THE APPLICATION OF TECHNOLOGY TO ENHANCE RIG SAFETY AND PROVIDE A SAFER WORK ENVIRONMENT

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AUTHOR'S NOTE

Suppose a guy walking down the street experiences pain in his arms and neck, shortness of breath, and feels a flutter in his chest. We all know these symptoms as the telltale signs of heart problems so this guy has to make a choice. He is at the fork in the road and Yogi says, "Take it." Wanting a long healthy life, he takes the safe path and goes to the doctor. The doctor runs a series of diagnostic tests, determines the problem, and recommends a fix. Depending on the problem diagnosed, the fix might be a safety device like a pace maker, or radical bypass surgery, or maybe just an improvement of lifestyle like a healthy diet, exercise, and a regular checkup hereafter. It would be pure speculation of what would have happened if he had taken the other fork and just went about his way.

This paper is like the guy on the street only our story is a bit more complex as in our industry; we have a rig and people trying to work in unison to accomplish an objective in a hostile environment. Wanting to live a long and fruitful life, we know we must do healthy things, be vigilant in watching for telltale signs that something is wrong, get diagnostic help when we need it, and ultimately find a fix for a problem if one is available. This is what this paper is about. We see forks in roads, and make decisions everyday that affect our performance and health. Hopefully, the technology disclosed herein will help our industry both choose and move down the right path to a safer workplace for our people.

INTRODUCTION

Our industry must continually develop and use technology to identify and modify the way we make our living and to ultimately provide a safer work environment for our people in the field. Studying and using data gathered from rig components, fast moving and heavy parts, safety statistics, work habits, rules of thumb, cultures, and paradigms can help in this undertaking. One presentation or paper cannot provide every answer, but as we add data gathering devices and controls to service rigs, we learn. Devices for an extra level of protection for the crew can be designed and implemented using new technology. We can provide information to facilitate training, procedural changes, and ultimately begin the behavior modification process. The difficult task lies ahead as we implement what we are learning and change the ways in which we operate a service rig.

Initially, accident statistics combined with many other sources of knowledge were analyzed and used to identify areas where technology might improve rig safety performance. Sensors and a PC-based data system were then installed on service rigs to capture data. This data was studied in detail, and motion studies were performed second-by-second to determine activity, moving iron, and the human action or reaction to events. This study was used in combination with the targeted areas to develop systems that could document unsafe practices, alert the crews and supervisory personnel, and automatically take control of the rig if a potential catastrophic event was likely to occur.

RIG SENSORS AND CONTROL DEVICES

Figure 1 illustrates sensor locations and various control apparatuses that were placed on a typical service rig. As each safety target area is discussed, Figure 1 will be referenced regarding which sensor, control, or display was being used. A summary follows:

Sensors:

1. Tubing Drum Encoder
2. Weight Sensors from pads
3. Weight Sensor from line indicator
4. Engine RPM sensor
5. Proximity sensor in top of mast
6. Clutch Air sensor transducer

Control devices

C-1. Air Clutch dump valve
C-2. Idle throttle control valve
C-3. Tubing Drum Brake actuator

RMC Box (Rig Mounted Computer)

HMI (Human Machine Interface)

We apply this technology to a general discussion of each target area without any priority based on frequency, cost of lives, or financial cost. Crown-out incidents, floor-out incidents, over-pull prevention, and mast tilt are some of the growing list of areas that can be addressed with this technology.

It looks good on paper but is that really how the real world does it? This is a fair question for anyone to ask. We know without a doubt that any implemented technology must measure and monitor, determine areas where safety SOPs are not being followed, implement a training and feedback loop, and motivate behavioral change.

CROWN-OUT INCIDENTS

Simple mathematics illustrate the near crown problem. A generic double triple service rig mast heights ranges from 96 to 107 feet and are designed to pull double stands of tubing and triple stands of rods. When rods are pulled or run and hung in the basket, the triple is 75 feet long. Accounting for the wellhead or floor height, the top of the uppermost rod is therefore 80 feet in the air. The length of the rod hook and the blocks must be added to the 80 feet to determine just how closely the blocks work to the crown when pulling rods. On a standard 96 foot derrick, the blocks must come within seven feet of the crown each and every time a triple is pulled or run. Considering the number of rigs running at any given time, this potentially happens literally thousands of times per day.

The current technology employed today to avoid hitting the crown is a cat hair “flag” or paint on the tubing line. Since the operator’s eyes cannot judge a seven-foot spacing when looking up in the derrick, he relies solely on the flag placed on the tubing line. The basic problem with this system is that this flag becomes the reference point of where to stop the blocks and it can move or it can become degraded. Using this system, the human element must then be infallible. Since the orientation of the rig cannot be controlled, (the sun might get in his way or he might be looking for his flag with a background of a pumping unit, which makes it hard to see), the system fails entirely if there is any distraction to the operator as the flag is passing the assigned stop point. The potential for human error must be eliminated.

There is some good news here. Rigs working in the field today have a torque converter that allows transmission slippage at slow speeds. In fact, pulling the blocks into the crown with the engine at idle does no damage and poses no threat to safety as the torque converter stalls out and the blocks just stop. This practice is not recommended, but it does illustrate that speed is the root problem when working near the crown.

APPLYING TECHNOLOGY FOR CROWN-OUT PREVENTION

For data acquisition, an encoder (Figure 1) was connected to the tubing drum shaft so that the Rig Mounted Computer (RMC) could monitor tubing drum movement. Simply put, the computer sees the movement of the drum by counting pulses generated at this encoder and the RMC can use this information in two ways. It can 1) measure how fast the pulses are being generated and compute a velocity value indicative of how fast the drum (therefore the blocks) is moving; and 2) index (operator input via the HMI) the lowest and highest block position desired and define a safe operating envelope for that particular wellhead and rig configuration.

Secondly, RMC input / outputs were installed to drive the rig-mounted control devices.

- A solenoid operated quick release valve is placed in the drum clutch air line circuit.
- A solenoid operated throttle control valve is installed on the engine.
- An air cylinder and relay assembly is installed on the brake system.
- A proximity sensor is installed near the crown for redundancy of the systems.

Figure 2 is a graphic illustration of how this information is used to monitor and control the rig when needed. A maximum upward block velocity was established by a RMC technician based on two regions. This maximum speed limit is the heavy dashed line marked as “Normal / Maximum Operating Envelope.” The “Upper Stop Limit” is set by the operator by simply pulling the blocks to the uppermost point where he wants the blocks to stop (or safe point) and then pressing an icon on the

HMI called “Learn Upper Limit.” The “Slow Down” point is based on rig design and known stopping distances and is a fixed distance below the stop point. To the safe operator, this system is totally transparent as long as the rig is operated within the “Safe Normal” mode. It is only when the operator pushes the envelope that the system begins to help.

Figure 3 illustrates two cases of how the RMC takes over when an operator gets out of that “Safe Normal” mode while pulling the blocks up.

1. When the upward moving blocks reach the “Slow Down” point and the RMC senses the block velocity exceeds the allowable speed for that region, a signal is sent to the throttle control which causes the engine to immediately fall to an idle.
2. If the blocks get too close to the crown or reach the upper set limit, three things happen quite abruptly. The throttle is taken away, the clutch air solenoid valve is actuated which disengages the drum clutch, and finally the tubing drum air brake is actuated, bringing the tubing drum to a full and abrupt stop.

Not shown in either case is a speed alarm in the lower region of the graph. Any time the operator exceeds a predetermined speed and is still in the lower region, an audible alarm will sound telling him to slow down. In the event of a RMC or encoder or software failure, there is a proximity sensor located at the crown. This magnetic field sensing device which is wired in series with clutch, throttle, and braking system is designed so that should an input fail and the blocks are approaching the crown, it will activate the safety systems.

Figure 4 graphically shows the measurements as computed and logged by the RMC. The operator’s maximum block speed is downward while tripping and he slows down prior to the blocks reaching their maximum height learned set point. This is the graphic a rig supervisor would use to counsel the operator in safe operating techniques.

