A new concept drilling hoisting systems rigs

Jan Artymiuk [1]

Koncept nového systému zdvíhacieho zariadenia vrtnej súpravy

In rig constructions two nev designs have been introduced apart from the conventional hoisting system. The first one is the Maritime Hydraulics A.S RamRig© drilling concept, based on hydraulic cylinders as actuators powered by up to 3.4 MW of hydraulic power in a closed loop hydraulic system. This synthesis of the well-known technology allows for the use of integrated active and passive heave compensation, as well as the storing and reuse of energy from the lowering phase of an operation. The RamRig concept makes mechanical brakes and clutches obsolete, since hoisting and lowering of the load is controlled solely by the closed loop hydraulics. This decreases the number of critical mechanical components in the hoisting system to a minimum. Safe handling and emergency shut down of extreme amounts of hydraulic power is taking care of by cartridge valves, which make rerouting of hydraulic power possible with minor losses of transferred effect.

The second is a new land rig concept based on a patented rack & pinion drive system with a new generation of rigs which can instantly switch between the workover, drilling and the snubbing operations. The new rig concept has a direct drive, thus no drill line. The mobilization time is reduced as the rig has fewer truck loads, a faster rig up and a higher automation level. One land rig currently under construction will be the world's first single operator unit, with a full pipe handling capability and a fully automated control system. The rig is fully equipped with the 250 T top drive which can be used for the rotation and snubbing, the purpose designed snubbing slips and other features supporting the multifunctional well operations. The paper will focus on features related to the land rig under construction, and how it may reduce the operational cost and improve the well performance.

Key words*: drilling hoisting systems, automated control system*

Introduction

The Rambing© drilling hoisting system, [2, 3, 4, 5, 7, 8 and 9].

Hoisting and lowering with the RamRig© is done by two hydraulic cylinders called rams instead of the conventional drawworks and derrick. The hoisting lines are parallel, fixed length, wires with one end anchored at the drillfloor, and the other end at the top drive (Fig. 1, 2). The lines are run over the yoke sheaves, transforming the push from the rams to an upward lifting force to the guide dolly and the top drive. The travelling distance and the speed of the top drive is twice that of the rams. The maximum stroking velocity of the rams is 1 m/s, allowing the Top Drive to travel 2 m/s. The powering of the RamRig is done by means of a central Hydraulic Power Unit (HPU) with eight to fourteen pumps of equal capacity. Any of the pumps can give a full hoisting force, but a lower speed, which means that the power can be saved for the majority of drilling operations. The pumps are of variable displacement type and are powered by constant speed AC motors. An additional flow can be supplied from an accumulator, which also acts as a reservoir when performing a passive heave compensation. The valve blocks in the system act as barriers sealing off different parts of the hoisting system. The valves in the manifolds are of the cartridge type. In order to evaluate the new design, which has not yet been tested full-scale, a computer simulation program has been developed based on the lumped capacity modelling in order to forecast the performance of the integrated heave compensation. The simulations as well as the limited running experience available for the RamRig show good a controllability for all loads.

The Hydraulic System-Closed Loop System. [1, 9, 10, 18, 19, 20, 21, 22 and 23] A closed loop hydraulic system normally consists of a rotating motor and a pump, forming a hydraulic transmission. The oil returning from the motor feeds the pump and the motor speed control is performed solely by varying the output of the pump. The pump varies the output and suction side by regulating the displaced oil per revolution of the pump. A good example of the conventional closed loop system is the hydraulic top drive. In the case of the cylinder based hoisting system, the motor of the transmission is replaced by a differential cylinder acting as an actuator. Different from the rotating transmission, the cylinder based closed loop system must consider a circuit returning less oil than put into the system, (which is the case when extending the cylinder), as well as handling an excess of oil, (which is the case when retracting the cylinder). To solve the problems connected to varying feeder conditions, a semi closed circuit was implemented. Each pump A- and B-side in the power unit is connected to a distribution block acting as an isolation for each pump [9]. Upstream from the distribution block, all lines are connected together and directed to the hoisting system or the top drive. The normally low-pressure side of the pump, the B-side, is connected to a charge pump

[1] *dr. inž. Jan Artymiuk*, University of Science and Technology, Krakow, Poland, art@agh.edu.pl
(Recenzovaná a revidovaná verzia dodaná 5. 10. 2006)

and a valve with a varying pressure setting. The charge pump supplies the pumps with oil when extending the cylinder. The pressure control valve controls the pressure at the B-side and returns the excess oil to the tank when retracting the cylinder. The excess oil is conditioned in a cooler and a filter arrangement prior to reaching the tank. This solution is implemented for the 14x450 kW pumps, handled by a distribution manifold containing 112 cartridge valves switching 14 pumps individually between 4 closed loop systems. Each main pump in the HPU is controlled by a closed loop regulator controlling the flow and the pressure from each pump, [9]. The set point for the closed loop control of each pump is given from by the RamRig control system.

