A DISCUSSION OF SERVICE RIG COMPONENTS AND CREW TECHNIQUES THAT AFFECT PROPER ASSEMBLY OF TUBING, DRILLPIPE, AND SUCKER RODS

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ABSTRACT

The primary function of a well service rig during the well maintenance process is to retrieve and run drill pipe, tubing, and/or sucker rods. Producers recognize that the proper assembly of these well components is critical to maximizing the time between maintenance jobs, and to maximizing profitability. Producer and contractor management alike, have the expectation that rig personnel can meet optimum torque requirements specified by manufacturers of these tubular goods. However, the equipment available to crews to accomplish their work has not significantly changed in decades. Generally, there is a minimal understanding at any level of the many affects that various rig components have on the assembly process. This paper will describe and illustrate some of the factors affecting the critical process of torque application to both shouldered and non-shouldered connections.

INTRODUCTION

Human/Machine Interface, or HMI, is a term commonly used to describe a person working with a computer; that is, the interaction of man and machine to perform a specific task in an efficient manner, to achieve a quality result. HMI involving a rig and a crew can be even more complex in that there are multiple humans simultaneously working with separate, yet interdependent, components of the same machine attempting to accomplish the task at hand. Rig operations might be compared to three men working on a computer at the same time; one on the keyboard, one on the mouse, and one observing the monitor. In each case, computer or rig, a quality product will not result without...

Understanding of the software, as well as the hardware
Proper and meaningful input
Accurate and timely feedback

By evaluating the individual components (both human and mechanical) of any process, specific problems or stumbling blocks can be identified. When “glitches” in a process are identified a course of action to remove them, or otherwise modify the process, can be initiated so as to ensure a quality result.

The information presented in this paper was acquired through the analysis of over 200,000 rig hours of data gathered by rig system monitoring devices, detailed study of rig components, on–site observations of crew techniques, discussions and interactions with crews, pushers, and company representatives. This paper is a critique of the tools and processes generally accepted, and utilized by both operators and well service rig contractors; it is not an indictment of those tools and processes. However, the facts documented herein do suggest that there are modifications that could be implemented that would have a significant, positive impact on some aspects of the well servicing process.

RESULTS OF HUMAN/MACHINE INTERFACE: ASSEMBLING RODS AND DRILL PIPE

Synopsis Of A Ten-Year-Old Sucker Rod Study (Figure1)

Everything about the traditional sucker rod is constantly under scrutiny; metallurgy, design, stress limitations, the right pre-stress (card), as well as downhole conditions that affect failures. There are also field assembly, or “make-up”, practices that must be examined.

Figure 1 illustrates the results of a study done 10-years ago by a major oil company; the age of the data serves as an indicator of both the longevity and severity of the problems represented by the data. On this well, 50-rod connections were made with tongs instrumented to measure applied torque, but the crew received no special directives or instructions; they ran the rods as per their normal routine for the task. The measured data suggested that only **8 (16%)** connections were made to specification. Recently collected data that appears elsewhere in the paper indicates little change in such statistics since this study was conducted.

Synopsis of A Drillpipe Damage Study (Figure 2)

Current business practices mandate that rental tool companies rent drill pipe with the understanding that any damages incurred will be repaired at the expense of the operator OR the pipe will be rented with "no inspections, no damages" in which case the cost of any repairs falls directly on the rental company.

The facts in the life of a rental tool company are:

> The drill pipe rental companies specify a longer tool joint when buying pipe to allow a connection to be re-cut due to damage. A tool joint can undergo 5 to ***6*** re-cuts before there is insufficient material for it to be repaired. This cost must be included in the pricing model of the rental pipe.
>
> Historical information is used to predict the frequency of damage to the joints. The amortization of the pipe is based, in part, on that damage frequency.
>
> The operator pays for both the specific damage repair as well as the increased amortization rate when damage frequency is high OR the rental company has a reduced profit margin if they must absorb these costs.

Figure ***2*** lists the results of a nine well study which compares damage to drill pipe under two distinct cases: The comment "no real time connection analysis" in column six indicates the pipe was made up by crews using their routine process. The comment "real time connection analysis" indicates crews had the benefit of additional tools to assist them in properly making up the pipe; the proper use of the tongs, pressure required for proper makeup was used, and the analysis of each connection was communicated to the crew before running it into the hole.

The data is clear; communicating expectations, proper job or task training, and constant feedback reduced the expected failures by over 50%.

Among the conclusions that can be drawn from the two studies presented above are...

> The problem of improper assembly is not new.
> Failure to properly run downhole equipment has significant economic ramifications
> There are methods by which improvements can be made

ANALYZING COMPONENTS OF THE RIG/CREW HMI WHEN ASSEMBLING TUBULARS AND RODS

Hydraulic Fluid and Temperature (Figures 3, 4 & 5)

Calculations for torque curves on all tongs are based on the use of a hydraulic fluid with a viscosity of 100 SSU. Using the wrong fluid, contaminating it with any foreign substance, or attempting to assemble materials before the temperature has stabilized, will result in a poor quality job. The most common factor that affects the viscosity of the hydraulic fluid is temperature. Figure 3 illustrates the effect of temperature on clean hydraulic fluids. Depending on the time of year, the range of temperatures of hydraulics fluids will vary from freezing to well above 140 degrees F. The viscosity of 100 SSU fluids varies from 3,500 to 45 cSt.