This system addresses the hardware that helps prevent the crown out but the more important issue is behavior modification and crew training. To define, isolate, and critique problematic crews when the near a crown incident occurs, the event data is captured into the rig’s database. By design, safety issues pop up on the website as “RED” and this data then flags the supervisor that a rig has had a notable incident. If the supervisor sees a safety incident, this is a coaching opportunity not to be passed up.

Figure 5 is a website shot illustrating the rig supervisor identifying areas for safety improvements. Be advised that altering the safe operating envelope shown in figure 3 to deliberate impossible minimums artificially created the incidents shown. This data was captured during the testing phase of development and by no means is indicative of an unsafe rig operation. The operator was not really hitting the crown or unsafely speeding as the sensors were deliberately set low to test the alarm and event capturing system. It worked.

FLOOR OUT INCIDENTS

Accidentally laying the blocks on the floor or hitting the wellhead was another area investigated. Evidence of this group of accidents or incidents included fatalities, bent floors, significant injuries, damaged wellhead equipment, and industry-wide bull room stories of floor hands getting knocked off of or jumping from the floor to avoid a wild operator hurting them. (*The author has run a rig and has personally witnessed his floor hands jumping off the floor*.)

Statistics indicate that floor outs normally occur due to the following:

- Lowering the blocks too quickly and not stopping in time due to distraction.
- Weight and speed combined with a misjudgment of required stopping distances by the operator.
- Brake failure or inefficiency due to heating while tripping.
- Total brake failure due to a mechanical problem.

If we are to protect the blocks from hitting the wellhead or rig personnel, we must measure and account for weight. In addition to all the sensors used on the crown out system, weight measurement needs to be incorporated into the floor out algorithms. The weight can be ascertained from either the pads or from a line indicator.

Since the stopping distance is both speed and weight related, multiple "Safe Normal" envelopes are defined as shown in **Figure 6**. The envelope is again divided into two basic regions, one of almost free travel and a lower region nearer to the working floor of mandated slow down. As long as the operator is traveling inside the "Safe Normal" envelope, the system is transparent as in the crown out system and it is only when he gets outside the lines that things begin to happen.

The RMC measures and computes drum speed as well as the hook load. As the hook load increases, so does the required stopping distance, and the maximum allowable speed is decreased. In effect, the envelope both moves in and up as the speed and weight increase. Since the hook load is zero on free falling blocks, this system allows maximum velocity for empty blocks and does not slow the rig down on trips.

Figure 7 illustrates the corrective action and alarms that sound when and if the operator gets outside the "Safe Normal" envelope. In the region above the mandatory slow down interval, an audible alarm signals the operator to slow down. In this region, no corrective action is taken yet. As illustrated in the far right drawing, when the blocks enter the floor out protected region or slow down interval, corrective action is taken if the operator is out of the envelope. In this region, if the excessive speed is noted for the measured weight, braking action via the brake cylinder is activated, bringing the blocks to a stop before any damage or incident occurs.

As in the crown-out algorithm, the RMC logs an event to the database anytime the system takes control of the rig as this is deemed as inattention to detail or unsafe practices by the operator. This floor event is reported in red.

Figure 8 is an example of how the operator slows down when the hook load is increased. The downward velocity is much higher (-12,500 cps compared to -4000 cps) when the hook load is 12K compared to 40K.

Brake failure or brake inefficiency due to heating while tripping into the hole or total brake failure due to mechanical problems is an area where studying crew and rig performance data might shed light on best practice issues. The majority of rigs working in the field today have conventional drum brakes while many have a hydromatic or water break. As rigs are remanufactured, the improved disk assist brakes are being installed, but switching the fleet over will take years; therefore, the industry is dealing and working with the conventional system currently in place.

Installing disk assist brakes on service rigs delivers the control and safety needed in the well servicing industry. As disk assist brakes are installed on remanufactured rigs, algorithms are being developed to control the speed throughout the range of downward block travel, but these algorithms are not currently being implemented. Because the conventional drum brakes are self energizing, they are difficult to use to finely control downward speeds and therefore, by default, the hydromatic or water brake earned its place on speed control. When the hookload gets high, the operator engages the hydromatic to both slow down and control the speed.

Heat is the brake's worst enemy. As hookloads get heavier and the blocks get faster, more braking action must be applied to control and stop the blocks. Downward moving loads have kinetic energy expressed by $1/2MV^2$. Bringing heavily loaded blocks to a stop from fast moving downward motion generates energy and this energy has got to go somewhere. That energy ends up being dissipated as heat. Hot brakes have control issues as the bands stretch, drums get out of round, and all sorts of bad things can happen. Spraying water on the brake bands is one solution used in the field. As the brakes heat, the rig has a nozzle system that is designed to cool the bands down, but this system has it problems too. Heat and water changes metallurgy and causes corrosion. This can lead to component failure and a host of bad things; therefore, it is incumbent on us to avoid heating the brakes too much.

Enter the hydromatic or water brake. The hydromatic brake is nothing more than a water pump connected to the tubing drum. When engaged, the falling blocks and hookload energy are dissipated into the pumping of water, thereby delaying the tubing drum brake heating. For years this has been a good system, but it must be used to be effective. **Figure 9** illustrates the engagement of the hydromatic brake as noted on the obvious change in curve shapes. The weight curve for the first half of the run is somewhat erratic and does not exhibit the smooth weight gain per joint that one would expect, primarily because the drum brakes are heating and the operator cannot control the precise action needed for a smooth run. Also note that the block velocity (bottom) curve is erratic on the downward block movement. At 15:55 and at 35,000 pounds, the operator engages the hydromatic. The second half of the run then becomes very smooth as noted in the uniformity of weight gained / joint as well as the velocity curve. One can also see the effect of the hydromatic on running speed. Prior to engagement, the rig was running into the hole at 1.8 stands per minute and after engagement, the speed was reduced to 1.5 stands per minute.

There are many Standard Operating Procedures, or SOPs that the crews must abide by to remain safe. An SOP which crews must adhere to is engaging the hydromatic when the weight is 40,000 (varies by rig) or above. Engaging the hydromatic promotes safe operation and reduces the probability of brake failures.

OVER-PULL PREVENTION

Figure 10 is typical data gathered from a rig pulling out of the hole with tubing. The top curve is hook load, the middle curve is block position, and the lower curve is block velocity. According to the data, the crew starts off at the bottom weighing 45,000 pounds at 10:20 on a single line rig up. Rigs are generally well designed, made just for this purpose; where is the problem?

With 7,000 feet of tubing in the hole, if the operator encounters a tight spot or a restriction of some sort, the system (man and machine) has time to react. If the TAC sticks or pulls into a tight spot, the transmission slips and tubing stretches, whereby the operator reduces the throttle, stops pulling up, and nothing bad happens. Back to the graphics. He continues to pull from 10:20 to 10:50, doubles back and starts to pull again at 11:00. The upward block velocity from 11:00 to 11:40 is much slower than before due to the double tie back rig up (a gear / horsepower thing) but as the weight drops off, this speed impediment is overcome and the block velocity from 11:50 to 11:55 is twice as fast as before. This is the region where bad things can happen quickly: there is little time for the operator to react. The tubing length is short so the safety in the stretch has disappeared and the engine RPM is maxed out.

This “speeding up when almost out of the hole” was a technique problem identified as a potential accident area. The solution was to allow the operator to configure within the RMC a “maximum allowable pull” for the rig. The operator provides maximum weight information to the RMC via the HMI and when the hookload exceeds that maximum allowable pull point, the RMC cuts the throttle, avoiding over pull.

There is ongoing research to find ways to detect when a packer or TAC is near the surface forcing the rig to slow down or alarm the operator that he has a potential problem coming. The working model is not yet available but the RMC is wired for this feature. The software is yet to be developed.

