A DISCUSSION OF FIELD TECHNIQUES AND RECOMMENDED OPERATING PRACTICES FOR USE WHILE ELECTRONIC SCANNING OF TUBING IN THE FIELD

Fred M. Newman
In conjunction with Key Energy Services

ABSTRACT

This paper reviews current electronic tubing inspection equipment and interpretative techniques as applied to inspection of tubing while pulling. It specifically addresses possible measurement and interpretative errors due to variances in rig pulling speeds. Finally, it recommends guidelines and standard operating practices that will allow the well operator to obtain the maximum value from the scanned data.

INTRODUCTION

This document is a sequel to a paper presented at the 2006 SWPSC entitled “Preventing Tubing Leaks in the Field, A Reality Check” wherein electronic scanning jobs in the field were studied. Primarily, that paper defined basic principles of measurement, introduced variables that could adversely affect the actual measurements or interpretation of data, and discussed a few actual field tubing scanning examples. Although the data curves seemed to indicate that there were significant job quality issues due to tubing pulling speeds, the lack of statistically significant and corroborating samples makes that paper less conclusive than desired. Attaining good data with just field examples is cost prohibitive and lacks control of variables.

With this work, tubing scanning is performed with a service rig in a controlled environment, as close to laboratory conditions as possible. Multiple scanning passes were made on 2-3/8 EUE J-55 tubing under known conditions. Results are summarized with specific illustrative example passes discussed in detail. Conclusions are developed, substantiated by good data statistics, corroborative observations, and irrefutable physical evidence and conditions. Finally, based upon the results of this study and the previously cited paper, suggested “Best Practices” are proposed to ensure job quality and safe operations.

THE PROJECT

The objectives of this follow-up experiment were to:

- Ascertain what the scanning data would look like in a known pipe defect region at different carefully controlled pulling speeds.
- Attempt to determine the optimum block speed while scanning pipe.
- Determine if the tubing could be scanned in either direction and not necessarily only during pulling phase,
- Draft a Best Practice policy to use during the electronic scanning process.

The Process

Key Energy has a test service rig over a 400 foot hole in Midland which is used to train crews and support science and research projects such as this. This rig is equipped with KeyView® a rig monitoring and control system, allowing in this case for measurement of block speeds and position. In addition to furnishing the rig, Key hired an independent electronic scanning company for a day for the purpose of gathering scanning data on two joints of 2 3/8” tubing. The selected measurement for the experiment was “Hall effect”. It is the measurement of choice commonly in the oilfield today. Radioactive densiometer wall thickness tools are deemed unsafe and are a regulatory nightmare. Inductive principled measurements are even more susceptible to inaccuracy due to variable conditions. Lastly, higher technology measurement devices are not readily field deployable. An air pressure based split detector was also included in the measurement.

The experiment was quite simple. The tubing string consisted of (1) a ten foot pup joint on top, (2), a known good joint with no defects (yellow band), (3) a red band joint with known rod wear but no holes, and (4) a short marker joint, all on top of several more joints of tubing provided for stability. The two target joints were scanned in excess of 100 times at varying but constant block speeds, as well as while accelerating and stopping, both moving up and down. The block velocity and position was recorded on each pull as well as the raw data from the scanning company and each file was numbered and cataloged. At the conclusion of the experiment, the individual scanned datasets were matched to their respective pull and the scanning response curves were plotted against the block position and block velocity.

The purpose of the ten foot pup joint on top of the two joints being scanned was to allow the rig to build up to and hold a constant speed across full length of the target 62 feet of the tubing stand. The scanning company was aware of the purpose of this experiment and they were asked to calibrate their equipment and to be as careful as they could on starting and stopping the files and tracking the file numbers on each scan.

There are two contributions to interpretation of the scanned data, the human factor and data acquisition capabilities and limitations, and both will be discussed. Figure 1 is what one would expect to see while this particular stand of tubing was being pulled through the scanning head. Remember the scanning data is being presented in a “time format” with the time running from left to right, meaning the first joint (yellow band) is on the left and the red band pipe is on the right. Clearly, from Figure 1; the technician would rightfully call the upper joint yellow and the lower joint red. The actual field process of inspecting the pipe is for technician to be looking at the data as it moves across the screen. He cannot be watching the rig as the pipe is being pulled as his eyes are glued to the screen. He sees the data just as it is presented in figure 1, except that it is a moving target until he hits the stop button.

The human operator routinely follows this procedure: The tubing is scanned while the tubing is being pulled out of the hole. The technician looks at the scanning data as it comes across his screen. At the end of each individual pull, he presses the stop button and on the spot, while the pipe is being dismembered from the lower section, makes the call over a speaker; “Yellow or Red or Blue or Green.” After the verbal call, the technician numbers the file (example joint 102) in an excel format and grades the pipe on percentage of wall loss or percentage of pitting type format based on his visual observations. The excel sheet is the end data that is normally presented back to the customer. When the elevators are latched to pull the next stand, the start button is pressed starting the whole process over again. A good analogy for this process might be: Imagine a home plate umpire that has to look at a 90 MPH fast ball coming across the plate to see if it was in the strike zone or not. He then makes the call, “Strike or Ball”, then has to number the pitch, capture the ball or strike on his PC, input to the PC how far high or low, inside or outside, and then grade the overall pitch. The umpire would have to get all that done while the catcher returns the ball to the mound and before the pitcher starts to make the next throw. You can now appreciate the pressure and possibility for errors present under these conditions. This is called multitasking to the highest degree.

First operational problem observation: The scanning technician has to manually start and end the recording so as to obtain the optimum image with which to evaluate, depending on individual operator preference. He tries to coordinate the start point just when the rig picks up off the slips and stops the file just as the slips are closed around the tubing and the blocks come to a complete stop. The next two figures depict what can happen when the rig operator and technician are not in sync.

