Storms, M. A., Natland, J. H., et al., 1991
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6. THE DIAMOND CORING SYSTEM PHASE II (4500 M DEPTH CAPABILITY)[1]

Dan H. Reudelhuber[2] and Steven P. Howard[2]

. . . Dedicated to the all of the many talented people (SEDCO/FOREX, Partech, DRECO, Tech Power Controls, Dr. Chuck McKinnon, and Duke Zinkgraf) who contributed to creating the diamond coring system.

EXECUTIVE SUMMARY

Leg 132 deployment and use of the Diamond Coring System (DCS) platform/mast assembly demonstrated the potential of the system for meeting scientific goals that cannot be realized with conventional drilling techniques. That was due to the tremendous and diligent efforts of all parties concerned, both before and during Leg 132. Although some limited equipment problems were experienced, the problems were solved and the system was made fully operational before the end of the first coring site. Equipment reliability was very good, and the improvements made to the system as a result of previous experience on Leg 124E proved to be useful and effective in accomplishing the goal of coring fractured basalt.

The new electric top drive and Silicon Control Rectifier (SCR) controls worked as designed and proved the concept of using an electric motor for high-speed mining-style coring. The capability to make and break connections with the top drive greatly improved efficiency. The closed-loop method of motor speed control worked flawlessly. Those two aspects of electric top drive control are unique to ODP's DCS coring system, and their successful first-time-ever use during Leg 132 sets a new standard for top drive controls with potential application to drilling units worldwide. Top drive operation at both low and high speed and torque was smooth at all times. Application of the same control techniques for low-speed control of the mud pumps was successful and allowed smooth operation of the large 1600 HP rig pumps at speeds as low as 3 SPM (3 strokes per minute = 6 gpm!).

The main hydraulic power system and controls worked quite well, as did all auxiliary systems. There is room for improvement in areas such as feed cylinder rod seals, wireline winch control, and the low-pressure return filter systems, and those areas will be improved before the next deployment of the DCS.

Leg 132 was blessed with good weather. For that reason, DCS operations were never hampered by excessive heave motion. It should be noted that the DCS operating window is limited in that regard, and it was pure chance that operations were never curtailed by the environment. Any future plans for DCS legs must certainly take into account the possibility of bad weather. The operating limits are considerably more restrictive than normal coring operations due to the location of the platform, which results in amplified roll and pitch motions. The heave motion limit is defined as a limit of primary heave compensator rod travel for safe operations, approximately 15 ft double amplitude. If roll and pitch motions hamper safe operations on the platform, operations may have to be terminated before the 15 ft limit is reached.

Heave compensation and controls functioning, although off to a shaky start, eventually were operational, and the system provided effective secondary compensation. A problem with servo velocity signal quality was resolved by taking a completely different approach to acceleration measurement. Control electronics were reliable, and the extra steps taken to protect the electronics from the environment were successful. Weight On Bit (WOB) control was good and allowed coring with measured WOB variations of ± 200–500 lb. Feed rate control mode was tested and worked quite well. A load cell accuracy problem will have to be solved so that load measurement can be corrected.

The new heavy-duty hydraulic wireline winch and 3/8 in. sandline system made the retrieval of cores and downhole tools easy, efficient, and safe. The addition of two types of brakes (hydraulic fail-safe and disc-type) assured that total braking control of the wireline was possible in all situations. Slow speed control of the winch was poor, but was quickly solved by adding another hydraulic control valve to the console. A permanent solution will require changing the joystick control to an alternate type.

Throughout the construction, deployment, and use of the DCS, special effort was devoted to maximizing the safety of the equipment and the operation. No system was ignored in the continual search for ways to improve safety. There were no injuries during the course of drilling. However, the main hazard remains that the platform is located 45 ft above the rig floor, and personnel must work while standing on a work platform attached to the primary heave compensator. That must be changed. Now that the DCS system is proven, efforts should be redirected to finding an alternative approach, the crux of which will be to eliminate the work platform in the derrick along with the associated hazards and inefficiencies.

Leg 124E was the first attempt ever at applying mining-style coring and drilling techniques to the offshore environment on a floating rig. The lessons learned during this first attempt laid the groundwork for optimizing and fine-tuning the drilling, coring, and handling equipment necessary to meet the challenges of coring in lithologies where rotary methods had repeatedly failed. ODP, SEDCO/FOREX and a host of companies met the challenge and succeeded in building and proving the DCS on Leg 132.

INTRODUCTION AND BACKGROUND

Throughout the history of the Deep Sea Drilling Program and the Ocean Drilling Program, there has been keen scientific interest in conducting geological investigations on mid-oceanic ridges around the world. A significant amount of data has been gathered with sophisticated seismic and sonar instruments as well as with camera sleds and visual observations using manned submersibles in these regions of the ocean. However, due to the formations on the mid-ocean ridges being characterized by young highly fractured basalts, only limited amounts of core samples from shallow holes have been recovered. To date, all coring operations have been performed with conventional roller cone core bits 9-7/8 in. diameter or larger. In highly fractured basalt formations, the cutting action of the roller cone core bits further fractures the rock, resulting in core jams in the throat of the bit. Typical core

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[2] Ocean Drilling Program, 1000 Discovery Drive, College Station, TX 77845-9547.

recovery using the roller cone bits has been repeatedly demonstrated in fractured basalt to be less than 10%. In addition to almost nil core recovery, the cutting action of the large-diameter roller cone bits damages the formation, resulting in a high degree of hole instability. The problems with hole instability preclude any significant progress with regard to depth. That, coupled with little or no core recovery, has rendered the use of more conventional drilling/coring techniques and equipment in this type of environment ineffective.

Conversely, the use of high-speed diamond coring bits by the mining industry has been demonstrated in land drilling operations as a very effective way to core fractured and highly unstable crystalline rock formations. The significant reduction in hole size and the technique of grinding/cutting the rock at high speeds and low bit weights result in extremely high recovery rates (typically 90%) and excellent hole stability. ODP has developed a high-speed, deep-water slimhole diamond coring system for deployment from a dynamically positioned drill ship. At present there are three specific types of formations that the DCS will be used to core. In addition to the fractured basalt formations described above, formations with sequences of alternating layers of chalk/chert and formations comprising eroded reefal limestone will be cored in the future. Attempts to core those three types formations with conventional large-diameter roller-cone core bits has resulted in unsatisfactory core recovery.

Phase I Development of the DCS

During the Phase I development of the DCS, the original concept was to deploy and evaluate proven mining coring equipment from a floating vessel. A proven mining coring system was integrated into a 40 ft mast which was in turn suspended in the existing ship derrick. A small diameter work string was deployed inside the ODP drill pipe to which a mining-type core bit was attached. In addition, all of the coring and wireline equipment was deployed from the DCS platform (Fig. 1).

To demonstrate the concept, a low-cost prototype system was deployed on Leg 124E and tested for a 2 week period. The entire system was suspended from the 400 ton primary passive heave compensator system. The residual heave in the tubing string was measured using state of the art sensor technology, coupled with a microprocessor unit used to drive the secondary heave compensator system. The system was designed to maintain extremely accurate WOB control (± 500 lb) on the narrow kerf diamond bit, in water depths of up to 2000 m with residual heave of ± 6 in. and heave periods as short as 6 s.

Rotation for the diamond bit was provided by a 3-1/2 in. tubing string rotated from the surface by a high-speed mining-type hydraulic top drive mounted on the DCS platform. Numerous cores were cut with the scaled-down prototype system in heavy seas (4–6 ft ship heave on 4–6 s periods). The cores were cut in sedimentary formations. Examination of the recovered core samples revealed little or no disturbance, an indication that the bit remained on bottom with good WOB control. Further indication of this was constant drilling torque at the surface and steady pump pressures. At the end of the sea trials on Leg 124E, although limited drilling/coring tests were conducted, the concept of adapting high-speed mining-coring techniques to a floating vessel was deemed viable.

Phase II Development of the DCS

During phase II development of the DCS, the operating depth of the system has been extended to 4500 m combined water and drilling depth below the seafloor. The secondary heave compensation capability was extended from ± 6 in. of residual heave to ± 12 in., again with as short as 6 s wave periods. As with the phase I system, the DCS involves suspending a 40 ft tall mast/platform assembly in the existing 147 ft derrick on the ship. The high-speed electric top drive, secondary heave compensator system, and wireline winch system for conducting the slimhole coring operations are all integrated into the DCS platform/mast assembly (Fig. 2). The high-speed diamond coring bit (3.96 in. O.D. × 2.20 in. I.D.) is attached to the outer core barrel assembly on the end of the tubing string. The small diameter tubing string is deployed inside the ODP 5 in. and 5-1/2 in. drill pipe. The small-diameter tubing consists of high strength 3-1/2 in. tubing with specially designed connections for withstanding the bending loads induced into the string by vessel motion. The tubing is rotated with the DCS top drive suspended from the DCS platform. All drilling functions for the slimhole diamond core bit (rotation, WOB, secondary heave compensation, pump flow rate, etc.) are controlled by personnel on the DCS platform.

The DCS platform, tubing, and ODP drill string are all suspended from the primary 400 ton passive heave compensator. The residual heave motion/weight fluctuation not compensated for by the primary compensator is removed from the tubing string by a secondary active/passive heave compensator system on the DCS platform. The secondary active compensator system is controlled by a computer, which in turn drives a servo valve. The servo valve controls the hydraulic feed cylinders to control (add and subtract) string weight fluctuations induced by the heave.

When the secondary heave compensator is activated by the driller, the diamond bit is automatically advanced to bottom and the desired WOB or feed rate is established. After the core is cut, the computer will automatically retract the bit off bottom when commanded by the driller. The inner tube assembly is then retrieved by wireline. An empty inner tube assembly is dropped/pumped down the tubing string, landed in the outer core barrel assembly, and coring operations are resumed.

A redundant secondary passive compensator mode has also been built into the system in the event the computer system fails. Depending on the heave motion, the driller may continue with the bit run using solely the passive secondary compensation. Also, in the event the computer control system fails in heavy seas, the driller may immediately switch to passive compensation to assist in retracting the string off bottom in an effort to prevent damaging the core bit and necessitating a subsequent time-consuming bit trip. Upon repairing the computer, coring operations using active secondary heave compensation may be resumed.

Application of the DCS to Specific Scientific Objectives

The use of high-speed slimhole drilling/coring techniques and equipment have considerable potential for achieving yet unattained scientific drilling objectives over the next 3–5 yr. The slimhole coring system has been demonstrated in a variety of unstable formations (both sedimentary and crystalline rock) to produce excellent core recovery and to provide good hole stability, thus allowing significant drilling depths to be reached. The constant speed characteristic of the new high-speed top drive is expected to further enhance core recovery rates.

As mentioned above, in addition to offering good core recovery and hole stability in fractured basalt, the DCS has application in other types of formations. In alternating layers of chalk and chert, the high-speed diamond core bits, small hole size and light bit weights minimize core jams resulting in recovering core samples that are normally lost when coring with large-diameter core bits. Several coring operations have also been conducted in atolls from barges and small work boats working in shallow water where

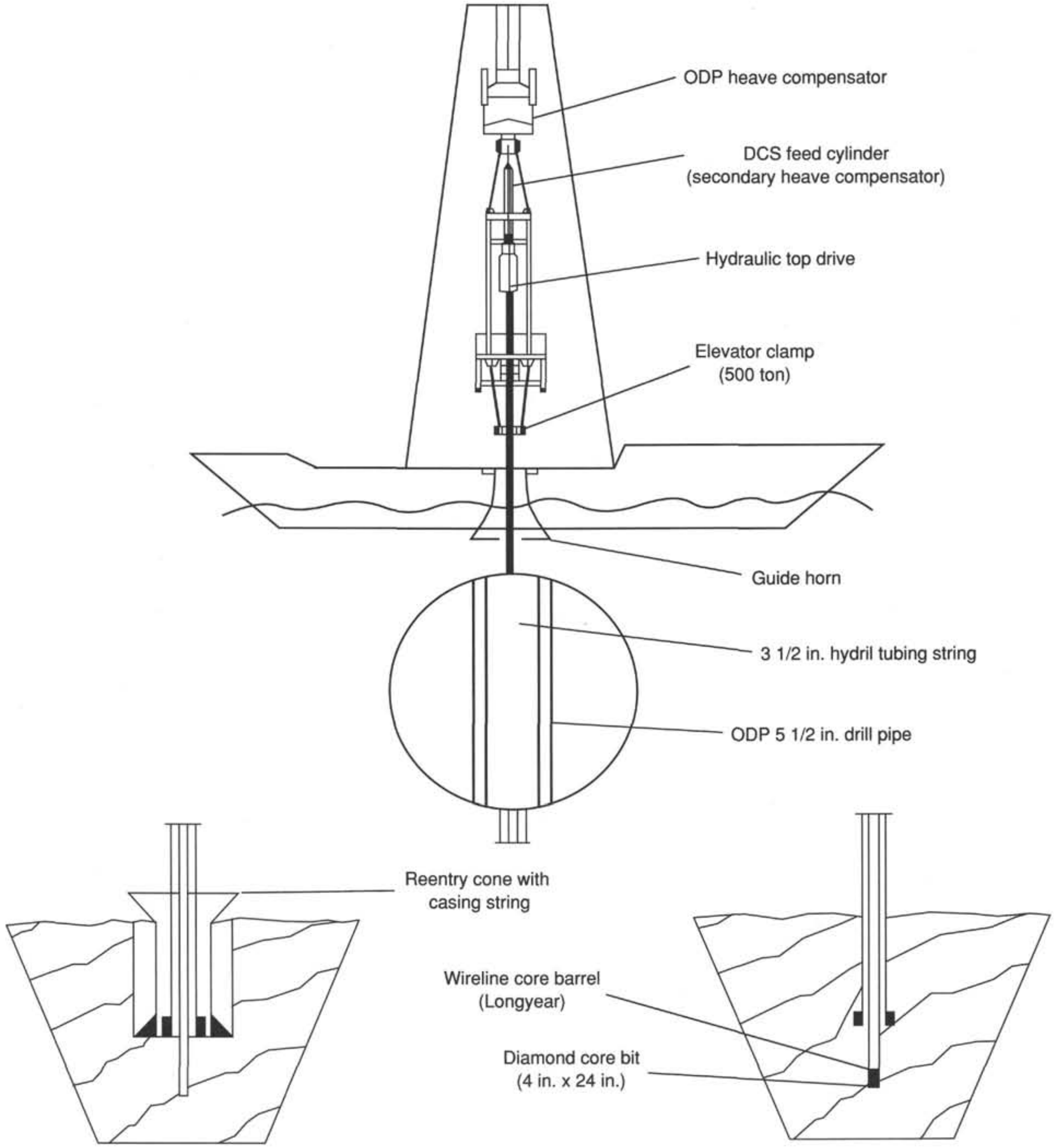


Figure 1. DCS top drive concept, showing reentry cone and coring arrangements.

the use of slimhole diamond coring techniques have yielded high core recovery rates in unconsolidated reefal limestone formations.

Longer range drilling objectives include extensive coring operations in the vicinity of and possibly through a network of seafloor vents and drilling/coring to the top of an active shallow magma chamber on the East Pacific Rise. That latter drilling objective will require the adaptation of geothermal well control equipment both at the surface and on the seafloor. The existing configuration of the 3-1/2 in. tubing run inside the ODP 5 in. and 5-1/2 in. drill pipe lends itself to the development of a mini-riser drilling system. The degree to which the DCS system may be used to accomplish these goals was further tested during the course of extensive sea trials on Leg 132.