MAST TILT

It does not happen often, but when a rig leans and falls, there is potential for hazards this happens due to high winds, unstable location foundations, poor rig anchors, or sloppy rig-up techniques. Improper racking of tubing or rods can compound any tilting problems. On rigs that use pad-type weight indicators, the RMC is configured to measure the weight on each pad individually and to compute, alarm, and capture any offset weight between the two pads. The first scenario illustrating this problem is the crew rigs up and works a heavy hookload. Due to this load, the rigup seals dig deeper and deeper into the ground. One side might have a softer foundation than the other causing the rig to lean as the load increases. Operators deal with this everyday by using the rig up jacks to pick up the low side and screw down one of the derrick legs to compensate for the offset sinking. This sets the rig back down level again. Normally, this is fine, but there is a point of no return and a minor problem of tilt can potentially become a much more serious event. We want to warn the operator that the rig is listing. The second scenario happens when an inattentive crew does not back the rig in over the center of the hole. If they are in a hurry and have missed the hole by a foot or so, simply lean the crown a bit using the rig up jacks causing the blocks to come down off center to the rig, but centered on the hole. **Figure 11** illustrates the difference between the two pads. The top curve is the computed total weight and the other two curves are the individual pad weights.

DOUBLE FAST LINE OR SINGLE FAST LINE ISSUES

Quite unique to Permian Basin, California, and the Rockies is the practice of running a rig with two lines anchored to the tubing drum. This process, called double tie back, doubles the speed of a rig on four lines but it is done at the expense of other savings like the time taken to tie and untie and crown out.

Two years ago, Jim Curfew with Oxy Permian presented an excellent discussion of rig tie back issues. Jim addressed the many issues surrounding this practice and asked some excellent questions:

- Do we really save any rig time by running a double fast line?
- What is the safe operating range of the rig when tied back?
- What hook load do we mandate running a single fast line?
- Should we run a rig with two lines at all?

There should be no doubt the double fast line is harder on the equipment and increases safety risk in certain areas. Without having all the answers, the service industry currently relies on the SOP that deals with this issue. Clearly, a rig following the SOP is supposed to single back when the hookload is above 40,000 pounds. This hard fast number can be altered based on the rig specifications, tri-scope, 4 lines, 6 lines, and the many variables of the equipment but the data suggest that other variables must be considered.

Figure 12 is an example of a rig that switches from a double tie back to a single while running into the hole. From this data, we can determine that 1) the hydromatic was being used, 2) it takes 11 minutes to switch from a double tie back to a single tie back (22 minutes RT), and 3) while running into the hole with a static tubing weight of 30,000 pounds, the rig is really sensing and the tubing is being subjected to instantaneous hookloads in excess of 60,000 pounds due to momentum. This slide might make us wonder why tubing parts from time to time. The data suggest concepts we need to challenge: Is a double tie back rig safer or faster or the right thing to do? Is the doubled back rig the best thing for my tubing and wellbore? Another concept to be challenged is: We are not currently but should we consider the tubulars being run when determining where to engage the hydromatic.

Here is data taken from the study of tiebacks. A rig can safely run tubing doubled back at 1.6 stands per minute. The same crew using the same rig can run the same tubing on a single fast line at 1.4 stands per minute. On a 5,000 foot well, running tubing on a double fast line, then tying back to set the TAC, and then doubling back to POOH, the time breaks out in the following table.

Task	Double Fast line	Single Fast line
Running 83 stands of tubing	52 minutes	59 minutes
Single Back to set the TAC	11 minutes	
Setting the TAC	15 minutes	15 minutes
Doubling Back to POOH	11 minutes	
POOH with 83 stands of tubing	52 minutes	59 minutes
Total Rig Time	141	133

Ironically, it looks faster and it sounds faster, but it is slower and the process induces safety concerns as there are a lot of pinch points associated with doubling and un-doubling. Crews get in between drums and cables, engines are running, hands are pulling lines, blocks are hanging, and the list goes on.

Now ask the questions, “When should we engage the hydromatic and when do we single back?”
Figure 13 is a copy of a rig incident that illustrates this discussion of tie back issues and hydrometrics.

TONG HEAD SWITCHING

Both rod and tubing tongs afford the floor hand or tong operator a myriad of pinch points. One danger area specifically addressed by a safety SOP is head reversal. All tongs have heads that bite the pipe, and these heads must be reversed or turned over when the pipe direction is reversed. They are in one way to pull pipe or rods and the other way to run them. To reverse the heads, the operator must both look at what he is doing as well as reach into the tong table with his hands. He rotates the table (a full half turn in the case of rod tongs), reaches and pulls, rotates the table, and then reinserts the heads.

The published industry SOP is to remove any power source that might accidentally cause the table to rotate while switching the heads with hands. This is almost identical to the lockout tag out for pumping units and serves the same purpose. So is the SOP being followed? **Figure 14** and many rig hours of data answer the question: yes, no, and sometimes, but not always.

SWABBING

There have been fatalities associated with swabbing operations, and we must examine the incidents, taking corrective action to prevent reoccurrence. Like the lockout tag out for pumping units or for tong head switching, there is an Industry SOP for flagging a sand line during swabbing operations. The SOP calls for the removal of the power source (shut down the engine) when grabbing the line, standing on the sand drum, or doing anything that might entangle the man into the machine. We must ask again what caused the accident, and was the SOP being followed? As illustrated in **Figure 15**, the answer is again yes, no, and sometimes, but not always.

SLOWING DOWN WHILE PULLING OUT WHEN ALMOST OUT OF THE HOLE

There is a 20 MPH speed limit while driving in a school zone for a reason. Children are unpredictable and bad things can happen quickly. In school zones, “We know not what to expect so we slow down to protect.” Now apply that to the oilfield. In recent years, fatalities have occurred while tripping out of the hole. Imagine for a moment pulling tubing at a very high upward velocity with full clutch air pressure and full RPM on the engine. Within the blink of an eye, a packer or TAC can hit the underside of the slips or wellhead or BOP. The best thing that can happen is for it to hang up. Things really go downhill from there: it might hang up and part the tubing, the opening in the slips might not be large enough to pass the device so the chain breaks sending the slips flying, or the chain holding the slips grabs the floor and throws the workers off the work floor. Nothing good can happen if we are not prepared for a large object trying to get through a small hole.

The solution: follow the SOP, train the operators to slow down and pull with caution when the load is light, and lastly, make sure they follow the prescription to safe operating. **Figure 16** (tubing) and **Figure 17** (rods) illustrate a crew doing this as it reduced the velocity by better than 50% when the tubing was six stands from being out of the hole.

This is a good time to bring up the training and feedback loop again and say: “The carrot is better than the stick.” Safety briefings, either the one-on-one type or group type, must generally be positive and constructive. There is assuredly, more meat in the conversation when one has the facts in front of him. Operators need to be complemented on using safe techniques and these techniques can become a model to others to do likewise. With the facts in hand, good or bad, this feedback is the starting place to kindle behavioral modification.