Each time a connection is made, the tongs stall. At stall, fluid flow is diverted from the tongs to the pressure relief valve and the hydraulic energy that was once used to turn the tongs is now expended in the form of heat. Every connection will heat the system until some stabilized temperature is reached. **It** is imperative that the temperature effect be understood, and compensation made for it by the crew.

If a connection is made with cold fluid and the operator selects that pressure to run the rest of the tubing or rods into the hole, with no adjustment to offset the temperature increase as the job progresses, the whole string will be torqued incorrectly.

Figure 4 illustrates the effect on actual measured circumferential displacement when a ¾ inch rod string is run into the hole with no compensation for the temperature effect. In this example, the first rod was properly carded to a pre-stress of

.340 inches with ambient temperature fluid (70°F)' and this pressure was used for the rest of the rod run. The rod card was not used again (which is contrary to API-RP 11BR) and as the system heated, the resulting CD grew less and less.

The heating-under-torque problem is compounded with worn pumps and motors. In the case of a worn hydraulic pump (Figure 5) with excessive gear-housing clearance, the pressure capabilities of the pump diminish rapidly as the heated, less viscous fluid leaks around the gears and housing.

Human Perception and Applied Torque (Figure 6)

It has been observed on a large number of rigs that neither the tong man nor the operator can safely watch the pressure gauge while making a connection due in large part to the physical location of the gauge. Additionally, there are too many things turning and moving to make this a safe maneuver; their eyes and hands must be clear, so they watch for the stall of the tongs to tell them the connection has been properly made. The joint or stand quits turning, and their interpretation of this feed back (stall) from the human-machine-interface is that the job is complete. However, this is not necessarily true as documented in Fig. ***6***.

The graph is an excellent example of a machine being used to enhance human performance when there is an understanding of what the machine is designed to do and how to make it operate properly. While running pipe, the first five connections achieved perfect and uniform torque using feedback to advise the operator that optimum had been obtained. The next five connections were run without the use of the feedback feature of the rig HMI and it can be seen that the torque began to vary and drop. When the feedback system was again activated, the crew had instant consistency and quality again.

The Pressure Relief Valve (Figures 7, 8 & 9)

The least understood but one of the most critical components in a rig hydraulic system is the pressure relief, or bypass valve. The regulator consists of a spool valve exposed to the regulated hydraulic fluid; the valve opens when a predetermined pressure or force (set by spring resistance) is exerted against it; the valve will remain in a closed position (no bypass of fluid is allowed) as long as the pressure against the valve is less than the force exerted by the spring. As long as the tongs are utilizing all the energy of the hydraulic system there is no bypassing of fluid. When the tongs stall, pressure builds to a point where the force on the spool valve exceeds the force being applied by the regulator spring, the valve opens, thereby allowing the hydraulic fluid to return to the tank.

Facts: All springs have a finite range of accuracy and no spring is perfectly linear. The initial compression of a spring requires little effort or force. As the compression process continues, more and more force is required to move that spring a distance equal to that observed in initial compression. It is the non-linear function of the metal itself that accounts for the spring phenomenon. Pressure relief valve designers have taken this characteristic into consideration and offer three different spring values, depending on what range of pressure is to be regulated. If the objective is to regulate low pressures (running rods) a more compression sensitive spring is used, but if the objective is to regulate high pressures (running tubing) a compression resistant, or stiff spring is employed. In fact, there are three springs offered in most pressure relief valves commonly used by well service rigs in their hydraulic systems. Figure 7 (reprint from Parker Hydraulics) is the pressure-compression range chart showing the reaction of each of the springs: Low, Medium, and High. The inaccuracy of repeatability of the springs occurs at the lower end of compression and the literature suggests that each spring can resolve 5% of the maximum rating without too much hysteresis effect. That is to say that a 2000-pound spring can accurately and consistently resolve 100 psi, and a 3,000-psi spring can resolve 150 psi.

The spring phenomena can create a problem for the well service rig. Approximately 500 **PSI** is required to properly torque ¾ in. rods, while approximately 1,800 PSI is required to properly torque 2 7/8 in. tubing. Almost all rigs use the 3,000 PSI (H) spring. Clearly the H spring can resolve with acceptable accuracy the pressure required for the tubing, but that same spring is going to have difficulty resolving, or controlling the 500 PSI needed on the ¾ inch rod. Choosing one bypass valve and spring for all rig tasks becomes a trade off which sacrifices resolution on the very low end of the pressure range.

There is yet another fact about the bypass valve that greatly influences make-up of rods or tubulars; the ability to control pressure is volume, or flow dependent. The sliding spool that works against the spring will open and close at different pressures, depending on the volume of fluid flow. In other words, to set it to open at one flow, but use it at another flow is wrong; the results will vary widely. Figure **8** is a reproduction from the Parker Hydraulics Handbook illustrating how fluid flow affects the regulated pressure of a hydraulic system.