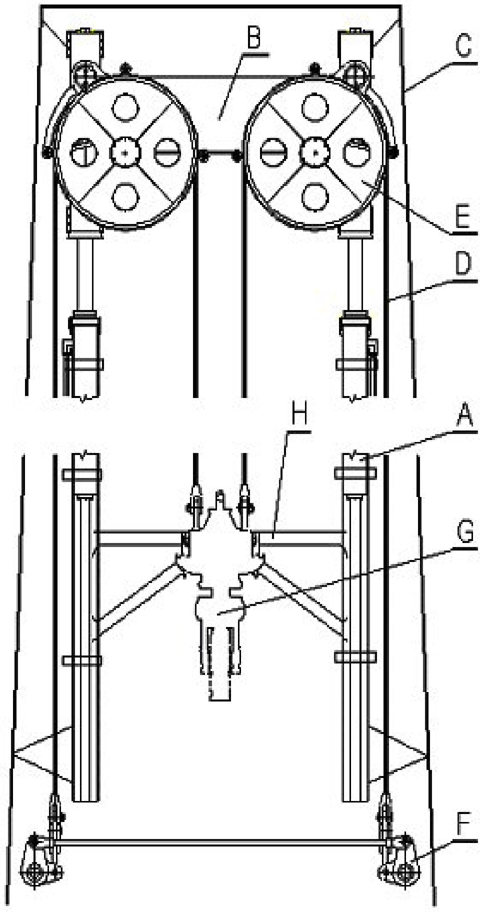


Fig. 1. The main elements of the RamRig© hoist assembly, showing the yoke (A), dolly (B), top drive (C), equalizer assembly (D), lifting wires (E) and the ramcylinders (F)

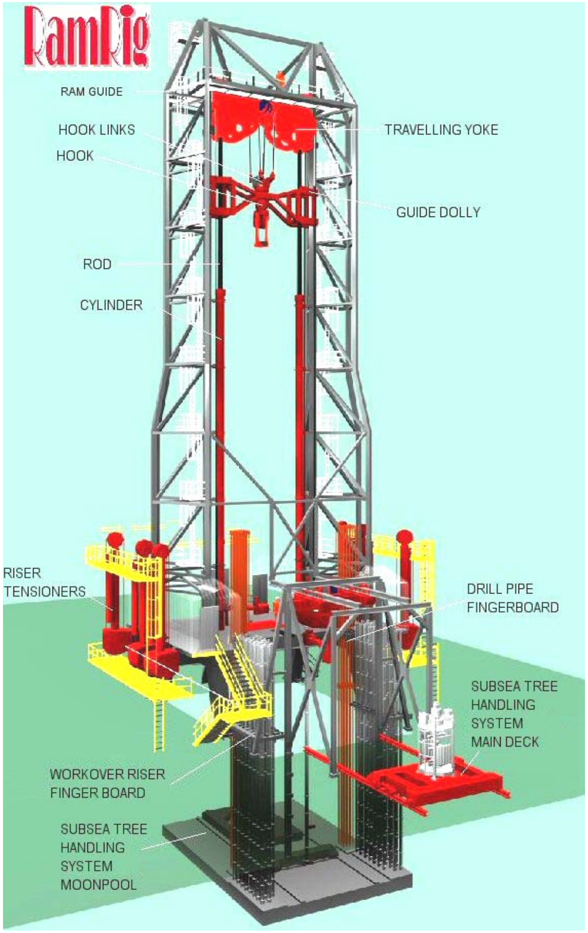


Fig. 2. RamRig© new rig offshore concept.

Operation

Hoisting. Hoisting of loads is done by allocating the desired number of pumps for hoisting via the operator stick giving the setpoint for the pump controller. Hence, the pumps will give an output flow proportional to the stick input. The flow from the pumps is directly proportional to the speed of the cylinder and the speed of the dolly. The load to be lifted determines the pressure. All loads are lifted with the same speed and accuracy within the pressure limitations of the pumps. The valve blocks in the near vincity of the cylinder serve two functions; securing the load when in the parked position and shifting the cylinder to act in the regeneration mode. The regeneration mode shifts the cylinder to act as a plunger cylinder. With the geometry of the cylinder, this indicates a half of the load and a double of the speed with the same power available.