DCS EQUIPMENT DEVELOPMENT

Electric Top Drive System

Because the Phase I top drive and heave compensation systems were both hydraulic, the available hydraulic horsepower had to be shared between the two. It was recognized early on that extending the drilling capabilities would require either more hydraulic power or a completely different top drive. That led to the choice of an electric top drive, thus freeing all available hydrau-

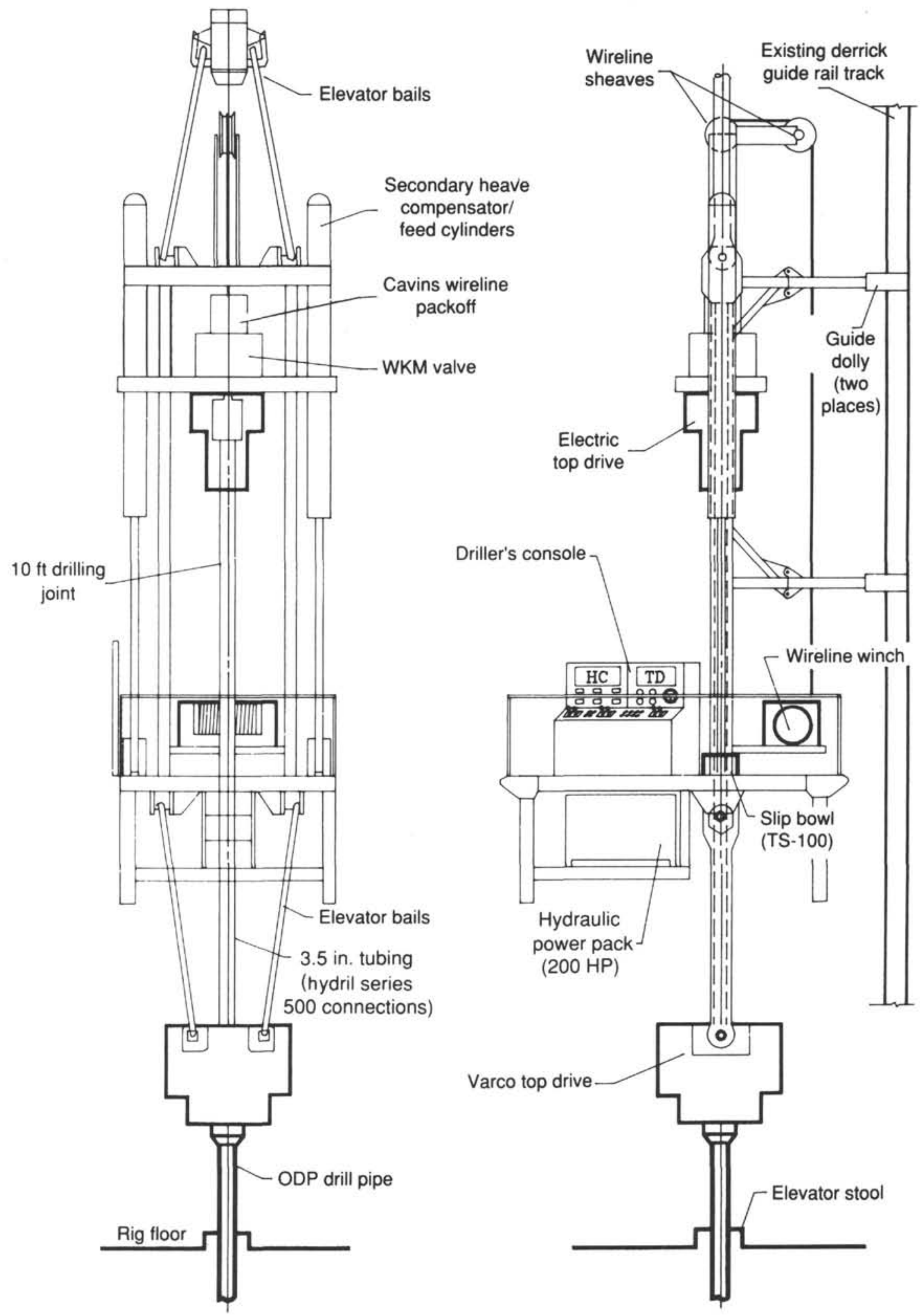


Figure 2. DCS platform configuration (Phase II, 4500 m depth capacity).

lics for the task of heave compensation. There are numerous electric top drives in use in the oil industry, of course, and, in fact, at least one well-known drilling contractor has designed and built several top drives for mining-type applications. ODP chose the same contractor to design and build the Phase II top drive drilling system.

The present top drive is not unlike existing oilfield units, with the exception of the gear ratio (Fig. 3). It is powered by an 800 HP DC traction motor, and is equipped with a gearbox and a swivel. The gearbox ratio is 1.5:1, resulting in a maximum rated torque of 8,000 ft-lb at a shaft speed of 520 rpm, as high rotation speed is necessary for efficient use of diamond coring bits. Those ratings exceed the anticipated requirements for successful coring with the present system, yet leave ample room for future growth. The top drive is API rated to 650 tons, again in excess of the present load rating of the heave compensation system. Special design seals for the swivel wash pipe assembly allow high-speed rotation while maintaining satisfactory lubrication and pressure integrity.

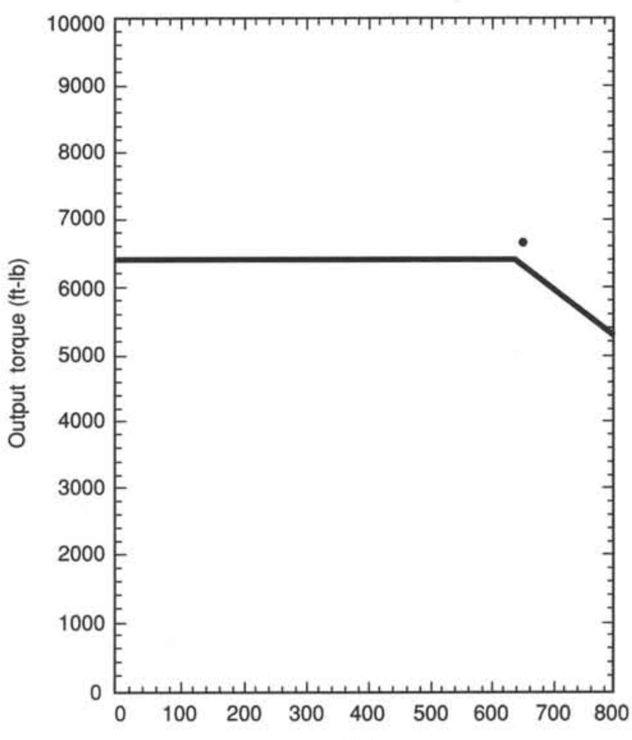
Top Drive SCR Controls and Modifications to Ship's SCR Equipment

Special controls were developed for the top drive (Fig. 4). Unique features have been incorporated to improve performance and efficiency. By utilizing a closed-loop feedback system to control the DC motor, the shaft speed is very accurately controlled, independently of torque. Torque limits can also be set for a variety of drilling conditions. Another unique feature allows one to make-up connections to a very precise torque, and also to break-out connections in a fully controlled automatic sequence without danger of overspeeding the motor. That is the first time those features have been included on an electric top drive. All controls are enclosed in a watertight panel located on the DCS platform.

By incorporating these controls into the design, the inherent advantages of hydraulic top drives has been maintained: (1) constant speed limited only by maximum desired torque, and (2) protection from too high torque and possible resulting twist-off of the tubing string. Use of a DC drilling motor further yields the advantage of large amounts of power in a small package.

To add those capabilities for the DCS, modifications and additions were required to the existing SCR controls circuitry and DC power system on the ship. Specifically, a newly designed throttle and summing amplifier printed circuit board was added to the present Baylor Co. control card racks in two of the SCR bays. The new board included circuitry necessary for closed-loop control of the motor. The primary control is effected by feedback from an optical encoder-type tachometer installed on the motor itself. The board also includes backup circuitry which allows operation in a "calculated speed" mode in the event of tachometer sensor loss, and voltage feedback mode is built-in as well. Substantial changes to existing power cabling were necessary to both preserve the present top drive capability while adding the DCS top drive. A large contactor/relay panel was installed at the base of the port-forward derrick leg, and the amount of derrick cabling was substantially increased. The contactor panel allows remote switchover from the main drilling unit to the DCS unit. New power and controls cabling was added from this point to the

Power swivel	
Height	101 in.
Width	33.5 in.
Depth	73 in.
Weight	12100 lb
Drilling/ coring	
Installed power	800 HP
Reduction ratio	1.5:1
Maximum torque	6400 lb at 640 rpm
Maximum speed	640 rpm
Air brake	12000 ft-lb at 75 psi
Make-up/brake-out	
Maximum amperes	1200
Maximum torque	9750 ft-lb
Spinning torque	8300 ft-lb
Tool joint sizes (two ranges)	6-3/4 in. to 5-1/2 in.
Loading capacities	
Loading rating	186 US tons
Drilling fluid passage	
Nominal pressure	210 bar/3000 psi
Tost pressure	420 bar/6000 psi
Inside diameter	3 in.
Connection	6 in. -3 ACME or 4 in. LP
Wash pipe	
Type	Dynamic seal
Nominal pressure	350 bar/3000 psi
Inside diameter	3 in.



Output characteristics series
wound DC motor reduction ratio: 1.5:1

Figure 3. Top drive (parallel shaft) technical characteristics.

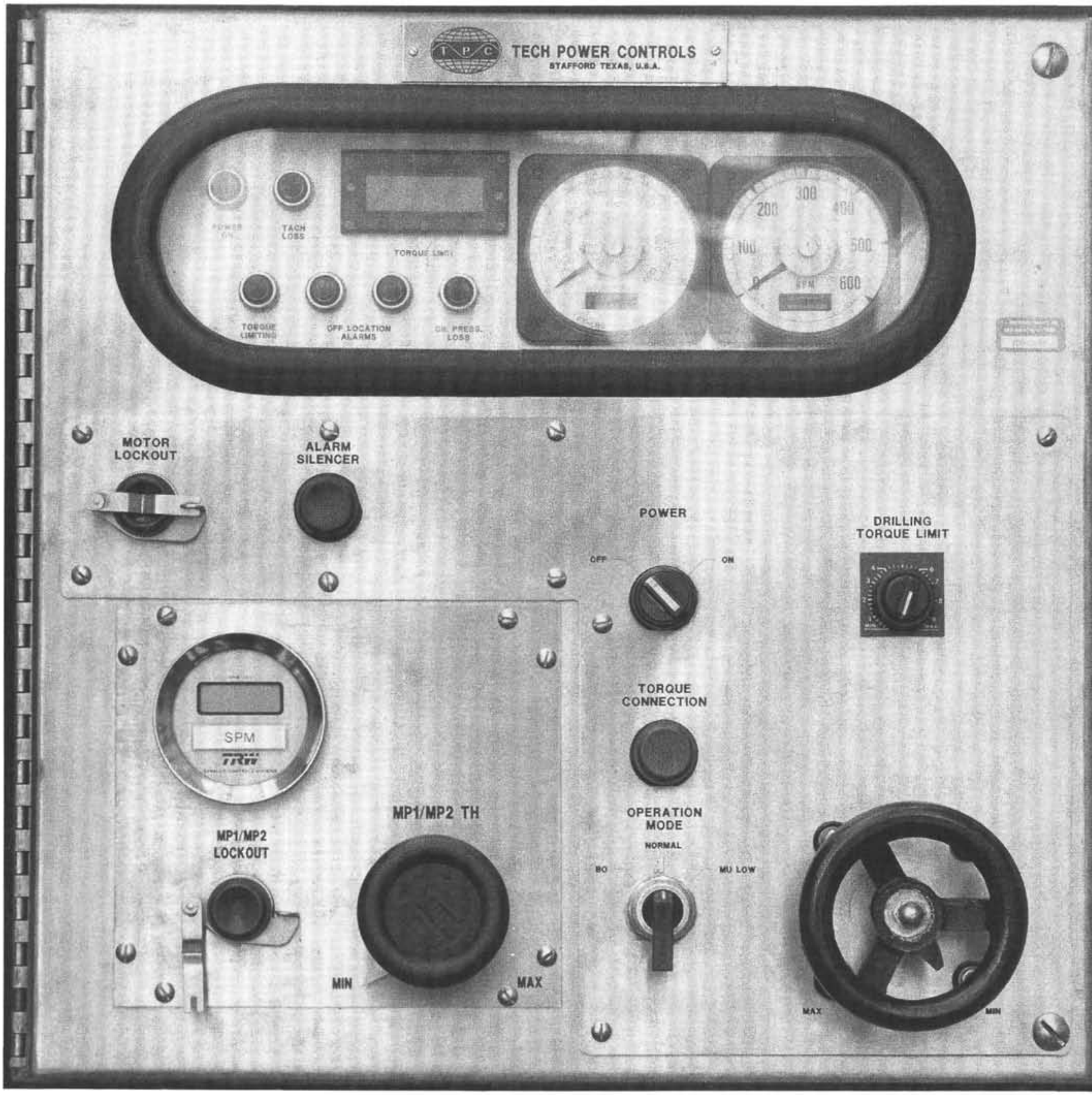


Figure 4. Top drive control panel configuration.

starboard-aft derrick leg, where the new DCS power umbilicals were added to convey power to the moving (heaving) DCS platform.

The top drive control panel on the DCS platform contains the standard switches and front-panel-mounted throttle for operating the top drive. Within the panel are two additional printed circuit boards: these are the (1) break-out board and (2) rotary unwind board. The break-out printed circuit board contains the logic circuit for control of the motor during tubing string connection break-out operations. Again, the digital tachom signal is used as the main control sensor. As the connection breaks out, the logic capability monitors angular rotation of the motor and when a preset amount of rotation has taken place, the logic circuit automatically reduces motor torque from the break-out value (typically 4500 ft-lb) to the spin-out value (1500 ft-lb). The circuitry thus prevents motor overspeeding when the connection is broken. The rotary unwind board is used to provide a warning to the driller when a preset torque limit is reached. The full capability of this latter board, while not used presently for DCS, also allows automatic controlled-rate unwinding of the drill string in the event the string torques up to the motor stalling point. This prevents a downhole connection back-off which could result from an uncontrolled torque release. That is effected by a slow, automatic reduction of the motor torque limit value, which then allows the string to unwind.

Mud Pumps and Controls

Flow rates required for slimhole diamond bit coring are much lower than those needed for rotary coring (10–70 gpm vs. 200–250 gpm). Existing mud pumps on the ship are Oilwell A1700-PT triplex units driven with two 800 HP DC motors each. Equipped with 6-1/2 in. liners, these pumps produce 5.2 gal per stroke (revolution). This means that for a 10 gpm flow rate, a single pump is required to rotate smoothly at 2 rpm—virtually impossible with standard motor controls. Two steps were taken to solve the pump rate problem. First, 4 in. liners were installed in one of the pumps to bring the flow rate down to 1.9 gal per pump stroke. To get good low speed operation, the same new design throttle and summing amplifier boards were added to the ship's SCR control card racks for the mud pumps. That allowed the pumps to be run at very slow, constant speeds since closed-loop speed feedback was used. The existing DC generator-type tachometer was effective in producing a useable speed signal for speed control.

Mud pump controls (throttle, on-off, and strokes-per-minute display) were incorporated into the top drive panel.

Secondary Heave Compensation

Secondary heave compensation is accomplished with a combination of passive static load support and active correction for load variation due to the heave motion. Passive load support is accomplished with accumulators plumbed to the piston side of the inverted feed cylinders (rod side down, piston side up, with the traveling equipment attached to the cylinder). The accumulator pressure is adjusted to support the static load of the tubing string and traveling equipment (top drive, dolly, swivel, etc.). The signal from an accelerometer on the working platform is integrated to produce a velocity signal which then drives an electro-hydraulic servo valve. A second control loop adds feedback from strain gauge load cells positioned underneath the rod side of the feed cylinders (Fig. 5). The accelerometer and load cell signals provide input to a platform-mounted computer that produces the appropriate servo commands.

The combination of passive/active compensation results in the rod side (only) being driven hydraulically and is referred to as three-way servo operation. Also incorporated in the design is the ability to operate in four-way mode, and in this case, both the rod and piston sides of the feed cylinders are actively driven by the computer. The three-way mode requires less average hydraulic horsepower, and this mode was added after experience gained during Phase I in an effort to further conserve hydraulic power while increasing load capacity. As mentioned above, the passive compensation capability is also very useful in the event of a computer failure or in cases when the environment is benign enough to preclude the need for active compensation.

The computer automates the drilling function by controlling the advancement of the feed cylinders to keep WOB constant, or if desired, the feed rate can be held constant while the WOB is allowed to vary within chosen limits. Other features include automatic, controlled approach to bottom, automatic touchdown and application of commanded WOB or feed rate, and automatic bit retraction upon completion of a coring sequence. The three basic modes of operation are "MANUAL" (no heave compensation or core bit advancement), "STANDBY" (heave compensation only), and "AUTO WOB/AUTO FEED RATE" (heave compensation plus automatic coring bit advancement) (Fig. 6).

Hydraulic Wireline Winch

All coring is accomplished using wireline core barrels. Therefore at the completion of each 10 ft coring sequence, a wireline must be inserted through the top of the tubing and lowered to retrieve the now full core barrel.

