IADC/SPE

IADC/SPE 11403

Drilling Improvements Using Power Swivels

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ABSTRACT

This paper presents the technical advances made in the use of power swivels in replacing the rotary table. The equipment, drilling techniques and accelerated drilling time are reported. Specifically, special features of the use of a power swivel are also presented, i.e., drill up, remote pipe stabs, safety, operating cost reduction, drilling down 90 ft. stands. The object of this report is to acquaint people with the recent advances in the use of the power swivel.

I. INTRODUCTION

A new electric power swivel drilling system has been developed and successfully placed in operation on two SEDCO jackup drilling rigs currently drilling for Abu Dhabi Marine Operating Company (ADMA-OPCO). The swivel, called a Top Drive Drilling System, consists of a 1000 HP electric DC traction motor and an innovative pipe-handling system developed by Varco Oil Tools.

The concept of rotating pipe directly with a motor connected to the top of the drill string, in contrast to a kelly sliding through a rotary table, is not a new one; it is commonly used on workover rigs that do not have rotary tables. However, power swivels, as they are often called, have not been used extensively for drilling due to pipe handling compromises and the poor performance of previous designs.

The Top Drive System described in this paper represents a significant step forward in the practical application of the basic concept. Its development and subsequent field use has been highly successful. Two significant improvements attributable to the new system are excellent reliability and very efficient pipe handling. Both factors are enhancing the operation of the rigs on which they are installed to a degree that both rigs have reduced overall drilling time 20% on the average well. Figure 1 illustrates the power swivel and pipe handling systems.

Illustrations at end of paper.

II. HISTORY OF POWER SWIVELS

The offshore use of power swivels and power subs started in the early 1950's. A Baash Ross hydraulic drive power sub unit was utilized offshore on the drill ship NOLA I. This was followed by a power swivel used on the dynamically stationed coring vessel EUREKA in the early 1960's. Several other hydraulic drive power subs and swivels were used for special applications, i.e. the GLOMAR CHALLENGER deep sea coring project. One of the first fully electric driven power swivels was a unit built and tested by ARCO for high RPM drilling tests. Brown Oil Tool and Bowen developed and marketed the first electric drive power swivels in the early 1970's. The VARCO power swivel system went into use in 1982.

History has proven that a power swivel is a tool which provides good economical returns. It drills hole faster and eliminates several drill problems. The power swivel, when used in conjunction with a handling system, gives even more advantages.

III. SYSTEM DESCRIPTION

A. Design Philosophies

The factor overriding all others in the design of any power swivel is reliability. Rotary tables, kellys and kelly drive bushings have an inherent reliability as a result of many years of experience. Almost all drilling personnel are well-schooled in their use, care and maintenance. Hence, their perceived reliability is very high. On the other hand, power swivels have had only limited use. Consequently, they will not have a perceived reliability unless they can function continuously without failure and experience only minor repairs. Anything less will be interpreted by most operators as poor reliability regardless of overall performance, and most would not risk power swivel use.

The power swivel's reliability can be broken down between two areas for analysis and discussion. Its primary purpose, rotating the drill string, dictates that the means to produce rotation requires the highest reliability. Secondary functions, such as making connections, handling pipe, etc., are not continuously done and can tolerate higher failure experiences. Their failure cannot, however, shut down the system, but only reduce its efficiency. Therefore, the primary design criteria used in developing the Top Drive System was rotating reliability.

The second design philosophy applied to the Top Drive System was pipe handling efficiency. Previous systems have ranged from providing no pipe handling equipment to including specialized equipment subject to frequent malfunction and/or reduced efficiency. No one to date had provided a well-thought-out system which performs as efficiently as conventional equipment found on all rotary rigs operating today. Some of the functions not previously provided are: swivel set back, breakout when backreaming in the derrick, and elevator positioning to facilitate tripping.

Pipe handling efficiency goals were to equal or reduce conventional connection time and equal conventional grip time. Set back goals were to set back the unit without having to use auxiliary equipment not normally available, such as cranes. Easy switching to conventional rotary table drilling was also a desired goal in the event of serious malfunction. Only after reliability has been adequately demonstrated would this last feature not be required by an operator.

B. Subsystems

1. Rotating Subsystem

The first objective, reliable rotation, was achieved by selecting existing components and packing them into a power system. The rotating system is shown in Figure 2 and consists of:

a. a standard swivel;
b. a railroad DC traction motor with a built-in reduction gearing; and
c. a standard air-actuated brake.

The motor and gearing shown in Figure 3 are standard railroad equipment manufactured by General Motors and General electric alongside the more familiar EMD D79 and GE 752 oilfield traction motors used on pumps, drawworks, and independent rotary drives. The railroad configuration used the same windings, armature, and bearings as the oilfield motors and differs only in the housing which contains two external journal bearings for supporting the locomotive axle. The gearing comes with the motor and has been used extensively for many years. In fact, production of railroad configuration motors exceeds oilfield versions 5 to 1.

The axle is replaced with an 8-in. diameter sub containing six 5/8 API Reg box and pin connections for mounting the motor to the swivel. The armature shaft is double-ended, and an Airflex 16VC600 air brake is mounted on the end of the motor opposite the gearing.

The use of a powered sub configuration mounted under the rig's standard swivel overcomes several potentially weak areas. First, mud circulation is external to the motor; hence, temperature and leakage problems will not affect motor operation. Secondly, the swivel's reliability is not compromised by its integration into a motor housing with different lubrication and load handling stresses and deflections.