CONCLUSIONS

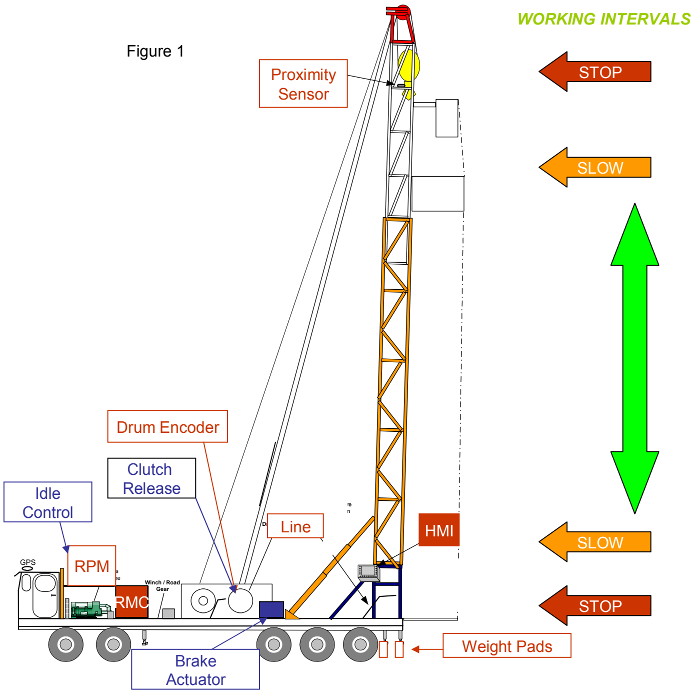
We, our collective industry, must do everything reasonably possible to protect our service crews. We can constantly improve their environment and safety performance by:

- Implementing new technology and safety systems on the rigs like COFO and speed alarms. Do all we can do.
- Identify and rectify violations of SOPs. Training and re-training using a periodic hit or miss system is no longer good enough. We must daily go to where our people live and work in the real world, insuring that SOPs are being followed. All humans take short cuts. SOPs are not a good place to practice this.
- Challenging our every thought and every process by examining our rules of thumb used to set limits. We need to measure and evaluate to conclude and justify. Use facts and science, not the old ways of myths and habits. Never accept, “I do it that way because that is how I was trained” at face value. Challenge the old and find the new.
- Challenging our constant quest for speed. It is understandably driven by the bottom line, but we need to analyze each and every step of our path, making decisions based on facts, not perceptions.

A harsh reality about service business is that it is one of compromise and mitigation. On one end of the spectrum, just don’t go out there and no one will get hurt. Of course, that’s not an option. On the other end, the crews can work too fast and with substandard equipment and the job is a total safety hazard. That too is not an option. We must operate daily with the goal of “zero accidents” and it is incumbent on the industry find the safest methods to mitigate the risk of being there. Developing and using new technology to identify and eliminate as much of the risk as we can should become our mission. In the end, working safer will save us money, lives, and a lot of heartaches.

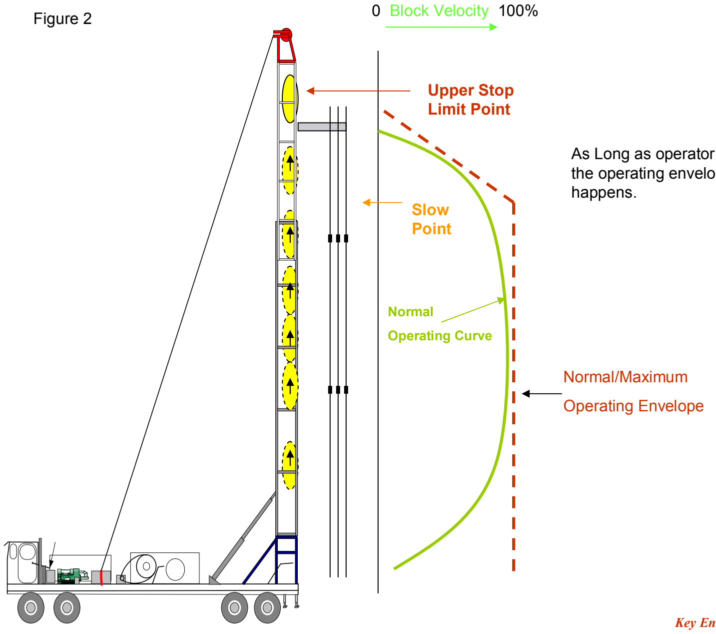
As with any new technology, there is a learning curve as well as a development curve. The rig systems discussed herein are being implemented as quickly as practicable and feasible. The systems and the people that run them are not foolproof and the technology should be considered as under development and on a best efforts basis.

Figure 1



Velocity Relationships for Crown Out Protection

Figure 2



As Long as operator stays within the operating envelope, nothing happens.

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Control Relationships for Crown Out Protection

Figure 3

Key Energy Patent Pending

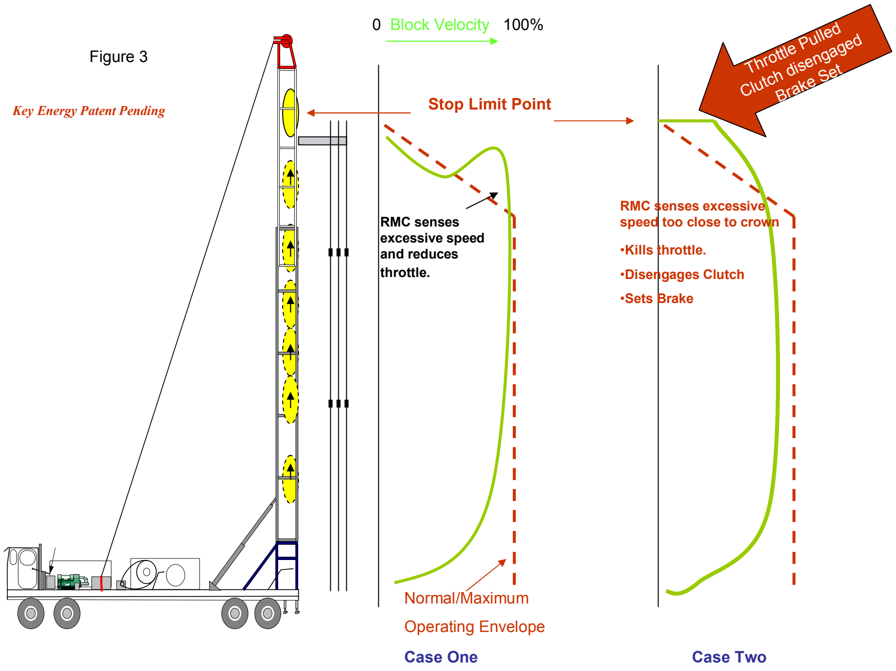
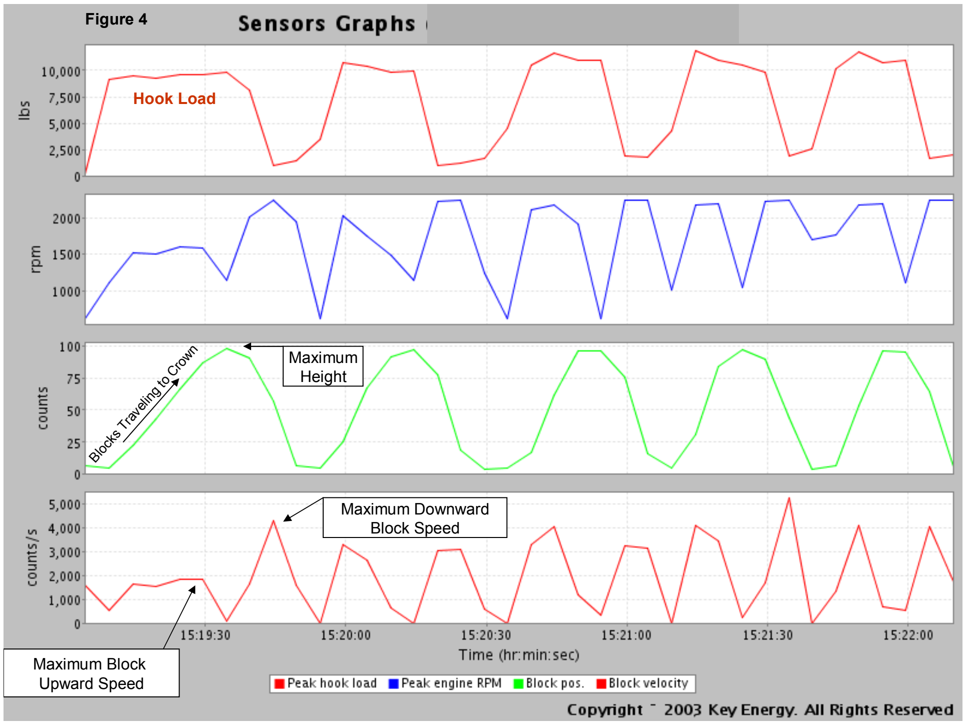
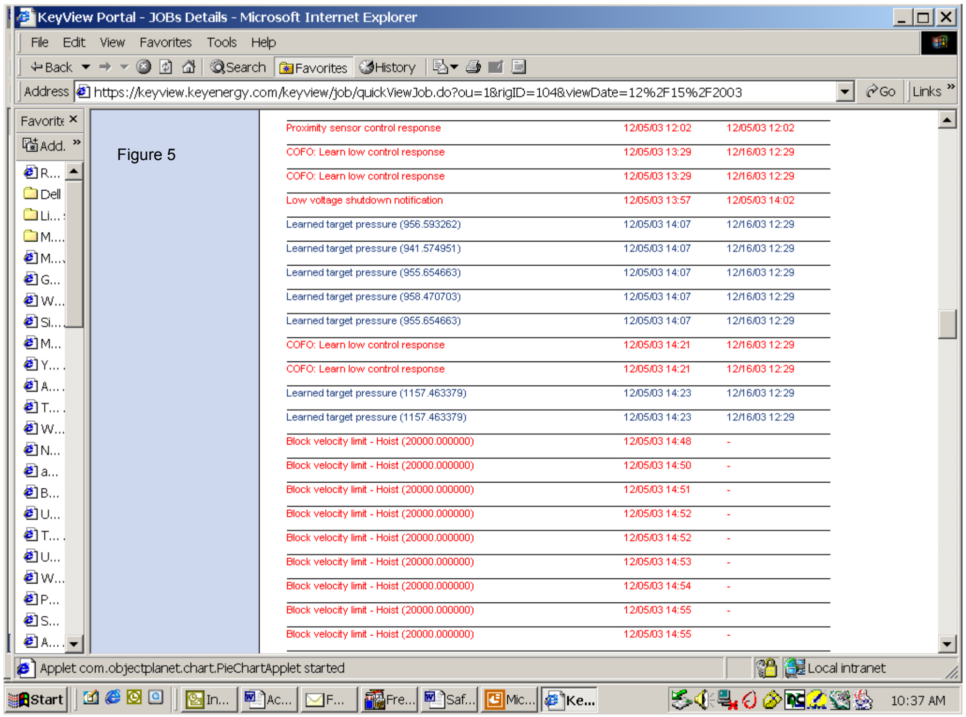