A large hydraulically powered winch located on the opposite side of the mast from the working area of the platform is used for this purpose. The wireline is routed upward through sheaves and down into the tubing string through the top of the swivel. The winch is equipped with a disc-type parking brake, and a hydraulically activated fail-safe brake which releases only upon powering the winch up or down. The wireline is presently 3/8 in., 7 × 19 construction with a breaking strength of 14,000 lb. Winch drum capacity is 18,000 ft. In addition, the drum is grooved, and a fleet angle compensator is mounted to compensate for the proximity of the turndown sheaves. Winch speeds of up to 600 ft per min can be achieved. An electronic wireline depthometer completes the system and allows very accurate accounting of depth of the wire and programmable depth flags.

During the time when the winch was integrated onto the DCS platform, long lead time precluded procurement of a proper pilot-operated valve. It was therefore necessary to install a winch control valve that was not well suited for operating the winch at very low speeds. Low-speed control is required when taking the sinker bar assembly and core barrels in or out of the tubing string on the DCS platform. Several different spools were installed in the winch control valve in a effort to improve the low-speed response. After initial testing on the ship, it became necessary to install a separate low-speed control circuit. A spare hydraulic control valve was plumbed into the auxiliary circuit to supply flow rates of 0–30 gpm to the winch. The low-flow-rate hydraulic circuit was plumbed into the hydraulic motor cross port relief valve system.

A hydraulic load cell mounted on the upper wireline sheave assembly coupled to a hydraulic gage in the DCS console provides a weight indicator for the wireline in the hole and indicates the amount of overpull induced by the winch when retrieving/unseating core barrels downhole. A magnetic sensor array installed on the upper wireline sheave assembly is coupled to a TOTCO electronic depthometer to monitor the length/depth of wireline that is in the hole when retrieving a core barrel.

A remotely actuated Cavins hydraulic wireline oil saver is located above the WKM (WKM Industries) ball valve assembly. The oil saver is used to seal off around the wireline to allow pumping the sinker bars down the 3-1/2 in. tubing and to prevent mud from being swabbed out of the tubing when retrieving the core barrels at high speeds with the wireline winch.

DCS Hydraulic Power System

The platform is equipped with a 200 HP hydraulic power pack, the primary purpose of which is to power the heave compensation system. As the platform is self-contained, the power unit requires only electric power for operation.

A full set of manual controls is provided on the main hydraulic control console for both main and auxiliary functions. The controls allow manual drilling in the event of failure of computer controls. That is effected with adjustable flow control valves that bleed the rod and piston sides of the cylinders. Feed cylinder position and the coring winch (described above) are controlled with joystick controls. Auxiliaries such as tuggers and tubing tongs also are functioned from the hydraulic console. Maximum use of electrohydraulic valves resulted in a comparatively compact arrangement of controls, given the number of functions

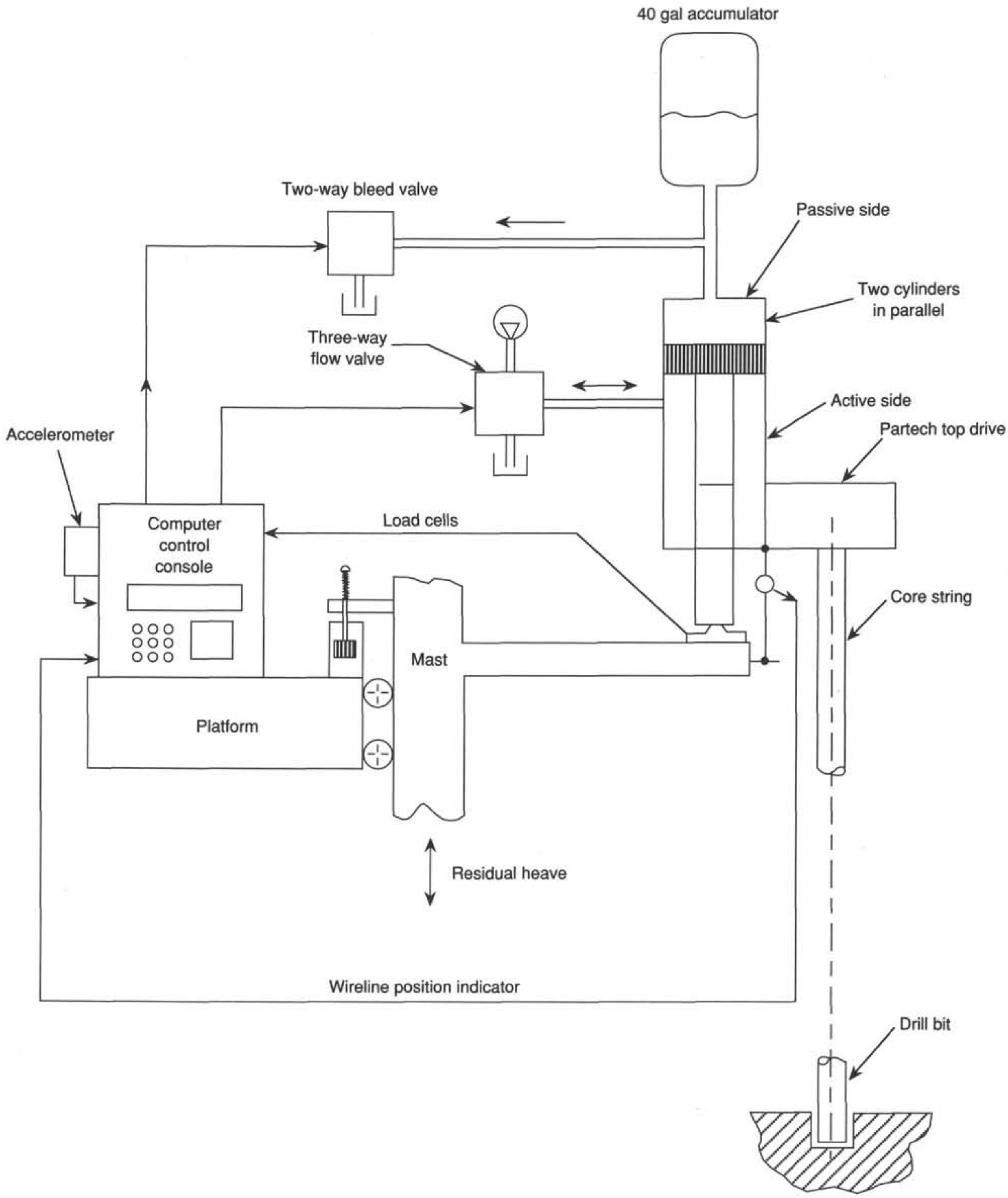


Figure 5. DCS basic controller physical arrangement showing only components active in automatic mode.

required. Main operating pressure is approximately 3500 psi, and the pump design is a variable displacement swash-plate type. A 400 gal oil reservoir provides ample system volume.

DCS Auxiliary Equipment

Auxiliary equipment on the DCS platform includes a pair of hydraulically actuated tong arms, two tuggers, a WKM ball valve with a remotely operated valve actuator, a Cavins wireline oil saver, and a hydraulic assist for the lower wireline sheave.

The primary purpose of the pair of hydraulically actuated KELCO full grip 3-1/2 in. tubing tongs is to serve as a back-up when making and breaking the 10 ft. drilling joints with the top drive. The tongs may also be used independently of the top drive for making and breaking connections as specific situations may

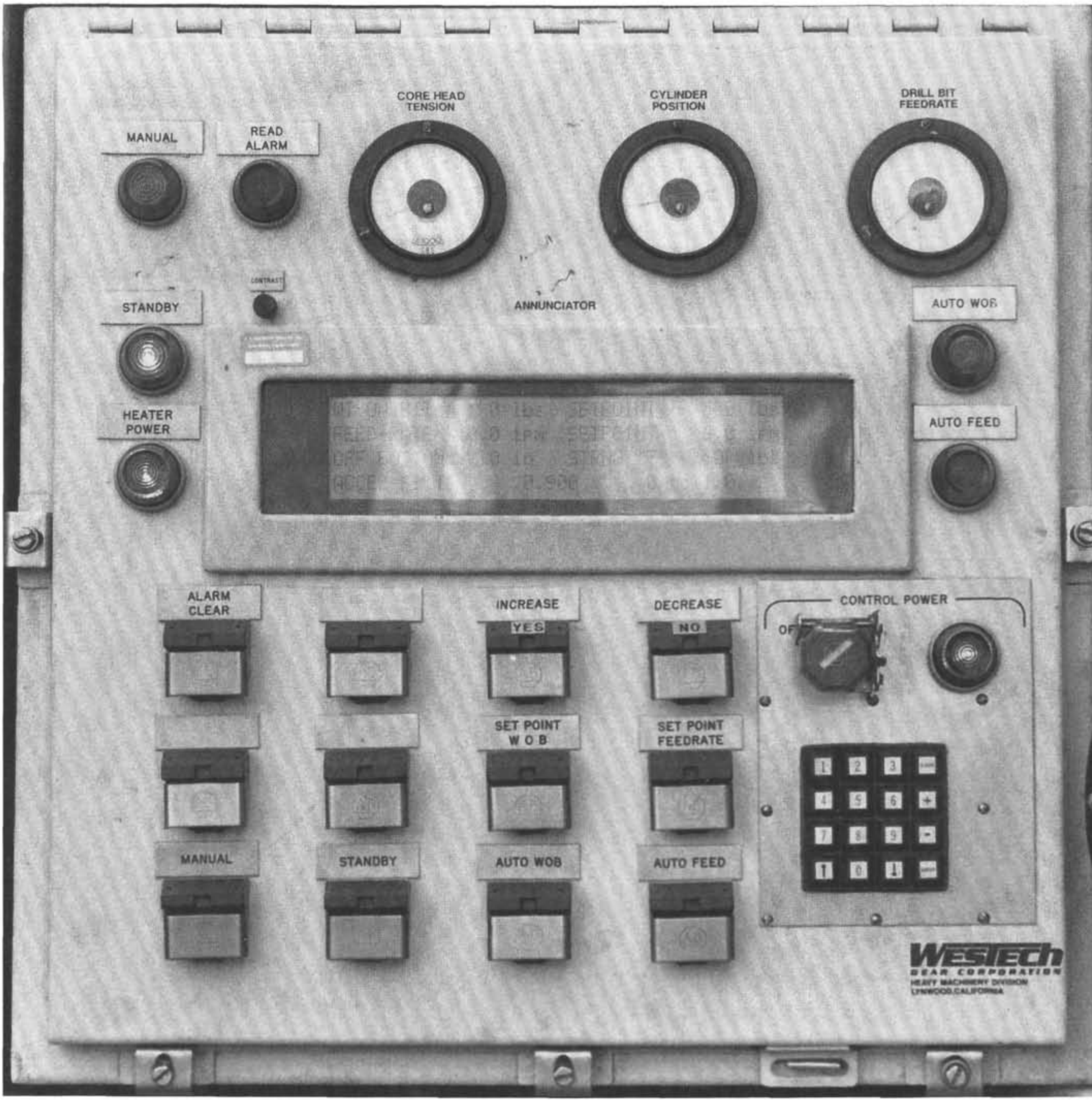


Figure 6. DCS control panel configuration.

dictate. The tongs are also used for making and breaking the lower connection of the top drive splined sub when it is necessary to replace the lower splined sub telescoping shaft. The tongs can be adjusted to apply up to 8000 ft-lb of make-up and break-out torque.

The two tuggers are used for handling core barrels both on the DCS platform as well as lowering core barrels and other related equipment to and from the main rig floor 45 ft beneath the DCS platform. The tuggers are also used for handling the 10 ft drilling joints between the drilling joint storage basket and the top drive when tripping and coring ahead. The tuggers are hydraulically powered, and the controls are located on the starboard side of the drillers console. The tuggers are rated for 1000 lb maximum hoisting capacity.

The WKM valve is located above the swivel on the top drive. The WKM valve seals off the upper end of the string when drilling fluid is circulated downhole. During wireline operations, the WKM valve is opened with a remotely controlled valve actuator. The valve has a 4-1/6 in. through-bore to allow wireline tools to pass down through the top drive. The sinker bar assembly is stored above the top drive in the DCS mast upper wireline sheave tube assembly. The sinker bar assembly is lowered down through the

WKM valve, through the top drive, and into the 3-1/2 in. tubing string suspended on the DCS platform, when retrieving a core barrel from downhole.

A hydraulic assist for the lower wireline sheave is attached to the wireline winch fleet angle compensator arm. The fleet angle compensator becomes ineffective for properly spooling the wireline onto the winch drum when there is approximately 2000 ft or less wireline left in the hole. The hydraulic assist was installed to guide the sheave to maintain proper spooling when pulling the last 2000 ft of wireline from the hole.

All of the equipment described above is controlled by the driller from the hydraulic portion of the control console. The controls for each piece of auxiliary equipment have been positioned on the console for easy access with consideration given to the activities the driller may be conducting when operating each specific piece of equipment.

Standpipe/Drilling Fluid System

Mud is conveyed to the platform through a 2 in. high-pressure hose normally used for cementing on board. The configuration of the mud pump standpipe manifold on the drill floor allows one to cross-connect the mud standpipe to the cementing standpipe installed in the starboard-aft corner of the derrick. The 2 in. hose terminates at an interface manifold on the platform equipped with a 2 in. high-pressure ball valve. Thence the mud enters another hose that is part of the so-called mini-umbilical, a collection of electrical cables and hoses that services the moving (heaving) top drive crosshead or dolly in the DCS mast. The mud then enters the tubing through the drilling swivel. At the platform, a standpipe gauge monitors surface mud pressure. The gauge is a compound type and provides the resolution necessary to allow accurate monitoring of small pressure changes. That is necessary because subtle mud pressure changes are an indicator of events taking place downhole, and it is important to monitor these changes in order to discern when, for example, a core block occurs. In that case, once a block occurs, a pressure increase takes place, and any further coring attempts are futile because core can no longer enter the core barrel. The core barrel must then be retrieved and an empty core barrel must be dropped to continue coring. Mud flow rate is monitored with the pump-stroke counter mentioned above.

3-1/2 In. Hydril Tubing String Design and Specifications

A significant amount of effort was put into the selection of a work string to rotate the diamond core bits. Prior to Leg 124E, numerous mining drill strings were studied and tested along with the 3-1/2 in. Hydril tubing. Design requirements for the DCS string included adequate torsional strength of the connection and tube body to withstand the expected drilling torque (500–8000 ft-lb) and high rotational speeds (200–540 rpm), adequate bending strength to withstand the fatigue loading the DCS work string is subjected to as it passes through the moonpool of the ship, adequate strength and rigidity to allow racking the pipe in 90 ft stands in the derrick, and a pipe upset geometry that would allow the pipe to be handled with oil industry type elevators and rig tongs. Prior to Leg 124E, numerous mining work strings and the 3-1/2 in. Hydril tubing were subjected to a rotational fatigue test. The test modeled the bending stress induced into the top of the DCS string by ship roll as well as the torsion and rotational speeds expected. The DCS strings under consideration were rotated at 500 rpm inside 5 in. drill pipe. A 60 ft string comprised of two to six joints, depending on the length of each joint, was bent cyclically from 0 to a 350 ft radius on 6 s periods, to model ship-induced bending of the pipe in the drill ship guide horn. All of the mining type drilling joints tested failed at between 100,000 and 200,000 rotating cycles. By contrast the Hydril tubing joints tested were rotated for 2 million cycles without failure. The initial string design length for phase I of the DCS Project was 2000 m.

Based on the tests, a string of 3-1/2 in., grade N80 (9.3 lb/ft) tubing, with series 500 type 501 connections was purchased from Hydril. The tubing connection has very good torsional and bending strength due to an interlocking "wedge" thread connection design. The pipe has a 2.992 in. I.D. with a 2.942 in. swaged-down area in the inside diameter of the pin connection. The tubing will pass a 12 ft long drift bar 2.875 in. in diameter. In addition to utilizing 30 ft range 2 tubing for the principal DCS string, tripped conventionally in 90 ft stands, 10 ft drilling joints are used to trip and core ahead from the DCS platform. The 10 ft drilling joints were manufactured to the same specifications as the 30 ft tubing joint.