2. Pipe Handling System

Perhaps the single most significant factor that has prevented widespread use of power swivels in the past has been the lack of efficient integrated pipe handling equipment. Conventional hoisting equipment, together with rig floor placement of mouse and ratholes, provides extremely efficient pipe handling methods. Placement of a powered swivel weighing in excess of 15,000 lbs. and rigidly guided by a torque reacting rail system in the hoisting string prevents normal pipe handling functions, such as connecting and tripping, from being accomplished efficiently. The swivel cannot easily be removed or unhooked for tripping, and the mousehole is useless for connecting a stand to the rigid swivel. Secondly, the swivel's biggest advantage, reaming in a tight hole while tripping, is difficult without some means to break and make connections in the derrick -- breaking out being the most difficult to accomplish.

The primary effort associated with the Top Drive System's development was centered in its unique "PIPE HANDLER" which is shown in Figure 4. Multifunctions are performed by the PIPE HANDLER, including connecting, tripping, running casing if desired, and reaming. The PIPE HANDLER also provides internal blowout control.

The PIPE HANDLER consists of a special shoulder sub with an external spline which is made up to the bottom of the rotating subsystem. Supported above the shoulder on springs is a link adapter. Suspended below the link adapter is a specialized breakout/makeup hydraulic torque wrench. Attached to the link adapter are standard elevator links and a drill pipe elevator. The links and elevator are conventionally positioned toward the derrickman during tripping and remain around the drill pipe while drilling. They can be replaced with longer, heavier links for conventional running of casing, if desired.

The PIPE HANDLER's components are fixed against rotation and remain disconnected from the drill string during rotation of the string. The torque wrench engages the spline of the shoulder sub only when required to break out the connection between the drill pipe and the motor. It engages itself by raising vertically into the spline. The link adapter remains suspended above the shoulder on the shoulder sub until hoisting loads are imposed on the elevator. The resulting load compresses the springs, shouldering the link adapter against the sub's shoulder and transferring the load directly into the swivel.

Connections when drilling ahead are facilitated by the availability of the elevator to handle the add-on stand, whether it be a single from the mousehole or a triple stand from the fingerboard. The complete connection process generally takes less time to perform than a kelly connection. This results from simultaneous spin and makeup of both ends of the stand.

One of a power swivel's most desired features is the ability to ream in or out of the hole. Because the PIPE HANDLER's torque wrench does not rotate, it can remain powered at all times and at any traveling block position. Consequently, the reaming process is easily accomplished. As a full 90-ft. stand comes out of the hole, its top need not be returned to the floor to break it out of the motor. The torque wrench remotely breaks it loose, and the elevator hoists it to the racking position in a conventional manner. Similarly, when going into the hole, a bridge can be drilled through without stopping to pick up the swivel and kelly and laying them back down once the tight spot has been passed.

The flexibility of the Top Drive System's PIPE HANDLER can lead to many drilling improvements not currently possible with a kelly, such as longer continuous cores, improved fishing flexibility, and a variety of simultaneous rotating and reciprocating tasks.

3. Guide System

Torque reaction of the rotation system is absorbed by a set of two vertical rails and a guide dolly. The guide dolly also incorporates a set back means shown in Figure 5. The main frame containing four sets of guide rollers at each corner was designed to support the torque load and the static weight of the Top Drive System, including the swivel. A motor frame attached to the motor is pinned with vertical connections to one side of the main frame. The other side is locked to the main frame with large clamps.

The swivel and drilling system can be set back without disconnecting the power or hydraulic connections, the rotary hose, or the swivel by lowering the main frame to the bottom stops in the rails. Once the weight is resting on the bottom of the rails, the swivel can be disconnected from the hook, if one is used, or from the traveling block becket, if no hook is used, and the completed system can be pivoted aside on the motor frame.

C. Components

1. Motor

The traction motor is rated at 1000 HP continuous at 1060 amps, which produces 24,000 ft.-lbs. of torque at 220 RPM. Its output characteristics are shown in Figure 6. Maximum speed is over 300 RPM, and maximum intermittent torque is 30,000 ft.-lbs. at 1325 amps. The gear ratio between the motor and the output sub is 4.133:1, and the gears have an expected life of over five years at full rated horsepower. Consequently, for actual drilling loads, they could be considered to have unlimited life.

Motor cooling is provided by a 15 HP, 3450 RPM blower mounted on the guide dolly. Inlet air is taken from a point located 25 ft. above the rig floor at the motor's lowest drilling position. Conventional interlocks prevent motor operation without cooling air.

The motor's commutator end bearing, normally radially loaded when the motor is horizontal, is replaced with an equivalent size combination thrust and radial load bearing. This modification has proven to be durable even under the most severe conditions.

2. Torque Wrench

The hydraulic torque wrench is rated at 60,000 ft.-lbs. makeup or breakout torque when supplied with 2,000 PSI hydraulic pressure. It consists of a 10 in. bore clamping piston, two 5 in. bore torque cylinders and a 3-1/4 in. bore lifting cylinder. The cylinders are sequenced as shown in Figure 7 to allow remote single control operation. Upon command, the left cylinder engages the spline before clamping can occur. After the wrench has clamped itself to the box of the drill pipe, the torque cylinders automatically stroke 30 degrees. A removable stop on the vertical cylinder allows the wrench to rise farther up the spline and clamp the pin of the saver sub located below the spline. This 9-in. long saver sub allows crossover to tool joints being used on the drill pipe and replacement of the pin, which experiences wear after many connections.