There is a speed element or how fast the blocks are moving that has to do with what the operator sees on his screen and this will be addressed later on in this paper. In addition, the technician can go back and review the file just as we did for this paper and stretch it for a full screen view, but this is not done in the field as it would slow the rig down too much.

Examining figure 2, the technician started the scan file long before the rig starting moving the tubing resulting in about half the screen being filled with dead data or flat lines. In this case, the meaningful data is therefore compressed into the other half of the screen.

Figure 3 is near perfect timing and coordination between the rig and the technician. Note the screen is full of data from left to right and the maximum width leads to more definition for proper interpretation. In addition to the starting and stopping for maximum definition, do not forget the pipe must be graded and filed after the measuring stops. Lesson one therefore becomes: Make sure you have a good, well trained, non-distracted technician scanning the tubing.

Relevant to the measurements themselves: There are three separate channels of data presented: The upper curve is an electrical response presentation based on the array of Hall Effect sensors surrounding the pipe, sensing or reacting to the magnetic flux field changes in the pipe wall. These sensor measurements are then processed through an amplifier and filtering system. Paramount to evaluating what is being presented and interpreted, is to understand that this is a digital and not an analog signal that is being processed and analyzed. Analog signals are continuous readings while digital signals are discrete (separated in time) measurements based on the system's sample rate and output rates. The chart readings from a digital system are derived from software that connects the dots from gate to gate and it is made to look continuous for aesthetic purposes. The typical generic electrical digital circuit works much like a camera taking photos: It opens a shutter, takes a photo or reading, closes the shutter, and waits for the next command to open the shutter again. Cinemas are shot with a camera that repeatedly, at a uniform rate, opens and closes a shutter, capturing the image each time the shutter is opened. While watching the movie, the film is played back at the same shutter speed of the camera and a moving horse, for example, takes on real life appearance as objects seem to flow in front of the eye. Actually, the movie folks know how fast our eyes can refresh and they keep that shutter speed just above the point where the blur and the jerking motions are gone.
Second Lesson: On the job, be aware of equipment age and capabilities. Newer equipment is usually capable of higher sample rates and dynamic signal amplification and filter changes, as well as enhanced presentation and recording.

The second or middle channel is a split detector. Intrinsic to the magnetic flux change measuring by a Hall Effect system, an array of sensors will not detect a thin longitudinal split in the tubing wall. The reason for this is, the magnetic flux lines want to go from north to south or along the axis of the tube and will therefore bypass the split like it does not exist. Unless the split is wide enough, or the edges are damaged, the sensors may not see it at all, or just detect the ends. To circumnavigate this, the scanning companies use a "pressurized cylinder" type device with wiper rubbers on each end that form a seal between the cylinder and the tubing. Air pressure is then applied to the cylinder resulting in the annular space between the cylinder and the tubing being pressurized. The split detector reading in channel two is nothing more than a graphic presentation of that annular pressure. If it drops, air is bleeding somewhere, presumably through a split or hole. In the case of our lower joint of tubing that had both external pits and rod wear, the air was bleeding off from severe external pitting and not holes or splits. Note the uniformity of a straight line on the top joint of tubing in Figure 4. This joint of pipe still had the mill varnish on it so a perfect seal was possible. The three humps in this curve are the couplings coming through the cylinder and the data is to be ignored in the coupling region.

Once again, hall effect sensors have some advantage over coil detectors of flux leakage in that they measure field strength directly in front of the sensor, with additional reduced contribution from flux distributions off center. The older coil sensor technology measured change in magnetic field strength, and therefore was highly susceptible to velocities. Neither sensor can directly measure how much metal is present. That is an inferred (interpretation) result. In actual field usage however, sampling rates and signal filtering insert velocity effects into the output data. Sampling rates give you an upper limit to pulling speed. For nine channels of data at 5000 samples per second rate, each channel would be sampled about 556 cps or once every .0018 sec. If you want to sample every 0.1 inch, you need to move no faster than .1/.0018 in/sec or 4.6 ft. per second. A 10 Khz sample rate would allow 9.2 ft/sec for the same amount of resolution. Filtering always adjusts current measurement amplitudes relevant to previous and following measurements. In this case low speeds cause data to be "washed out". A detailed explanation follows.

The absolute value of magnetic flux density in gauss, or sensor signal, are not useful for evaluation. The technician uses a calibration procedure to convert signals to a wall thickness, or in practice, metal loss. For example, if the wall thickness of a section of 2 3/8" tubing is .19 inches on one sample and the next sample measures the same .19 inches, it is fair to conclude there is no anomaly or pit or hole in the pipe at that section or between those to samples. This is best illustrated by looking at Figure 5 and comparing the wall thickness at point B to that at point A. The net change is zero and the resultant curve will be flat when the dots are connected.

This is a "Yellow" region. Likewise, if the pipe wall thickness is .24 inches at one sample and again .24 inches on the next sample, the same conclusion can be drawn by comparing B to A, no flaw or defect. The point here is, in scanning, the actual thickness is not measured and it is not the issue: It is the change in thickness or maybe the change in air pressure if you are looking at the split detector curve, that is interpreted as to presence of a defect.

As a pit or deformity is passed under the sensor, there is a change in voltage within the sensor in reaction to the change in the magnetic flux line density. (See a detailed explanation of how the Hall Effect sensor works in the 2006 SWPSC paper)

As before, we compare reading B to A, the variation is a be zero, from C to B, the change would be a net 50%, and from D to C there would be another 50%, and from E to D, the change would be again zero. Connecting the dots, the unfiltered curve would look like the curve illustrated in Figure 7.