Figure 4





Proximity sensor control response	12/05/03 12:02	12/05/03 12:02
COFO: Learn low control response	12/05/03 13:29	12/16/03 12:29
COFO: Learn low control response	12/05/03 13:29	12/16/03 12:29
Low voltage shutdown notification	12/05/03 13:57	12/05/03 14:02
Learned target pressure (956.593262)	12/05/03 14:07	12/16/03 12:29
Learned target pressure (941.574951)	12/05/03 14:07	12/16/03 12:29
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COFO: Learn low control response	12/05/03 14:21	12/16/03 12:29
COFO: Learn low control response	12/05/03 14:21	12/16/03 12:29
Learned target pressure (1157.463379)	12/05/03 14:23	12/16/03 12:29
Learned target pressure (1157.463379)	12/05/03 14:23	12/16/03 12:29
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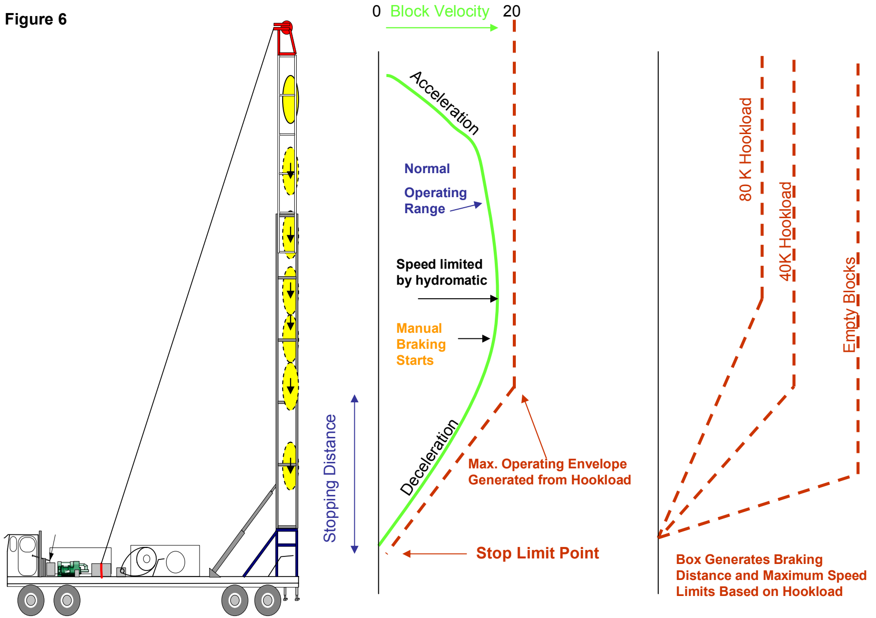
Block Height, Hook Load, and Velocity Relationships for Floor Out Protection

Figure 6



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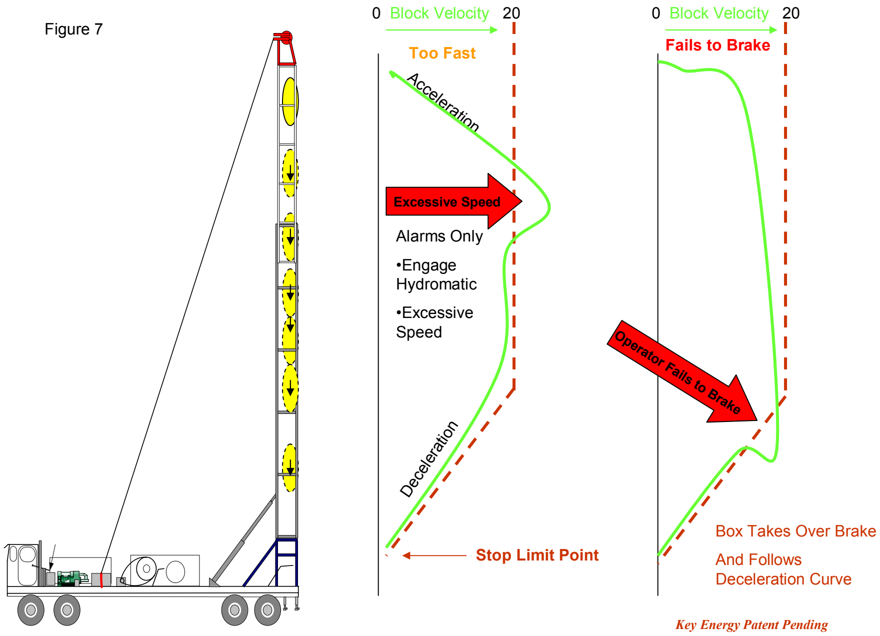
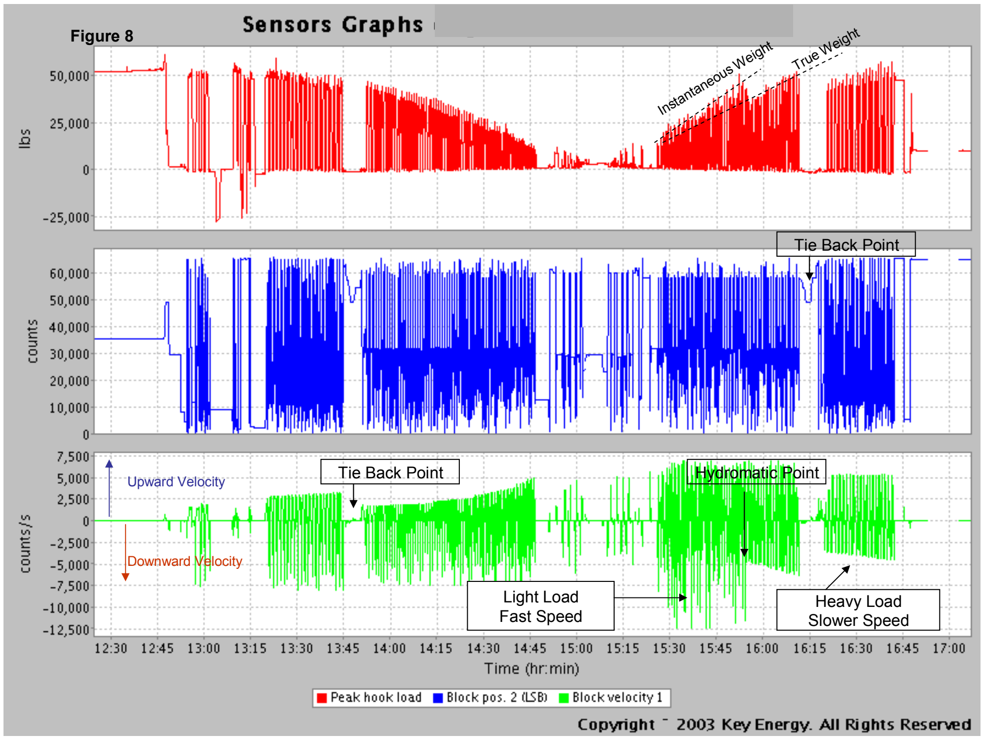
Control & Alarm Relationships for Floor Out Protection