Regeneration of energy. The regeneration of energy is a storage of the power available when lowering the cylinders. This is done by pressurizing the B- side of the pumps by shifting the variable pressure setting valve in the distribution block. The B line is connected to the accumulator via a check valve. Independent of the precharge pressure in the accumulator and the pressure created by the load, the accumulator is filled via the pumps [9]. This mode makes it possible to store the energy independent of operation. The oil stored in the accumulator can be boosted into the circuit when an extra speed is desired.

Heave Compensation. Three different types of compensation are possible with the RamRig©: the active compensation, the passive compensation and the semi active compensation.

Active Heave Compensation. The active compensation is done by means of letting a heave sensor to control the pumps. The vessel heave velocity and the vessel position are used as inputs to the pump setpoint. The actual position and velocity are measured and used as corrective values, determining the setpoint of the pump and consequently the cylinder position in a closed loop regulator. Hoisting and lowering is possible by operating the control stick and moving the position setpoint for the cylinders.

Passive Heave Compensation. The passive compensation is done by means of the same accumulator used for the storing of energy. The gas pressure in the piston accumulator and the pressure vessels connected to the accumulator is variable. Prior to a passive compensation operation, the piston in the accumulator is centered and the gas pressure is set equal to the load pressure measured in the cylinder. When the equilibrium is reached, a hydraulic connection by means of cartridge valves is opened and the cylinder piston rests upon a gas spring. The cylinder and the accumulator piston will now act the in inverse phase, i.e. when the cylinder is moving downward the accumulator piston is moving upwards and vice versa. The apparent Weight on Bit variations are due to various losses within the hydraulic circuit. Typical losses are mechanical in addition to losses connected to the fluid flow and pressure variations in the pressure vessels due to the compression when the accumulator piston is moving. The maximum heave compensation depends on whether the rig is operating in the regenerative mode or not. The typical values of maximum heave are 7.6 and 15.2 m in the normal and the regenerative mode, respectively. Hoisting and lowering can be done by adding or removing the fluid from the circuit. Due to the pressure balance, the level will stabilise and prevent the accumulator piston from reaching the end stroke before the ram cylinders start to move.

Semi Active Heave Compensation. Temi semi active compensation is done by over-pressurizing the pressure vessels creating a positive force on the piston side of the cylinders and operating the pumps on the rod side. The pump output is controlled by a heave sensor as in the active compensation. Hoisting and lowering is performed as in the passive compensation.

Safety

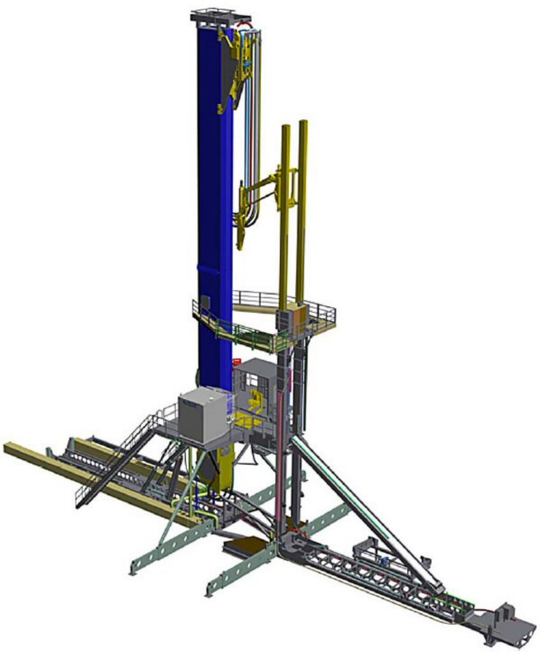
Braking. The braking of the load is done by means of an increase of the pressure on the piston side. The force equals the product of the pressure and the area of the surface on which the pressure acts. The acceleration is simply the force divided by the mass. The mass is constant, so an increase in the pressure at the piston side will result in an immediate acceleration against the velocity direction. Even at the maximum load, there is still 35 Bar available for the braking purposes, which can instantaneously stop any load. The instantaneous stop of the load must be avoided due to the high stresses applied to the structure. This is done by using a filter at the operator stick to slow a sudden operator input.

Floor Saver. Compared to a winch-like drawwork, the position monitoring of the cylinder is easy and reliable. There is an incremental pulse counter integrated in the cylinder assembly, with an accuracy of 1/10 mm. A continuous monitoring of the load velocity, weight, and the position allows for an effective monitoring of the kinetic energy of the load. The control system calculates the necessary braking distance based on the above mentioned parameters. If the operator moves the load beyond the point where braking should start, the control system will interfere and brake the load at the calculated distance. The compensation is $\pm$ 0.06 [m] while the rig amplitude is ± 3.5 m. Hence, the RamRig© compensation capacity in this mode is well within the design criteria for permissible position variations.