In the previous example, (Fig 5) five samples (A-E) were taken over this finite section of pipe. If the same section of pipe is passed under the sensor but at half the velocity, and if the electronic circuitry behaves the same, the net result would be twice as many samples along the axis of the pipe as illustrated in figure 6 below.

Note there is still the same 50% metal loss (Pit) between E and C, but since there was a sample taken at D and the filter circuitry logic computes and compares the net change (sensor response) between the respective samples, the resultant or displayed curve shows a 25% net change (or some other value, depending upon filter constants) and not the 50% as before.

The two different looks for the same tubing defect because of different sampling techniques (Pipe Speed) is illustrated by comparing Figures 7 and 8. This is important because the technician's "call" or interpretation of these two curves using the wellhead scanning industry standards, moves Figure 7's section of pipe from Red band to blue band as shown in figure 8.

The first objective of the experiment on the test rig was to: "Ascertain what the scanning data would look like in a known pipe defect region at different carefully controlled pulling speeds" and Figure 9 clearly indicates the changes noted on the technician's screen.

This is the lower known red band section of pipe that was scanned repeatedly. Run A on the left was pulled at a uniform 7 feet/ second. Run B was the same joint of pipe pulled at uniform speed of 3 ¾ feet/ second and Run C on the right was a pull at ¾ feet per second. Note the diminishing spikes as the speed slows down under the inspection head. Clearly, the slower the pulling speed (or the increased samples per unit of length) has an effect on the data and if the pipe is scanned too slow, red band goes to blue or even yellow.

Using the data, we next examined what happened when a hole passes under the inspection head. As previously discussed, the top section of pipe was new with most of the mill varnish still on the surface. We scanned both joints 32 times prior to artificially adding more defects. Figure 10 generalizes what the scan looked like.

Note that the split detector picks up the rough surface of the red band pipe as it appears to loose air pressure in several places. Also, observe the flat line effect of the smooth yellow band pipe on the left.

After the initial 32 passes, we drilled holes and made pits with drill bits as shown in figure 11.

Figure 11 is what the technician's screen looked like when the stand of pipe was pulled at 7 feet per second. Note in the upper-previously called yellow band joint, the two quarter inch pits show up quite nicely toward the end of the joint. The 1/16" holes do not show up at all and it would be a stretch for someone to see or call the 1/8 inch holes. Clearly the split detector curve has not changed and the lower wall curves do not seem to change.

This stand of tubing was scanned over 50 times and Figure 12 is a representative sample of data pulling it at 4 feet per second.

The 1/16" and 1/8" holes are evident but the two ¼" pits seem to be lost at this speed. As before, the split detector and wall curves do not change but note the lower red band joint changing in character.

It was only after the blocks were slowed to 1 to ¾ feet per second, definitive curves in Figure 13 started to point the man made pits and holes placed in the yellow banded tubing.

At that speed, the split detector takes on the expected ripple and even the wall detector starts to show character. At least for this equipment, there is a paradox. You have to go very slow to detect very small defects, but you loose resolution for larger pits and areas of wear.

A lesson learned in this experiment: It is possible to calculate approximate block speeds by plotting the total net counts across the scanned joint or stand and using the known sampling rate, plot counts versus distance. The result is shown in figure 14.

A word of caution, all equipment is not the same, so do not use this particular chart. Count the number of samples across the stand or joint and build a chart for each job or company and use it to compare the uniformity and speed of the various scanned stands. This can become a real quality control chart. Example: If you tell the company you want the tubing scanned at a uniform speed, this can be a check and balance system to ensure orders were followed.

Most tubing leaks occur in the lower part of the string as this is where the fluids are as well as temperature and pressure. When a rig pulling tubing gets close to the TAC, the crew normally slows down and starts looking for the TAC coming into the scanning head. The speed of the pull goes up and down depending on how close the operator thinks he is to the coupling.

Figure 15 is a special, graphically illustrating sensor activity as it relates to speed. The upper (top) channel is all of the scanning channels of data plotted. The lower channel is the block velocity during that pull as captured from KeyView. The point of the slide is: As the blocks slow or go slower, the overall sensor activity, even the noise, drops. The block speed in this illustration varies from .5 to 2.5 feet per second and it is apparent, when the speed varies this much, it is going to be very difficult to find wear patterns or pits.

Another point: Ask the service company how many sensors are being used in the scanning head and this information will help you understand some resolution issues. The sensors overlap in their measurement regions, but the influence of the magnetic field strength off to either side is reduced due both pipe curvature and sensor characteristics.

BEST PRACTICES AND QUALITY ASSURANCE ISSUES

Fact: The more variables there are in an equation, the more difficult the solution becomes. Obviously, there are a host of variables to consider when tubing is electronically scanned in the field and the following can be used as a check sheet of many of the things to look for.

First of all, make sure all parties are on the same page and after the same objective. Caution: If the objective is to find a hole only, do a quick economic study as there are more cost efficient ways of finding holes in tubing. If the objective is to find weak joints due to corrosion and wear and to reduce future failures, institute a Quality Assurance Program. **Publish It and Enforce It**.

Before selecting what company to use, interview various scanning companies and learn how they do business as it certainly affects your business and bottom line.

- Ask what kind of equipment they are using. Make sure the equipment is standard across their company. It does make a difference.
- Ask what the "resolution" or capabilities of their equipment is.
- Ask to see their training program and gage the experience of their field people.
- Request a copy of any interpretation techniques they use.
- Ask what kind of calibration standard they use and insist the equipment be calibrated before each job.
- Request a copy of their published SOPs they use for quality assurance.
  *If the proposed vendor cannot provide you with these requests, shop elsewhere.
- Be sure to ask about the affect of block speed on their results. If they tell you speed doesn't matter, find another company or get them to explain how and why. When they give you a speed range, capture it and communicate those numbers to the field.