It can be concluded from the chart that the regulated, or opening pressure, increases as the flow rate increases. Most rigs working in the oilfield today have an engine driven hydraulic pump of which the output rate varies from 10 GPM at engine idle to 35 GPM at full engine speed. With this knowledge in mind, consider the following description of the process that the average rig crew can be frequently observed using to initially set the limit for tong make-up pressure:

The first stand of rods is made up using the appropriate CD card. The engine is at idle as repeated checks of the "card" are made.
The operator decides the "card' is correct, and the pressure regulator set. The process **of** running rods begins
As the crew falls into a rhythm, the crew gains momentum, their speed increases, and most connections are made at full throttle.

A rod string assembled in the above-described manner is generally going to be over-torqued due to the phenomena described in the previous illustrations. The rod CD was determined with the flow rate through the pressure relief valve at a fairly low level, but most subsequent connections were made with a much higher flow rate through the valve resulting in the valve operating at a significant percent (up to 50% by field observation) higher than anticipated/planned.

Figure **9** is an actual example of the affect of engine speed on applied torque while running rods. Two rod connections are shown in the chart. On the first rod connection note that the maximum stalled hydraulic pressure was 260 psi. On the second connection the hydraulic pressure reaches 510 psi, which was the target pressure. The under torque of the first rod connection originates not with the tongs or tong man, but with the rig operator as he is allowing the engine RPM to drop off before the stall; less RPM, less energy, lower bypass valve opening as per Figure **8.** Everything works together and all aspects of the HMI must be considered to achieve satisfactory results.

This crew had a history of rod failures and repeat failures. In fact, they became the object of a study by a major company. It was determined that the root cause **of** the problem was in the technique they were using while running rods. The operator was running the blocks back in the air at full speed and in high gear. The blocks arrived at the stabbing board before the tong man had completed the makeup process. When the blocks were at the top, the operator reduced the RPM before the stall, and the bypass valve opened at a lower pressure due to the lower fluid flow rate.

The Hydraulic System Pressure Gauge (Figure 10)

Most rigs use a liquid filled, 2-¼ inch face gauge to measure hydraulic pressure (the gauge in Figure 10 is printed in actual size). The gauge might be mounted on the tongs, but more frequently the pressure is sensed from the downstream side of the regulator with the gauge itself mounted in the most obscure of places.

Consider the following traits of the gauge:

The width **of** the needle itself represents about 5% of full scale. If the operator aligns his eyes perfectly perpendicular to the gauge face, he can most likely not set it within 5% with any degree of repeatability.
The tolerance of a new gauge, depending on price and model, is generally stated to be +/- 5%, which introduces another margin of error in setting the torque.

The fact that the gauge is exposed to a very hostile environment is another area of concern. It can get painted, the face broken, the needle bent, and it is generally neglected. **A** recent field survey of rigs indicated:

No gauge was accurate within 10% at low ranges.
One gauge was off by a factor of 20%
On another rig a gauge was not found at all.

The harsh fact is a small gauge that cost less than thirty dollars, is hard to read, is subject to abuse, and is constantly exposed to the elements becomes the standard to which the tubing and rods are run.

Tongs (Figure 11)

Figure 11 illustrates a problem when there is a modification **of** equipment. Two different motors, which are very similar in physical appearance, (Commercial Shearing 25H 1-1 ½ and 15H 1-1 ¾) can be installed on BJ Hughes Tubing Tong models R, **S,** RS, and BTS. The motors result in significantly different hydraulic pressure to applied torque ratios.

The chart shows that for assembling 2-7/8 inch EUE J-55 tubing in low gear, there is a 180-psi difference in pressure required to achieve the 1650 ft-lb optimum torque. Depending on the motor, the operator needs to vary his pressure from 450 to 630 psi. That is a 30% spread if he picks the wrong motor or does not know the difference, and that spread moves him out of the minimum-optimum-maximum torque range for all grades of tubing.

It is safe to say that crews, pushers, and company representatives need to work with charts like this daily. A recent field survey of ten rigs yielded the following statistics...

Only two crews actually had a tong pressure-resultant torque charts.
Three operators knew how to use the charts once they were provided.
Three operators could identify what model tongs his rig was currently using.
One rig had a chart but it was for Foster 58-93 tongs. The tongs on the rig were a set of B-J R tongs. (25% difference in torque)
One rig switched tongs during the well, used the same pressure for the new high torque tongs he always used for his normal tongs and over torqued the pipe by 300%.
Most crews use the same pressure for J pipe as they do for N pipe. (N pipe optimum is 47% more than J)

The Correct Rod Pre-Stress (Figure 12)

Much work is being done by manufacturers of rods, as well as the **API,** to increase reliability of sucker rod pins and couplings; pin and coupling failures account for over 20% of well failures in some fields. Among the tools designed to help rig crews and operator representatives ensure proper make-up of rods is the CD card. The cards are to help ensure that a specific size and grade of rod is made to the proper *circumferential displacement* (CD) so as to apply the correct pre-stress (torque) loading. Some manufacturers of rods specify their own unique pre-stress requirements, and even go so far as to print their own CD card to assist the crews. The API card might vary from a particular manufacturer's card for the same size rod. There are "re-run" cards and "first run" cards; there are cards for HS and standard rods of the same OD. The number of cards available in the field is confusing to the crews, and often the company men. Therefore, by default, the crews use whatever they have, which is in some cases, wrong. If they are not told, or do not understand, they cannot be held accountable.

