Re-thinking MODU jack-up raising systems

Virtually all jack-up Mobile Offshore Drilling Units (MODUs) built in the last forty years have used rack and pinion drives to raise and lower their drilling platforms. As these jack-up drilling units have become more massive these raising systems have reached their practical limit and re-thinking of the raising and lowering systems for jack-ups is mandatory before larger rigs are designed for deeper water depths.

Even though great strides have been made in the design and refinement of rack and pinion drives, it is impossible to overcome the extremely high stress between the spur gear and the rack and the unequal loading of the multiple spur gears with the present designs. By using new computer technology coupled with old proven methods, hydraulic cylinders, a new jacking system has been envisioned which overcomes the inherent problems of the present systems.

Jacking systems of the past

In 1955 the U.S. Army Corps. of Engineers constructed radar stations along the New England coast, which were commonly referred to as 'Texas Towers'. In constructing these radar stations, the radar platforms were lifted on supporting legs, using hydraulic cylinders. While the legs and the platform were pinned together, a number of hydraulic cylinders were manually attached between the supporting legs and the platform. The pins holding the platform stationary with respect to the legs were then removed, and the hydraulic cylinders were pressurised to extend their pistons and raise the radar platform. At the end of the pistons' stroke, the pins to hold the platform in position with respect to the supporting legs were manually replaced. The hydraulic cylinders were then manually reattached between the platform and the legs, the pins were again manually removed and the hydraulic cylinders operated to raise the platform once more. This procedure was repeated again and again until the platform was lifted to its desired position. This method of raising the platform was labour-intensive, slow and expensive.

Jacking 40,000 T

The increasing need for oil and gas has led to extensive offshore exploration. Such drilling operations are accomplished from mobile offshore drilling units (MODUs), generally submersible, semi-submersible and jack-up types.

Jack-up MODUs are massive structures which can have platform surface areas as large as two acres to support the drilling equipment, drilling supplies, power sources, living quarters, helicopter landing port and the stores and fuel that are necessary to maintain a drilling crew and operate the MODU and its drilling equipment, hundreds of feet above the seabed. Jack-up MODUs use a variety of leg designs, mostly three legs, that are moveably engaged with the MODU platform. Following their construction, such MODUs are floated out, supporting the legs like a large vessel with three 700 foot tall masts. Once the MODU is positioned at a drilling site offshore, the MODU legs are lowered onto spud-cans to the seabed. Thereafter the platform is lifted or jacked-up sufficiently above the water level to reduce exposure of the MODU platform to wave action during severe storms. It is not uncommon for jack-up MODUs to weigh 30,000 to 40,000 tons, or more, with the MODU platform and its variable loads comprising as much as two-thirds of the weight. In addition, it is not uncommon for the MODU supporting legs to have lengths of 600 to 700 feet, and, to provide stability in their support of the MODU platform, to have cross sections, most commonly triangular, up to 50 feet on a side. The jack-up MODUs currently in use and being constructed include, as the apparatus to adjust the relative position of the MODU platform and MODU supporting legs, a number of motor-driven spur gears, which engage toothed racks running the length of each corner leg chord of each support leg. The leg chords that comprise the corners of the support legs of such currently existing jack-ups are constructed with a central toothed rack of expensive high strength (e.g., 100 KSI) steel, running the length of the supporting leg, with rigid semi-circular, tubular structural members welded along both sides of the toothed rack to increase the strength, section modulus and rigidity of the leg chords. Because the spur gears engage the toothed racks of the leg chords in raising and lowering the MODU with respect to the platform support legs, the spur gear teeth and the teeth of the leg chord racks have cycloidal cross sections, and the spur gear drives are each engaged with the leg chord racks by line contact between a single tooth of the spur gear and a single mating tooth of a toothed rack, exposing the teeth of both the spur gear and the rack to extremely high shear forces and requiring that the spur gears and the toothed rack be made of an expensive high-grade steel, with a modulus of elasticity, for example, of 100,000 pounds per square inch (100 KSI). Because of the great weights being handled and the high stress engagement between the spur gear teeth and rack teeth, as many as 18 spur gear drive units may be engaged with the six toothed racks on each supporting leg. In such systems, the plural spur gear drives are mounted vertically in sets of three units, one above another, so their pinion gears can engage the toothed racks that comprise the leg chords; however, the load is unequally shared by the plurality of engaged pinion gears, the lowest pinion gear and its engaged rack tooth carrying a significantly disproportionate part of the load. Because the tooth loading in current spur gear driven jack-up MODUs is approaching the stress and fatigue limits of the available materials, complex controls for the electric motors of the spur gear drives have been developed in an effort to equalise the loads that are borne by the engaged gears and the associated stresses and fatigue. Such equipment controls the torques generated by the electric motors to balance the loads on their pinion gears and gradually accelerate and decelerate in an effort to avoid over-stressing and fatiguing the engaged teeth. Further, during operation of the spur gear drives, grease must be mopped onto the rack teeth by the crew to reduce the friction between the pinion gears and the leg chord racks. And the grease inevitably falls into the sea.