3. Link Adapter

The link adapter is rated at 500 tons in accordance with API Specification 8A. It can accommodate 250-ton, 350-ton, and 500-ton standard elevator links. Normal drilling assembly consists of 96-in. long, 250-ton links and a standard center latch drill pipe elevator.

The link adapter is supported on two torque arrestor assemblies pinned to a positioning bearing mounted on the bottom of the drive motor's gear case. The torque arrestors contain compression springs which provide 12,000 lbs. of support at full compression of 6-1/2 in. The torque arrestors function in place of the hook spring and support the link adapter above the load bearing shoulder on the shoulder sub while drilling.

The positioning bearing is locked in one of 78 equally-spaced positions for orientation of the drill pipe elevator for tripping. The spring-loaded lock allows rotation of the elevator, if required.

4. Kelly Cock

A conventional kelly cock is positioned between the motor sub and the shoulder sub and is operated in the same manner as an upper kelly cock. However, unlike a conventional kelly cock which is set back with the kelly during trips, the Top Drive's valve is positioned for remote stabbing and makeup in the event of an internal kick during a trip.

5. Link Tilt Assembly

Located on the front of the link adapter is a link tilting arm actuated by an air spring shown in Figure 8. The shorter 96-in. long links used on the PIPE HANDLER are difficult to manually swing over to the mousehole for picking up or laying down pipe. The air supply provided for the brake is used to operate the tilting unit.

6. Hydraulic Power Unit

Hydraulic power is supplied for the torque wrench at 2,000 psi. Maximum flow is 32 GPM produced by a variable volume pump. The pressure is controlled by a two-position valve located in a derrick junction box. It is normally blocked unless electrically actuated, and no pressure is present in the hydraulic hoses connecting the torque wrench to the power unit. The power unit has a standby system for switch over in the event of a malfunction. Forty-horsepower AC motors drive the pumps.

D. Operation

1. Drilling

Drilling ahead can be accomplished with full 90-ft. stands, doubles or singles. Normally 90-ft. stands are used to maximize rotation time by eliminating two out of three conventional connections.

Connection of a 90-ft. stand requires that the stands be made up and racked in the fingerboard. Depending upon the well program and rig type, this can be accomplished many ways. Rigs that are skidded from well to well can leave their stands from the previous well in the derrick. Where it is necessary to lay down the pipe in singles, the surface hole can be drilled with singles, or the rig crew can make up stands prior to spudding in. After surface pipe is run, additional stands can be made up while cement sets or BOP testing is under way. Another option is to trip singles back into the hole equal to the number of stands required prior to the next trip.

Connection of a 90-ft. stand is illustrated in Figure 9. As the present stand is drilled down, the elevator slides up toward the motor until the last tool joint is just above the floor. The slips are then set, and the torque wrench is used to break out the motor from the stand. The elevator is unlatched and hoisted up to the monkeyboard, and the derrickman feeds the next stand into the elevator. The driller hoists the pipe off the floor, and the floor hands stab the lower connection into the string in a conventional manner and connect the backup tong to the box. Meanwhile, the driller continues lowering the motor until it stabs itself in the upper connection with the aid of a bell guide attached to the torque wrench.

The motor is next used to spin in both connections and, upon shouldering up, the current is increased with the throttle control to the required makeup torque. An ampmeter calibrated in foot-pounds assists the driller. The motor may be stalled for up to one minute at 30,000 ft.-lbs. if required. After makeup, which usually requires only a few seconds, the string is hoisted to release the slip and drilling is resumed.

Considerable controversy exists as to whether or not leaving the bit on bottom invites potential problems. Experience to date does not support evidence of problems. However, this is only true for the formations drilled and cannot be generalized for all cases. Since the connection is made fairly rapidly (two to three minutes), less time exists for sticking to develop. The alternative, if a certain formation presents a problem, is to drill with either a pup joint or doubles. When drilling with singles or doubles, the string can be pulled up thirty feet prior to making a connection, and the single above the floor can be used as the kelly. Experience in other areas of the world will be required before general statements can be made about this condition.

2. Reaming/Tripping

Reaming with the Top Drive System, particularly backreaming, has the potential to significantly reduce the time loss on stuck pipe. One major oil company estimates that over one hundred million dollars per year in drilling costs could be attributed to stuck pipe.

The PIPE HANDLER's elevator is ready to trip as soon as the last stand is drilled down and broken out with the torque wrench. No time is lost in setting back the kelly in the rathole, normally a difficult process.

The system hoists pipe out of the hole at conventional speed since all tripping equipment is conventional. In the event a tight hole is encountered, the slips can quickly be set and the motor spun in and made up quickly. Full drilling capability for backreaming or punching through a bridge is now available. Pipe may be moved up or down while simultaneously circulating and rotating.

3. Running Casing

The Top Drive System can be set back for running casing or remain in the hoisting string. The set back option allows access for maintenance without the rig being down. On the other hand, if used to run casing, the rotary hose/swivel can be used for filling operations or with a swage nipple, pressure circulation without steel chicksans in the derrick. Although not yet tried, a special head could be developed to simultaneously rotate, circulate and reciprocate casing for either better cementing or setting casing in a damaged hole.