- Ask them if they measure and record the block speed on their files.
- Make sure every truck has an ultrasonic thickness gage to check their work. This is very inexpensive insurance.
- Tell them you want a copy of the raw data files on a CD and let them know you are going to cross check their data. You are going to need a reading program tailored to their dataset so ask for it.
- Ask if the company has a quality control program and if someone in the office spot checks the field technician's techniques and interpretation.
- Before selecting a preferred service provider, get input from the field as well as the downhole specialist who uses the data.

General Suggestions within Your Company

- Never enter into an agreement allowing the inspection company to buy the rejected tubing.

- Every company has subject matter experts to call upon. POC data, electric logs need interpreted, or frac jobs need evaluation and these are normally done with end users working in conjunction the subject matter experts. Scanning data should be no different. So within your company have a go-to person who is an expert in scanning. If your company does not have one, get one trained.

- Select a company based on quality and not just price. Do periodic as well as spot service quality reviews. Get the field input and get an opinion from an expert as to data quality and data interpretation. Ask for a scanning company representative to sit in on the evaluation.

In the Field

- During the JSA, coordinate the objectives of the scanning job with the crews, company representative, and scanning company.
- Mandate block speed limits, both maximum and minimum.
- Have the rig tie back to a single fast line configuration. This will not slow the job down but will help immensely on controlling the speed.
- Have the operator pull the blocks and measure the time it takes to pull a stand with a watch. Calculate the speed and when everyone is satisfied the rig is in the rig gear and you know the desired RPM, hold that gear and RPM. Bricks work well for a governor or make a mark on the throttle handle.
- Make sure the scanning equipment has been calibrated correctly.
- Early in the job and again after a defective joint has been located, run a repeat scan. This makes sure the equipment measurements are repeatable. Be sure and have the technician document which joint scan is the repeat.
- Pull the tubing as close to a uniform speed as possible throughout the full length of the tubing string.
- Overpull each stand by ten feet if possible and then lower it back down for setting the slips. This takes a lot of the slower speed issues out of the equation. **BEFORE** you do this, make sure the derrick is tall enough.
- About ten stands before being out of the hole or near the TAC. Stop Scanning and set the head aside. Pull out of the hole, remove the TAC and run the tubing back in the hole. Re-install the inspection head and resume scanning. This is a huge safety issue and this process eliminates the variable speed issue discussed in the 2006 paper.
- Take the time to examine the laid down joints. Use a mirror to look inside the joint. Use an ultrasonic thickness gage to look for thin or rod worn tubing.
- It is recommended that at least a few joints of tubing be taken the shop for shop inspection. This is a good test of how accurate the technician is on his picking the right band.
- Do not talk to the poor technician while he is running the scan anymore than you would talk to the home plate umpire during the pitch.
- If there is doubt on a joint, scan it twice and take a look.
- Do not be afraid to stop the job and play back a file. In fact, this is encouraged as a random check.

Last point: The author is often asked two questions when giving seminars on electronic inspections in the field.

Question one: Can you scan going into the hole. The answer is yes and in fact, I encourage the inspector to look at a stand of pipe twice if there is a question on it. Simply drop down and re-scan. Remember to use the hydromatic for speed control as rig drum brakes are always out of round and jerky.

Question two: I always-always get this one. What is the best pulling speed? The answer is, I cannot say as it depends on the vendor. There is just too much variation in the vendor's field equipment's as it the ability to resolve holes and pits and wear to nail this number down. I do however; I encourage your vendor choices to be based on science and service and not on price.   Ask them for the technical information you need to make an informed decision.