In addition to requiring expensive controls, materials and manufacturing procedures, spur gear-driven jack-up MODUs also require expensive separate locking apparatus for each supporting leg to maintain the MODU platform in a stationary position with respect to its supporting legs. The jacking systems of jack-up MODUs are currently expensive to design and manufacture and are not expected to satisfy future requirements. There is an increasing demand for larger jack-up MODUs with dramatically greater topside loads. The ability to meet this demand has, however, approached its practical limit with existing materials and technology, and a new jack-up MODU and MODU jacking system is needed.

Jacking systems next innovation

A new system that can reliably handle loads several times greater than can be currently handled, can be readily and inexpensively designed and scaled for different jack-up loads, and can save millions of dollars in the manufacture of a single jack-up MODU. By using continuous linear motion motors, engaging the MODU support legs to provide relative motion between the MODU platform and its supporting legs, and to also maintain and be able to lock same in a stationary relationship, a new jacking design can be accomplished. As used herein, the term 'continuous linear motion motor', refers to a number of hydraulic piston/cylinder units N, whose piston operations are phased so that N-1 of the combinations of piston/cylinder units are engaged with a support leg and providing relative motion, while one of the piston/cylinder units is disengaged and being repositioned for re-engagement with the supporting leg to continue the relative motion. The new system design thus permits a MODU platform to be automatically jacked up hydraulically with continuous motion, avoiding the excess forces needed to overcome static friction and to accelerate the heavy masses of the MODU.

A Programmable Logic Controller (PLC) to jack the MODU up or down, or to lock the MODU in any stationary position is used. Such a combination of continuous linear motion motors are substantially less expensive than a comparable combination of spur gear drives, electric motors and gear boxes.

A multiplicity of teeth are engaged in providing relative motion (and in lifting the MODU platform) at any given moment of time, eliminating high tooth stress by spreading the load imposed by the large weight of the MODU. Furthermore, in the new design, the teeth of the rack engagement members being driven by the pistons of the hydraulic cylinders, and the teeth of the many racks being driven thereby are formed with substantially planar engagement surfaces that spread the stresses from the driving forces uniformly over and through the engaged teeth, and the substantially planar engagement surfaces of the engaged teeth are preferably angled to be normal to the central axes of the pistons within the central portion of the pistons' movements.

In another aspect, the new design eliminates the large forces acting transversely on the toothed racks of the leg chords of the support legs in the previously used spur-gear driven jack-up systems and eliminates the solid toothed racks of expensive, high modulus (e.g., 100 KSI), steel that extend centrally through each leg chord and provides, instead, a leg chord comprising tubular columns with one or more toothed racks of a steel with significantly reduced modulus of elasticity (e.g., 34-58 KSI) welded on their sides, permitting the jack-up leg chords to be reconfigured to have equal or greater section modulus with less cross-sectional area, permitting huge weight and cost savings.

Without a full structural analysis of the jack-up rig leg chords, the exact savings for using this new design concept can only be estimated. Typically, a jack-up rig with three legs and three cords per leg require each chord to have an area of about 278 sq. in. Since the forces reacting on the rack in the new design concept do not require a member to resist crushing of the tube comprising the leg chord member, the steel in the leg chord member can be used more efficiently.

A typical leg chord member would be approximately 24 inches in diameter. By assuming the axial stress requires 50% of the total stress on the leg chord, the Section Modulus required to have a leg of the same strength can be calculated for a chord section without an internal member. In this calculation a 24 inch diameter section will be used. The larger the diameter of the leg chord the bigger the weight savings and the larger the percentage of leg chord stress due to moment the bigger the savings in weight.

Formulae:

$$F = P(f)(.50)/A+M(f)(.50)/S$$

Where

P = axial force (lbs.) $P = 278\ (10{,}000)$

A = area of chord (in^2) $P = 2{,}780{,}000$

M = moment in chord (in-lbs.) $M = 10{,}000\ (866)$

S = section modulus (in^3)

F = total stress =20,000 psi

866 = S of leg chord with 278 sq. In. of area including 7"x 16.58" cross member

Calculate the Section Modulus and Area for a chord member with a 3.71 in wall with the same outside diameter:

$$A = 3.14(24^2 -16,58^2)/4=236.49$$
$$S = 3.14(24^4-16.52^4)/(32)(24) = 1052.50$$

Calculate total stress in chord member:

$$F = P/A+M/S$$
$$F = 278,000/236.49+8660000/1,052.50$$
$$F = 11,755+8,228 = 19,983 \text{ psi} < 20,000 \text{ psi}$$

Calculate the weight savings in lbs. and the cost savings in U.S. Dollars using approximately $2.50 Dollars per lb.:

Weight Saved = (278 - 236.49)(12)(490)(650)(9)/(1728)=847,807 lbs.