For the DCS Phase II system, the upper portion of the string was manufactured from grade 130 ksi yield material. To provide additional strength (wall thickness) to the connection, the connections were cut on Hydril "CS" upsets with the basic connection geometry being the same as the N80 grade pipe. To provide a wear indicator and also prevent excessive over-torquing downhole, the pin connections were provided with a new shoulder design that stands off 0.100 in. from the box connection shoulder when the tubing is made up. As the connection wears, the stand-off gap closes, indicating the degree the threads have worn during repeated make-up and break-out cycles associated with tripping the string in and out of the hole. Also, in the event the string is over-torqued downhole, the shoulders on the box and pin make contact and prevent further make-up downhole and possible connection failure. The shoulders on the outside of the connection are designed to contact before the nose of the pin connection reaches the bottom of the box connection. Several other vendors submitted designs for consideration, but the Hydril connection was the most desirable from both design and economic viewpoints. The manufacturing and heat-treating processes were monitored carefully at the tubing mill by ODP representatives. Both 30 ft range 2 and 10 ft tubing joints were manufactured for use on Leg 132.

DCS Safety Study and Results

Numerous safety studies were conducted to ensure the safety of the personnel and equipment suspended in the derrick. The studies revealed that in the unlikely event that the main 5 in. and 5-1/2 in. drill strings were to break, the DCS mast and platform would be subjected to 5 g accelerations and decelerations. The accelerations and decelerations would be caused by the primary 400 ton heave compensator closing instantaneously when the drill string weight is lost, the event occurring in 1/16 of a second. To isolate personnel on the platform from the high forces, the platform is attached to the mast with four hydraulic cylinders, called shock cylinders. During the acceleration phase of the drill string loss event, a relief valve opens at approximately 1.5 g acceleration. The shock cylinders then extend, reducing the peak acceleration of the platform and personnel to between 1 and 2 g. As the main heave compensator comes abruptly to a stop, the platform (along with personnel on the platform) decelerates at 1 g. As the platform travels upward during the deceleration phase and comes to rest, the check valves in the shock cylinder system lock the platform back into place. Drop tests were conducted prior to Leg 124E to confirm that the relief and check valve plumbing for the shock cylinders functioned properly. The results of the safety studies and tests were jointly reviewed by SEDCO/FOREX, DRECO, and Westech. Robert Sexton, an outside engineering consultant, also reviewed the studies.

All personnel on the platform are required to wear safety harnesses, and a detailed safety program with regard to platform abandonment and fire procedures was written and reviewed with all members of the crew.

Derrick/Racking Board Modifications

It was necessary to modify the racking board finger system in the derrick to provide the capability of racking 4500 m of 3-1/2 in. tubing in the derrick. New sets of fingers spaced for 3-1/2 in. tubing were fabricated to replace the existing fingers at the 90 ft derrick level. The existing fingers at the 90 ft level are set up for the 5 and 5-1/2 in. drill pipe strings. The new racking board is designed to be interchangeable with the existing drill pipe racking board. By installing a set of fingers properly spaced for the smaller 3-1/2 in. diameter tubing string, more rows of tubing could be racked in the limited set-back area on the rig floor.

The new tubing racking boards were designed to provide capacity to rack 104 stands (approx 3000 m). Additional fingers were added to the existing intermediate tubing racking board to increase its capacity from 2000 to 3000 m of tubing. An aft racking board, to be located in the drill collar set-back area in the derrick, was also built and has capacity for 56 stands of tubing (approx 1500 m), thus providing a combined capacity with the forward racking board of 4500 m. Due to the configuration of the derrick, it was not possible to provide an intermediate racking board below the new aft tubing racking board. All new tubing racking boards were fitted with interlocking bar latches for each stand of tubing, similar to the existing latches on the drill pipe racking fingers.

DCS Wireline Core Barrel System

As mentioned above, all coring is accomplished with a wireline retrievable core barrel/inner tube system. The core barrels used are slightly modified, proven models used successfully throughout both the oil and gas and the mining industries. Modifications include a greater cross section through the inner barrel, stronger inner barrel threads, and improved stabilization of the outer barrel. The core barrel inner tubes are pumped down the 3-1/2 in. tubing string and landed in an outer core barrel which is attached to the bottom of the 3-1/2 in. tubing string. See "Diamond Coring System Modified Core Barrel Assembly" chapter (this volume) for a detailed description of the core barrel system.

One other significant addition is the provision for a butyrate liner installed within the inner barrel. The core liner acts as the handling and curation vehicle for all core samples. In place of the plastic liner, split stainless steel liners can also be used if desired. An extended reaming shell/stabilizer with diamond and tungsten carbide pads, used as part of the outer barrel, greatly improves outer barrel life in abrasive hard rock formations. The barrel design was developed specifically for ODP needs.

Subsea Hardware

In addition to the surface hardware described above, it is necessary to provide a Mini Hard Rock Guide Base, modified reentry cone, and limited amount of drill-in bottom hole assembly (BHA) hung off in the reentry cone hanger assembly. The guide base acts as a platform for releasing/latching in the drill-in BHA that is used as conductor pipe. The seafloor hardware incorporates a mechanical latching device that allows the ODP drill pipe to be attached to the reentry cone/guide base and allows it to be in tension while drilling with the diamond coring system out in open hole (Fig. 7). Due to the nature of highly fractured basalt, it is necessary to drill the conductor pipe into the ground rather than running it in a more conventional manner. In the past, in has been observed that at the end of a bit run in fractured basalt, the hole caves in when the drilling assembly is removed from the hole. The drill-in BHA, when once drilled to depth, is latched in the cone hanger assembly and left in the hole minimizing the possibility of the hole caving in. In regions where there is adequate sediment cover, a more conventional reentry cone may be washed in and

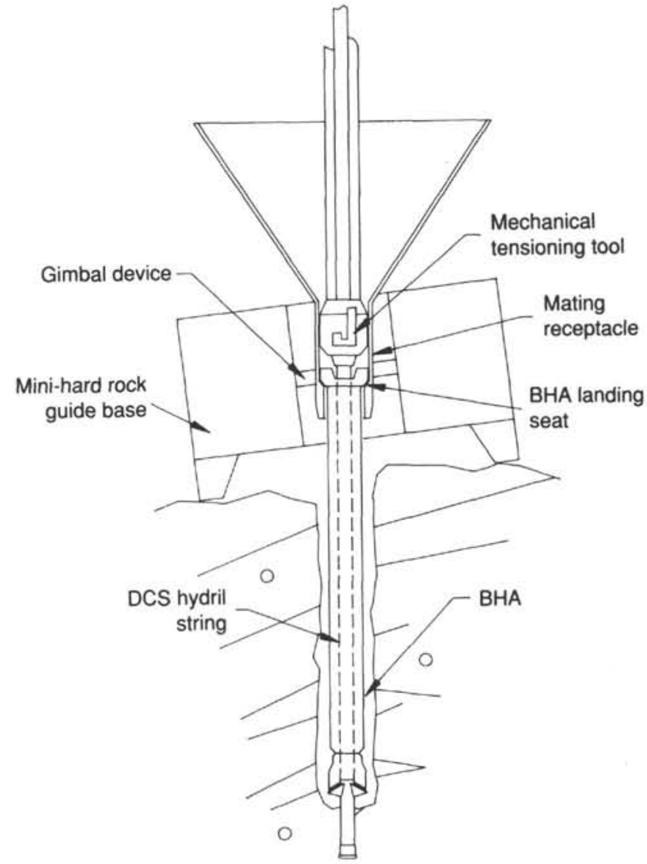


Figure 7. Weighted mini-guide base for bare rock operations using backed-off BHA for upper hole stabilization.

placed in tension, using the drill-in BHA inside the large diameter casing. This supports the slimhole tubing string to the point where the diamond coring system drills out ahead in open formation. See "Diamond Coring System Seafloor Component Hardware" chapter (this volume) for a detailed description of the subsea hardware systems.

INITIAL DCS ASSEMBLY AND TESTING DURING THE PUSAN PORT CALL

During the port call, many of the DCS electrical and mechanical components were assembled and function-tested. The DCS mast/platform assembly was fit-tested in the derrick. The DCS handling dolly was skidded back and forth across the rig floor with the DCS mast/platform in place. The DCS hydraulic equipment was function-tested and the secondary heave compensator was tested using the built-in test cylinders on the mast to induce artificial heave motion into the primary feed cylinders and top drive assembly.

DCS Mast/Platform Hardware

Upon arrival of the DCS mast dockside, work was begun immediately on repairs of the DCS feed cylinder lower gland seal nuts. After initial field testing at the KREMCO fabrication facility in Clearfield, Utah, both feed cylinders were observed to be leaking hydraulic oil from the lower gland seal nuts. An attempt was made during the DCS rig down, in preparation for shipment from the KREMCO yard, to remove the nuts with no success. The nuts would rotate three to four turns, then bind up. Due to the short time available it was necessary to repair the nuts and install new seals during the port call.

Using a slitting saw the gland seal nuts were grooved on two sides 180° apart. To prevent damaging the threads on the feed cylinder rods, the grooves were not cut completely through the nuts. With considerable difficulty, the nuts were backed off using a 36 in. pipe wrench and a hammer to effect jarring blows to the nut body while inducing torque into the nuts. The front three to four threads on the feed cylinders were found to have major galling damage. The cause of the galling was the absence of thread reliefs in the back of the gland seal nuts. The new nuts had properly machined thread relief grooves. Two 12 hr shifts (two DRECO personnel and two ODP personnel) were required to complete the repair job on the cylinders. The seal glands were removed by pumping them out of the cylinder cavity with a portable hydraulic pump. The aft seal gland body and cylinder wall were found to be scored. The damage was done during assembly of the cylinders at the factory. The forward inner seal was also found to have been damaged during assembly. New seal kits were installed in both of the seal gland assemblies. A tremendous amount of time and effort was required to hand grind the galled threads on the cylinder rods. Consideration will be given to reworking/replacing the feed cylinders at the end of the leg. Upon completing repairs to the DCS feed cylinders, assembly of the system on the rig floor was begun.

The DCS handling dolly tracks were installed on the rig floor. Due to part of the track assembly being new, it was necessary to make modifications to the aft starboard track to clear a support beam for the roof located on the starboard side of the rig floor. Shims (tapered and straight) were cut from 2 in. plate to shim between the tracks and the rig floor. The flat shims were placed on approximately 3 ft centers, and the tapered shims were placed on 2 ft centers. Eight hours was required to initially install the DCS handling dolly tracks. Upon completing the track installation, the DCS platform dolly was assembled and installed on the tracks which required 2 hr. Several of the dolly track wheels were found to be frozen due to corrosion. One wheel was freed but one remained frozen. Due to the considerable amount of time required to free the wheels, it was decided to go ahead and install the mast and platform on the rig floor and free the wheels as necessary while underway to the first site.

The platform was installed on the guide dolly without incident. The mast was slung and moved into place on the rig floor. Difficulty was encountered attaching the slings to the mast. The decision was made at DRECO to attach the slings to the link pins. A four-part sling was attached, with two sling arms pinned in to the top of the mast. The sling arms were attached to the bottom of the mast by placing a two-part shackle arrangement inside the mast box structure and allowing one of the shackles to protrude through the pin holes in the side of the mast beam pin hole. The sling legs were then attached to the protruding shackles. Two additional 20 ft slings were attached to the top mast link pins for transferring the weight of the mast from the number one crane to the rig elevator bails.

To make the future attachment of the sling assembly less difficult, some type of lift bracket assembly could be devised and pinned into the lower mast box assembly. That would eliminate the somewhat cumbersome shackle arrangement used. Due to the increased weight of the top drive assembly, the use of weld-on pad eyes was deemed inappropriate from a safety standpoint. Also, it was no longer possible to weld pad eyes onto the mast beams because of an interference problem with the axial travel of the cross member up and down the mast.

The mast lift sequence was first to use the number one crane to lift the mast horizontally to the rig floor, using the four-part sling arrangement described above. Then the two loose 20 ft slings were attached to the 500 ton elevator links, and the mast was slowly handled from horizontal to vertical using the draw works. The platform was then rolled into place on well center and the mast was stabbed into the platform guide roller assembly without any difficulty. Four hours was required to assemble the mast and platform on the rig floor.

The DCS guide dollies were attached to the DCS mast and test-fit in the derrick guide track. It was discovered that the guide dolly arm counterweight contacted the side of the mast strong-back preventing the dolly roller assembly from clearing the track. The counterbalance weights were trimmed to provide the appropriate clearance. The rollers were attached in the track and the mast was raised up and down in the derrick to check for proper operation. No interference problems were found. Lifting pad eyes were welded onto each guide dolly assembly to facilitate installation of the assemblies in the derrick. Some difficulty was encountered getting the guide dolly roller assemblies into the derrick guide tracks. That may have been caused by the platform handling dolly tracks being slightly off the axis of well center and the mast not being aligned vertically in the derrick. The mast was rolled far enough port to allow the upper mast roller assemblies to be pinned into the derrick tracks. The platform was then rolled slightly starboard and the lower mast rollers were installed. Eight hours was required to initially fit up and modify the guide dollies in the derrick with the DCS mast. With additional handling experience by the rig crew the operation will become more efficient.

The DCS platform/mast assembly was skidded back and forth on the dolly tracks with ease. The one port-aft handling dolly wheel that was frozen did not appear to hamper the movement of the dolly. Therefore no further effort to free the dolly wheel was made. The dolly track was greased to enhance movement of the dolly wheels on the tracks.

The wireline winch and lebus fleet angle compensator were installed on the DCS mast strong-back. No problems were encountered with the installation, which took a total of 4 hr. The winch was lifted onto the mast strong-back using two soft slings wrapped around the winch drum. The soft slings were attached to two wire rope slings that were in turn attached to the 500 ton links.

DCS Electrical System and Controls

Both the control panels (top drive and heave compensator) were unpacked and checked in preparation for installation. An air-purge system was installed on the heave compensator panel that, along with the space heater already mounted in the box, would effectively eliminate any chance of moisture within the panel. Once this was done, both panels were installed in and bolted to the steel frame that mounts to the main hydraulic console. The entire assembly was then lifted and bolted in place. Sensor and control cables were connected and preliminary checks performed.

The new throttle and summing amplifier boards were installed in the two SCR bays for the top drive. Checks of all the previously installed control and power wiring revealed only one minor mistake which was quickly corrected.

The data acquisition system (DAS) cable for monitoring heave compensator computer data, which had previously been run to the downhole measurements laboratory, was terminated and checked. This cable was later used to monitor the computer during function testing of the system. In the downhole measurements laboratory, a computer was connected to log and analyze data for troubleshooting and to help make measurements concerning the effectiveness of heave compensation under actual field conditions. Although the system had been significantly tested and further software development had taken place during the test drilling phase in Utah, it was known that significant changes would still be required once the system was installed on the ship.

DCS Hydraulic Systems

Two DRECO service representatives connected the hydraulic umbilical between the mast and platform in a 6 hr period without incident. Upon completion of installation of the hydraulic hoses, all primary and ancillary hydraulic equipment was tested. All systems (feed cylinders, wireline winch, hydraulically actuated tongs, secondary test cylinders, and winch spooling assist) functioned properly. The main feed cylinder and test cylinder system were carefully bled to remove all air from the system. The newly installed feed cylinder gland nuts did not appear to be leaking at this time. However, it should be noted that later in the leg, while drilling at the first site, both seal glands seeped hydraulic fluid at a noticeable rate.

All of the primary and secondary hydraulic controls (tripping, feed cylinders, tongs, WKM valve, spooling device, etc.) on the driller's console were tested and found to be in good working order. The control console was designed to hinge down and lie on the platform, to protect the controls and gauges from damage during shipment. No damage to the console was incurred either during the shipment or assembly of the DCS on the rig floor.

Installation of Tubing Racking Board in Derrick

Thirty six hours was required to install the forward and aft racking boards for the tubing in the derrick. No major difficulties were encountered with the installations. Safety chains were welded to all of the hinged fingers at both the 90 ft and the 45 ft levels in the derrick. The 90 ft tubing racking board was designed to pin into the existing pad eyes that supported the drill pipe racking boards. Tugger lines repeatedly became tangled in both the forward and aft racking board fingers. Hinge-down line guards were welded on the 90 ft racking board finger sections to alleviate this problem.

A total of 89 stands of tubing were made up and stood back in the derrick. There were six rows each with 13 stands per row and one row with 11 stands. The operating depths for Leg 132 did not necessitate utilizing the aft racking board. It should be noted that when the aft racking board is used, additional handling effort will be required because of the proximity of the tubing to the drill collar set-back area. To diminish that handling problem, only the minimum number of drill collars required for drilling operations should be racked in the derrick.