The rack and pinion rigs

History of Rack and Pinion Rigs, [25]. The rack and pinion technology has been with us in various applications for decades. The method is well known for a long durability and a high efficiency. The experience on the using rack and pinion technology in the drilling industry dates back to the mid 80's, when it was used mainly for the pipe handling equipment and other relatively slow moving machines. With the forming of Engineering and Drilling Machinery (EDM) in 1997, significant advances and refinements of the technology contributed to several patent applications which later have been granted internationally. During the late 90's, EDM was engaged in several projects involving the equipment for workover and snubbing operations in the North Sea area. At that time, such operations were dangerous to people and surroundings, often consisting of a suitable or not suitable equipment stacked on the top of each other without a consistent design and consideration to the HSE and the optimal functionality. To improve the situation, EDM designed a workover machine utilizing the rack and pinion technology allowing a faster and simpler rig up and rig down, a lower weight and a higher safety level. The main value, however, was that the rig could easily shift from the drilling, workover into snubbing and the underbalanced operations, without modifications to the rig, such as the use of temporary wires, sheaves and winches. The rack and pinion rig concept allowed for a true multi-functionality in the well operations. This form of operation was later discovered by the U.S. oil company contractor Breitburn Energy, who bought a rack and pinion rig from EDM in 2001, for their drilling operations planned downtown Los Angeles. The breitburn needed a compact rig that could do drilling, workover and snubbing. Being in an urban district of LA, it was imperative that the rig made a little noise. The Breitburn rig was enclosed in a church-like building, put to work and has since been moving around on the property servicing about 40 wells, probably making the neighbors wonder what's going on in the backyard. Capacities of the Breitburn rack and pinion rig is 250 sh ton pulling, 120 sh ton pushing, equipped with a top drive with a similar capacities, manual pipe handling and mud systems. All the movement is by AC motors [7], which runs off the LA downtown power grid, (Fig. 3). The later development of the rack and pinion rigs includes a series of 16 trailer mounted rigs to a Canadian rig operator with basically the same multi-functionality as the Breitburn rig, although with a lower ratingof 120 sh ton. Using the rack and pinion technology to package these rig to reduce the rig up and rig down time, it enables less truck loads and the rig owner can offer a wider variety of services in the same machine. In the midst of the delivery program, these trailer-mounted rack and pinion rigs have already proven their versatility and competitive edge. Other deliveries include modularized rack and pinion rigs for the offshore workover, rack and pinion land rigs, as well as other versions. Plans for thehelicopter rigs are on the drawing board, as well as the rigs with higher ratings and capabilities. The rack and pinion technology described in here is thoroughly protected by international patents.

CWDS. In an industry, in a deep love with acronyms, these multi functional rigs are the source of yet another. They have been designated CWDS (Combined Workover, Drilling and Snubbing) rigs by some operators to describe that they can deliver a wider array of functionality than the standard or specialized rigs. One man the operated land rig. In 2005 an order to build a Rack and Pinion Land Rig for the European drilling market was awarded. It was decided to equip the rig with the latest technologies, not only related to the rack and pinion drive, but also at the level of automation, the „robotic" pipe handling system, [10, 16, 17, 25], the state of the art operators chair, [13, 14, 15, 16], as well as offering an increased safety with less people on the drill floor. Consequently, the rig is equipped to enable one man operation of all basic drilling tasks.



Rack and Pinion Technology [16]. The main concept of the rack and pinion technology is to replace the Drawworks, drill line, blocks and tackle with a linear, direct driven hoisting system [5]. This leads to the use of a closed mast construction housing the entire hoisting system, instead of a conventional open derrick or mast with the hoisting system split in several elements (Fig. 3). The „secret" behind the rack and pinion technology are the rack modules connected together in a special way to form a stiff linear rack when it travels on the (driven) load side. A turning wheel in the bottom of the mast makes the rack modules turn so that the (non driven) dead side is vertically opposite of the load side. The pinions driven by the reduction gearboxes and the drive motors engage with the rack elements on the (driven) load side, making the rack move upwards for hoisting and downwards (around the turning wheel) for lowering.

Fig. 3. New rig land concept (500K R&P Land Rig).