Recently, a crew working for a major company was asked to card the rods before running them in the hole. The operator explained he never used the card, as he knew what pressure to use for that particular rod. Since this was a training exercise, and the process was being observed, the operator, trying to make everybody happy, used the only card he had. The card was for a Norris 97, but the rods being run were type 78. Using that card on those rods pre-stressed the connection to 40% over minimum yield. He did not know the difference, and he did not understand what damage was being done.

The graph (Figure 12) is a perfect illustration of what the laying down of a damaged rod string looks like to the computer. Here, the rods are being laid down as singles. The middle curve with the circles is the tong hydraulic pressure applied to the connection to break it out.

Note that every third connection is very tight (2,000 psi) and the first and second connections break out at 1,000 psi. The only explanation for this curve pattern is that at sometime during the life of this well, the rods were run out of the derrick in triples and on that run, the rods were severely over torqued. (This is an actual field example pulled from a well with a high failure rate due to 7/8" pin problems. The rod string was being junked at a cost to the operator of $28,000.)

Additional Human Influences on Quality Make-Up (Figure 13)

A flaw in technique commonly observed in the field is to a great extent speed related. Sometimes, depending on the respective speeds of the blocks, operator, and tong man, the rods are made up or broken out while still on the transfer line; at other times, they are made up after the stand is in the elevators on the block. This lack of rhythm on the part of the crew can cause serious problems, and has the same results as running or pulling rods in high wind conditions.

The chart in Figure 13 dramatizes the effects of high wind and/or slacking off too much on the transfer while rods are being turned. Threads and faces are damaged. The energy of a spinning rod at 3 ½ RPS when straight and perfectly aligned is easily calculated. The amount of energy of the same rod turning at the same speed but allowed to bow out 1 foot is astronomical. Wind warnings are normally issued and rigs will not pull rods when the wind reaches 20 MPH as history has shown this is not a good practice. The chart clearly shows the same damage will occur when too much slack is allowed even during calm days.

Turning **Speed** (Figure 14)

When trying to obtain joint makeup perfection, the tong turning speed is a critical factor. It is not as critical on a tapered thread, but with unquestionable certainty, it is a major factor on fragile shouldered rod connections. A field run set of BJ or Oil Country rod tongs can turn anywhere from almost not moving to 3 ½ revolutions per second. A triple rod being run out of the derrick weighs about 200 pounds. Add a 40-pound turning tong table and the mass approaches 250 pounds. That mass of 250 pounds turning at 1 RPS has a certain finite amount of energy. The exact same mass turning at **3** ½ times that speed contains 12 times more energy as the energy of a rotating mass varies with the square of the speed.

The logical question might be: What does that have to do with sucker rods, pin failures, and most of all money? The answer lies in the following explanation: The energy of the turning rod is totally expended at impact of the shoulder point. Impact affects the pressure (applied torque) needed for Circumferential Displacement. Speed, Energy, Impact or Impulse, and Torque all are related. This should come as no surprise as the amount of damage done to a car when it impacts a light pole is proportional to the speed at the point of impact. If a precise pre-stress is the task at hand, then speed and pressure must be controlled and/or measured; there is no solution to one equation with two unknowns. One of the variables must be controlled. On a service rig, both variables exist: turning speed and pressure. The by-pass valve controls pressure and speed is controlled by the operator's foot. As the result, the crews are being asked to accomplish the impossible.

The three dimensional chart in Figure 14 graphically illustrates the relationship between turning speed and applied hydraulic pressure on over a hundred rod connections. Both the tong speed as well as stall pressure was measured and plotted against the resultant Circumferential Displacement. The data clearly indicates that if the turning speed is increased, the pressure must be decreased to obtain the ideal CD. If the turning speed is decreased, the pressure must be increased. The service rig, using the bypass valve, controls and adjusts the pressure, but this is only one of the two variables of this equation and relationship. Speed is the other, and rigs vary the speed by a factor of three on most rod runs.

It is fair to say that this information is valid for shouldered pipe. It is not valid for tapered threaded pipe like **8** Rd. tubing. In making up tubing, the tongs sense resistance as the threads are mating, and this resistance constantly slows them down from full speed to a stall. There is no abrupt impact on 8Rd. pipe so this above argument is invalid. The argument above is valid for drillpipe and rods.