Testing of DCS Heave Compensator System in Port

Test cylinders within the main feed cylinders on the platform allow artificial heave (a sine wave signal drives a test servo) to be induced for testing. That was done repeatedly during the port call once the DCS was assembled in the storage location on the drill floor. Of particular interest was testing the system in drilling mode since the Utah tests had been cut short in order to ship the system to Pusan. The system appeared to function normally in that it compensated against the artificial heave.

Modifications and Testing of DCS Platform Shock Cylinder System and Additional Safeguards Added to Platform/Mast

Upon completion of the initial assembly of the DCS on the rig floor, the shock cylinder reservoirs were filled with fluid. With the DCS picked up high enough for the platform legs to clear the handling dolly, the shock cylinders were allowed to stroke out completely. The cracking pressure on the relief valves (four each) was slowly raised until the shock cylinders would support the entire weight of the platform with all ancillary equipment (drill rod basket, heavy tools, etc.) installed on the platform. The required pressure for the shock cylinders to support the platform was determined to be 1750 psi. The shock cylinders were noted as traveling 17-3/4 in. prior to the platform contacting the stops bolted to the bottom of the mast. The upper set pressure as specified by Dr. Chuck McKinnon (Westech Representative and leg participant) was set at 2700 psi.

To provide additional safeguards, a second set of platform stops was added between the platform and mast. The design of the secondary stops was submitted to DRECO in Houston for approval prior to installation. In addition to the secondary stops the forward link pin was installed with the pin protruding to the outside of the mast to provide an additional contact surface between the platform and mast. Because the mast was offset to the aft of the center line of the platform, it was not possible to use the aft link pin for additional contact surface.

DCS MODIFICATIONS, ADDITIONS, AND TESTING WHILE UNDERWAY AND PRIOR TO DEPLOYMENT AT THE FIRST DRILL SITE

While underway and prior to deployment of the DCS at ENG-5, the first scheduled drill site for the diamond coring system, a considerable amount of both electrical and mechanical work was performed. All of the auxiliary DCS drilling equipment was installed including the hydraulic rig tongs, pipe handling sling assembly for 10 ft drill joints, rotary plug, and slip bowl. The pipe basket was loaded with 10 ft drilling joints. The safety harnesses were installed with tension-reel safety lines. The kelly hose and standpipe were installed on the DCS platform. Handling pad eyes were welded on the upper wireline sheave assembly arm to aid in telescoping the assembly up and down when standing the platform back in the derrick. The Cavins oil saver was installed on top of the swivel. Flooring was installed on the platform over the existing grating consisting of 1/8 in. steel plate underlying a 1/4 in. thick rubber mat and a top layer of cocoa matting. The DCS core barrel shucks were modified for handling the 10 ft core barrels.

Electrical tasks consisted of function-testing the top drive and controls. When the system was first energized, rotation was incorrect (the shaft turned in reverse when it should have turned in the forward direction). Also, it was found that the motor quickly accelerated at an uncontrolled rate of speed, and came close to overspeeding several times. The motor direction problem was due to the fact that the SCR system on the ship was configured to effect rotation reversal by changing polarity of the motor armature, not the field circuit as has been previously assumed (all motors on board are configured as series motors). The solution was to swap field and armature leads on the platform. It was necessary to correct the problem that way owing to the fact that the motor current measuring device on the platform was installed within the armature circuit. That meant that if the cables had been left connected as they were, measurement of the motor current would have been possible in only one direction. Because torque is proportional to motor current, it thus would have been impossible to measure torque in one direction—inconvenient when one is trying to break-out or make-up connections within accurate torque limits. The overspeeding was corrected by changing the throttle and summing amplifier board; the same board that was removed was later used in another SCR card rack and, after adjustment, worked satisfactorily.

Once the above two problems were solved, the motor was observed to be operating erratically. It tended to run roughly, and a clunking noise indicated that the motor was being driven with bursts of voltage at a rate of approximately 1 Hz. Examination of the control voltage emanating from the board revealed a square-wave response, as opposed to a smooth DC control voltage. After many hours of investigative work, it was determined that the feedback/control section of the board was oscillating at high frequency. SEDCO/FOREX personnel were able to remedy the oscillations by judicious placement of a few capacitors on the board. Also, a zener diode and a resistor were used to limit the control voltage swing so as not to drive the SCR bridge quite so hard. All of that resulted in satisfactory operation and smooth motor response to both throttle and current limit signals. Once running smoothly, adjustments of the various current limits were completed within the control panel. Make-up torque for the 3-1/2 in. tubing connections was set at 2500–3000 ft-lb, and break-out to 4500 ft-lb, after calibration of the current measuring transducer on the platform. A complete running sequence was successfully performed with tests of make-up, break-out, and high rpm operations. All this troubleshooting took several days as operation of the DCS top drive was subject to availability of the top drive SCR bay. Since the main Varco top drive uses the same bay(s), no work could be done while drilling operations were in progress.

The electronic depthometer was installed in the console and quickly found to be inoperative. A substantial amount of water was found inside the enclosure although the unit was supposed to be waterproof. Even though the water was easily removed and the electronic components dried out, the keyboard was also discovered to be flooded and all efforts to dry it were fruitless. As there were two other identical depthometers in use on board, one was quickly pressed into service for DCS.

Various components critical to the proper operation of the heave compensator were checked during that time as well. The bleed valve, controlled by the computer, had not been checked during the test phase in Utah. That valve is used during the approach sequence and during "AUTO WOB/AUTO" feed rate modes of control. The function of the valve is to bleed fluid from the piston side of the feed cylinders so that the trapped fluid does not build pressure to the point of stalling servo operation on the rod side. If fluid was not bled off at a controlled rate, the rod side pressure would quickly reach a maximum, at which point the rod- and piston-side forces would be equal, and the system would no longer be able to make progress downward. When checked, the valve was noted to function incorrectly one time, then function correctly the next time. The valve was disassembled and checked. Function-tests with the valve out of the circuit showed that the return side of the valve was incorrectly plumbed. Once this problem was solved, the valve seemed to function correctly every time.

Numerous heave compensator software changes and checks were in process during this time. The main problem was in the velocity signal to the servo. This control signal is present in all modes except "MANUAL," and it serves to compensate for vessel heave (as opposed to the other servo control variables which control WOB, feed rate, approach, retract, etc.). The problem was that the signal lacked long-term stability and tended to drift with time over several minutes. That was not a new problem since it was also experienced in Utah during the testing. The velocity signal is calculated based on an accelerometer sensor input, using an integration technique. The accelerometer sensor, however, is not temperature-stable, and the signal must be continuously checked for drift. As originally conceived, the software computes what are called zero crossings and corrects the measured accelerometer voltage such that the signal is centered about zero, which it must be long term. Work on the algorithm did in fact continue during most of the drilling on the first site. A totally different method of velocity signal calculation would eventually be used on Leg 132.

Mud pump operation was checked with the now modified throttle and summing amplifier boards. Further minor modifications had to be made, along with slightly different adjustments, but in the end very smooth low-speed operation at rates of 10 SPM and less was confirmed. Once all adjustments were made, the panel-mounted SPM gauge was calibrated. The full range of pump speeds was available, i.e., 3–120 SPM.

Many hours of effort went into function-testing the components of the DCS prior to shipment. However as can be seen by the above list of tasks performed, a considerable amount of time and manpower was required to ready the DCS for deployment. In the future, consideration should be given to installing the DCS on a leg or near the end of a leg that precedes the cruise during which the system is to be used. There is a considerable amount of system testing and troubleshooting that would otherwise use up a significant portion of a regular science leg. At least 2 weeks should be allowed for testing and making all systems operational after the initial assembly in a 5–7 day port call. For a detailed list of items done prior to and between bit runs see the shipboard work list (Appendix).

DEPLOYMENT AT THE FIRST SITE (ENG-5)

Brief Description of Lithology, Subsea Hardware, and Hole Conditions

The first site on Leg 132 was the primary site for testing the DCS in preparation for drilling zero-age crustal formations on the East Pacific Rise. ENG-5 (Bonin back-arc) was identified as a site where conditions would allow the DCS and subsea systems to be tested in a bare rock basalt environment. The site was selected by scientists who had both drilled in the area as well as conducted a survey in a manned submersible. Upon arriving at the site, a short underwater television survey was conducted to locate an area on the seafloor suitable for setting a guide base. The intention was that the guide base and a short length of drill collars are then drilled into the seafloor, and when landed and backed-off in the guide base, the collars serve as a seafloor receptacle for latching the ODP drill string. The DCS tubing string and outer core barrel are then tripped inside the drill pipe from the surface and drilled out through the bottom of the drill-in BHA that is landed out in the guide base. The guide base and the drill-in BHA provide lateral support for the tubing string and outer core barrel assembly as it is drilled into the seafloor.

During Legs 106, 109, and 118, techniques were developed for setting subsea structures (hard rock guide bases) on the seafloor in regions of the ocean where there are basaltic formations devoid of sediment cover. Techniques were also developed for conducting exploratory coring operations using a 9-1/2 in. positive placement coring motor to drive a conventional four-cone roller core bit. The coring motors can be used for retrieving core samples or for conducting drilling operations depending on how they are dressed. For Leg 132 the motors were dressed for use in the drilling mode only. The motors were provided with an internal spline mechanism that allows 1 in. balls to be dropped down the drill string and into the spline grooves in the motors. The balls lock the rotor and stator together allowing the motor to be rotated from the surface in the event more torque is required for actuating the back-off sub than the motor can produce (6000 ft-lb). With the balls in place, up to 25,000 ft-lb of torque can be transmitted.

Prior to setting a guide base at ENG-5, a series of test holes was drilled with the coring motors to determine the length of drill-in BHA that could be safely drilled in without exceeding the life of the bit, and also to demonstrate that adequate hole stability exists for conducting the limited shallow drilling operations required. After completing a series of test holes, a guide base was run. The guide base was moved three times and three holes were drilled before a BHA was successfully drilled in and latched into the guide base. For additional details on the sequence of operations that were required to establish a viable test hole see the "Operations Report" chapter (this volume). A 6 m drill-in BHA was drilled into the seafloor with an 11-5/8 in. core bit. A center bit was latched into the throat of the core bit while drilling the BHA into the seafloor. Once the BHA was landed out in the guide base, a back-off sub was activated with the coring motors, leaving the drill-in BHA in place in the guide base. A jay-type tensioning tool was then tripped into the hole and jayed into the throat of the reentry cone in the guide base and 35,000 lb. tension was pulled against the drill string and the center bit was retrieved. The tensioning tool was then unjayed in preparation for tripping in the tubing string.

The series of test holes drilled (Holes 809A through 809E), revealed that hole conditions deteriorated at 8–13 m below the seafloor (mbsf). In several instances throughout the drilling operation, particularly at depths between 9 and 13 mbsf, the drilling assembly became stuck in the hole, requiring overpulls as high as 55,000 lb. to come free. It was also observed that the first 5–6 m of hole drilled very rapidly. Intermittent rotation of the motor typical of that experienced on Legs 106, 109, and 118 was observed throughout the drilling of the test holes. It was also observed that the motors appeared to rotate much more smoothly when drilling Hole 809B using a 9-7/8 in. core bit (with center bit in place). That may have been due to a combination of hole size as well as localized lithology for that particular hole. Overall indications from the drilling tests were that fractured basalt pillows were being drilled and that they should be suitable for testing the DCS.

Tripping the DCS 3-1/2 In. Tubing String to the Seafloor

After running the guide base hardware and drilling the bottom hole assembly into place, the 5 in. drill pipe was tripped into the reentry cone with the tensioning tool in place. With the drill pipe positioned above the seafloor, the 90 ft stands of 3-1/2 in. tubing were tripped into the hole. A tubing slip bowl (100 ton) with a hinged adapter sleeve was placed on top of a 20 ft knobby tool joint hung off on a 500 ton elevator on the rig floor (see Fig. 8 for surface stackup). Due to the height of the floor stackup, a tripping platform was assembled on the rig floor to allow the rig crew to be positioned at the correct working height with respect to the elevated tubing slip bowl. The tubing was lowered in the hole using a B.J. "YT" 75 ton slip type tubing elevator.

Due to problems with the "YT" elevators not functioning properly, numerous joints of tubing had been damaged previously on Leg 124E. A set of lift plugs was built to use with a set of square shoulder elevators. The lift plugs were screwed into the box connections and the square shoulder elevators attached below the lift plug shoulder. The plugs and square shoulder elevator proved to be unsatisfactory. The plugs were difficult to handle back and forth to the rig floor and, in one instance, a lift plug unscrewed, momentarily releasing a piece of pipe in the derrick. At that point, it was decided to switch over and try the "YT" elevators. The elevators had been rebuilt prior to shipping for Leg 132 and were found to be functioning properly. All trips with the tubing were subsequently made using the "YT" elevators without incident.

The tubing was tripped down to the top of the stress joint. One 10 ft drilling joint was made up to the tubing string and hung off in the slip bowl at the rig floor in preparation for the strip-over operation required to pick up two 20 ft knobby space-out joints from the mousehole, after the Varco top drive was picked up. At this point the DCS was ready to be moved into place on well center.

Initial DCS Deployment and Derrick/Seafloor Space-Out

The DCS platform was rolled into place on well center and the guide dollies were installed onto the derrick guide rails. The 500 ton links were attached between the heave compensator and the upper DCS mast attachment points. The platform was then picked up in the derrick and the lower set of 500 ton links was pinned into the lower end of the mast. The DCS platform was raised high enough in the derrick to pick up and attach the Varco top drive to the links below the DCS platform. The Varco top drive is used to rotate the drill pipe when "jaying" and "unjaying" from the guide base.

With the DCS platform positioned approximately 45 ft above the rig floor, 10 ft drilling joints were tripped from the DCS platform to the rig floor, and the lowermost 10 ft joint was made up to the tubing hung off in the slip bowl on the rig floor. The slip bowl was then removed and the weight of the entire tubing string was supported by the DCS top drive. The Varco top drive was then lowered and made up to the 20 ft knobby hung off in the dual elevator at the rig floor. (The angle of the tilt function on the top drive is such that a 20 ft joint must be on the top drive to provide the correct angle for making a connection in the mousehole. One 20 ft knobby was made up on top of the 30 ft knobby drilling joints, when the drill pipe was initially tripped in the hole.) The DCS platform along with the Varco top drive assembly was raised 20 ft and the uppermost 30 ft knobby was hung off on the dual elevator. The lower connection on the 20 ft knobby was broken out, and the tubing slip bowl was reinstalled. The 10 ft drilling joints were broken at the main rig floor and either tripped back to the DCS platform or laid out using a DCS platform tugger. To speed the operation up a tugger was used. The string of five to six 10 ft joints (that extended from the platform to the rig floor) was broken out at the DCS platform and lowered into the top of the Varco swivel assembly so that the Varco top drive could be tilted back for making a connection in the mousehole. The 10 ft drilling joint string remained hung off on the tugger line, while the knobby joint in the mousehole was made up to the 20 ft knobby on the Varco top drive.

The Varco top drive was then tilted back and the 10 ft drilling joints were made up again to the DCS top drive. The 10 ft drilling joints were then lowered down and made up to the tubing string hung off at the rig floor. The entire weight of the tubing string was taken by the DCS top drive, and the lowermost 20 ft knobby on the Varco top drive was made up to the 30 ft knobby hung off at the rig floor. The lowermost 20 ft knobby was run back in the hole and hung off in the dual elevator. At that point the process was repeated and the second space-out knobby was picked up in preparation for reentry. It should be noted that the drill pipe space-out was adjusted so that the tensioning tool was located 3 m above the reentry cone with the lowermost single 20 ft knobby hung off at the rig floor (Fig. 9). When the reentry was made, the space-out was such that the DCS platform was at the 45 ft level in the derrick. That allowed personnel to get on and off the platform with ease, using the walkway at the 45 ft level.

Once the reentry operation was complete, the DCS rig crew tripped 10 ft drilling joints in and lowered the tubing string and core bit through the stress joint and the drill-in bottom hole assembly to the 11-5/8 in. core bit (referred to as the casing shoe), in preparation for DCS coring operations.