Cost Savings ($) approx. = 2.50 (84,7807) = $2,119,518

This new design concept eliminates the requirement to use special high-tensile strength (e.g., 100 KSI) steels in the toothed racks and in the plurality of piston-driven rack engagement members. In addition, where the plurality of piston/cylinder units are pivotally mounted to the MODU, the angled substantially planar engagement surfaces of the teeth generate forces resisting the disengagement of the engaged teeth of the rack engagement members and toothed racks when the pistons are substantially retracted within their cylinders to assist in locking the MODU in a stationary position, and the angled substantially planar engagement surfaces of the engaged teeth of the rack engagement members and toothed racks generate forces assisting the disengagement of the teeth for repositioning of the rack engagement members at the end of the pistons' stroke. In the new design concept, the driving piston/cylinder units, for at least each leg, are subjected to the same hydraulic pressure when providing relative motion between the MODU and its supporting legs, and any restriction to movement that may result in the exertion of increased pressure on one set of teeth results in increased pressure on all of the acting cylinders, thereby overcoming the restriction to movement without an excessive and unequal force being exerted against any one set of teeth.

As indicated above, the new design concept further includes a locking mode wherein all of the pistons are retracted substantially entirely within their cylinders, with their attached toothed rack engagement members engaged with the toothed racks, and providing, in their engagement, forces resisting their disengagement. The locking mode of operation eliminates the expensive separate locking apparatus for each supporting leg that are necessary in current spur gear driven jack-up systems and engulfs the cylinder piston rods in oil which eliminates corrosion during well drilling operations.

The new jacking system

A method of jacking a MODU without interruption, comprising the necessary hydraulic piston/cylinder units, toothed racks fastened to the required number of MODU supporting legs, capable of withstanding the maximum load W and providing a number of toothed racks R, and selecting a number of hydraulic piston/cylinders N, having commercially available diameters d; while providing a source of hydraulic pressure P, said selection of the number R of toothed racks, the number N of hydraulic piston/cylinders per rack, and the diameter d of the pistons being defined by:

1 PRd 2 (N - 1) 4 W

The number of toothed racks and engaged teeth necessary to carry the maximum weight W of the MODU platform and all of its topside loads may be determined by:

SxTxN>W

where S is the acceptable tensile stress of the material from which the engaged teeth will be manufactured, T is the total root area of the engaged teeth of each toothed rack and N equals the number of toothed racks. The total root area T equals the tooth pitch of the engaged teeth times the number of the engaged teeth (i.e., TxN). The total root area T may comprise as large an area as necessary to permit the use of readily available and inexpensive steels having modulus of elasticity, for example, on the order of 34-58 KSI, thereby eliminating the requirement for use of the special high strength steels required by the spur gear drive systems of the rack and pinion raising systems.

In a continuous linear motion motor the geometric relationship of tooth pitch, vertical cylinder stroke, vertical distance between base mounting pins of cylinders, number of cylinders used, and cycling arrangement must meet certain geometric criteria for satisfactory operation. When configured as described below, the jacking operation will move the legs of the jack-up rig up or down in relationship to the jack-up platform and will lock the legs in position for extended periods for drilling operations or for transit.

Example of typical calculations

Step 1:

Calculate the total number of cylinders required at each leg to raise the jack-up platform, including safety factor. The number of cylinders must be evenly divisible by the number of leg chords. This result must be the next higher even number.

54 cylinders in sets of 2

Step 2:

Divide the number of cylinders by the number of leg chords. (9 leg chords for 3 triangular legs)

54/9 = 6 in sets of 2

Step 3:

Add one set of cylinders per leg chord.

6+1 = 7 sets of cylinders

Step 4:

Select the desired tooth pitch (AT@) by calculating acceptable bearing stresses on the chord teeth.

3 inch pitch

Step 5:

Multiply the tooth pitch (AT@) by the number of cylinders on each leg chord to find (AV@) the vertical travel of the tooth (or teeth) engaged with the chord rack.