4. Coring

Continuous coring up to 90 ft. without intermediate connections can potentially improve quality of cores, as well as reduce the number of trips required.

5. Kickoffs and Other Miscellaneous Operations

Locking the motor's brake, which is rated at 35,000 ft.-lbs., on the drill string provides the ability to drill 90 ft. of hole with a downhole motor between connections. Orientation need not be potentially lost every 30 ft.

Generally, the Top Drive Drilling System provides the drilling rig with previously unavailable flexibility by permitting the running of fishing tools, completion assemblies, and any other equipment that requires right and left-hand rotation while raising or lowering the string over a 90-ft. interval.

IV. SYSTEM INSTALLATION

A. Interfaces

The Top Drive Drilling System interfaces with the rig's hoisting system, derrick and electrical power system.

1. Hoisting System

Inasmuch as the system replaces the kelly but uses the conventional swivel, the attachment of the unit to the traveling equipment is through the hook. The system's total weight is over 25,000 lbs., including the guide dolly. Consequently, the hook is fully extended and its spring system is nonfunctional. The only reason for it remaining in the string is for switching over to conventional drilling without having to take the time to install it. Otherwise, the swivel bail can be attached directly to the traveling block's becket and the total height of the hoisting string reduced by the hook length.

The required travel of the swivel is approximately 100 ft. compared to about 75 ft. when using a kelly. This necessitates the replacement of the rotary hose, which is normally 60 ft. long with a 75-ft. long hose, and the stand pipe height is extended by 12-1/2 ft. to correctly position the hose loop at its lowest position.

The system does not require a rathole for set back, and future rigs not requiring a backup rotary table and kelly system can eliminate both the rotary and the rathole. This will greatly simplify the rig floor. Such a rig is probable in the future when the new system has demonstrated its reliability over a significant period of time. If the rotary is removed, a structure has to be provided for support of the master bushing. The bushing should be free to rotate on a flat plate to ensure that the normal tong operations do not rotate the pipe in the slips.

2. Derrick

Derrick height is probably the single most critical interface requirement. The Top Drive System has a total length of 19 ft. from the base of the drill pipe elevator to the top of the motor sub. A 500-ton swivel, traveling block, and hook assembly would typically require 26 more feet for a total system length of 45 ft. Handling a 90-ft. stand typically requires 95 ft., resulting in an overall height from the floor to the top of the traveling block of 140 ft. A 160-ft. derrick would provide a 20-ft. margin between the crown and the normal height of the traveling block. By removing the nonfunctioning hook, another 9 ft. could be saved, reducing the derrick height requirement to approximately 150 ft. A recent redesign of the system has reduced the length another 8-1/2 ft. for installation in standard 142-ft. masts and derricks.

Guide rails in the derrick are necessary for torque reaction. Two symmetrical I-beams, located 6 ft. apart, are used for guide rails similar to those found on offshore floaters. Torque loads are reduced to 5,000 lbs. on each beam at 30,000 ft.-lbs. of string torque. The 5,000 lbs. is easily absorbed by braces located at each horizontal girth. Derrick strength is sufficient, considering that full set back wind loading can produce greater twisting moments on the derrick.

3. Electrical Power System

The traction motor's electrical requirements are identical to those of the rig's other DC motors. The SEDNETH rig's DC power is supplied from a Model 2000 integrated power system SCR system. All the rig's motors, including the Top Drive unit, are series wound EMD Model D79 traction motors. Normally, each SCR unit is assignable to one of three motors. The two units connected to the rotary table motor have an additional assignment position for the Top Drive motor. Hence, the rotary throttle and torque limit controls are either connected to the Top Drive System or to the rotary table. This limits the modification of the standard SCR system to addition of assignment contactors.

The DC power is cabled up the side of the derrick to a junction box located at the monkeyboard for easy access. From there, a service loop shown in Figure 10 brings the electrical power to the motor junction box. The service loop also contains hydraulic and air lines for operation of the PIPE HANDLER and the air brake. The service loop is 90 ft. long and enclosed in a 4-in. suction hose with flanged ends. The hose protects the electrical wires from rubbing on cat lines, tong suspension lines, and other hanging equipment in the derrick.

B. Controls

The overall system is shown schematically in Figure 11. The system controls are all located on the driller's console. The motor torque and speed controls are those normally provided for the rotary table in the electrical control console and consist of a speed throttle, a reversing switch, and a current limit potentiometer. A rotary torque ampmeter is placed in the driller's console below the weight indicator and has a calibrated scale for both amps and ft.-lbs. A second ampmeter located in the electrical control console also reads motor amps and verifies the primary meter's calibration.

Motor speed is independently measured with a magnetic speed sensor located in the gear box and set to indicate off of the pinion teeth. It is recorded on the rig's recorder and indicated on an RPM meter.

The driller also has two two-position electrical switches for operating the motor brake and the link tilting system. Both systems are controlled by electrical solenoid valves located on the motor and feed with a single air supply line in the service loop. A third pushbutton electrical switch operates a hydraulic solenoid valve located in the derrick junction box for sequencing the torque wrench. The driller must hold the switch down for the torque wrench to remain clamped on the pipe, preventing accidental engagement of the torque wrench while drilling.