CONCLUSION

The number of factors that affect rod, tubing, and drill pipe failures/damages is almost infinite. There is some percentage of these factors over which no control can be exercised. In order to lower cost, increase profit, and maximize the life of every domestic reservoir the industry must be diligent in identifying those factors that can be controlled or influenced. Both the producing and service sectors must be relentless in implementing changes to those processes that will maximize the effect on those controllable factors.

This paper has identified and analyzed a small number of commonly observed circumstances that could be readily and economically resolved. The modification or correction of these circumstances would yield both immediate and long-term economic benefits. Once a problem has been ***identified*** and ***analyzed,*** change must be ***initialized*** to make improvements. The only impediment to initializing change is the lack of a decision, or commitment to do so. Those committed to change, improvement, and maintenance of high standards should be judged on performance and value, more so than on price. Well servicing is not an art as much as it is a science, but until available technology is applied to the business rigs will be treated as a commodity.

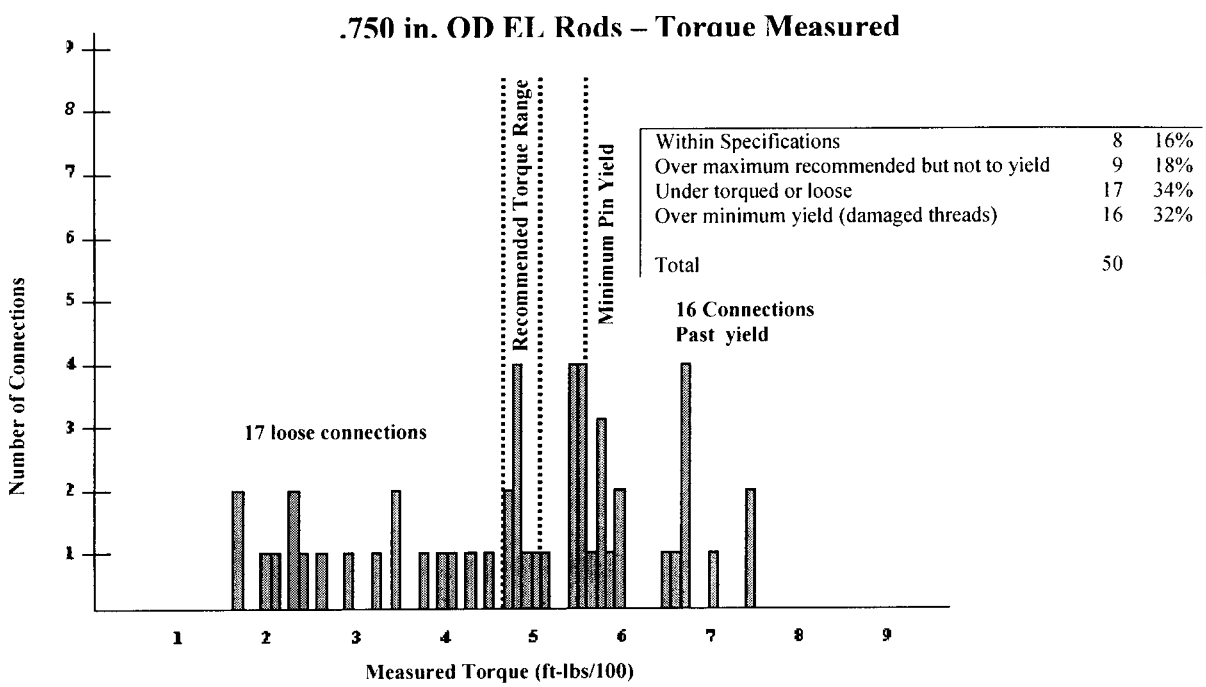

Figure 1

ell	Drill Pipe	Total Jts. Run	Expected Damage	Actual Damage	Comments
	2 7/8 RFO	205	6.5%	41%	connection analysis
	2 7/8 RFO	242	6.5%	1%	Real time connection analysis Same crew as well #1
	2 7/8 RFO	395	6.5%	2%	Real time connection analysis Same crew as well #1
	2 7/8 RFO	335	6.5%	5.3%	½% due to over torque. 4.8% due to not using stabbing guide.
	2 7/8 RFO	317	6.5%	7%	No real time connection analysis
	2 7/8 Ht-90	312	11.5%	7.6%	1.8% due to torque problems 5.8% due to no stabbing guide
	2 7/8 RFO	192	6.5%	4.9%	1.3% due to Torque problems 3.6% all failures
	2 7/8 RFO	220	6.5%	4.3%	1.3% due to Torque problems 4% all failures
	2 7/8 RFO				Rig Changed tongs. New tongs had 4 times the torque per psi as original tongs. String laid down when error caught.