Figure 7



Key Energy Patent Pending

Figure 8



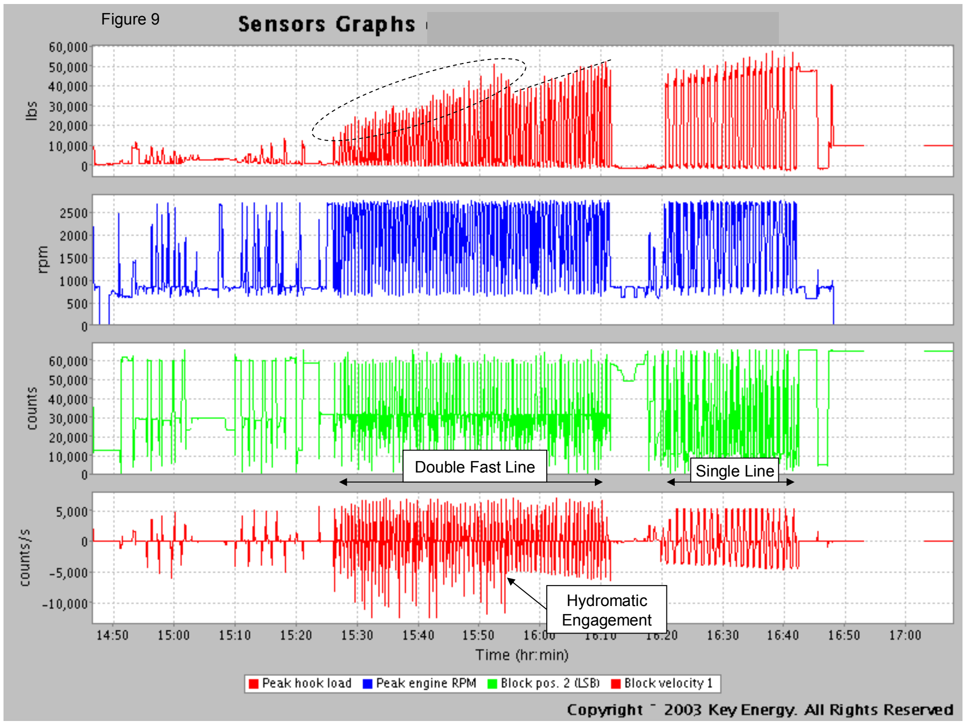


Figure 9

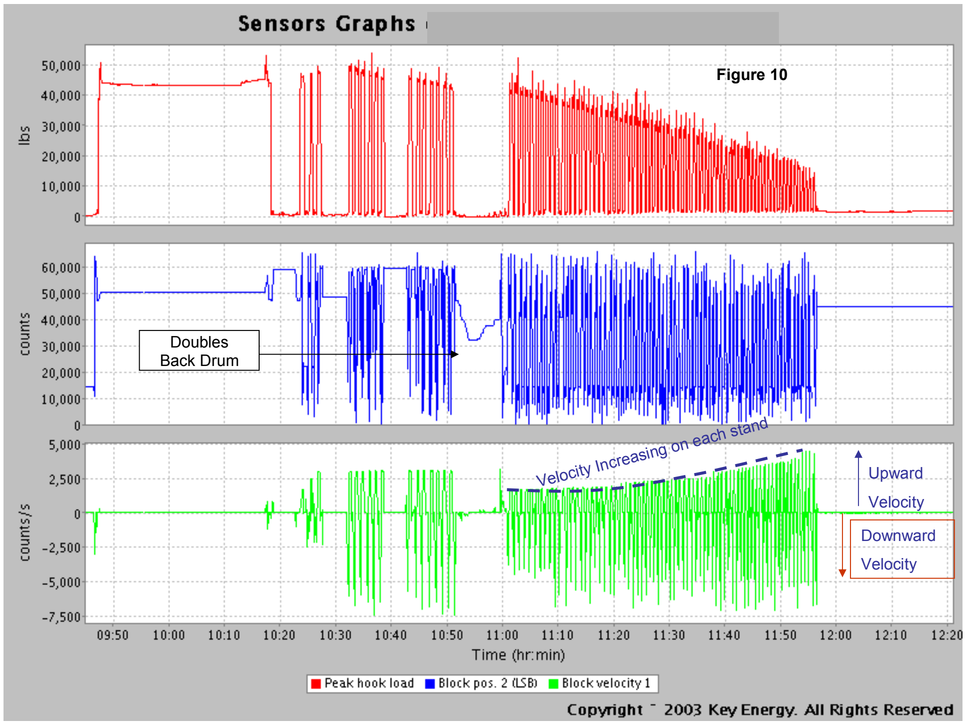
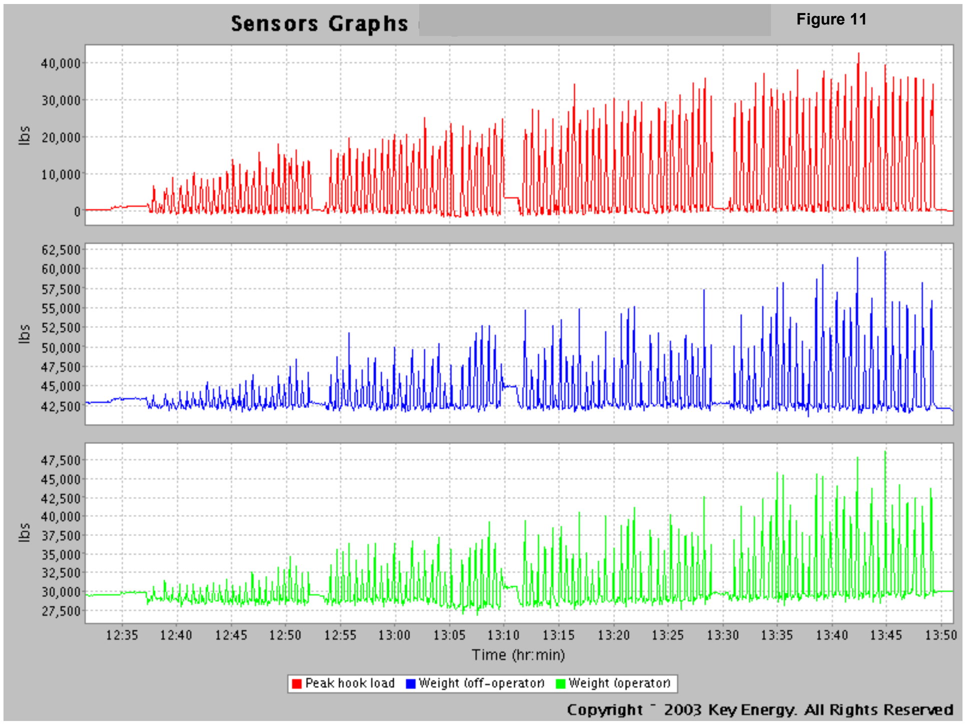