The rack elements slide in a special guide arrangement. As such, the design is attractively clever and simple, as of all great inventions. In fact, the rack and pinion rig is the first drilling system with a *directly driven* drill string, completely avoiding the use of a wire (drill line). This means that the vertical movement of the drill string can be controlled with an unprecedented accuracy, for pulling, pushing and holding still. There is no stretch in wires, efficiency loss or inertia in sheaves, a fast line running at ridiculous speeds, gear ratios in Drawworks and blocks, layers of wire on the drum, cut and slip. In a direct comparison with a conventional rig setup, the rack and pinion rig exhibits a better efficiency factor, less start and stop inertia, no cut and slip, a drastically reduced need for the maintenance, as well as a reduced weight. In dollars, it is more cost efficient. In the R&P Land Rig application described in this paper, the pull load rating is 250 sh ton, enabling efficient drilling operations down to 5000 m. For the snubbing operations, the push rating is 125 sh ton. Fully equipped for drilling with doubles, the free height between the drill floor and the top drive is 23 m (75 ft). With a total mast height of 37 m it is necessary to split in two mast sections for the transportation along roads. A mating system connects the sections together while in the horizontal position before being raised to the vertical position. The mast erection is by two skid jacks operating raising bars fixed to the mast.

The Top Drive [2, 3, 4, 7, 8, 11]. Supplementing a modern drilling operation, the rack and pinion rig contains an AC-driven top drive system, [10], permanently mounted by a retractable dolly to the mast by sliding pads and a pin engaged into one of the rack modules. Accordingly, during the transportation, the top drive resides horizontally with the full service loop connected down to the interface at the drill floor level. When the mast is raised, the top drive is ready with little hook up. The top drive is fully equipped with a mud swivel, gearbox, rotating head, torque wrench and two IBOP's, one remote operated. With lower and upper thrust bearings it can be rotated during both the drilling and snubbing operations.

A Pipe Handling Mast. To offer a safe and „hands-free" drilling operation, a fully automated pipe handling system is used [10, 11, 16]. With a basis in the patented fingerboard design, the pipe handling machine is smart and easy to operate. Using the„curved rows", the circular to the rotational center of the pipe handling machine, the movement of tubulars into and out of rows is simplified, (Fig. 4). The vertical movement of the tubulars is, of course, by a rack and pinion system, enabling an accurate, safe and a simple remote control. The necessary lifting height is achieved by an H-structure design allowing a telescopic elevation. Thus, the pipe handler can be compacted for the road transportation. On location, the pipe handler mast is simply raised to vertical using skid jacks and raising bars, and then ready for operation. The gripper head uses a wedge design with push safety latches to equally facilitate the horizontal and vertical handling. With the design, tubulars of various sizes are picked up without the need to change claws or dies. Furthermore, the gripper head engages on the flush area of tubulars and is not dependnt on tool joints. The tubulars are picked up by the pipe handling machine by extending the arm to the well center position, gripping the pipe, lifting off the stick up, turning to fingerboards on either side of the mast, then lowering down to simple „setback mats". All weight of the tubulars in the setback is thus supported on the ground (no load on the rig structure).

Catwalk Machine and Stand Building. [16]. A Catwalk Machine is attached to the H-structure of the pipe handling mast. A cylinder tilts the catwalk from the horizontal to the drill floor elevation. The singles are moved towards the drill floor using a pusher. At a correct position the pipe handling machine picks up the single, turns it to the vertical and into the mouse hole, which is located between the well center and the iron roughneck. Using the hydraulic slips, the single is secured. The catwalk machine returns to get another single, using a pipe feeder mechanism to tilt singles onto and out of the catwalk machine. With the second single picked up by the pipe handling machine it is stabbed and made up by the iron roughneck. The pipe handler picks up the double, elevate, turn and rack back to the finger boards or - racks it to the well center for the drill string. All movement of the catwalk machine, pipe handling system, fingerboards and the iron roughneck is fully automated. The operator uses pushbuttons to advance the machines in predefined steps. As no manual intervention is necessary, the pipe handling operations are safer, faster and more efficient.

Drill Floor (Fig. 5), [16, 25]. When transporting the pipe handling mast, both the drill floor main sections and the finger boards are attached as folded wings. Using cylinders, the wings are unfolded when the pipe handler mast is raised. Both the drill floor and fingerboards „wings" are attached to the rack and pinion mast. The two masts with the cross connected „wings" form a strong and rigid structure and, with the setback load in the ground, make the rig capable of high winds forces, without the need for guy wires. The drill floor supports the hanging and pushing (upwards) loads. Again, the R&P Land Rig is prepared for the fast rig up and rig down with a minimum of assembly and mounting work. The drill floor extensions are used to mount the driller's cabin and the iron roughneck. The extensions are used to mount the driller's cabin [14, 15] and the iron roughneck [12], forming a rather large drill floor area compared with other land rigs of similar capacities. Underneath the drill floor there is an adequate space for a 13 5/8″ BOP, easily rigged up as a parallel activity during raising of the R&P Land Rig. Snubbing Slips. As a part of the development program, The sense EDM patented a special type of slips that are used efficiently for holding both pulling and pushing loads [25].