Figure 2

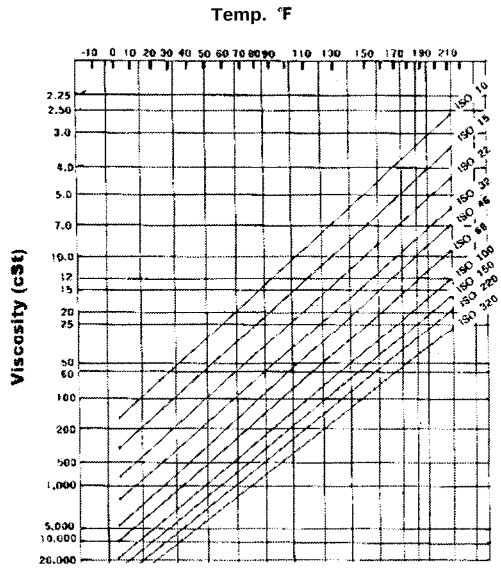

Figure 3

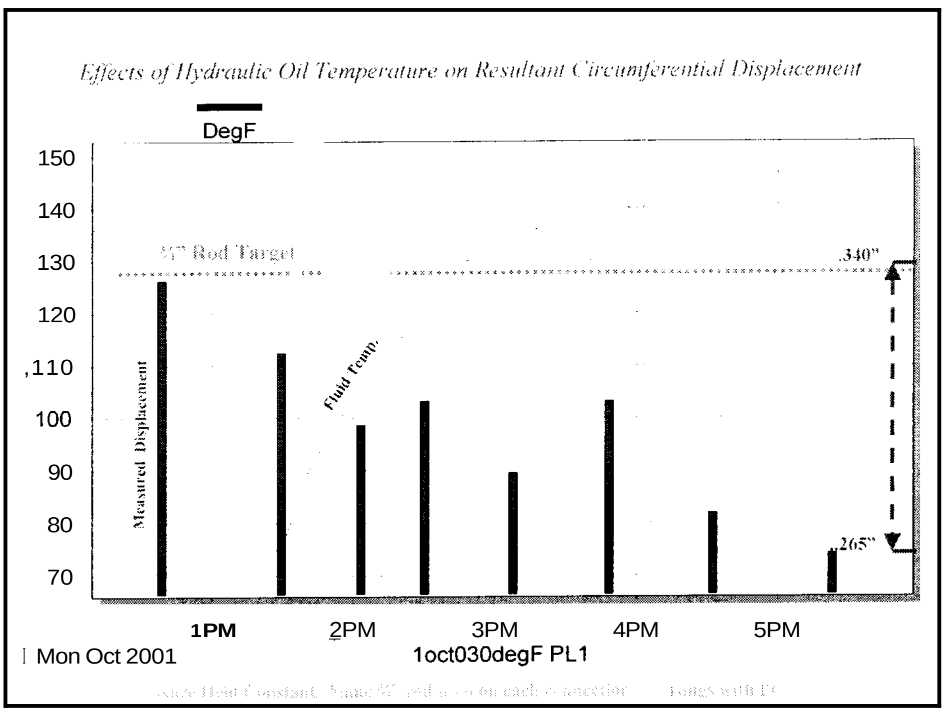

Figure 4

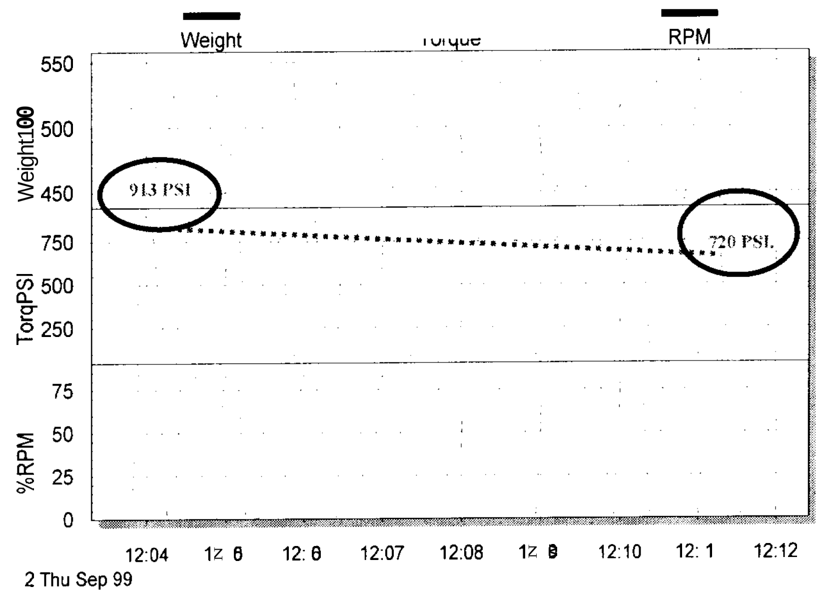

Figure 5

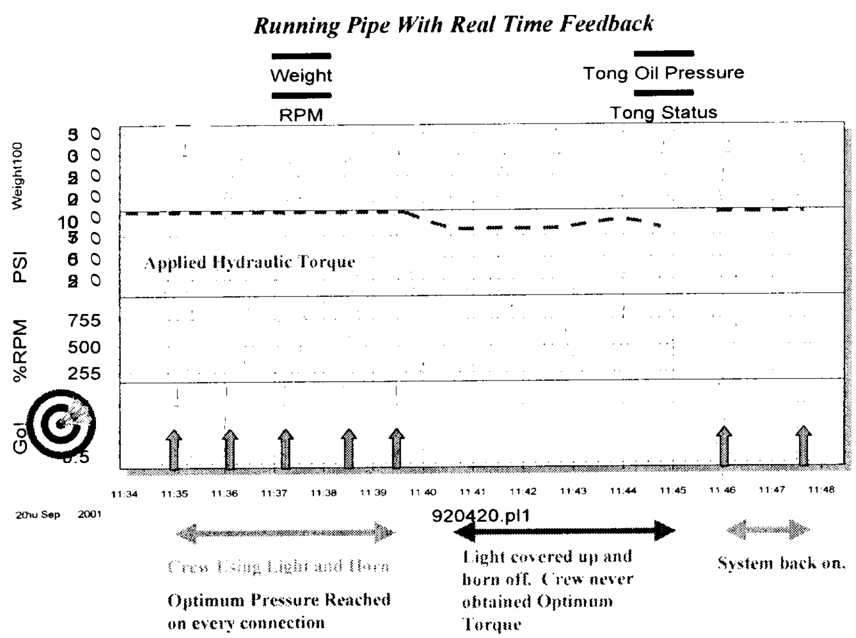