BIT RUN NUMBER 1

The core bit selected for DCS bit run number 1 was a Longyear series 2 impregnated bit (3.960 in. O.D. × 2.2 in. I.D.). A Longyear

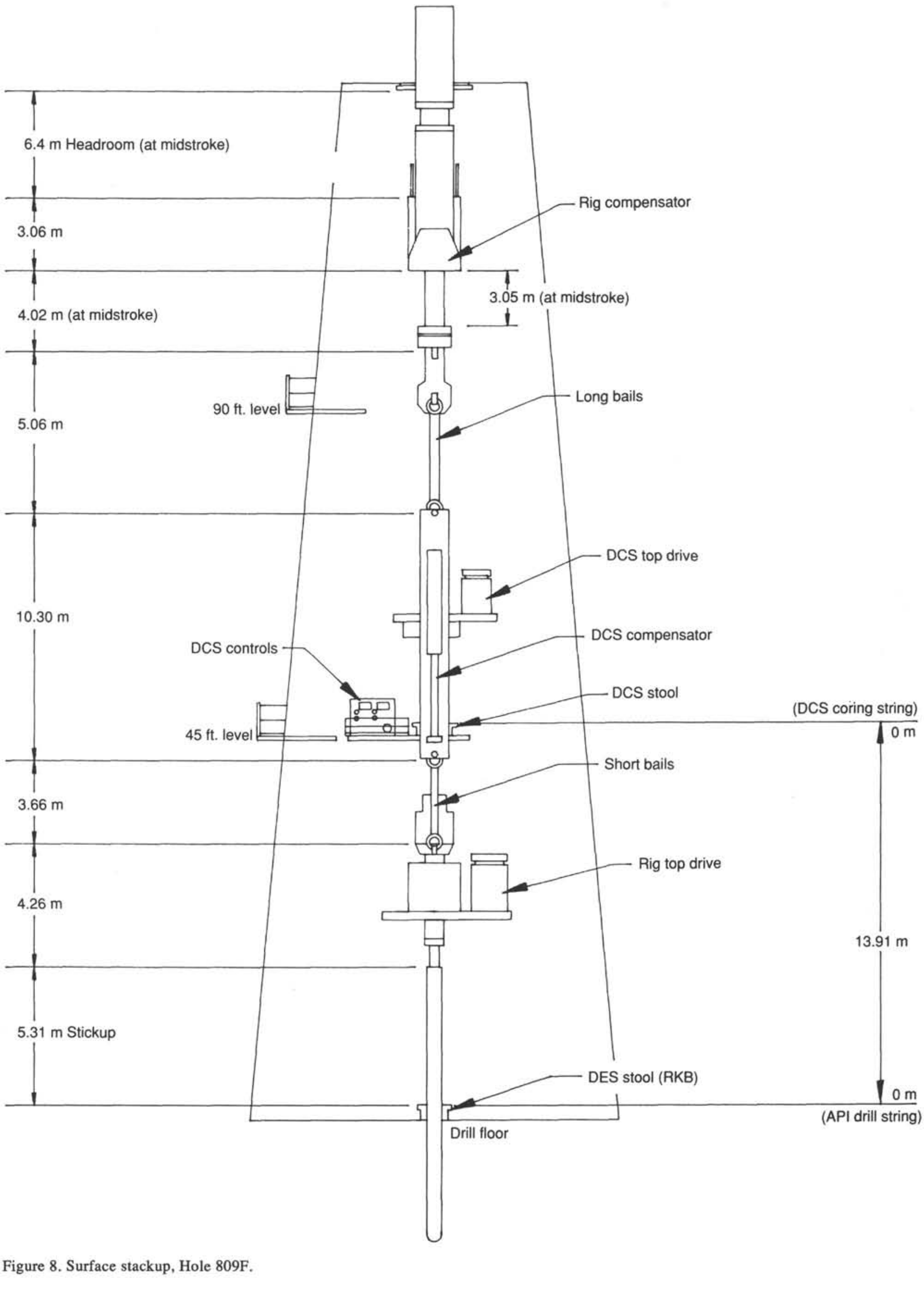


Figure 8. Surface stackup, Hole 809F.

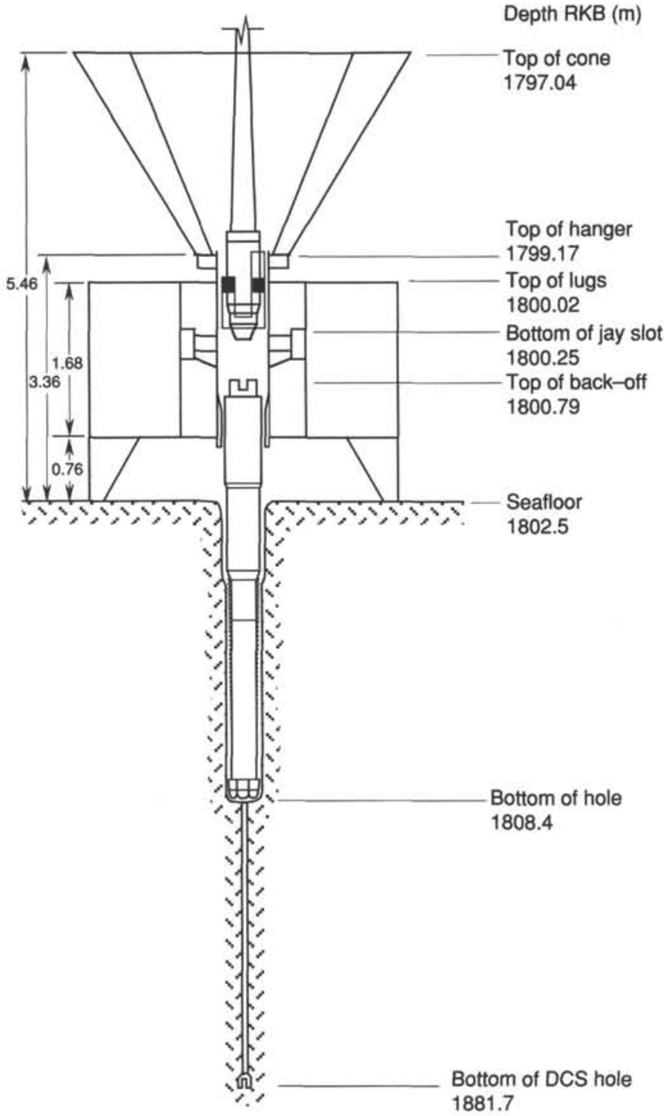


Figure 9. Seabed stackup, Hole 809F.

Longyear reamer shell was run above the bit that has been used successfully in the oil industry. The 10 ft drilling joints were tripped into the hole using the secondary heave compensator to slowly feed the drilling assembly through the void between the bottom of the tensioning tool and the top of the back-off sub. No difficulty was encountered lowering the bit through the section. The 10 ft joints were advanced to the casing shoe and the secondary compensator was engaged. The computer repeatedly would touch the bit on bottom, then go into the retract mode. An increase in pump pressure was noted indicating a core jam. The core barrel was recovered and found to have 13 cm of vesicular basalt rubble in the barrel. Repeated indications of core jams were reflected by pump pressures. The second core barrel was pulled and found to be empty. It was suspected that the rubber core block washers were in some way causing the false indications of core jams. The rubber washers were changed out with steel washers. It was recognized that without the rubber washers it would be more difficult to see the core blocks. The next core barrel run resulted in the recovery of 0.85 m of fractured basalt. Typical coring parameters were 20 gpm, WOB varied from 1,000 to 2,000 lb, bit speed varied from 80 to 100 rpm, and pump pressure was 80–280 psi. After limited recovery on the first two coring runs, no additional core was recovered for the next four coring runs. It was initially thought that the core barrels were not latching in. The space-out on the inner tube was shortened up by 0.625 in. in an attempt to correct the erratic pump pressures observed. During coring runs 3 through 6, pump pressures varied from 200 to 750 psi. Numerous center bit runs were made to clear any obstruction that might be in the bit. The core barrel latch dogs, landing shoulder, and core catcher were painted prior to dropping the barrel. This gave a positive indication when the barrel seated properly. On Core 6 difficulty was encountered latching onto the core barrel with the overshot. Apparently there was a significant amount of fill on top of the core barrel. Two wireline runs were made in an attempt to pull the core barrel. It was decided to swab the pipe using a core barrel latch head assembly in an attempt to clear the fill above the core barrel. The swabbing attempt worked and the core barrel was recovered. Coring operations were resumed and four more cores were recovered with recovery ranging from 0.2 to 2 m. Again pump pressures were observed to be very erratic. Coring parameters were as follows: flow rates varied from 20 to 70 gpm, bit speeds ranged from 80 to 200 rpm, and pump pressures ranged from 150 to 750 psi. The drilling rate fell off significantly during the last three coring runs. It took 45 min to an hour to advance the bit 0.1–0.3 m as compared to 15–20 min to advance the bit 1–2 m earlier in the bit run. It was decided to pull the bit at the end of Core 9. Total core recovery for bit run 1 was 1.63 m.

Inspection of the bit revealed that 70% of the usable bit matrix had been worn away significantly limiting the flow paths across the face of the bit. This could explain the erratic high pump pressures observed at the end of the bit run.

Secondary Heave Compensator Performance

As mentioned above, there were problems with the heave compensator velocity signal that were not solved at the time drilling commenced. However, because the environment was benign, there was no real need for the velocity signal. Instead, the bit was slowly lowered to bottom in approach mode, without heave compensation, and once the bit touched down, the "AUTO WOB" mode took over and provided sufficient compensation to keep the bit on bottom, although the WOB control was sloppy (weight varied by as much as ± 1000 lb). It was eventually decided that since the quality of the velocity signal was in question, and given the environment, no velocity signal would be used. The ultimate problem with the velocity signal, once the signal was stabilized with respect to long-term drift, was that the platform was suspended in the derrick, and the string placed in tension to a 30,000–35,000 lb overpull, the spectrum of the accelerometer signal was found to contain broadband noise caused by drill-string response. This condition of course never appeared during on-deck testing and tune-up. The pronounced difference in the accelerometer response was a complete surprise. The accelerometer frequency spectrum contained the expected fundamental heave response at approximately 0.14 Hz (corresponding to 7 s heave response of the vessel). However, the spectrum also contained significant peaks covering the area between 0.14 and 1 Hz, the upper limit of frequency measurement. Most, if not all, of the energy found between 0.14 Hz and 1 Hz was due to drill-string fundamental excitation and related harmonics. As the existing accelerometer fourth-order filter was designed with a break frequency of 4 Hz, it could not remove such noise so close to the desired signal. Further, any effort to reduce the break frequency of the filter would introduce undesired phase shift at the desired signal frequency. The noise, given its considerable amplitude compared to the desired signal, was affecting the velocity calculation to the point that the resultant servo velocity control signal was in essence unusable. At first it was theorized that platform response had something to do with the noise, but after placing another accelerometer on the pipe string directly at the drill floor, it was obvious that the noise was due to the pipe. Some other method of measuring acceleration or velocity would have to be found.

At the commencement of coring, there were numerous "VOID HIT" alarms, which occur as a result of a measured rapid loss of WOB. That alarm was designed to alert the driller when the bit falls into a void such as is experienced in vuggy carbonate reef formations. When that or any other alarm occurs, the bit is automatically, and sometimes violently, retracted off bottom. A rapid software change took care of the problem, wherein the threshold for a "VOID HIT" was relaxed to a loss of 1000 lb WOB.

During the entire first bit run, WOB control had to be constantly aided by manual reduction of piston side pressure, in order to keep weight on the bit. That was due to the fact that the bleed valve was not working, although it was confirmed that the computer was in fact issuing proper commands to the valve.

Tripping Out the 10 Ft Drilling Joints

Tripping out the 10 ft drilling joints and laying down of the 20 ft knobbies was done in a similar manner as described above when the joints were initially picked up. After the drill pipe was unjayed from the guide base, the DCS platform was positioned such that two knobby drilling joints were above the rig floor. The knobby joint at the rig floor was broken out, and the tubing was hung off at the main rig floor in the slip bowl. Using a tugger on the platform, the 10 ft drilling joints were lowered from the platform down into the Varco top drive so that it could be tilted over to the mousehole. The lowermost 20 ft knobby was broken out in the mousehole, and the top drive was tilted back in preparation for laying out the second knobby. The tubing string was made back up to the DCS top drive and again the entire weight of the tubing string was taken up on the DCS platform. The remaining knobby on the Varco top drive was made up to the 20 ft knobby hung off on the rig floor. The DCS platform was again raised so that two 20 ft knobby drilling joints were positioned above the rig floor. The drill string was hung off on the uppermost 30 ft knobby, and the connection on the lower 20 ft knobby joint was broken at the rig floor. The tubing was again hung off at the rig floor as was done before, and the stripping operation was repeated to lay the second knobby joint out. This time the 10 ft drilling joints (six of each) were lowered down from the DCS platform through the Varco top drive and laid out in the mousehole. The 10 ft joints were then transferred to the "V" door. The 10 ft drilling joints were later broken out on the rig floor and transferred back to the drill rod basket on the DCS platform.

The Varco top drive and the DCS platform were then set back on the rig floor. The DCS mast guide dollies were removed from the forward side of the mast and hinged back on the aft side. It is necessary to remove the guide dollies on the forward side of the platform because of interferences with the tubing racking operation.

For a detailed list of tasks performed prior to and in between bit runs see the shipboard work list in the appendix.

BIT RUN NUMBER 2

Coring and Drilling Operations

The second bit run was made with a Longyear series 2 impregnated bit, exactly the same as was used on bit run number 1. There was nothing unusual about the wear noted on the first bit run that would call for a change in the bit matrix or crown design. The 90 ft stands of tubing were tripped in the hole, followed by reentering the reentry cone, pulling 35,000 lb tension on the drill string, picking up the DCS platform and tripping the 10 ft drilling joints in and lowering the bit back to the bottom of the hole. Once outside the casing shoe, the secondary heave compensator computer was used to lower the bit to bottom while rotating at 100 rpm. While rotating through the casing shoe and down to bottom of the hole, up to 2000 ft-lb of torque was observed on the top drive torque read-out. The high torque was attributed to the absence of lubrication between the tubing and drill pipe string, possibly being accentuated by high ocean currents bending the drill string. After pumping a mud lubricant into the annulus, the high torque dissipated. When bottom was tagged, 3 m of fill was encountered. Initially, a center bit had been run. Once on bottom the center bit was retrieved and coring operations were commenced. Nine consecutive cores were cut. Drilling parameters were as follows: weight on bit 500–2000 lb, flow rate 30–50 gpm, bit speed 100–300 rpm, and pump pressures ranged from 100 to 300 psi. Core recovery ranged from 0.14 to 1.87 m. After advancing the hole with the DCS 32 m out ahead of the casing shoe, core recovery dropped to zero. Apparently a zone of highly friable volcanic tuff, unconsolidated basalt known as volcanic breccia, was encountered. Repeated attempts were made by dropping the bit deplugger and center bit to clear any possible obstruction that might have prevented the core barrels from latching in, on the premise that this might be the cause of the nil core recovery. A total of 64.9 m was drilled/cored on the second DCS core bit run. Due to indications that the bit was plugged, the bit run was ended. Numerous attempts were made to clear the bit of the obstruction in preparation for logging the hole. These attempts were unsuccessful and it was necessary to trip the tubing out of the hole. An attempt was made to run the logging tool down the drill pipe string into open hole, but a bridge was encountered at the top of the hole which ended the logging attempt.

Examination of bit number 2 revealed that all of the matrix had been worn off the bit. It is not known at what point the bit actually failed. It is possible that it failed prior to drilling out of the unconsolidated zone as evidenced by the extremely long drilling times that were required to advance the bit. A total of 13.4 hr rotating time was logged during the bit run. It is possible that coring the breccia zone (volcanic sand?) may have prematurely eroded the matrix of the bit to the point that, when competent basalt formation was encountered deeper in the hole, the bit had little or no coring life remaining. Total core recovery for bit run 2 was 9.5 m.

Throughout both DCS bit runs, hole stability was not a problem, with very little fill being encountered. As mentioned above, when drilling with the 11-5/8 in. drilling assembly, both hole sloughing and stuck pipe were encountered as shallow as 9 m below the seafloor. The observation was made on Legs 106 and 109 that when drilling fractured basalt formations, reducing the hole size enhances hole stability. It was postulated that if reducing the hole size from 14-3/4 in. diameter to 9-7/8 in. diameter enhanced hole stability significantly, a reduction from 9-7/8 in. diameter to 3.960 in. diameter would create hole conditions that would allow significant penetrations into lithologies that were characterized by highly fractured formations. That phenomenon was demonstrated while coring with the DCS system on Leg 132.