V. SYSTEM DRILLING EXPERIENCES

Nine wells have been drilled by SEDCO utilizing the VARCO power swivel. Well depths have varied between 10,000 ft. and 13,000 ft. Hole angles have varied between 0° and 50°. Based on historical data, it appears that drilling time has been decreased by approximately 20%. In drilling the nine wells, the standard rotary table was not routinely utilized. The power swivel and handling system recorded 3 days downtime drilling the nine wells and most of this downtime was recorded on the first two wells. The ADMA-OPCO drilling programs have utilized power swivels for the past four years and their results show approximately 11% decrease in drilling time. Figure 12 is a comparison of drilling times for a well using a power swivel and one using standard rotary drilling.

VI. CONCLUSIONS AND PLANS

The development objective of providing a highly reliable power swivel system has been demonstrated by the successful drilling of several wells over the last year without the occurrence of significant problems associated with the swivel. The operator, ADMA-OPCO, as well as the contractor, SEDCO, are extremely pleased with the results and are developing additional applications for the system.

Pipe handling efficiency, a second objective, has been met by applying the technological advancements made by Varco over the last ten years to the new system. The newly developed PIPE HANDLER has performed well enough for owners of previously-built power swivels to adapt the PIPE HANDLER to their existing units. Without the unique unit, the potential benefits of the system could not be realized.

The total objective of drilling more hole more efficiently and safer has been demonstrated with this newly developed power swivel/pipe handling system. The plans are to extend the use of the equipment on existing drilling units.

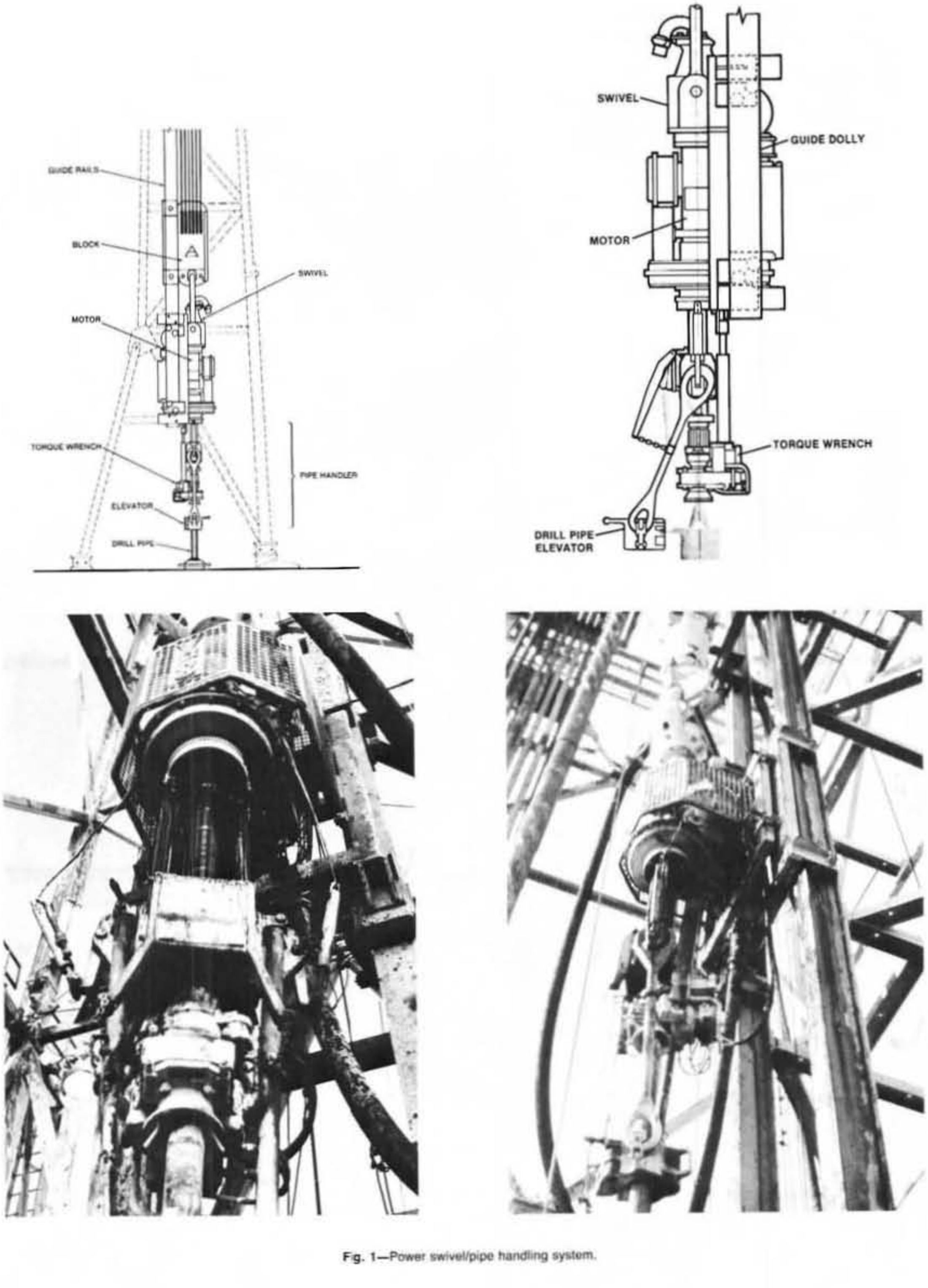


Fig. 1—Power swivel/pipe handling system.