Figure 6

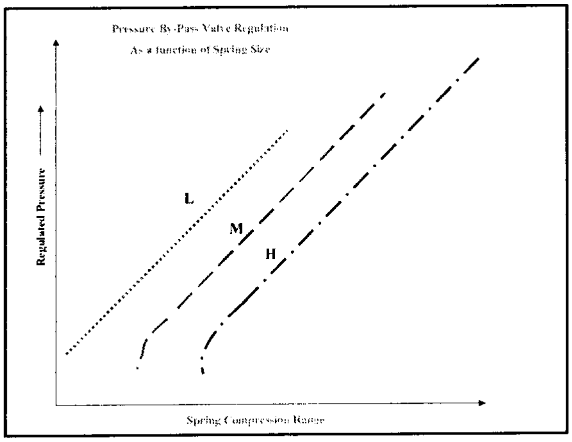

Figure 7

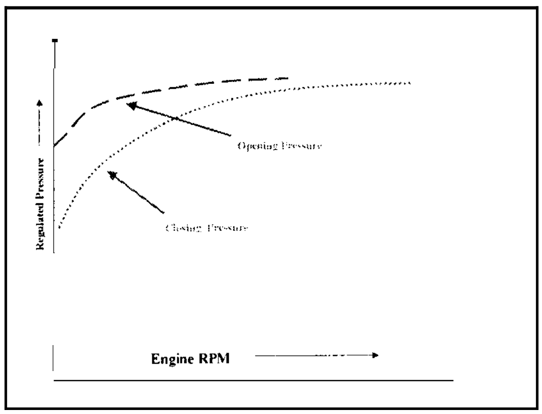

Figure 8

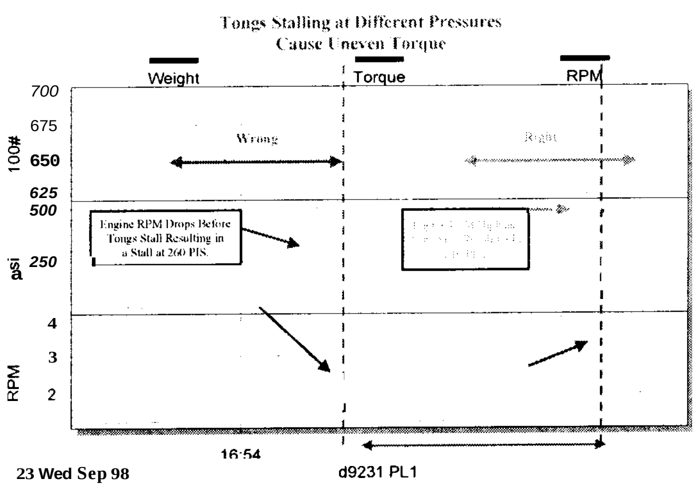

Figure 9

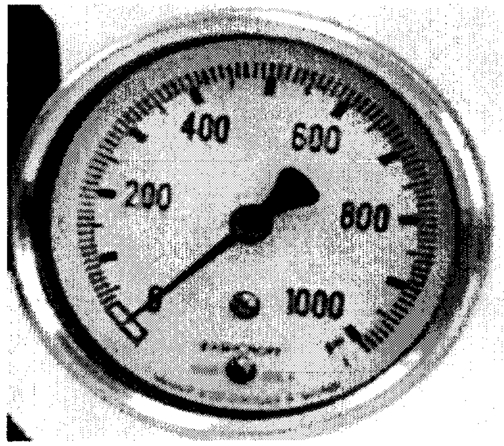

Figure 10