V = T x 7
V = 3 x 7
V = 21 inches

Step 6:

Calculate the vertical distance between the base pins of the cylinders (AD@), i.e. mounting distance by subtracting maximum tooth pitch from the vertical travel of the tooth engaged with the chord rack.

D = V - T
D = 21 - 3
D = 18 inches

Step 7:

The piston travel S is then determined and will form the result and the mounting geometry. Since the cylinder may be mounted with the cylinder base pin outboard from the rod end pin AS@, the cylinder stroke, will be larger than AV@.

Plc controls & electro-hydraulic system

The preceding discussed the structural and mechanical improvements of the design. In conjunction with these improvements and inclusive of the patent features are significant improvements made to the current jacking control systems and are discussed and described in further detail below.

The following describes the operation of a three-leg Programmable Logic Controller (PLC) and Electro-Hydraulic jacking control system with central and remote PLC station control capabilities. While the design discussion uses a three cylinder (CLM) configuration per rack chord section, other designs may involve a greater number of cylinders i.e., five or seven to complete the CLM required for a specific design.

The three-leg jacking PLC system control has six components. The first component is the Main Control Desk which houses the power supplies for the rest of the system as well as the Main Control Relay (MCR) for the entire system. This unit must have power at all times for any of the five other stations to operate. However, communications between the panels does not need to be present to operate the system. If communications between the panels fail, each station can be operated independently. The main control desk can control the entire system, provided there is communication between the panels.

After the Main Control Desk the Main Control Console (MCC) PLC unit is the next station that has to be operational. This unit starts and stops the motors from the Main Control Desk. To start a motor manually the control switch on the MCC bucket for the corresponding motor must be in the manual position. Once all needed motors are running the Hydraulic Power Unit (HPU) PLC Station, used to control the HPU, has to be activated. This unit can also operate independently or from the Main Control Desk. To operate the unit independently, the station control switch on the front of the panel must be turned to the 'Activate' position. This will take control away from the main desk and enable the push buttons on the front of the panel.

The final three stations are the Leg PLC Stations, which control each leg. Once the other units of the system are running the leg stations can be operated either locally or from the main desk. The remainder of the Leg Stations functions are like that of the HPU Station with the exception of the Panel display found in the door. This display will relay operator messages and faults present in the system, provided all panels are communicating. The fault will correspond to a fault that can be looked up in the Main Control Desk. All Stations have an Emergency Stop Button located on the door. These buttons will interrupt power to the MCR, which will in-turn remove all output power from the remote units, and stop the system in a fail-safe mode.

As discussed the control system is comprised of a Programmable Logic Controller (PLC) that monitors and allows the operator to perform all jacking operations from a central control location. Located at each leg is a subsystem set PLC for interface of all the functions for that particular leg. The main control communicates with the other PLCs through a high speed network and performs a redundancy check of all the functions in a real-time mode of operation. Commanding multiple variable speed Continuous Liner Motors (CLM) on each leg performs the lifting, lowering and levelling operations.

The control is based on a GE Fanuc Series 90 platform. As discussed before multiple PLCs are used to distribute the control and greatly reduce the amount of interconnecting wire. The main processor communicates to the distributed processors across a high speed communications bus using GE Fanuc EGD protocol. The remote hydraulic manifold valving is connected to the Local PLC by a Remote I/O link.

Main enclosure description

The main enclosure will be used to control normal jacking operations. The enclosure is a painted NEMA 12 stand-up desk with a stainless steel surface. The main PLC processor is located in this enclosure. The PLC system consists of a 10-slot rack, power supply, 90-30 processor, Analogue Input module and 16 point digital I/O modules (24 VDC).

A GE Fanuc Quickpanel View provides screens for operator set-up entry, calibration, diagnostics and system operation. The GE Fanuc Quickpanel View is connected to the processor by a Ethernet link.

The pilot devices, such as push buttons selector switches and pilot lights, are located on the face of the main console. They are wired to the 24 VDC input and output modules in the PLC rack.

Power is distributed throughout the control system by a series of power distribution circuit breakers and terminals located in the Main Console.

A Master Control Relay is hardwired to an Emergency Stop pushbutton on the enclosure's control surface. The Master Control Relay supplies 24 VDC output power to all remote enclosures.

Remote enclosure description

There are three identical wall-mounted enclosure stations. One enclosure station is at each leg. The leg stations include a PLC system with a processor, digital and analogue I/O, housed in a 10-slot rack. Operator interface devices, such as push buttons and pilot lights, are located on the door of the enclosure. The PLC system reads digital inputs and sets digital outputs. It also communicates by a remote I/O connection to the three CLM Valve servo drive controllers for each set of linear motors. All digital I/O operates at 24 Volts DC.