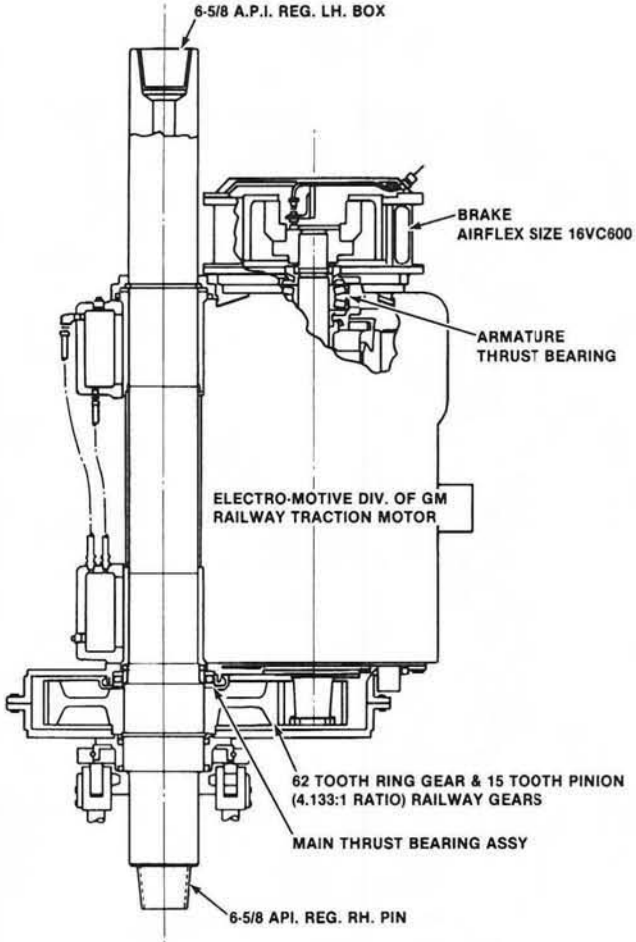


Fig. 2—Overall design of rotating subsystem.

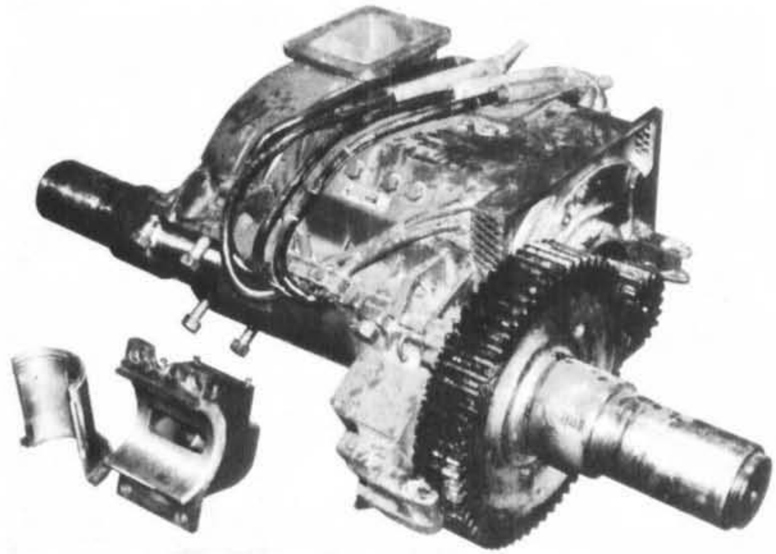


Fig. 3—EMD D79 railroad traction motor with reduction gearing.

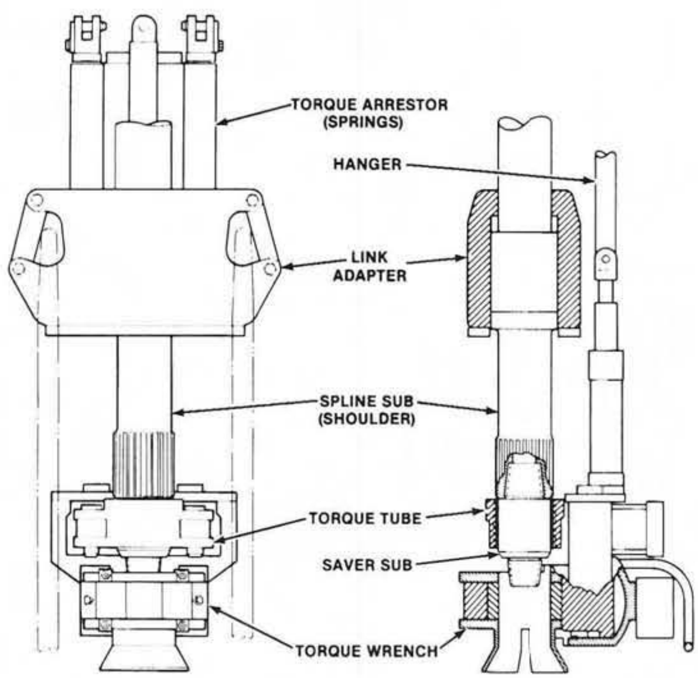


Fig. 4—"PIPE HANDLER" pipe handling system.