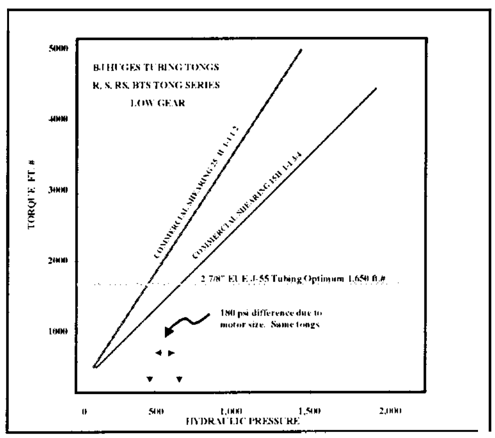

Figure 11

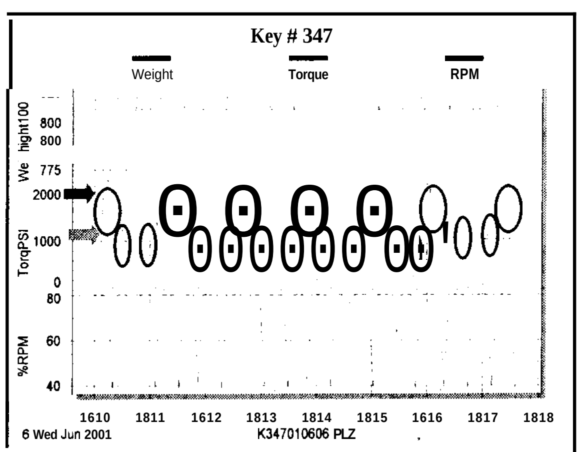

Figure 12

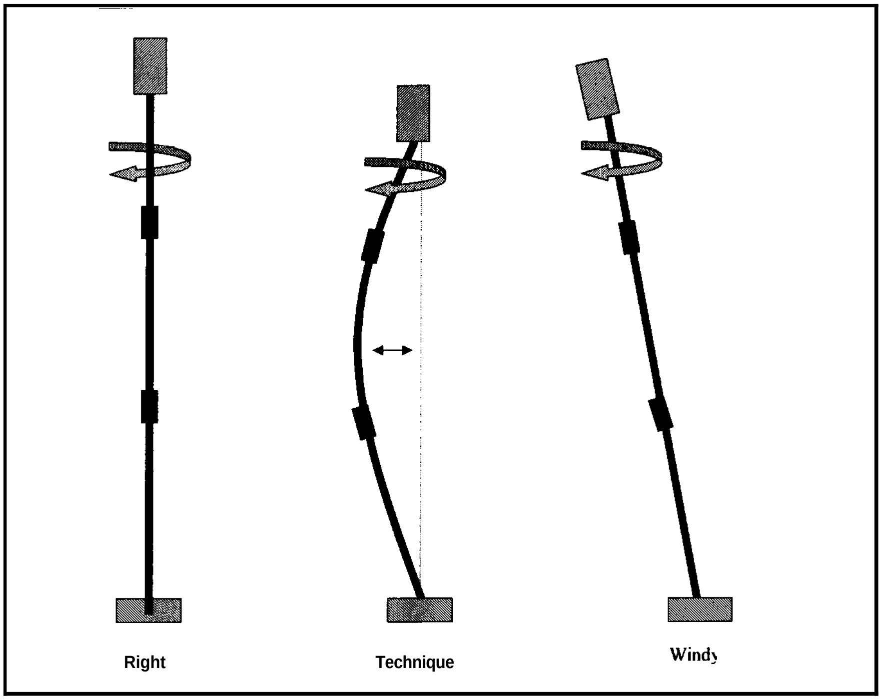

Figure 13

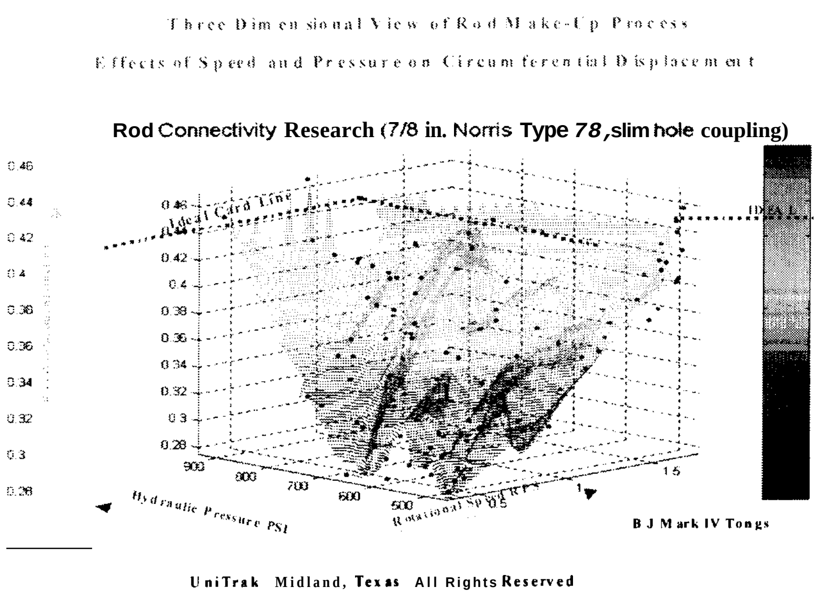

Figure 14