The operation of the DCS surface drilling equipment is controlled from the DCS platform. Crew on the platform for the first two bit runs included a SEDCO/FOREX driller, assistant driller, and an ODP engineer intimately familiar with the operation of all equipment on the platform. Initially the ODP engineers operated the equipment and familiarized the rig personnel with its operation. The DCS top drive controls were purposely arranged to be very similar to the Varco top drive controls on the rig floor. The rig personnel very rapidly became proficient with operating the DCS top drive making and breaking connections, and tripping 10 ft drilling joints in and out of the hole. The hydraulic rig tongs also posed no operational problems for the crew and were used in conjunction with the top drive when making and breaking connections.

After the low-speed control was installed on the coring winch, no difficulty was encountered in handling the core barrels at the surface on the DCS platform. Once in the hole, the high-speed winch control worked very well running the sinker bars, landing the overshot out on top of the core barrel, and retrieving the core barrel from the hole.

Initially the secondary heave compensator was only partially operational. The system was run in load control mode without the use of a velocity signal on the first bit run. During this time the ODP engineers cut most of the cores, making manual adjustments to the weight on bit by bleeding fluid into and out of the piston side of the hydraulic feed cylinders. During the second bit run the secondary heave compensator computer became fully operational, and the rig crew took over complete operation of the DCS system. Very rapidly the drillers became familiar with the operation of the automatic drilling controls on the secondary heave compensator console.

As sophisticated as the DCS system is, there is no doubt that the system can be operated by qualified rig personnel. The SEDCO/FOREX drillers and assistant drillers did an excellent job running the DCS equipment as well as troubleshooting the systems when there was a problem.

With regard to keeping track of drilling and coring depths, additional effort was required in keeping up with two pipe tallies located on two rig floors in the same derrick. However, with good coordination between the two rig floors, no major problems were encountered. Weather conditions significantly affected the efficiency of the DCS operations. When it rained it was necessary to put up a makeshift canvas roof over the DCS platform. That hampered visibility and slowed the operation somewhat. The wind and ship roll also made it difficult at times for personnel to remain agile which again resulted in slowing the operation somewhat.

The low-speed mud pump controls allowed flow rates as low as 6 gpm. The overall layout of the drilling controls posed no problems either when tripping or during drilling/coring operations. The crews very rapidly became proficient with all aspects of operating the DCS control systems. Refinement of the layout of critical drilling parameter gauges will improve the ease which the driller may scan the panel during actual drilling operations. The present layout of the gages made it necessary for both the assistant driller and the driller to monitor the control panel during critical operations.

Heave Compensator Performance; Evolution and Testing of New Servo Velocity Signal

As the second sequence of coring began (bit run 2), the velocity signal problem had still not been resolved. A solution had, however, been formulated. The new approach was to make use of two new sensors. First, a position (displacement) transducer was mounted on the underside of the platform, with the fixed end of the wire made fast at the drill floor. The sensor consists of a spring-loaded wire reel axially coupled to a multi-turn potentiometer, and the sensor produces a voltage proportional to the position of the platform relative to the drill floor (vertical position). This signal was to be summed with a displacement signal taken from an existing accelerometer package mounted in the vessel's mud pit area, at the proximate center of pitch and roll. This latter sensor produces outputs of vessel acceleration, velocity and displacement in the vertical axis (heave axis), and is normally used as an input to the active Schlumberger wireline heave compensator. The two displacement signals were to be summed in the computer, with the resultant displacement differentiated to produce a velocity signal for the servo. Several attempts to make this idea work were met with only limited success due to noise being present on one of the signals. However, a very interesting result of these efforts was the ability to establish, with a reasonable degree of accuracy, the efficiency of the primary heave compensator in removing heave from the main drill string and hence the platform. On the average, it was found that for the conditions present at that time (heave, period, drill-string dynamics, water depth, hook load), the efficiency was typically 85%–90%. In other words, the net difference in displacement of the ship relative to earth vs. the displacement of the platform relative to the ship was about 10%–15%, with the drill string connected at the seafloor and with an overpull of say 30,000–35,000 lb. The efficiency was found to be relatively constant with respect to primary compensator rod position. Armed with this knowledge, it became apparent that only one displacement was necessary, and the existing ship's accelerometer sensor was chosen because of its noise-free characteristics. Because that sensor measures vessel acceleration only, it is free from the deleterious effects of drill-string nodal response. Since the front panel keyboard allows operator choice of the quantity of velocity servo signal, it then becomes a straightforward matter, through trial and error, to fine-tune the system for minimum heave-induced displacement of the bit relative to the bottom of the hole.

Load cell signals and the resultant DCS hook load indication had been suspect during the first bit run. While it was known with suspected reasonable accuracy that the traveling equipment weight was approximately 22,000 lb, and since tubing string weight was easily calculated at 48,000 lb (1800 m of 9.3 lb/ft pipe in seawater), the indicated load should have been approximately 70,000 lb. Instead, the indicated load was 60,000 lb. As a temporary measure during the first coring episode, a software change was made to correct the reading. Between the two bit runs, the load cells were unloaded and rezeroed. At that time, the measured weight of the traveling equipment increased to 28,000 lb, a suspect value. When the tubing string was initially picked up during the second coring run, the indicated weight was still low at about 60,000 lb. It appeared that one or both of the load cells had a nonlinear response.

During the second bit run, the new software was installed in the computer and a test of the new velocity signal was performed. In order to maximize heave induced into the system, the vessel heading was changed to take the swell on the beam. This yielded an increase in heave from 2–3 ft to 8–10 ft. By trial and error, the velocity control signal amplitude was adjusted to account for the estimated secondary heave. Some small amount of phase lag was noted, but on the whole, the new velocity signal was much smoother than the original signal, in that it drove the servo in a truly sinusoidal manner.

While the seas were being taken on the beam, an approach sequence was achieved successfully, and a smooth touchdown resulted. Adjustment of the bleed valve control constant from the keyboard allowed control of the approach rate, thus confirming that the bleed valve was working correctly after moving the return line connection from the return manifold directly to the tank. That reduced the back pressure on the valve to zero.

Coring operations with the now fully functional heave compensator proved to be much easier. "AUTO WOB" control was essentially fully automatic, with little or no adjustment necessary.

"AUTO FEED RATE" mode was successfully used for the first time and also performed well. The compensator controls were finally working.

EVALUATION OF DCS COMPONENTS

Top Drive

The mechanical and electrical components that make up the DCS top drive all functioned as designed. The gear box, 800 HP DC electric motor, and 450 ton swivel assembly all were observed to run smoothly, as an integral unit with no indications of vibration. When the top drive was initially designed, there was concern about personnel working so close to the unit, specifically, that the noise and vibration associated with top drive components might pose a problem. The unique design and placement of the blower motor and ducting was found to allow the unit to operate very quietly. With background noise from the hydraulic power pack, there was little audible indication that the top drive was running. There were no leaks of drilling fluid detected in or around the wash pipe. The special design high-speed wash pipe seals performed well. On occasion a squeaking noise in the wash pipe pressure body could be heard at various speeds. However, this appeared to present no problem. The lubrication system for the wash pipe seals was checked and found to be functioning properly. On two occasions it was necessary to tighten up the pressure body on the wash pipe because it had become loose. The top drive was operated for long periods of time at rotational speeds ranging from 100 to 360 rpm. At no times were there any indications of high oil pressure or temperature. Typically the oil pressure was observed to be 25–30 psi.

Top Drive Control System

The top drive control system worked extremely well. The controls were used extensively for making and breaking connections on the 10 ft drilling joints. The driller was able to reliably and safely make and break connections with no operational problems throughout Leg 132. Due to the similarity in the layout of the controls between the Varco and DCS top drives, the crews very rapidly became proficient at operating the top drive. The throttle provided smooth control of the top drive rotation because minute adjustments in rotational speed were possible. The use of tachometer feedback rather than voltage or current feedback resulted in much more constant rotation speed than normally seen with the Varco unit.

It was recognized during Phase I of the DCS that mining-type hydraulic top drives offered the capability of making and breaking connections, thus significantly speeding up the repetitious handling of the 10 ft drilling joints. Hydraulic top drives also have the built-in capability to limit torque due to the fact that a specific hydraulic operating pressure can be selected. When rotating the tubing string at high speed, a hydraulic top drive will stall if the string suddenly becomes stuck, minimizing the possibility of placing too much torque on the string. Both of these features were designed and built into the electronic control system for the DCS electric top drive.

Overall, significant breakthroughs were made in the design and development of the top drive control system. The ability to break out a connection using an electric top drive did not previously exist. The degree of control is recognized as very important to the efficiency of the DCS, yet it also has immediate application and utility on the many drilling rigs that are using electric top drives throughout the drilling industry today.

Mud Pumps and SCR Controls

In the design phase, there was considerable concern as to the method of providing the extremely low flow rates (10–60 gpm) required for coring with the small diameter/narrow kerf diamond coring bits. Consideration was given to purchasing a small mud pump that would provide the optimum fluid output for the DCS. That had the drawbacks of considerable costs and limited space on the ship for installation. Consideration was also given to using the existing Halliburton cementing pumps on the ship. The idea to use the cementing pumps was attractive because of the pump's inherent ability to operate at very low flow rates. The disadvantage, however, was the inability to readily take suction from the mud pits. The third and most attractive option was to fit low-speed controls to the existing Oilwell A-1700PT mud pumps, and install 4 in. liners to minimize any pump surge that might occur at low pump rates and to provide a reduced flow rate. By using the same control boards as used in the DCS top drive, the mud pumps could be run at speeds as low as 2–3 SPM. The control system provided excellent control and adjustment of fluid flow to the diamond core bits. The new SCR control boards allowed the use of existing equipment on the ship and eliminated the costly purchase of additional pumping equipment that would see only limited use on those cruises when the DCS was to be deployed.

Secondary Heave Compensator

Once the velocity signal problem was solved, and the bleed valve fully operational, overall heave compensator performance was satisfactory. One aspect which must be changed is the rate at which the bit retracts at the end of a coring sequence or when the bit retracts as a result of an alarm condition. The rate of retraction is presently a sole function of the pressure present on the piston side of the feed cylinders at the moment of retraction. During a retract cycle, the computer removes all control voltage from the servo instantly. If piston pressure is in excess of that pressure needed to statically support the dead load, then the head will retract at a speed directly proportional to the overpressure. If there is no overpressure, the head will not retract and must be brought up manually with the joystick control. That is actually preferable to a violent head retraction. One way to solve the problem would be to make the servo signal decay at a slow rate. It is important to retract the head in a slow, controlled manner because as the head retracts, the core is breaking loose from the formation. Should that action occur too rapidly, there is a good chance that the core or some part of the core may slip through the core catcher and be left in the hole.

It was difficult to determine the effect of the apparently small amount of phase delay between the velocity signal and the heave displacement. More experience with the system in moderate to heavy seas should yield a better appraisal for the efficiency of the method used. Meanwhile, phase delays caused by hardware can be quantified by calculation and perhaps compensated through hardware or software changes.

The use of air-purging and a space heater within the control panel proved to be very effective in solving the hardware reliability problems experienced on Leg 124E. There were no hardware reliability problems during Leg 132.

The cause of incorrect hook load measurement is not known at this time. That situation must be resolved in order to allow accurate control of WOB. Since the measured load was found to be 15% less than it should have been, WOB accuracy suffered the same error. It was also noted that to keep the bit on bottom (as judged by the behavior of other parameters such as pump pressure and torque) required a minimum of approximately 1000 lb indicated WOB.

Hydraulic Wireline Winch

During the initial at-sea testing of the wireline winch, difficulty was encountered raising and lowering the sinker bars and core barrels on the DCS platform. This problem stemmed from the pilot-operated control on the winch being too sensitive for safe operation at low speeds. While testing the winch operation, it became apparent that a low-speed control circuit for surface wireline handling would be necessary. After the addition of a low-speed control circuit, the winch could be operated safely in all required modes. The high-speed control worked very effectively downhole for landing out the sinker bar/overshot assembly and for running and retrieving core barrels and other downhole tools.

The lebus fleet angle compensator worked well when spooling the line onto the winch, with the exception of the last 2,000 ft of line. The lebus sheave/eccentric shaft assembly is driven by the tension of the wireline acting on the sheave. With less than 2,000 ft of wireline in the hole, there is not enough load to drive the lebus fleet angle compensator sheave properly. To counter this problem, a hydraulic spooling assist device had been installed on the fleet angle sheave to aid in spooling the last 2,000 ft of line onto the winch. The device was cumbersome and slow. The final solution was to disable the spooling assist and to tie a piece of rope to the sheave, laced around the side of the mast and brought forward to the front of the platform. Then, while spooling the top two layers of line onto the winch, the crews would pull on the rope as needed to maintain proper sheave alignment. That remedy allowed the last 2,000 ft of line to be spooled onto the winch drum at normal operating speed, which was approximately 300 ft per min.

Operation of the winch on the many wireline runs became routine very quickly. No mechanical problems were encountered with the winch, save for loss of holding power on the disc-type parking brake at one point. This turned out to be lack of brake fluid on the hydraulic side of the brake and, once the fluid was replenished, brake operation returned to normal. The disc brake system proved very reliable. The vane motor which drove the winch also operated without trouble. Overall the winch proved to be a very rugged and reliable piece of equipment.

DCS Hydraulic Power Supply

The 200 HP hydraulic power pack was operated around the clock whenever operations were being conducted on the DCS platform. No major mechanical problems occurred with any of the many hydraulic control valves and circuits, except for rerouting the bleed valve hydraulic return line as necessary to allow the valve to function properly. The main hydraulic supply pump (200 gpm), the auxiliary pump (30 gpm), and the charge pump performed with no breakdowns. However considerable problems and loss of rig time were caused by the low pressure filter system. Filter seals blew on at least four occasions resulting in the loss of 50–100 gal of hydraulic oil in seconds. The cause of the problem is believed to be pressure spikes induced when rapidly stopping and starting the feed cylinders while supporting the tubing string load. The pressure spikes may have been accentuated by the excessive return manifold pressure. This problem also occurred during the initial land testing of the system. As a solution, a 1 qt accumulator was installed in the filter system to dampen out the pressure spikes. That solved the problem while operating and testing at the fabrication yard. However, the system was not operated at full load until deployment at sea. The 1 qt accumulator was replaced with a 5 gal accumulator, and the latter was precharged with nitrogen to 90 psi. After installation of the larger accumulator, no more filter seal failures occurred.

The power supply was quiet and there was very little discernible vibration. Vibration had been a major concern because the power pack was located directly underneath the floor of the platform where the crews stood for 12 hr shifts. Thin metal sheet overlain with both rubber matting and cocoa matting provided a sound and vibration insulation barrier for rig personnel that made working conditions on the platform as comfortable as possible.

DCS Auxiliary Equipment

Hydraulically Actuated Tongs

The hydraulically actuated rig tongs were used for making and breaking connections in conjunction with the top drive. The tongs proved to be reliable, easy to use and safe for rig personnel to operate on the constantly moving DCS platform. The KELCO tong heads were easy to latch onto the tubing and did not induce heavy die marks on the pipe compared to the Petol chain tong heads used in Phase I of the DCS project. The hydraulic control levers located on the console were easy to use and operated reliably.

Tugger System

The two hydraulic tuggers were used extensively for handling 10 ft drilling joints when tripping in and out of the hole, for handling core barrels up on the DCS platform, and for lowering core barrels down 45 ft to the main rig floor. The tugger controls proved to be too sensitive, however. Extreme care had to be used when operating the controls so as not to overspeed the tuggers, which would result in jerking equipment around on the platform.

The 400 ton heave compensator hoses located on the forward side of the derrick interfered with the top main beam of the jib tugger. The hoses were tethered back away from the DCS platform as far as possible, but on occasion still would make contact with the jib arm/winch. assembly. In one instance the hose contact damaged one of the hydraulic hose fittings on the tugger motor. A guard was installed to help protect the tugger from damage should the hoses contact it. The proper solution is to eliminate the jib tugger mast and column completely. The jib tugger arm could be rigidly attached to the bottom of the top drive cross member, and once located here it would be out of harm's way.

The second tugger, mounted under the top drive cross member, worked well for handling core barrels. With the exception of the hydraulic control valves being too sensitive, both tuggers functioned well.