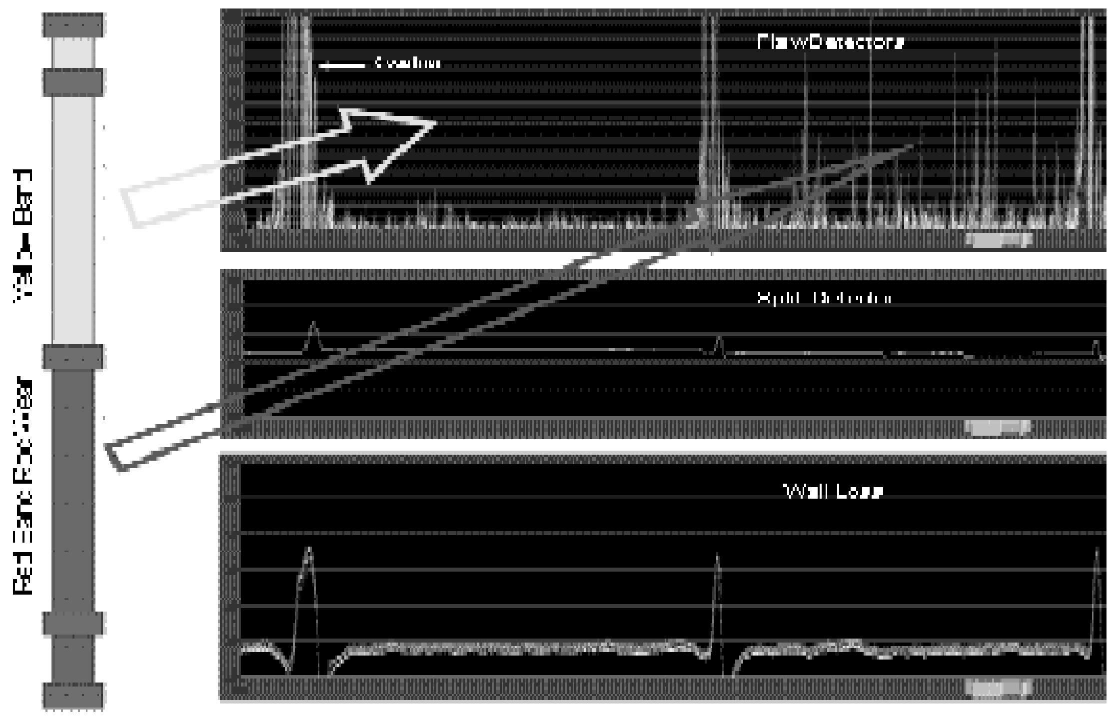


Figure 1

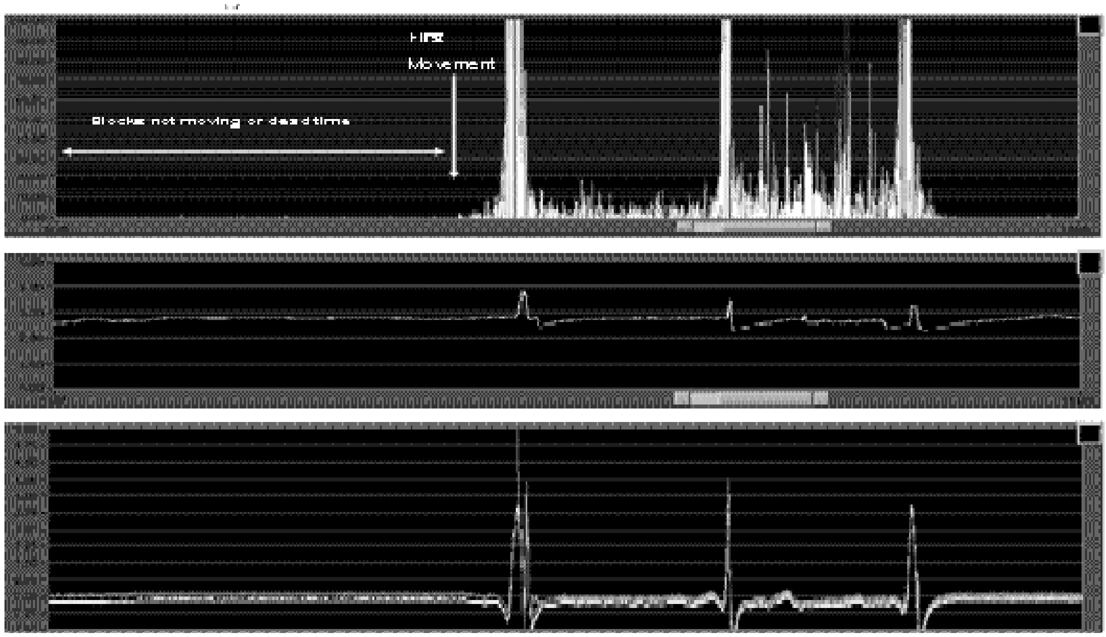
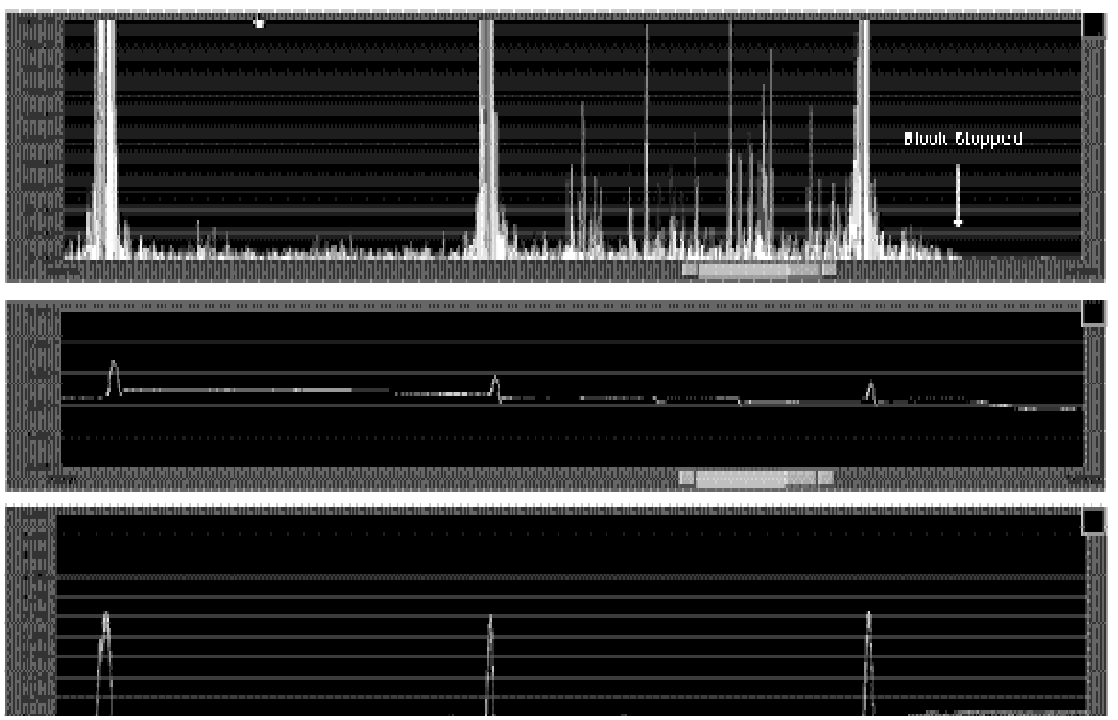