Additional equipment contained in the enclosure includes a +24 Volt DC power supply for Digital I/O power, a +5 Volt DC power supply for encoder power, interface terminals to connect remote devices and an electric heater to maintain the interior temperature of the remote enclosure.

Scan times for the system are expected to be less than 50 msec so reaction to an operator's command or feedback data to the operator is considered more or less instantaneous.

Digital

The processors in the individual Leg enclosures read digital inputs and pass the information to the main processor. The digital inputs include operator input devices (pushbuttons and selector switches). Digital outputs include operator interface devices (pilot lights and a digitally controlled message display unit).

Operator controls include Station Activate pushbutton, De-Activate Station pushbutton, Motor Start/Stop 2-position pushbutton (pull to start/push to stop) and Jog Up / Jog Down controls for the leg.

Analogue

The Leg control PLC systems read analogue input from Load Cells and Liner transducers. The load cell measures the load at each of the cylinders of the CLM jacking assembly, additionally position feed back signal is also read for each cylinder. The clamping cylinders are monitored in the same way as a feed back signal. All this information depending on the operational mode: jacking up/down, lock-off, storm, transit is used for co-ordination of the system and monitoring of the loads.

In addition to the analogue inputs, there is an encoder input for each of the legs. The encoder monitors the position of the leg. The PLC system uses this information to determine the depth each leg has been lowered, the air gap of the rig, and the rate of speed between the rig's hull and the leg.

Drill rig legs can be controlled from the Main Enclosure or from any of the remote stations. The main enclosure can be used to lower or raise all of the legs together or each leg independently. The remote stations can only control the leg to which they are connected.

In the event of a communication loss between the main processor and the remote stations, independent operation of the legs is still possible at the remote stations , safety lock out switches are utilised to prevent operation without notice given to the responsible personal on the rig.

Screens

This section highlights some of the main screens in the system. The main menu allows the operator to access the various screens. The operator may select the desired screen by pressing the designated function key located on the keypad under the screen.

Motor Screen

The Motor Screen allows the operator to start the electric motors. There are three screens for electric motor starting to control operation of the HPU.

Set-up

The set-up screen allows input of operation variables.

Leg control screen

The Leg Control Screen displays the status of each leg (speed, position and force) along with the air gap. This screen is normally viewed when the legs are being extended or retracted for raising, levelling or lowering operations.

Additional standard screens

The Offshore Source control system provides additional standard screens for diagnostics and troubleshooting. They include PLC input and output screens that provide the ability to view the state of system digital I/O and motor diagnostic screens that provide the ability to view the command and feedback for all CLMs.

The hydraulics subsystem and PLC controls are designed to be redundant and meet all the Certification requirements and operational standards with respect to ABS, Lloyds etc….

There are five modes of operation for the jacking system control. The first of them, the warm-up mode, is used to generate heat in the oil throughout the system to get the oil temperature up to a safe running level. Next the system has raise and lower legs modes, each, which has an auto or manual procedure for operating the legs. This mode is used to raise or lower the legs to and from the seabed. To lift and lower the rig out of and back into the water there are separate raise and lower modes.

Motor starting

Motor starting can either be done locally at the Motor Control Centre or remotely from the Main Control Desk. To locally start the motors at the MCC the corresponding bucket for the motor being started must be in the manual position.

Starting the motors from the Main Control Desk is done with a push of the 'Start Motors' button. Pressing the 'Start Motors' button will automatically start all the systems motors in correct order, provided all the safety conditions are met.

If all the conditions are met the auto start sequence will commence and the 'Start Motors' light will flash until all motors are started, then it will remain on lit. To stop all motors in auto sequence press the 'Stop Motors' button and the auto stop will begin, starting by stopping the main pumps. During the stop sequence the start light will flash again, but much slower this time. Once all motors are stopped the light will go out and the emergency stop can be pushed to turn off the control power.

In the case that a pump motor is running and boost pressure drops below the recommended level or the inlet valve is closed, the corresponding pump motor will shutdown automatically. If the pump that shut down was one of the boost pumps the remainder of the motors will also stop.

Warm-up mode

Before any movement can take place the oil in the reservoir and pipes needs to be at an adequate operating temperature. To run the warm-up mode the following conditions must be met and maintained.

By pressing the 'Warm Up' button on the main control desk the rig will automatically cycle through a warm up sequence. The 'Warm Up' button will start to flash and will remain flashing until the sequence is complete. In this sequence the boost pump is started automatically, provided all safety conditions are met. The boost pump will run for a time until the temperature in the reservoir reaches 30ºC. Pimping the oil from the boost pump across a relief valve generates the required heat.