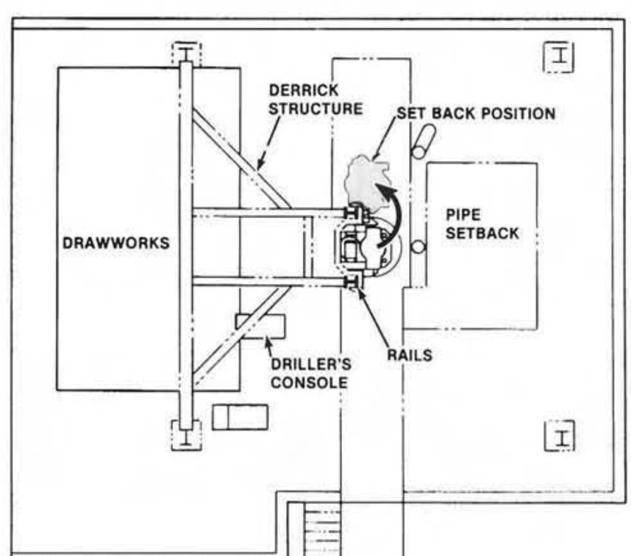


Fig. 5—Top view of guide dolly and set back position.

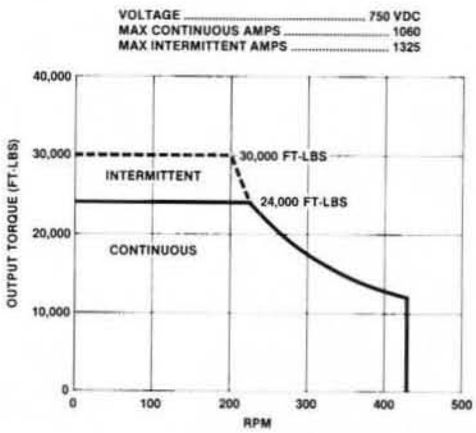


Fig. 6—Motor torque speed characteristics.

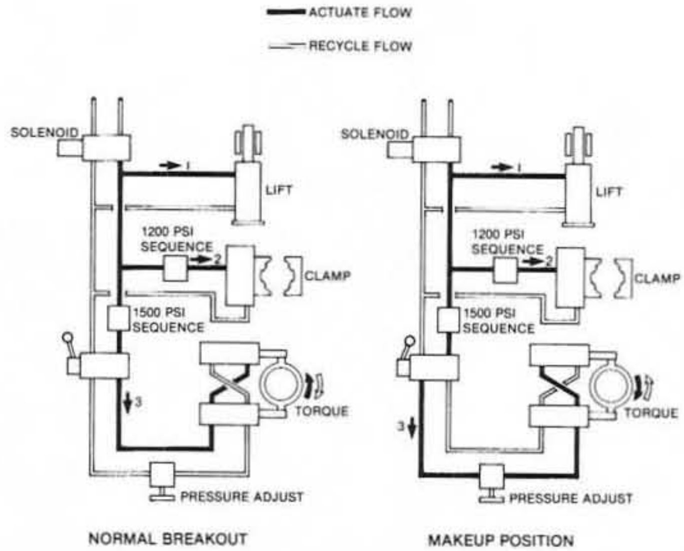


Fig. 7—Torque wrench control circuit.

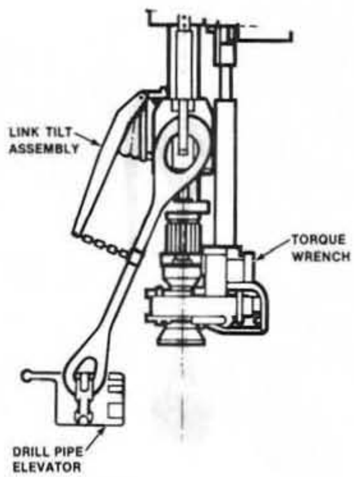


Fig. 8—Link tilting assembly.

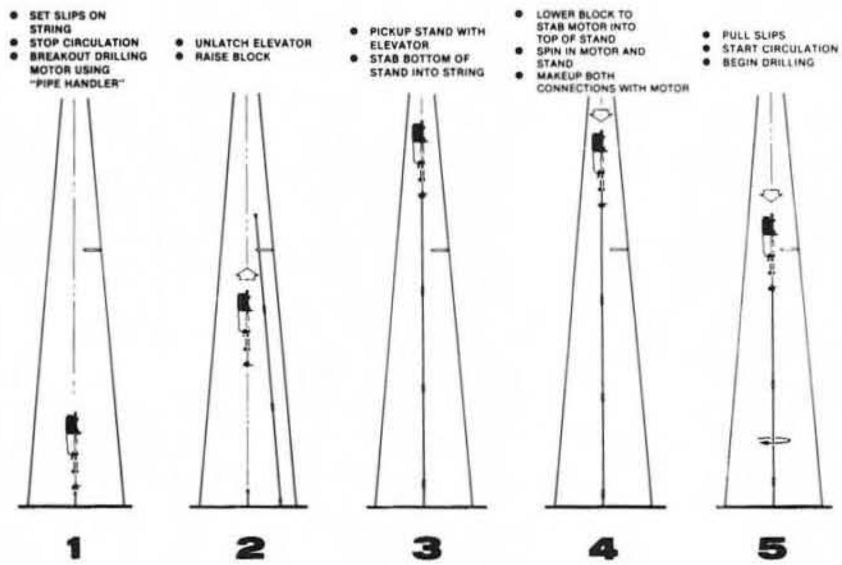


Fig. 9—Connection sequence.

Fig. 10—Service loop connected to guide dolly.