Figure 2



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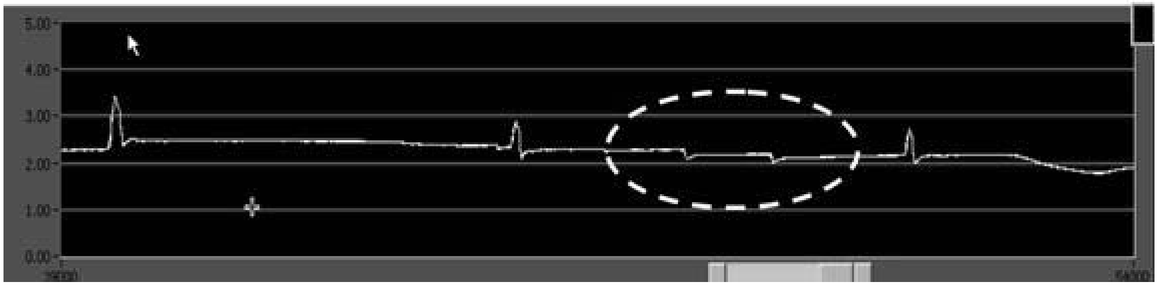

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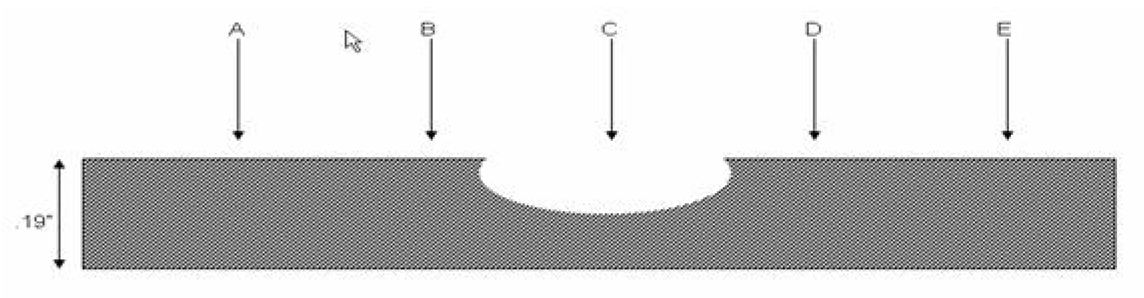

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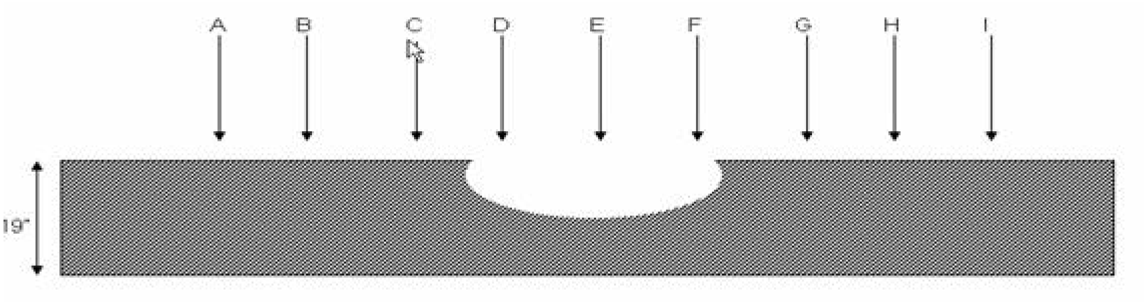

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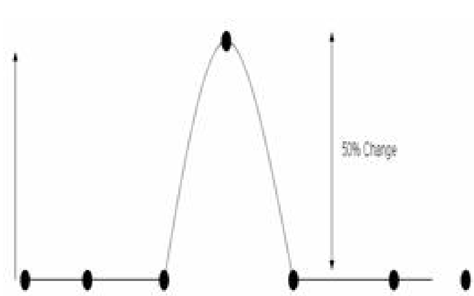


