data.

Sonic Tool Quality Control

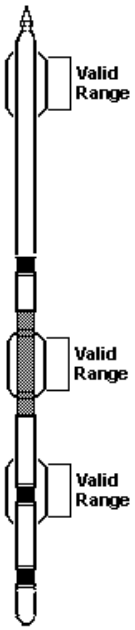
The sonic logging tool requires close scrutiny of the curve responses to insure accuracy of the log data. The following guidelines should be followed to quality control recorded acoustic data.

Sonic tools are designed for a limited range of borehole sizes and formation types. When borehole conditions are such that the sonic signal approaches the limits of the tool capabilities, intermittent data in inaccuracies will be included in the log data. These inaccuracies are referred to by type as cycle skips or noise skips. Cycle skips are caused by the tool electronics picking an increased travel time on one or both receivers. The tool picking a first arrival, which is faster than expected, causes noise skips. Other potential problems with sonic tools are poor centralization, road noise in small diameter holes, or slow travel times in non-compact formations.

Borehole Size: The borehole size is probably the most limiting factor, as the size increases, accurate travel times become more difficult to measure. Recommended hole sizes are 10.2 to 20.32 cm (4 to 8 in.) in diameter. At these ranges, the plastic centralizers need to be adjusted so that the tool is sufficiently centralized in the borehole. If this is not done properly, the tool can show numerous cycle or noise skips.

In small diameter holes (6.35 to 8.9 cm (2.5 to 3.5 in.)), the centralizers need to be removed prior to logging. Once this is done, a small rubber tube needs to be taped to the tool above and below the transmitter and receivers to eliminate direct coupling to the formation, and road noise. In large diameter holes (greater than 20.32 to 25.4 cm (8 to 10 in.)), the transmitter does not have enough power to produce a "loud" enough signal for the receivers. Therefore, it is recommended that the tool is run sidewall, or without the centralizers in place. Running the tool decentralized will adversely affect the full wave data, but in large holes, may enable a good P wave arrival to be measured. With either of these methods, borehole washouts or hole size problems can cause considerable problems with arrival detection.

Tool Centralization: Sonic tools are intended to be run centralized. Proper location on the tool and size adjustment needs to be done prior to recording a log. Also, in some instances, readjustment of a centralizer can improve the log quality.



In general terms, the centralizers need to be expanded so that the tool maintains itself in the middle of the borehole. However, too much expansion of the centralizer can cause noise due to the centralizers rubbing the borehole wall.

Placement of the centralizers on the tool should be such that they are as far away from the transmitter and receivers as possible. The center centralizer should be placed near the uppermost part of the rubber acoustic isolator. A diagram of the tool and centralizers follows.

Figure 4 and **Figure 5** show the difference in results from a centralized and an uncentralized tool.

Figure 4: Sonic Tool: Centralized:

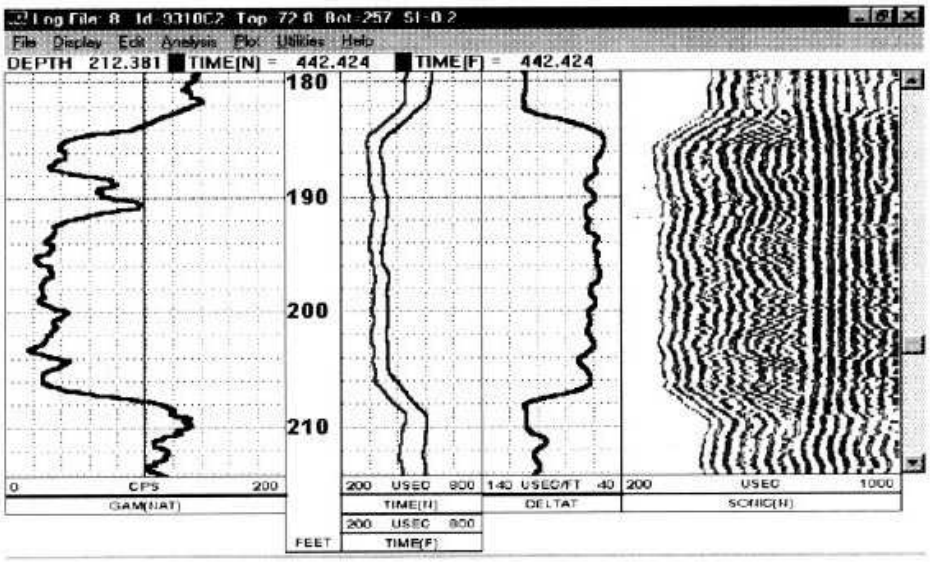
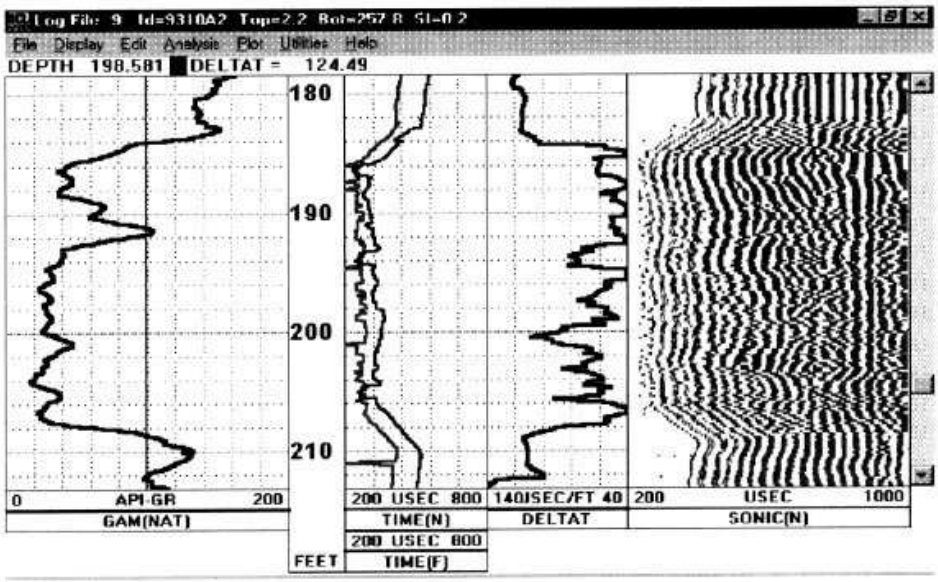


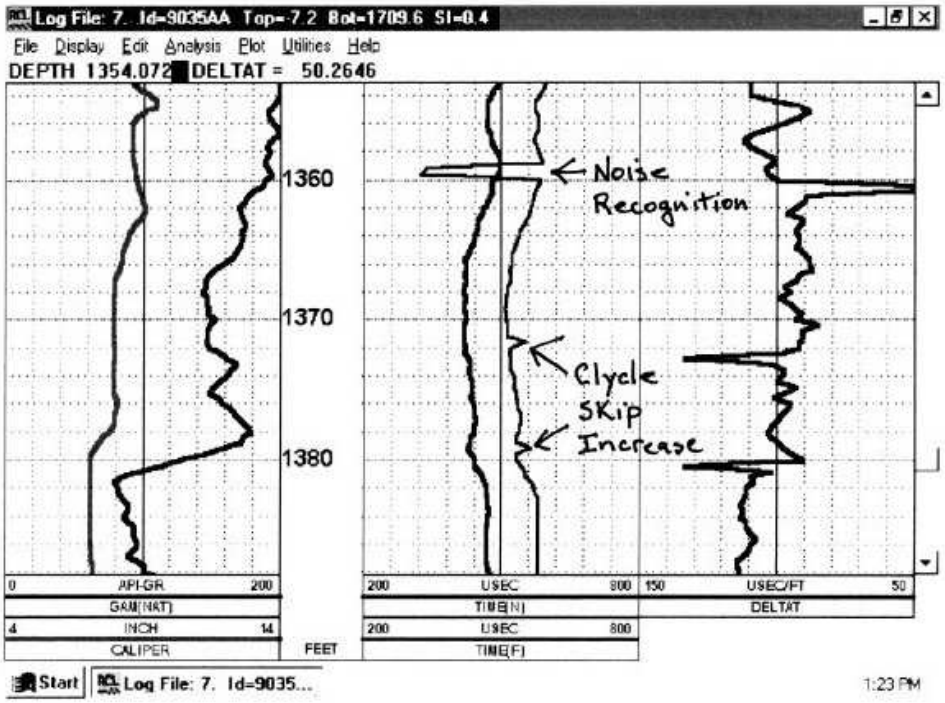
Figure 5: Sonic Tool: Decentralized:



Cycle Skipping: In the measurement of travel time, the amplitude of the first arrival may be such a magnitude to cause cycle skipping. The detection threshold is set for automatic detection at -260 units. If this signal level is below this threshold, the tool will detect the first cycle, which exceeds the threshold. This may be one or more cycles after the proper first arrival. It can be easily recognized on the log by an increased travel time on the near or far travel time for one sample interval. Most often these cycle skips are increased in time. But on some occasions, it can be a decrease in time, in which case the detection was made on an invalid noise signal.

In **Figure 6** the far travel time shows two positive and one negative cycle skip. At the period of the signal of 42 usec, cycle skips usually increase to the next arrival, with an increased time of 42 usec. Noise spikes may occur at any time prior to the first proper arrival. Also notice, the computed delta time shows invalid travel times at these three points.

Figure 6: Sonic Tool Cycle Skip Recognition:



Increased Hole Size and Washouts: As the hole size is changed, the sonic tool can show significant problems due to first arrival detection. Therefore it is recommended to run a caliper log with the sonic tool. The caliper log is then a log quality control parameter that needs to run with the sonic tool. Rough holes, or hole enlargement can cause excessive noise and cycle skipping. It may be necessary to re-adjust the centralizers to achieve a better log.

Formation Problems: Some formations, especially non-compacted shallow sediments are not conducive to sonic logging. These are typically coastal sandstones with very little cementation and are quite porous. Normally there is nothing that can be done to fix this type of problem. But the user should at least be able to recognize that the tool is performing properly, and the response is due to the formation type.

Sonic Log Corrections

Of the many things that can affect the sonic log, cycle skipping and noise spikes, which result in bad travel times, are of most consequence. As the delta time log is derived from the near and far travel times, an invalid log can be corrected by using one or both travel times, to re-calculate delta time.

In boreholes with frequent cycle skips or noise spikes, the travel time may be improved by post processing of the near travel time to determine a delta time. The amplitudes are higher, and it is less likely to cycle skip. The only difficulty in this calculation is the estimation of the mud travel time. The distance to the receiver is three feet.

Therefore a close approximation of the delta time per foot is calculated as below:

Delta Time per meter or foot = (Time Near - Mud Travel Time) / 3, given;

Time Near = 480 usec
Mud Travel Time = 75 usec
Delta Time = 135 usec/m or ft

To accurately determine the mud travel time, select an area in the borehole where good near, far, and delta t travel times exist. Insert the near time and delta time values into the equation above and solve for mud travel time.

Both the near and far travel times can also be used to recalculate a delta t. In cases where intermittent cycle skipping and noise spikes has occurred, the logs can be filtered using a median filter (5 point recommended) to remove these spikes. See example logs following showing filtered log. However, this only works where the spikes are intermittent and not continuous. Once this

has been accomplished, the delta time is calculated as:

Delta Time = Far Time - Near Time, given

Far Time = 615 usec, Near Time = 480 usec

Tool Checkout Procedure

The recommended procedure to check the tool is in steel pipe of at least 8 feet in length and six inches in diameter. The pipe should be placed in a vertical position, filled with fresh water, the tool placed inside so that the transmitter is covered by water, and the centralizers properly adjusted.