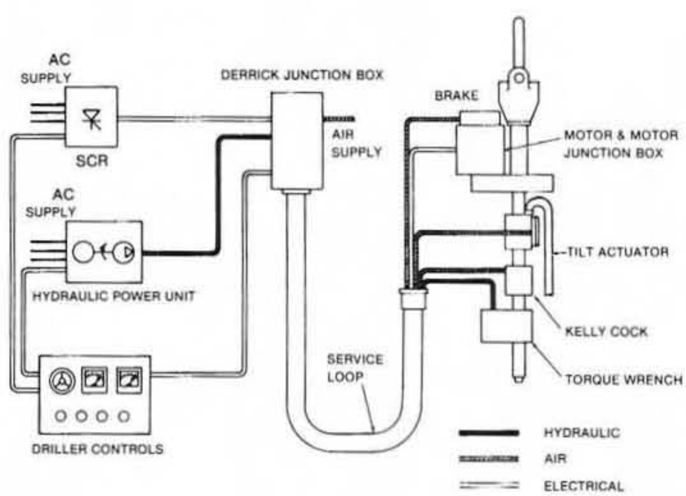
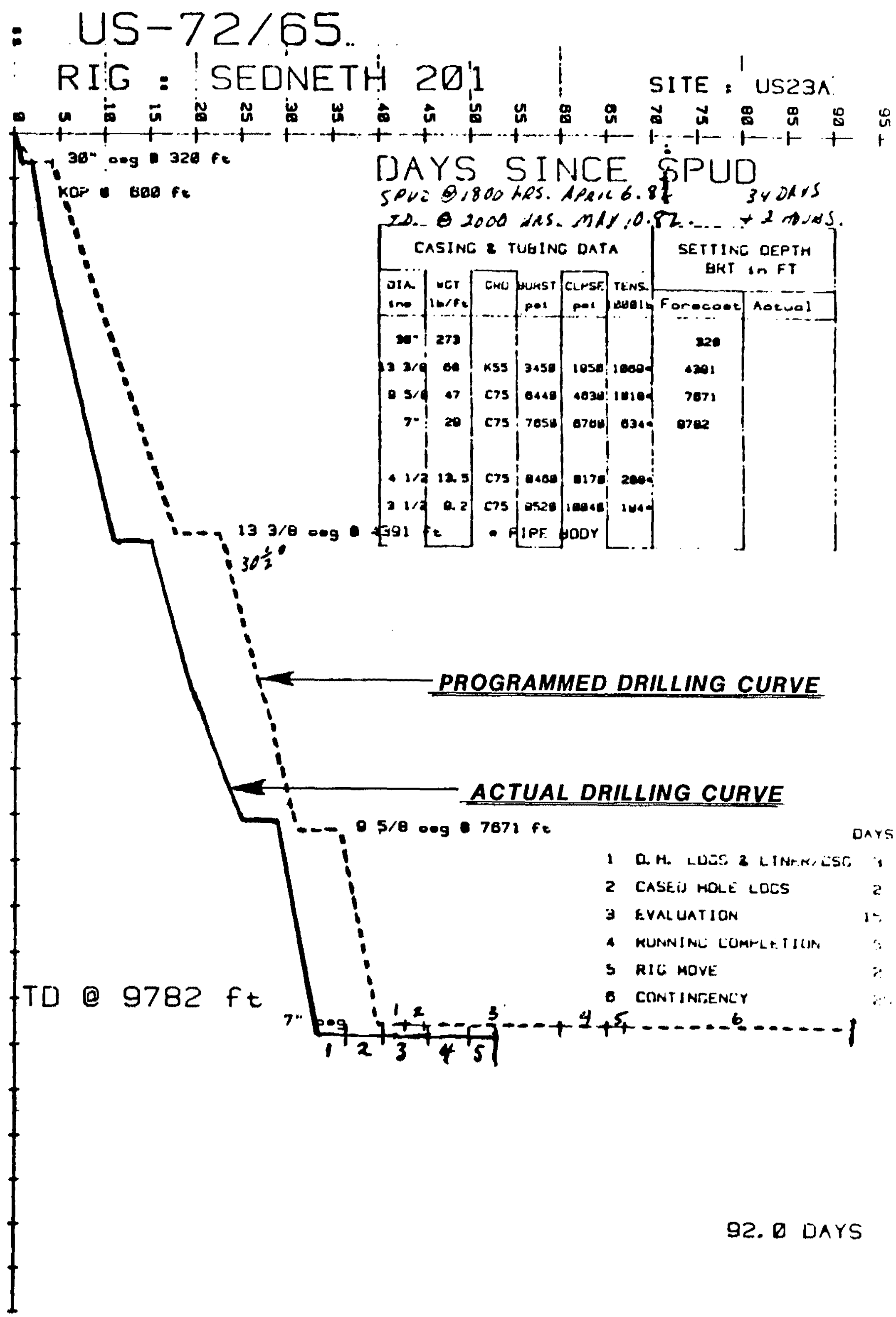


Fig. 11—Overall system schematic.



CASING & TUBING DATA						SETTING DEPTH BRT in FT	
DIA. ins	WGT lb/ft	GRD	BURST psi	CLPSE psi	TENS. 1000lb	Forecast	Actual
30"	273					320	
13 3/8	68	K55	3450	1950	1069*	4391	
9 5/8	47	C75	6440	4630	1010*	7671	
7"	29	C75	7050	6700	634*	9782	
4 1/2	12.5	C75	8400	8170	209*		
3 1/2	9.2	C75	9520	10040	194*		

* PIPE BODY

Fig. 12—Drilling time comparison.