Figure 7

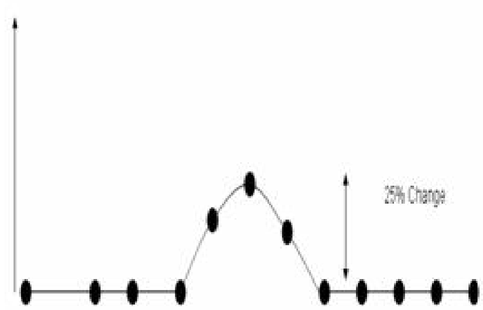


Figure 8

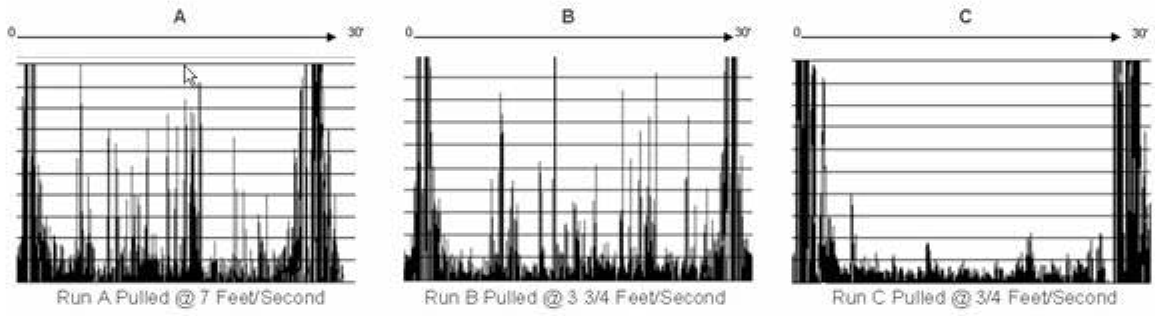


Figure 9

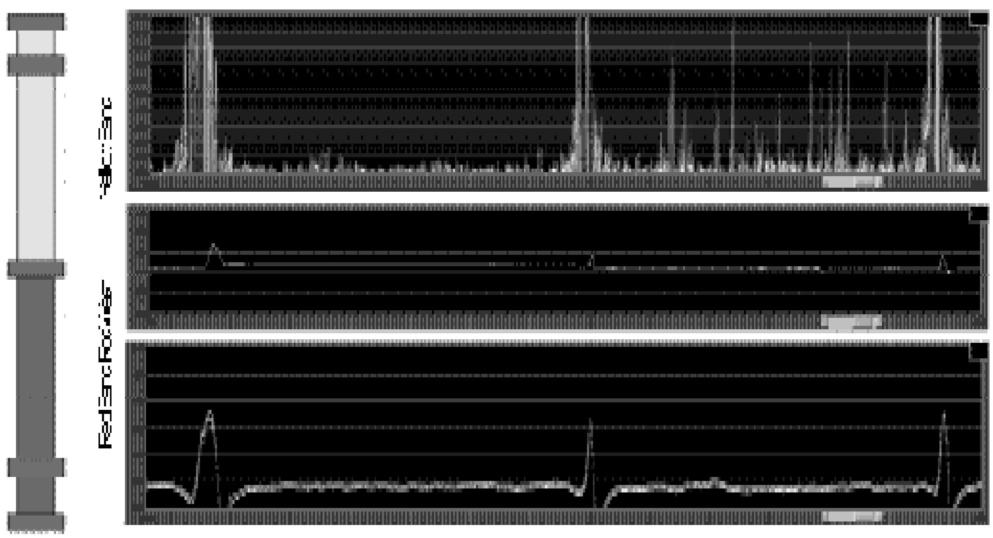
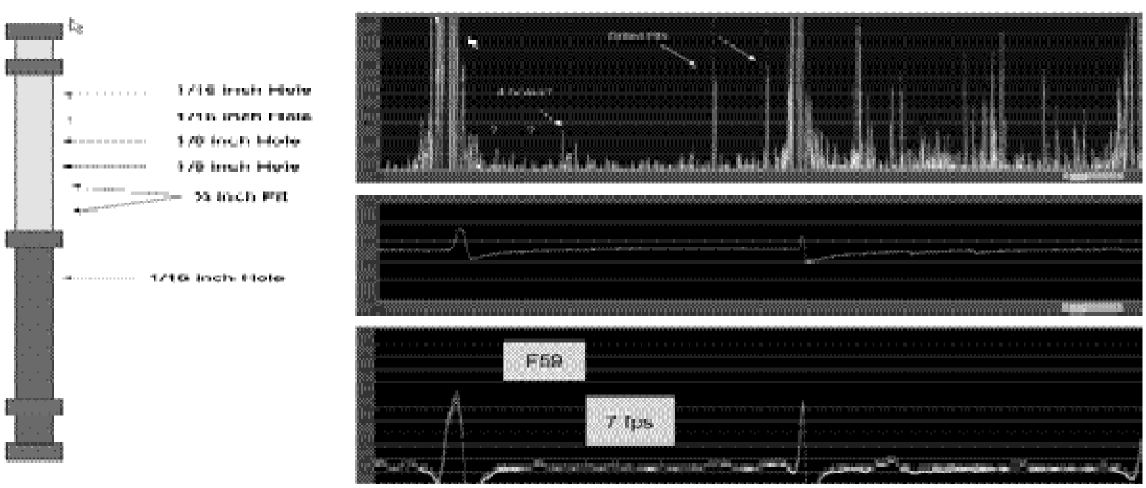


Figure 10



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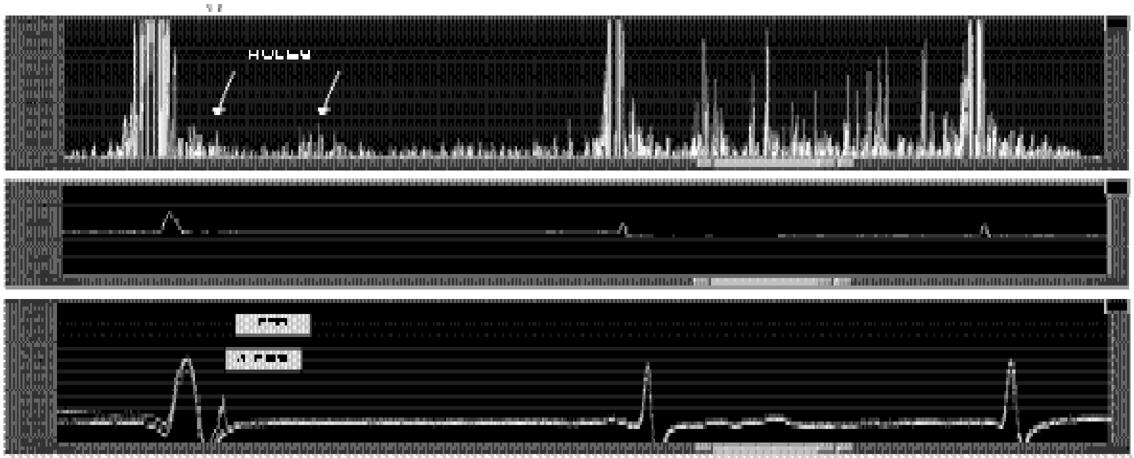