A timedrive log should then be recorded in engineering units. The operation mode should be in CLIPPED MODE, with the recommended start times and window duration. The log should show a consistent delta t of 187 usec/m (57 usec/ft). The amplitudes should be within a range of 10 to 20 MV. Both near and far gains should show a maximum gain of 260. The first arrival should show amplitude greater than 700, but less than 2000. **Figure 7** and **Figure 8** indicate how the screen will display these checks

Figure 7: Steel Pipe Tool Check:

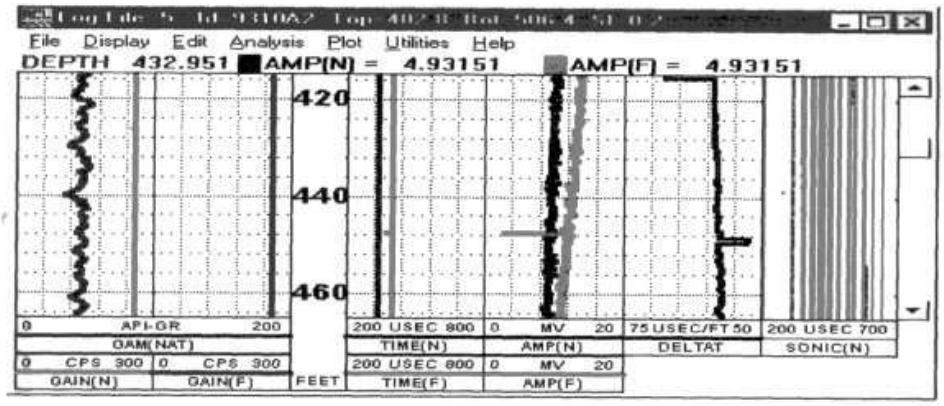
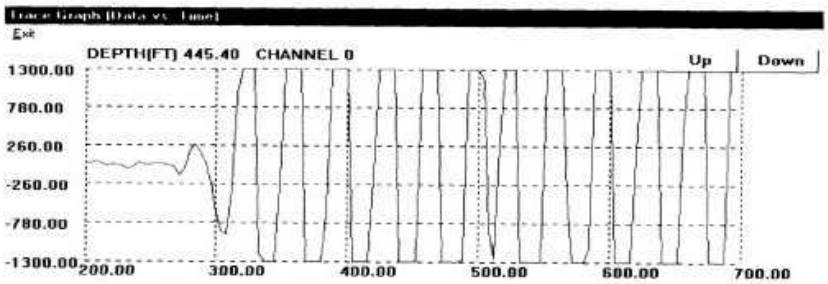


Figure 8: Near Receiver Signal:



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Maintenance and Storage

No specific maintenance of the external surfaces of the tool is required. General cleaning with soap and water should only be necessary. The centralizers do need some maintenance to make sure they are sufficiently rigid and properly located for tool functionality.

Storage of the tool should be in a rigid position to maintain the acoustic isolator without any large bends. Do not store the tool in a "U" shape. The centralizers also must be stored so that they are not bent or crushed, to avoid damaging them.

Standard Log Applications

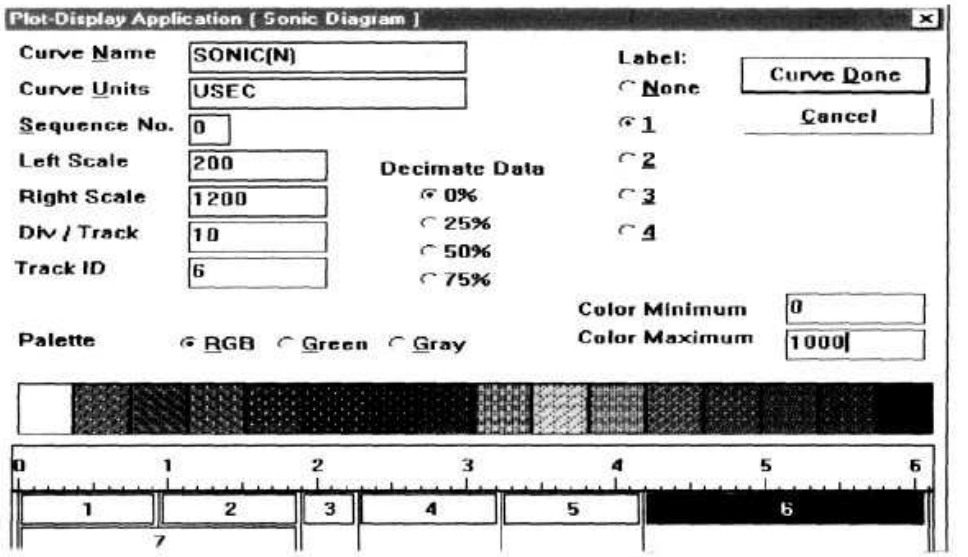
Client Application: The traditional 21 cm (8.25 in.) API grid is the recommend display. The natural gamma ray is presented in track 1 with increasing units to the right. The delta time in tracks 2 and 3. Normal log scales for delta time should be 600to 200 for the metric scale, or 140 to 40 (or at least 100 units across the grid) for English units. Near and far travel times should also be printed for the client reference and quality control, usually in the far right track. Smoothing of the data should be kept at a minimum with good logging conditions and proper tool operation. If a caliper log is available, this should be merged with the sonic, and presented in the gamma ray track. The calibration file should also be printed to show last calibration date and values.