A wedge design makes the slips function safe and versatile for a wide range of tubular sizes. For the R&P Land Rig, it means that no special operation is necessary to go from the drilling to the snubbing operation, other than to „reset" the slips. The hydraulic slips are remotely controlled from the operator's chair. Iron Roughneck. A conventional iron roughneck mounted on a pedestal is used for a make up and break out of the drill pipe and casing. The roughneck is remotely controlled from the operator's chair [12].

Rotary Table. A dummy 37 $^{1}/_{2}$″ rotary table is used to hang off the loads. Future options include a rotary table rotation to the position tubulars for a make up, as well as two hydraulically operated slips with bearings and a locking brake to safely handle the light drill strings.

Fig. 4 The pipe handling machine

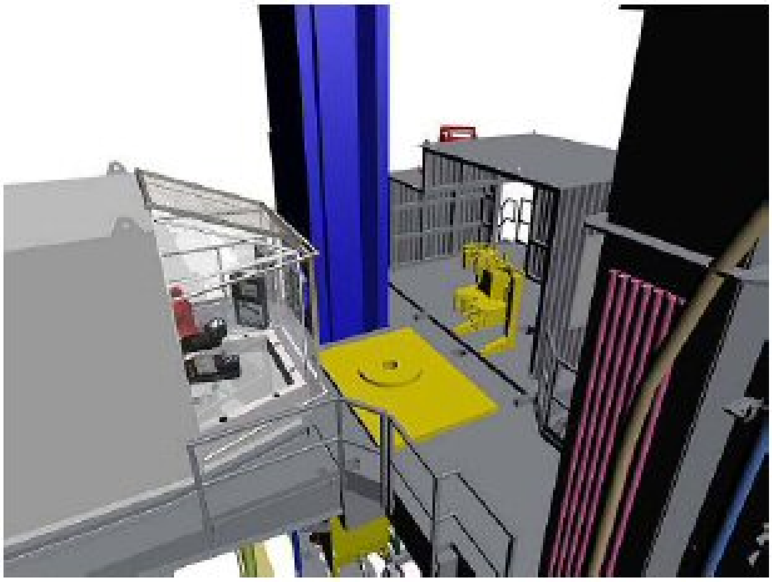


Fig. 5 Drill floor sections in new rig concept

Fig. 6. X-COM operator's chair

Operators Chair. Complimenting a modern automated rig system an X-COM operator's chair is housed inside of the climate controlled driller's cabin [13, 14, 15] (Fig. 6). The operator has a nice view over the rig with large windows. The operator uses two large LCD screens to monitor all the equipment, systems and the operations. This is the operator's information central, where the traditional gauges, indicators, bar graphs and the video screens are integrated into one, compact, graphical interface that may take any shape. The control of the equipment is by two touch pads and two joysticks mounted in the arm consoles attached to the chair. This substitutes the traditional switches, buttons and throttles. As the interface is graphical and drawn on the screens, the X-COM chair change to reflect the status of the current operation. This makes operation of the R&P Land Rig more intuitive and simple, as the user is only exposed to the information and functions that are currently used. An additional information is provided with a full alarm system, rig status screens, trend screens.

Rig Support Systems. The R&P Land Rig is equipped with the diesel generators, the electrical distribution, the AC drive systems, [7], two mud pumps, the well control equipment, and the mud system. The mud system is prepared for the Underbalanced drilling operations.

Control & Power System. A networked control system connects the different modules/skids together to operate as single system. During the rig up, the operator can „see" as the skids are being connected and started up, getting an access to the sensors, motors and functions as they come alive. This also makes troubleshooting easier. The rig is equipped with a full set of drilling sensors enabling the monitoring of loads, torque, speed, volumes, strokes, loss/gain, trip tank volumes, steel displacement etc. All information is stored in a historical database for a later retrieval.

Real time data delivery. Becoming increasingly popular, the real time data delivery enables the drilling contractors and operators to make a critical drilling as they happen. The R&P Land Rig is equipped with a satellite dish and a data acquisition system that can forward the drilling and well data to any secure Internet location in seconds. Using the industry's well site data format of choice - WITSML – the users can tap into the data stream to look at trends, directly load data into 3D reservoir simulations, and automatically populate reports, to mention some. The same system is used to enable the remote troubleshooting facility. With a secure access, the monitoring, problem solving and, if necessary, the re-programming of the entire R&P Land

Rig control system can be done from the company offices in Norway, independent of where the rig is located.