Figure 12

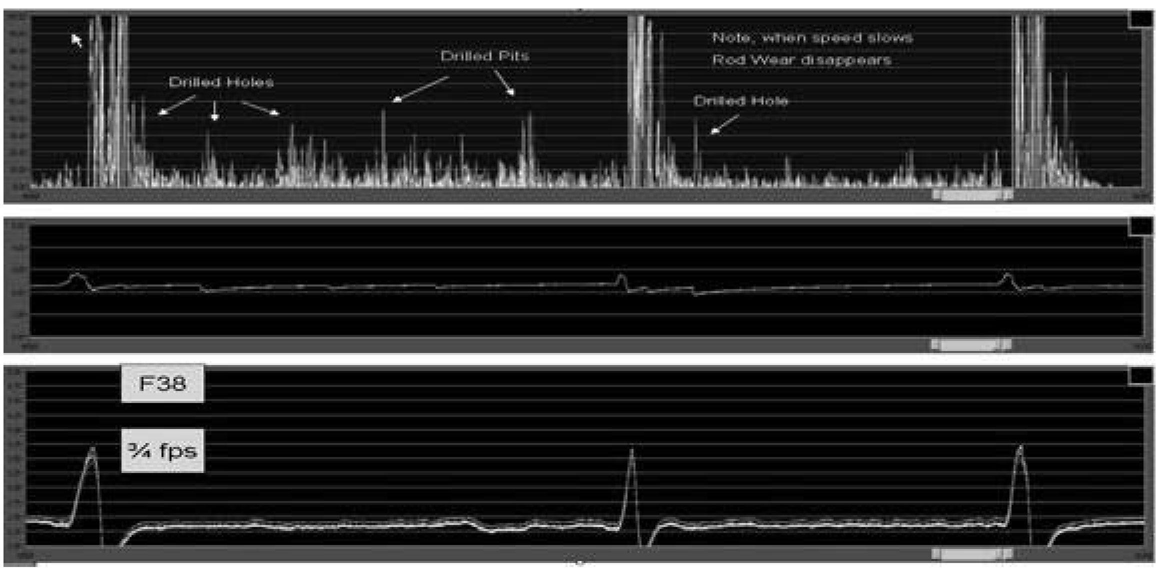


Figure 13

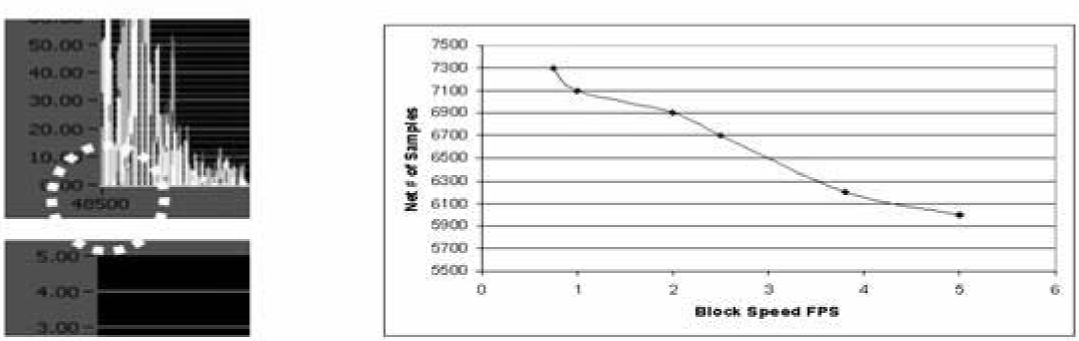
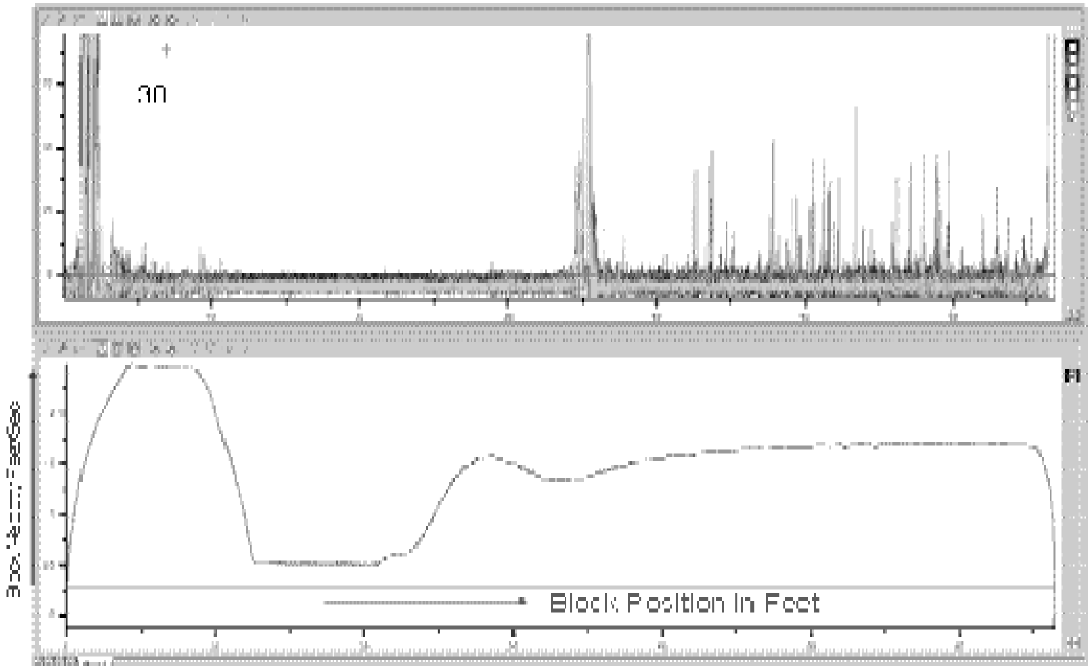
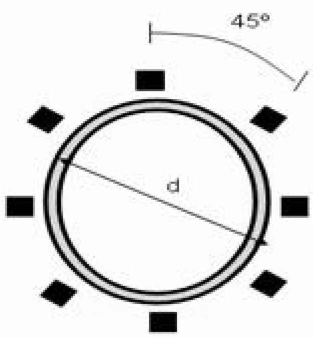


Figure 14





Assuming an array of Eight Hall Effect Sensors

For 2 3/8" Pipe, the radial distance between sensors is 2.375 * π / 8 = **.932 inches**

For 2 7/8" Pipe, the radial distance between sensors is 2.875 * π / 8 = **1.12 inches**

Figure 15