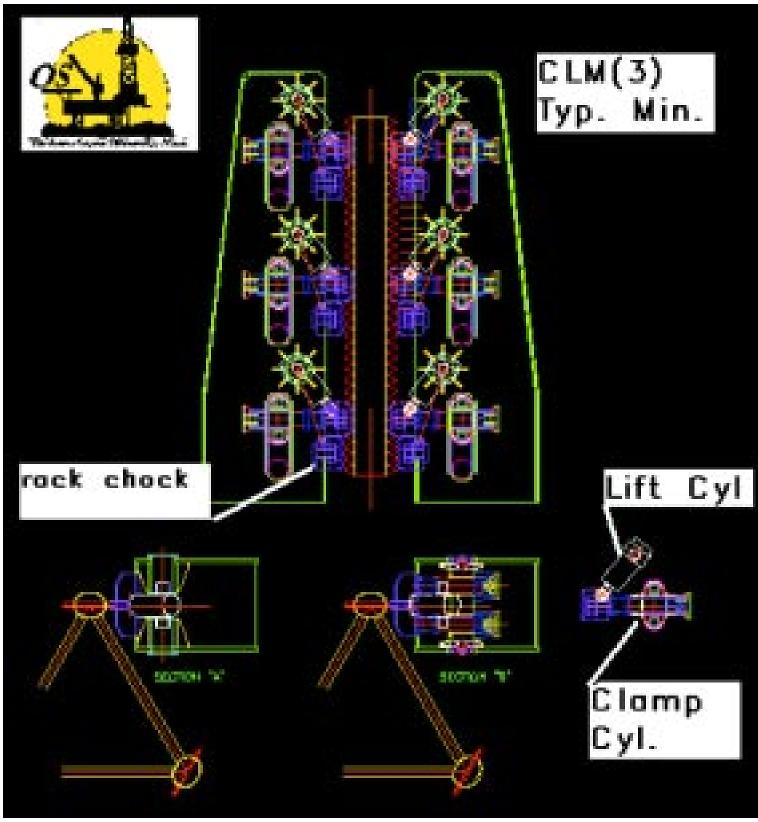
When the proper operating temperature in the reservoir is achieved, the PLC will choose a main pump to start, provided all safety conditions are met. The corresponding load solenoid energises, which loads the pump to full system pressure. The oil is circulated from the selected pump through the piping to the motor control manifolds. At the motor control manifolds, solenoids are energised. This allows warm oil to circulate from the reservoir to the motor control manifold and back to tank. This allows pilot pressure from the boost pump to go through the Speed Control Manifold and back to the reservoir. The circulating of warm oil through the pipes and manifolds will operate for a specified period of time based on the lengths of pipes. Once this procedure is complete, the 'Warm Up' lamp on the main operator's desk will stop flashing and stay lit, to let the operator know that the jack up rig is ready to be operated.

Lower legs

Legs can be lowered individually from the Main Control Desk or at the local leg station, or automatically at the Main Control Desk. In most cases the auto mode will be used, from the Main Control Desk.

Auto lower

To perform an Auto Lower the selector switch for operating the legs all together or individually must be in the 'Operate All' position. The operator then can initiate the control to lower the legs by holding the key switch on and pressing the 'Auto Lower Legs' push button. All of the main pumps that are running are loaded by energising solenoid for pumps 1, 2 and/or 3 respectively. Before the chocks are released, the legs are pressurised in the 'up' direction. The servo valve is driven towards the up direction for the leg. The pressure generated by sending the pump flow to the hydraulic cylinders in the up direction is sensed in pressure transducers. Liner transducers for position control will monitor the leg movements. The chocks are then energised for use; remaining at their home position (locked) each CLM is auto positioned for jacking mode to a 120 degree phase separation (0-120-240 degrees) provided sufficient pressure is present at each leg. The rack chock cylinder for the cylinder to be repositioned is released and pressurised by energised solenoids. This is only allowed if there is no pressure present in pressure transducers or the non-load side of the CLM. Directing flow from port P to A on the servo valve lowers the legs. The pressure in Port 'A' pilots open the counterbalance valve CB1 that allows the oil that is holding up the leg to flow through from Port B to Port T on the servo valve. The



rate at which it flows is dictated by the command to the servo valve.

It can only come down as fast as the pumps can fill port A of the cylinder. If the cylinder (CLM) starts to go faster than port A can be filled, the pressure on the port A will drop to zero and the counterbalance valve will close not allowing flow across it. The legs continue to lower until they reach the seabed. Each leg may reach the seabed at different times. Once a leg reaches the seabed the pressure in transducers load side will decay and the pressure in transducer non-load side will rise. This is the indication that the leg is on the seabed. At this point the control will drive the leg down for a timed period and a minimum pressure reading to ensure that the spud can is secure in the seabed. Once the set time and pressure is achieved the counterbalance valve will reset on this leg. The first leg will remain in active jacking standby mode and wait for the other legs to reach their seabed position. All three legs must reach the seabed and the counterbalance valves **must** be applied before this mode of operation is completed.