Rig Capabilities. As discussed earlier, the R&P Land Rig concept has a number of advantages in terms of how an efficient rig can be realized with a low weight, fewer truck loads, and a smart rig up and rig down. Operationally, the rig delivers a unique portfolio of capabilities:

- drilling,
- well intervention,
- under balanced drilling,
- snubbing operations,
- slim hole drilling,
- re-entry,
- workover,
- sidetracking.

For driller's, such a flexibility opens up new possibilities. For example, with the ability to push, top holes may be drilled with a less drill collar weight. The shallow depth horizontal wells may be drilled differently, as the need to trip to get the drill string weight is not necessary. With the direct vertical drive of the Drill string (and no wire), an extremely accurate control of tools in the reservoir section can be achieved. This is true both if the well is in overbalance or in under balance, with the well flowing. With it's built in multi-functionality, the R&P Land Rig replaces the conventional drilling rigs, hydraulic workover units, snubbing units, and to a certain extent the coiled tubing units.

Sense EDM, [17]. Late in 2005, two Norwegian companies (EDM and Sense Technology) merged to form the Sense EDM. The company has a unique product portfolio, skills and experience in the drilling machinery, pipe handling systems, advanced control systems, and the drilling packages, and has an extensive delivery program to the international oil and gas industry ongoing.

Conclusions

The RAMRIG© drilling hoisting system. The majority of the cycles are in the compensation mode, for which similar cylinders have been used for many years. Our experience shows that the seals are replaced at every other classing because of ageing, not because of wear. If, however, it is used as a benchmark for 8 years, a minimum of 5 years lifetime can be expected for a similar continuous operation (8/1,65 = 4,85). The RAM RIG Drilling Concept, developed and designed by the Maritime Hydraulics, is found to have many technical advantages compared to a conventional drilling concept, which will lead to a field development of cost savings when applied.

The main advantages are: the lower weight, and lower Centre of Gravity (CoG).

The concept is technically feasible. It contains a well known technology and equipment, and the drilling technique remains virtually unchanged. The main difference is the procedure of how the new equipment is operated during the drilling operation.

A reduced number of moving parts, and operations on the drillfloor and none in the ram structure will result in: a lesser maintenance, safer working environment, and a reduced crew.

The reduction of crew members is not concluded yet, except for the one man in the derrick. The various drilling contractors involved have different opinions on the matter. The concept provides a potential to reduce the crew down to 18 persons.

The resulting weight reductions and lowered CoG in this particular study, give a total deck load benefit to Aker P-45 of 900 tonnes.

The rack and pinion rigs. Designed for: Drilling, Under balanced drilling, Slim hole drilling, Work over, Well intervention, Snubbing operations, Re-entry.

Replaces: Conventional drilling rig, Hydraulic work over units, Snubbing units and Coil tubing units.

500K R&P Land Rig.

- Mast only guides the top drive, no load exerted by pulling. No drill (block) line required.
- Low center of gravity, low mast weight.
- AC-driven, fail safe brake and excellent block position control during tripping, drilling and snubbing.
- Noise reduced to a minimum.
- First rig with direct drive of drill string (no wire). No efficiency lost in sheaves, wire and drums.
- Rigs can switch between drilling, workover to snubbing operations in seconds.
- Perfect for underbalanced drilling.
- Snubbing operation executed on drill floor instead of in elevated work baskets.

- One-man operate rig during normal drilling tasks.
- Automated pipe handling system, setback supported on ground.
- Hands off operation at the drill floor and routine operations.
- Entire rig with all skids integrated in a network, enabling a complete overview for the driller.
- Real time data delivery with a remote diagnostics, troubleshooting and optimization of the drilling operation. Fully prepared for e-field.
- Smart, modular design, facilitating easy moves from location to location by trailer.
- Reduced risk for dropped objects as all activities are at the drill floor or below the area.

References

[1] Tysső, A.: Automatiseringsteknikk, modellering, analyse og syntese av reguleringssystemer, *2 utgave 1985.*

[2] Artymiuk, J.: Kierunki rozwoju hydraulicznych napędów urządzeń wiertniczych. *IX Międzynarodowa Konferencja Naukowo-Techniczna, Kraków, 2-3.07.1998*.

[3] Artymiuk J.: Kierunki rozwoju w urządzeniach wiertniczych - głowica obrotowa i hydrauliczna konstrukcja wyciągowa. *Konferencja Naukowo - Techniczna, Jasło, 19.06.1998*.