Figure 10


Sensors Graphs
Figure 11
lbs
40,000
30,000
20,000
10,000
0
lbs
62,500
60,000
57,500
55,000
52,500
50,000
47,500
45,000
42,500
lbs
47,500
45,000
42,500
40,000
37,500
35,000
32,500
30,000
27,500
12:35
12:40
12:45
12:50
12:55
13:00
13:05
13:10
13:15
13:20
13:25
13:30
13:35
13:40
13:45
13:50
Time (hr:min)
🟥 Peak hook load
🟦 Weight (off-operator)
🟩 Weight (operator)
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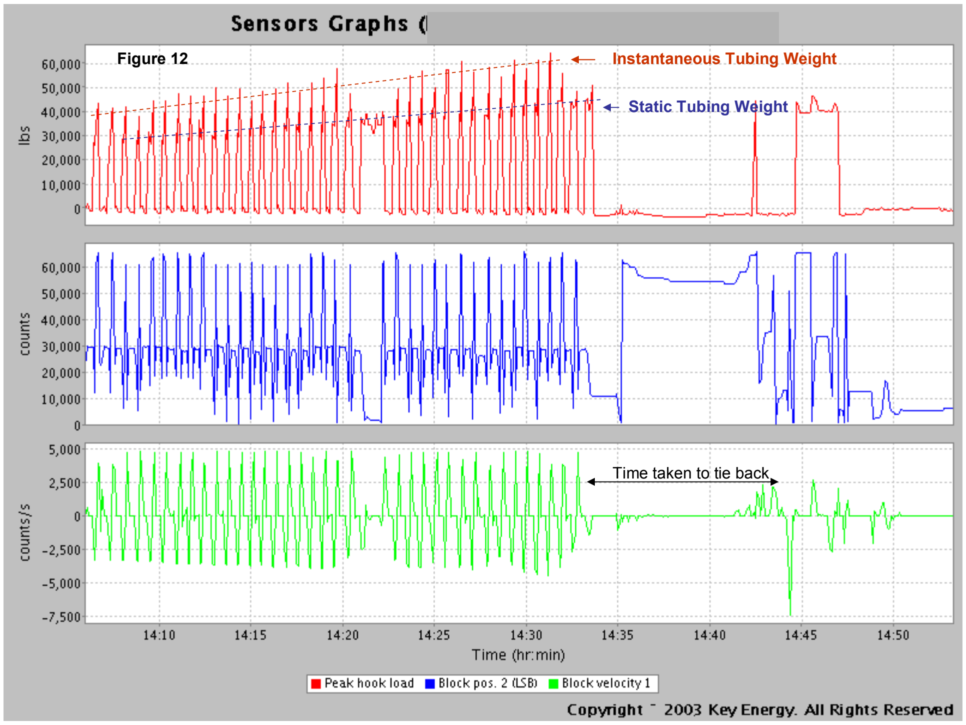
Sensors Graphs (
Figure 12
Instantaneous Tubing Weight
Static Tubing Weight
lbs
60,000
50,000
40,000
30,000
20,000
10,000
0
counts
60,000
50,000
40,000
30,000
20,000
10,000
0
counts/s
5,000
2,500
0
-2,500
-5,000
-7,500
Time taken to tie back
14:10
14:15
14:20
14:25
14:30
14:35
14:40
14:45
14:50
Time (hr:min)
🟥 Peak hook load
🟦 Block pos. 2 (LSB)
🟩 Block velocity 1
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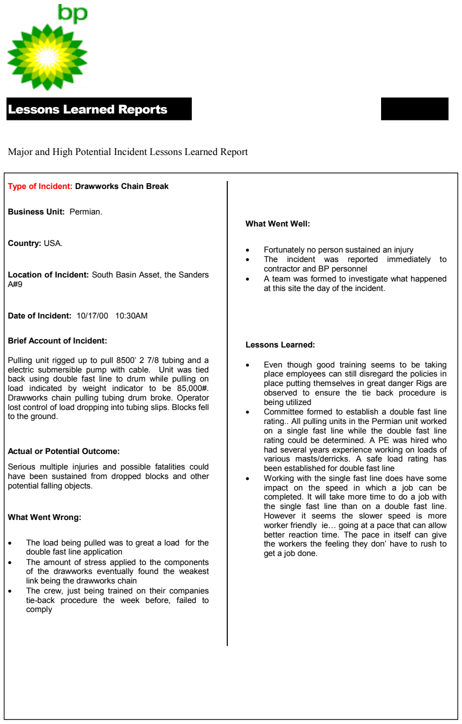
Figure 13



Lessons Learned Reports [redacted]

Major and High Potential Incident Lessons Learned Report

Type of Incident: **Drawworks Chain Break**

Business Unit: Permian.

Country: USA.

Location of Incident: South Basin Asset, the Sanders A#9

Date of Incident: 10/17/00 10:30AM

Brief Account of Incident:

Pulling unit rigged up to pull 8500' 2 7/8 tubing and a electric submersible pump with cable. Unit was tied back using double fast line to drum while pulling on load indicated by weight indicator to be 85,000#. Drawworks chain pulling tubing drum broke. Operator lost control of load dropping into tubing slips. Blocks fell to the ground.

Actual or Potential Outcome:

Serious multiple injuries and possible fatalities could have been sustained from dropped blocks and other potential falling objects.

What Went Wrong:

- The load being pulled was to great a load for the double fast line application
- The amount of stress applied to the components of the drawworks eventually found the weakest link being the drawworks chain
- The crew, just being trained on their companies tie-back procedure the week before, failed to comply

What Went Well:

- Fortunately no person sustained an injury
- The incident was reported immediately to contractor and BP personnel
- A team was formed to investigate what happened at this site the day of the incident.

Lessons Learned:

- Even though good training seems to be taking place employees can still disregard the policies in place putting themselves in great danger Rigs are observed to ensure the tie back procedure is being utilized
- Committee formed to establish a double fast line rating.. All pulling units in the Permian unit worked on a single fast line while the double fast line rating could be determined. A PE was hired who had several years experience working on loads of various masts/derricks. A safe load rating has been established for double fast line
- Working with the single fast line does have some impact on the speed in which a job can be completed. It will take more time to do a job with the single fast line than on a double fast line. However it seems the slower speed is more worker friendly ie… going at a pace that can allow better reaction time. The pace in itself can give the workers the feeling they don' have to rush to get a job done.