Manual lower

Lowering the legs manually can be done from either the Main Control Desk or locally at the leg. To operate a leg manually from the Main Control Desk the selector switch for operating the legs all together or individually must be in the ‘Operate Individual’ position. The operator then can initiate the control to lower a leg by holding the key switch on and pressing one of the lower leg push buttons on the desk. There is a separate button for each leg. These buttons must be held in for the leg to keep moving; releasing the button will stop the leg. The control will send 50% command to the leg for the first three seconds the button is held in, after that the command switches to 100%. The remainder of the control works the same as it does in the auto mode. To operate the leg from its local control station the switch on the front of the local station box must be turned to the ‘activate’ position. This enables the controls at the leg and takes control away from the Main Control Desk. The controls at the leg operate the same as the ones at the Main Control Desk In the manual mode it is up to the operator to observe the seabed pressure transition to CLM1 and stop the sequence

NOTE: If the legs are lowered to the seabed by means of individual move you MUST use Auto Lower to complete the seabed contact sequence.

Raise platform

The platform can be raised with each leg individually in the same manner that the legs were lowered. However, if the platform is raised individually at the local station boxes there is no tilt error in the control. If the platform is raised with the legs individually or together from the Main Control Desk, tilt error checking will be active. Before the platform can be raised the following conditions must be met.

Once all the above criteria has been achieved, the “Ready to Lift” light on the Main Control Desk will light to indicate the platform is ready to be raised. If one leg or all of the legs are switched to the local control mode, operation from the Main Control Desk is not possible. There are two ways to operate the Lift from the Main Control Desk each leg individually or all legs together.

To raise the platform with each leg individually make sure the selector switch for Individual/All mode is in the ‘Individual’ position. Tilt warnings are active in this mode even though the legs are being operated individually. If the platform begins to tilt more than the ‘tilt stop’ set point, set on the Quickpanel View, the control will automatically stop the lift. Raising the platform with all legs together can be achieved by having the selector switch for Individual/All mode is in the ‘All’ position. The joystick and the right side of the Main Control Desk can then control operation of the lift. The farther the operator pulls back on the joystick the faster the hydraulic CLM will lift, speeding up the lift. In this mode the legs’ speeds are controlled to keep them synchronised while lifting, typically no more than a half of a degree max. Returning the joystick to the neutral position will stop the flow of oil to the hydraulic CLMs.

As a lift begins the rack chocks are energised until the needed pressure to hold the platform up is applied to the legs. This can be done with one, two, or three main pumps running. The three servo valves open flow from Port P to Port A. The servo valves are only opened enough to build pressure and not enough to raise the platform. Once there is adequate pressure on the CLM the rack chock for the are activated by energising solenoids. The CLM repositions to jacking mode, and cylinders are set to 120 phased (0-120-240) After the rack chock reaches its home position, first phase of the platform motion can begin. The servo valves are opened from Port ‘P’ to Port ‘A’ as much as is necessary to achieve the desired speed. The speed is determined by the position of the joystick. The farther the operator pulls back on the joystick the faster the hydraulic CLM will lift, speeding up the lift. The Platform continues to rise to the level desired by the operator. After the platform has reached the desired level, the joystick is returned to the zero speed position, which returns the servo valves to the blocked centre position. The Rack chocks are then reset by de-energising solenoids and repositioning of the CLM to lock-off mode.

Lowering the platform and raising the legs from the seabed is a direct reversal of the above described operation.

Lock-off mode

Basically this is the rest position of the cylinders when not doing active lift and lower operations. The added aspect of this mode is that it functions and performs the same duties as a conventional lock-off system of transferring the load of the vessel directly to the vessel legs. In this mode all CLMs are in a home position ('0') where the rack chock, CLM or cylinder and the jack stand frame are all solid or form a direct load path for the load transfer.

Storm mode

In this mode of operation severe weather or storm conditions are expected and the rig is non drilling, rig for storm conditions. The CLMs are left in the lock-off mode for proper load transfer and the system is activated to place a minimum amount of hydraulic fluid on the top or load side of each cylinder, a manual three way valve located at each jack stand structure is positioned to storm mode position, normally the valve is manually locked in normal operating mode. Once in storm mode there is a open communication pilot line to a hydraulic accumulator, the accumulator is designed to dampen any shock loads applied to the system and allow it to balance the loads between all CLMs equally.