[4] Artymiuk J.: Directions of development of the „Top Drive" heads. *X Medzinárodná vedecko-technická konferencia „Nové poznatky oblasti vŕtania ťažby, dopravy a uskladňovania uhlovodíkov". Podbanské, s. 5-7. Oct. 1999*.

[5] Artymuik, J.: Stare wiertnie do lamusa. *Nafta & gaz biznes, nr 12/2003. s.18-23*.

[6] Artymiuk, J., Loland, J.: Use of computer stimulation during designing early stage. *13th international scientific-technical conference. Kraków: WWNiG AGH, 20-21 czerwca 2002. S. 29-31.*

[7] Artymiuk, J., Loland J.: Top drive technology-electric PTD. *Nové poznatky v oblasti vrtania, tazby, dopravy a uskladnovania uhl'ovodíkov Podbanské 2002: XI Medzinárodná Vedecko-Technická Konferencia, 29-31 októbra 2002, Podbanské, Slovensko, conference contributions Technická Univerzita v Kosiciach. Fakulta Baníctva, Ekológie, Riadenia a Geotechnológií. S. 3-11*.

[8] Artymiuk, J., Hollekim, H., Sokalski, M.: New Drilling Technology-Top Drive System. *VII Międzynarodowa Konferencja Naukowo-Techniczna, Kraków, 20-21.06.1996*.

[9] Artymiuk, J., Rudshang, B., Skibelid. T.: Modern use of closed-loop hydraulics for controling and powering of cylinder-based hoisting systems. *X Międzynarodowa Konferencja Naukowo-Techniczna pt. „Nowe metody i technologie w geologii naftowej, wiertnictwie, eksploatacji otworowej i gazownictwie". Kraków, 24-25 czerwiec, 1999.*

[10] Artymiuk, J., Sokalski, M.: Nowe technologie w wiertnictwie – automatyzacja procesu manewrowania rurami. *14-th INTERNACIONAL SCIENTIFIC AND TECHNICAL CONFERENCE. New Methods Technologies in Petroleum Geology, Drilling and Reservoir Engineering. Zakopane, 11-13 Czerwca, 2003*.

[11] Artymiuk, J., Sokalski, M.: Nowe technologie w wiertnictwie - automatyzacja wybranych procesów wiercenia. *XIV Międzynarodowa Konferencja Naukowo-Techniczna pt. „Nowe metody i technologie w geologii naftowej, wiertnictwie, eksploatacji otworowej i gazownictwie". Zakopane, 11-13 Czerwca, 2003. S. 1-4 (zeszyt strona 15)*.

[12] Artymiuk, J., Sokalski, M.: New technologies in drilling: assurance of appropriate tubular torque moment - values. *Drilling Oil Gas. Annual 21/1-2004. AGH University of science and technology. S. 51-59*.

[13] Artymiuk, J., Sokalski, M.: The new drilling control and monitoring system. *Acta Montanistica Slovaca. 2004 R. 9 \v{c}. 3 s. 145–151*.

[14] Artymiuk, J., Wróbel, Ł.: Nowoczesne systemy decyzyjne w wiertnictwie. *Wiertnictwo Nafta Gaz, AGH. Uczelniane Wydawnictwa Naukowo-techniczne, Rocznik 20/1-2003. S. 33-38*.

[15] Artymiuk, J., Zachariasen, E.: New technology in drilling - Internet technology reveals significant potential for drilling sites. *Wiertnictwo, Nafta, Gaz, 18/1, 2001, s. 33-40*.

[16] Artymiuk, J., Zachariasen, E.: New Combined Drilling, Workover and Snubbing Rig Concept. *Drilling Oil Gas. Annual 23/1-2006. AGH University of science and technology press. Cracow. s. 69-78*.

[17] Bednarz, S., Artymiuk, J.: Principles of Drilling and Production machinery Admittance in Operation. *Międzynarodowa Konferencja Naukowo-Techniczna, Ostrawa 12-14.11.1998*.

[18] Benjamin, Wylie, E., Victor, L. Streeter.: Fluid transients corrected edition 1983.

[19] Breunighaus Hydromatik GMBH RD 00 190

[20] Frank, M. White.: Fluid Mechanics, *Second edition 1996*.

[21] Fridtjov, Irgens.: Dynamikk, *2. utgave 1985*.

[22] Reuben, M., Olson.: Essentials of engineering fluid mechanics, *fourth edition 1980*.
[23] Richard, E.: Sonntag, Gordon Van Wylen.: Introduction to thermodynamics, *classical & statistical, second edition 1982*.
[24] Ward Cheney, David Cincaid.: Numerical mathematics and computing, *second edition 1985*.
[25] Sense EDM-papers and catalogs.