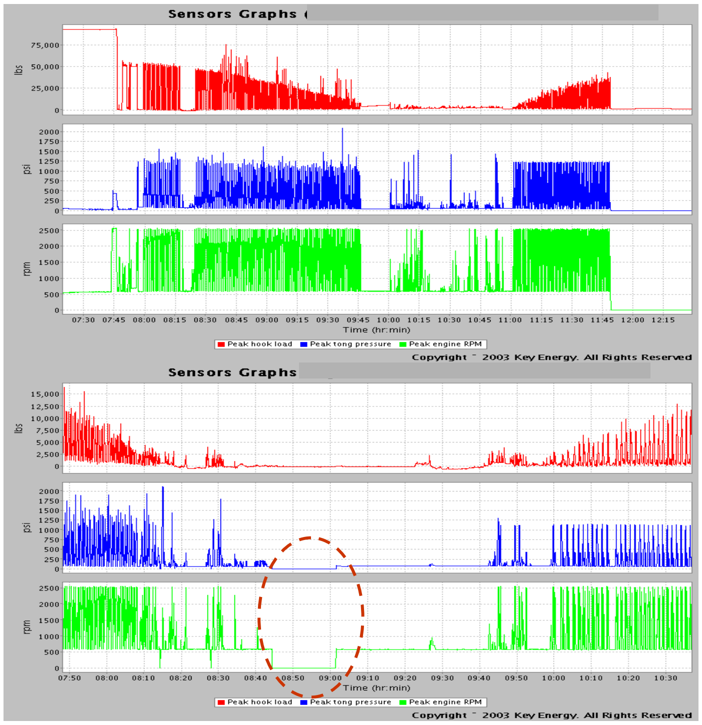
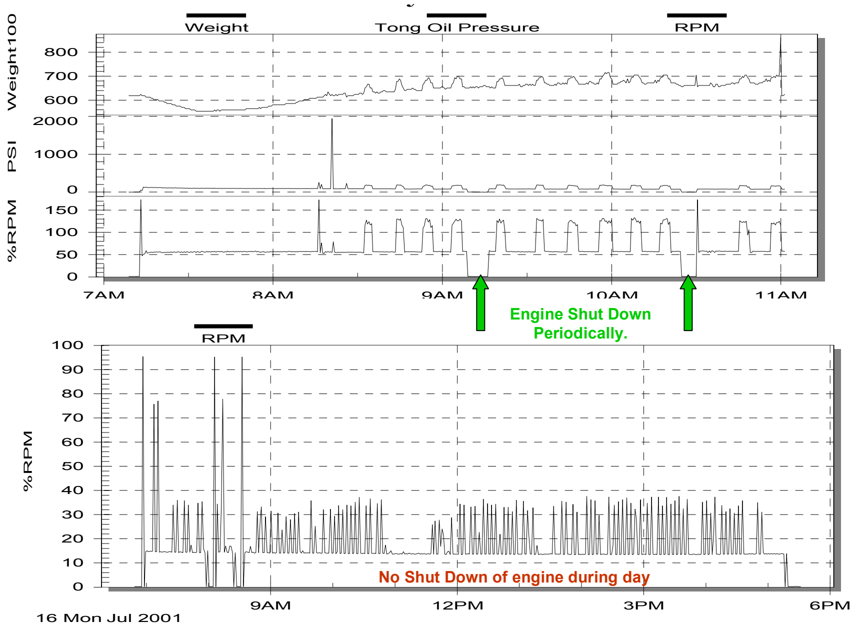


Figure 14

No RPM Drop
Indicates SOP
Not Followed

RPM Drop
Indicates SOP Followed

Figure 15



Engine Shut Down Periodically.

No Shut Down of engine during day

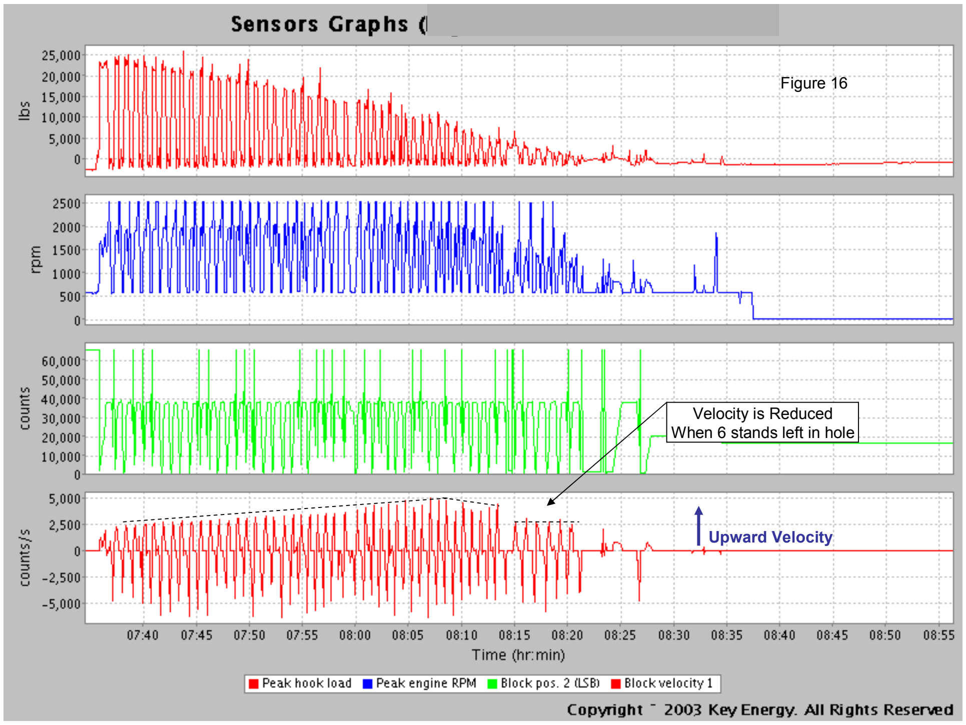

Sensors Graphs ([redacted]

Figure 16

Velocity is Reduced When 6 stands left in hole

Upward Velocity

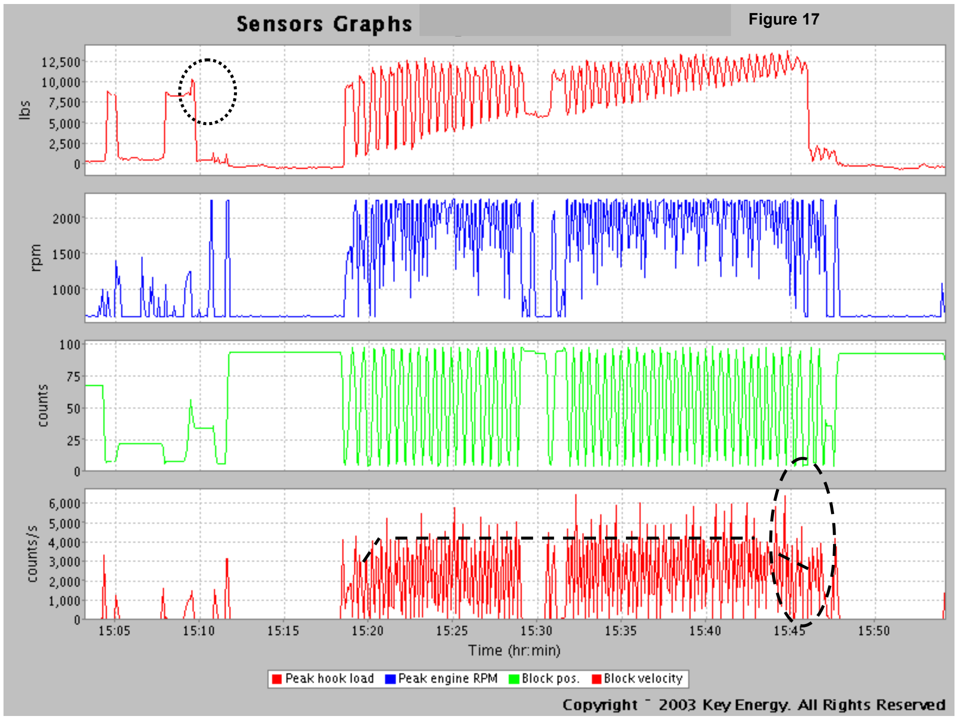


Figure 17

Sensors Graphs
lbs
12,500
10,000
7,500
5,000
2,500
0
rpm
2000
1500
1000
counts
100
75
50
25
0
counts/s
6,000
5,000
4,000
3,000
2,000
1,000
0
15:05
15:10
15:15
15:20
15:25
15:30
15:35
15:40
15:45
15:50
Time (hr:min)
🟥 Peak hook load
🟦 Peak engine RPM
🟩 Block pos.
🟥 Block velocity
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