Cavins Wireline Oil Saver and WKM Ball Valve

The Cavins wireline oil saver performed satisfactorily. As the pack-off rubbers became worn, fluid on occasion did leak out somewhat hampering DCS platform operations. To enhance the performance of the oil saver, proper sealing rubbers should be purchased for a better fit around the wireline. The rubbers provided had a 1/2 in. diameter opening for use on 3/8 in. wireline. A smaller diameter opening in the pack-off rubber will enhance both the life of the rubber as well as increase the initial sealing capability of the system.

The remotely operated WKM ball valve, located on top of the swivel, operated throughout the leg without incident. The hydraulic valve actuator eliminated having to open and close the valve manually. In at least one instance, there was some confusion by the rig crew as to the position of the valve. Indicator lights are needed on the control console to give a positive indication as to whether the valve is open or closed. There is a visual indicator on the valve actuator but it is difficult to see when the top drive is positioned high in the mast.

Standpipe/Drilling Fluid System

No problems were encountered with the DCS circulating system. On one occasion the core barrel plugged off downhole and pump pressure increased to over 3,500 psi before it was noticed. As a result, the safety pressure relief valve on the pump discharge activated. Hoses, the DCS standpipe valve, manifold valve, and standpipe plumbing attached to the DCS top drive all contained the pressure with no observed leaks. During the initial installation of the 2 in. kelly hose from the main derrick onto the DCS platform, there was a mismatch between the union on the cementing hose (used as the DCS kelly hose) and the union installed on the platform standpipe. This problem was corrected by installing a 15,000 psi union mating body on the DCS standpipe manifold. In the future, any unions provided by ODP should be rated 15,000 psi to insure interchangeability with hardware on the drill ship. The standpipe pressure gauge had sufficient resolution to observe pressure changes which occurred when core barrels landed downhole, when core jams occurred, and when bit wear restricted the flow paths in the bit. To enhance the gauge resolution, the pressure range should be reduced from 5,000 to 3,000 psi.

3-1/2 In. Hydril Tubing String Design

There were no problems with tubular pipe. There was no cross-threading of the Hydril threads. The 75 ton "YT" slip-type elevators functioned properly and did not damage the pipe. A set of 250 ton 2 1/4 in. × 108 in. elevator links was used with these elevators and allowed the "YT" elevators to be handled in the derrick with ease. Because the elevator is a slip-type, the tubing cannot spin in the elevators as the tubing stand is being spun up at the rig floor. It therefore is necessary to unlock the hook on the traveling block assembly when tripping the tubing in and out of the hole. As mentioned previously, use of the lift plugs was time-consuming, and one stand of pipe did come loose in the derrick after one of the lift plugs inadvertently came unscrewed. The lift plugs are very difficult to make up in the stands of pipe in the derrick. In the future, it is recommended that the lift plugs not be used. Instead it is recommended that a second set of "YT" elevators be purchased with spare parts. In the event a problem occurs with the elevator in use, the spare elevator could be put into service while the other elevator is being repaired without loss of rig time.

The "TS" 100 ton tubing slip bowls worked efficiently both up on the platform as well as on the rig floor. The slip bowl adapter that allowed the slip bowl to be mounted on top of the knobby tool joint hung off at the main rig floor poised no operational problems and was readily installed and stripped off the pipe as needed. The tubing running platform also posed no operational problems and allowed the tubing to be tripped in or out of the hole efficiently. The Weatherford power tong purchased for tripping the tubing allowed the connections to be spun up and torqued accurately with ease.

RECOMMENDED DESIGN MODIFICATIONS AND IMPROVEMENTS

Itemized below are recommended design modifications and improvements that should be made to the Phase II diamond coring system prior to deployment again at sea. All of the required modifications to the DCS should be able to be made with the system set up at the ODP test facility in College Station within a 2–3 month time period. That time period is required for ordering items with long lead times, such as hydraulic control valves.

1. Order and install new wireline winch control valves to allow proper low-speed and high-speed control of the winch at the surface and downhole by the wireline winch operator. A temporary low-speed control was installed on the DCS platform using a spare tugger control valve to provide adequate low-speed control of the winch until the proper valves can be installed. The rig crew recommended that consideration be given to installing a DC motor in place of the hydraulic motor drive in an effort to make the winch as responsive as the existing winch presently in use on the ship.

2. The feed cylinder valves on DCS leak, allowing the top drive head assembly to slowly fall. The valves either need to be replaced or fitted with spools that do not leak.

3. The jib tugger needs to be eliminated. The heave compensator hoses have damaged the hydraulic hoses on the jib tugger as they swing in the derrick and pose a danger of becoming seriously fouled with the jib support column. A rope attached to the forward-port tugger on the rig floor was used to keep the hoses from becoming seriously fouled. This technique would not have worked if sea conditions had worsened throughout the time the DCS was in the derrick. The jib arm with the tugger needs to be removed from the column and welded onto the top drive cross member. The jib column can then be permanently removed from the DCS platform.

4. A tool rack needs to be devised that will prevent the hand tools from becoming lost overboard in the event of a drill-string loss.

5. Improvements need to be made to the Cavins/sinker bar assembly to allow the rig crew to stab the sinker bar assembly/Cavins oil saver and connect the hydraulic hose without having to climb up on the DCS mast.

6. A metal roof should be installed on the back of the platform to provide both protection from the weather as well as a place to seek refuge/protection from falling objects in the derrick. Consideration should also be given to walling-in the forward and starboard sides of the platform with hinged light-gauge metal sections to replace the canvas winch walls that functioned only marginally.

7. Improvements need to be made as to the placement of critical drilling parameter gauges, i.e., pump pressure and weight indicator. A larger weight indicator is needed that can be easily read by the driller. Considerable thought needs to be given to the panel layout so all critical gauges can be easily scanned by the driller during drilling operations. At the present time it requires two people to monitor all of the systems during critical drilling operations.

8. The design of the wireline weight indicator needs to be modified. At present the weight indicator load arm that supports the upper sheave assembly hangs up intermittently. This results in the fleet angle sheave assembly jumping and in intermittent function of the weight indicator gauge. The length of the moment arm also was found to be calculated incorrectly as was evidenced by incorrect wireline weights observed while pulling core barrels. The gauge needs to be recalibrated with the proper moment arm correction factor to reflect the correct wireline weights.

9. The tugger controls are too sensitive and need to be replaced with a less sensitive valve control system. Several mishaps occurred as a result of the control's sensitivity. A secondary tugger control also needs to be installed on the forward side of the platform rail to allow the tugger operator to view the rig floor when lowering core barrels and various items to the rig floor. Presently, the tugger control is located on the starboard side of the control console which the driller must use while operating the top drive making and breaking drill rod connections. Two controls are therefore justified.

10. A high-pressure filter system should be installed to replace the present inadequate lower pressure system. The filters have repeatedly blown out resulting in the loss of hundreds of gallons of oil and many hours of rig time. A 5 gal accumulator was installed to replace the 1 qt accumulator to dampen the pressure spikes. It should also be noted that the 1 qt accumulator originally installed was found to have lost its nitrogen charge and was therefore providing no dampening to the system. The pressure spikes to the system are possibly accentuated by the insufficiently

sized return manifold. It is recommended that the same type of high-pressure filters be installed on the DCS power pack that are used on the SEDCO/FOREX pipe racker and the Varco iron roughneck (Marvel 350 psi filters).

11. The safety harness system utilized needs to be studied in a effort to improve the ease of donning and to improve comfort while being worn for 12 hr shifts. Also thicker rubber matting should be installed to minimize the discomfort induced by the residual accelerations personnel are exposed to over long periods of time, while working on the DCS platform. Several rig crew members reported backaches during and at the end of long periods of time spent working on the platform. Four full derrick harnesses need to be purchased.

12. An umbilical guard made from 2 in. pipe needs to be installed to protect the umbilicals at their attachment point on the aft side of the platform to prevent the tugger lines in the derrick from making contact.

13. Fire retardant insulation is to be installed below the existing steel plate fire barrier in the floor. Also a CO_2 fire extinguisher system is to be installed below the floor of the DCS platform that can be triggered by the driller by actuating a control located on the driller's console.

14. Most of the plumbing in the hydraulic portion of the console was done with soft hosing rather than hard plumbing with stainless tubing initially. This was done to facilitate changes in the prototype hydraulic system as required during the initial testing of the many complex hydraulic systems. Now that most of the systems are functioning properly, the console needs to be hard-plumbed to clean up/remove the maze of hoses and to ease the lack of space for working on the system. At present it is almost impossible to use a wrench on the hose fittings in the console, because of the lack of adequate space in and around the valve systems in the console.

15. A modified sheave arrangement should be installed on the forward side of the platform to keep the DCS tugger lines off the side of the platform.

16. Heavier pad eyes rated for the full DCS mast top drive load need to be welded on the upper DCS mast cross member for use during rig up/down operations (as specified by and to be installed by DRECO in College Station).

17. Attachment points need to be provided on the lower end of the mast for the Varco top drive counterbalance cables.

18. A study should be made of modifications that can be done to the DCS platform/starboard derrick doghouse in an effort to allow the DCS to be rolled further from well center to provide more rig floor space for the iron roughneck.

19. A 2–3 ft extension of the top drive spline sub is required to allow adequate hole to be overdrilled to facilitate making connections when adding additional joints for advancing the hole. At present when a 10 ft joint is drilled down only 1 ft, it can be overdrilled. In heavier seas, larger amounts of residual heave and/or hole fill problems would result in the core bit contacting/heaving on the bottom of the hole when making a connection. The problem with doing this is the lack of adequate head space in the DCS mast for installing/removing 10 ft core barrels and other wireline coring tools.

20. Add a totalizing/resettable stroke counter to top drive console for the mud pumps.

21. Add a top drive blower shutdown switch.

22. Add an ammeter for the mud pumps at top drive console.

23. Add a second, smaller floodlight for illumination of coring winch and a separate switch.

24. Add a digital, resettable stopwatch/timer to the console for timing coring intervals.

25. Add a set of indicator lights on the control console near the WKM valve control to give a positive indication when the valve is in the "open" and "closed" positions.

26. Rebuild/repair the feed cylinders. The lower seal gland nuts are leaking. See discussion of port call activities above.

FUTURE CONSIDERATIONS FOR THE DIAMOND CORING SYSTEM

Derrick and Rig Floor Modifications to Enhance Operation of the Phase II System

For future deployments of the DCS, there are several modifications that could be made to the derrick and the rig floor to significantly enhance the rig floor operations. The modifications are targeted at providing more floor space for routine tripping operations that require the use of the Varco iron roughneck. In the present configuration, with the DCS platform rolled back as far starboard on the rig floor as possible, there is only marginal floor space for making connections in the mousehole with the iron roughneck. Presently the control console on the DCS platform makes contact with the starboard doghouse roof beam preventing further travel starboard.

Several modifications could be made to the doghouse roof and the derrick that would provide 8–10 ft additional travel of the DCS platform to the starboard side of the rig floor. The doghouse could be reconfigured/raised 6 ft to allow the DCS console and back railing to pass underneath the doghouse roof. A slot also would need to be cut in the roof to allow the mast to travel to starboard the full distance. In addition the derrick would require some modifications to allow the mast to clear several derrick beams at the 45 ft level in the derrick. In addition to the above, the DCS handling dolly tracks would need to be mounted flush in the rig floor. Presently the 12 in. tall "I" beam tracks are obstructions that hamper routine operations, and the port sections of track have to be repeatedly assembled and disassembled during drill pipe tripping operations. It is also necessary to repeatedly remove the 8000 lb iron roughneck from the rig floor each time the DCS platform is positioned over well center.

As mentioned above, the considerable time required to rig and wire up all of the equipment on the DCS platform makes it a worthwhile consideration to install the DCS and required support hardware on the preceding leg before the DCS is to be used. Otherwise an inordinate amount of operational time on a science leg would be used bringing the system up to a fully operational status. Once the DCS is initially assembled, the DCS could be stored on the starboard side under the modified doghouse, and all systems could be brought on line without hampering routine coring operations on the preceding leg. If adequate floor space were available, this also gives rise to the possibility that if the DCS was to be scheduled for several legs or portions of several legs, the system could remain on the ship indefinitely, saving considerable rig-up time and providing much greater utility of the DCS for the scientific community.

Phase III : Design and Implementation of a Drill-String Tensioning System

There is still a great deal of work to be done in the long term to make DCS safer and more efficient. The two primary tasks are:

1. The working platform must be removed from the derrick to eliminate working hazards and improve drilling efficiency.

2. The ability to utilize 30 ft joints for tripping, drilling, and coring and hence to core full 9.5 m sections must be developed.

Fortunately, the solution to both of those problems may lie in one common concept: a drill-string tensioning system which would allow the entire 5 in./5-1/2 in. string to be suspended below the rotary table. That would make the DCS operation very similar to the other coring methods routinely used on the ship, i.e., all personnel are on the rig floor handling 9.5 m cores and core barrels.

As far as a possible timetable is concerned, it is envisioned that the effort may require 12–18 months from concept through installation. There are several ideas already proposed, and there will be several more that no doubt will be developed and considered. It should be realized that the reinstallation of the ship's original riser tensioners is not necessarily the only possible solution.

As in the development of the DCS, ODP will solicit input from a variety of sources, and SEDCO/FOREX should be involved both from an engineering and review standpoint as well as from the ultimately important perspective, personnel safety.

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APPENDIX

Diamond Coring System Work List I

Prior to picking up the platform, tasks on this check/work list were performed in advance of the first bit run.

1. Charge accumulator bottles and pre-charge accumulators for drill rod string weight (charge pressure to be approximately 750 psi).
2. Plug in rod oven.
3. Select tools to take up on platform.
4. Load drill rod basket.
5. Check shock cylinder reservoirs.
6. Test heave compensator.
7. Fix SPM counter.
8. Install safety belt lanyards.
9. Locate hand-rail bolts, put in tool box on platform.
10. Check temperature gauge.
11. Replace nitrogen bottle on rig floor.
12. Get spare Cavins rubbers and cups for platform.
13. Review hydraulics with rig mechanics.
14. Bleed hydraulic lines for standpipe gauge and sandline weight indicator.

Diamond Coring System Work List II

Prior to picking up the platform for the second bit run, the following tasks were performed.

1. Load cell zero calibration (one load cell had drifted 0.7 V).
2. Plumb bottom hose back to tank on bleed valve.
3. Adjust top drive controls.
4. Fix platform 120 V outlet/light circuit. Install fluorescent light fixture. (3 amp fuse blew; replaced with higher amp fuse.)
5. Consider making filter adapter for hydraulic system (filter head had two threads and would accept both types of filters).
6. Top off nitrogen bottles on platform.
7. Top off hydraulic oil reservoir as required.
8. Install position indicator for new heave compensator system.
9. Install bolts that were sheared in umbilical bracket.
10. Repair doors on power pack so they will open. (Also: added bolt on feature to aft shock cylinder guard (tacked in place); cut hole in grating for easy access to oil filler cap; installed fold-down seat for driller; modified secondary top drive stops to compensate for primary stop extension modifications done on first bit run.)
11. Considered attachment of Varco top drive cables on bottom of mast; decided against.
12. Trouble-shoot upper wireline sheave TOTCO pick-up (jumper cable was found to have two wires connected to wrong terminal).
13. Put swivels on tuggers.
14. Modify Cavins rubbers to provide better seal.

Diamond Coring System Work List III

In preparation for deploying the DCS at ENG-6 (Site 810), the following tasks were performed.

1. Top off hydraulic oil and nitrogen as required.
2. Fix hydraulic hose bundle.
3. Install other fold-down seat of forward side of platform.
4. Cut opening in 1/8 in. plate for access to oil filler cap.
5. Adjust fleet angle compensator weights.
6. Build guard to protect feed cylinder hoses from the wireline when running the sinker bar assembly down to the rig floor(s) for various operations.
7. Install a small work platform (already built) on the forward side of the DCS platform for working on the filter system; install inertia-type safety belt.
8. Grease everything in sight in accordance with manufacturers' instructions.
9. Grease sandline sheaves.
10. Grease coring sheave bracket and grind paint off.
11. Modify clamshell with centralizing ring.
12. Disassemble and inspect oil saver (piston and seals); clean ball latch, grease, and reassemble.
13. Check all guide dolly rollers for wear and replace upper aft guide dolly roller.
14. Tape up DC cable where nicked.
15. Repair oil temperature switch.