Log Quality Control Application: For quality control, the additional curves of near and far gains need to printed. From this data, the logging engineer should be able to recognize cycle skipping problems. There should be no smoothing of the data so that bad samples can be easily recognized. Correlation of cycle skipping due to hole size problems should be noted. Notice on the far detector the frequent large cycle skips from approximately 685 to 690 meters 2,247.4 to 2,263.8 ft.). The near detector is also affected through this zone, but not nearly as bad. Now compare this log to the median filtered near and far travel times. A substantially better log is produced, but not all of the problems are removed.

Display using the VDL - Full Wave Form: With the sonic tool, full waveform display is done in DISPLAY. It is recommended that the near wave form trace is printed, as it has better resolution and usually a greater difference in amplitude magnitudes. Again the API plot is used, with natural gamma in track 1, delta time in track two, and near receiver wave-form in track 3.

Prior to printing, the Decimate Data must be set to 0. Amplitude color selection is controlled in the Plot-Display Application (Sonic Diagram) section as shown in **Figure 9**. The color maximum value should be adjusted to maximize visual resolution according to the recorded log.

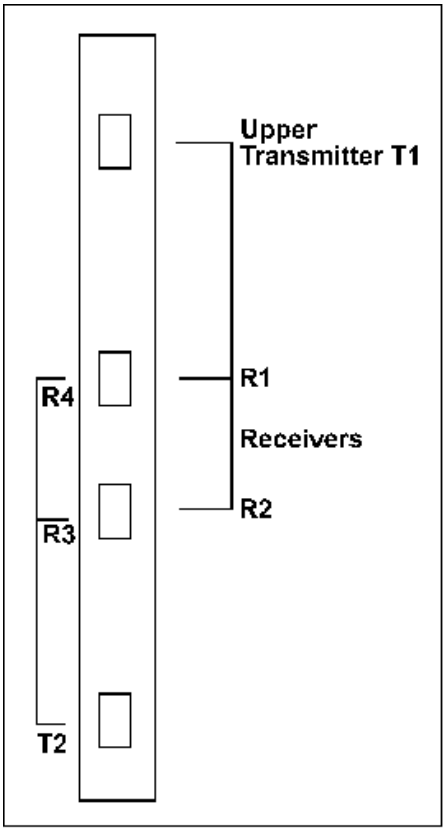
Figure 9: Plot-Display Application:



Borehole Compensation

The standard method of doing borehole compensated Delta T is to have two transmitter crystals and two receiver crystals. (See **Figure 10**) Averaging of the two delta t measurements cancels some of the errors from logging tool tilt and hole-size changes.

FIGURE 10



BHC Delta T = Average of Delta T from T1 to R1 and R2, and T2 to R3 and R4.

Phone: 918-838-9811
Fax: 918-838-1532

Century
Geophysical Corp.
1223 S. 71st E. Ave
Tulsa Oklahoma, 74112

sales@century-geo.com
www.century-geo.com