The PLC and Electro-hydraulic controls for this jacking system brings the operation of jacking a platform to current day standards of technology. PLC controls have been used with great success in many industries including the drill floor automation processes and production platform process offshore for a considerable period of time. The jacking systems of the resent past all used much older 1970 technologically inferior systems. The present control system technology is PLC based and proven by design and application on jack-ups.

Combining the advancement of the suggested rig elevation systems mechanical, structural and controls provides to the industry a significant improvement in technology as well as considerable cost savings as compared to present day systems.

Re-thinking of a jack-up drilling rigs jacking system has defined many mechanical advantages as discussed above. Many subtle advantages, although important to the design of the rig, are not as apparent as the mechanical advantages. The centre of gravity of the weight saved, due to the elimination of structural members in the chords, is located approximately 350 feet above the rigs deck, when the rig is in transit. By lowering the centre of gravity of the rig the distance between the Metacentric Height and the centre of gravity is increased. This significant change makes the rig more stable by increasing the length of the rigs righting arm, or additional length can be added to the legs, or the size of the rigs hull can be reduced.

By adjusting the volume of hydraulic fluid flowing from the variable volume hydraulic pumps, supplying fluid to each leg, the raising or lowering rate of the rig may be adjusted. Using the Programmable Logic Controller (PLC) in the control house, the rigs operator can determine the load reaction on each leg, determine the raising rate of each leg, and determine the effect of storm loading on the rig.

It is estimated that construction costs of one jack-up drilling rig (MODU) can be reduced by about $10,000,000 by designing the jack-up rig using the system described in this report.

This MODU jacking system has been patented in the U.S. by patent No. 6,652,194 issued in November, 2003 and patents have been applied for in other countries.

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Chart: 36 Pinion System Comparison

Comparison of features of the proposed design vs a conventional rig jacking system
Design series - 36 pinions (@ 1000 Kips per pinion 350-400 ft water depth

.	Conventional	Hydraiack
Gross wt leg chord (lbs.)	5,533,938	4,707,629
Area req. W x L x H	10.4x15.6x18.7	2.6x9.3xl 2.1
Centre of gravity (ft)	9.3 + lock	6.05
Rack width required	10 in.	5 in.
Rack replacement est.	yes	no
Reduction in leg wt.	0	(847,807)
Material strength requirements	100 ksi	60 ksi
Lock-Off Device	extra cost/equipment	included
Design life	20 years	25 years
Leg sect. Strength req.	1052	1052
Class Certifiable ABS, DNV	Yes	Yes

Economics (Savings) based on 2004 1st Otr. survey

Rack material cost ($/lb.)	$1.30/lb (90ksi)	$1.00/lb (50-60ksi)	
Rack material cost rig	$4.57 mil	$1.9 mil	($2.6 MM)
Leg construction cost	$13.8 mil	$ 11.76 mil	($2.1 MM)
Jacking system cost Est.	$ 8 mil	$ 6	($2 MM)
Future rack replacement cost	$4.57 mil	$0 (no wear)	
Lock-off cost	$ 3-4 mil.	$0 - Included	($3 MM)

Total rig construction cost savings			**$9.7 MM**

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PET

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James E. Ingle P.E. graduated from Rose Polytechnic Institute (now Rose-Hulman Institute of Technology), Terre Haute, Indiana, in 1953 with a Bachelor of Science degree in Civil Engineering. He is a Registered Professional Engineer in Indiana (No. 09188) and in Oklahoma (No. 12987) and Registered Professional Land Surveyor (retired) in Indiana (No. 10058). During his career, spanning over 50 years, he has been engaged in the successful engineering of unusual and innovative projects for the offshore oil drilling industry, the inland waterways system, and the road building and mining industries, and has been responsible for conceptual designs, preliminary engineering, final engineering, estimates, specifications, contracts, selection of contractors, quality control and initial start-ups of major projects, some of which exceeded $100,000,000 in construction cost.

As a result of working with the design and construction of barges, towboats and mobile offshore drilling rigs, he is knowledgeable about the rules of the US Coast Guard, the American Bureau of Shipping, and foreign shipping certifying organisations. He has been a member of the American Bureau of Shipping Advisory Group, API, IADC, OSPE, ISPE and he has served as President of the SW Chapter of the Indiana Society of Professional Engineers and as a member of the Monroe County Plan Commission, Storm Water Management Board and the Monroe County Drainage Board.

For much of his career he was employed by Transworld Drilling Company and Transocean Drilling Company, subsidiaries of Kerr-McGee Corporation, one of the largest domestic oil companies, and he successfully completed many major projects.