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DEVELOPMENT AND IMPLEMENTATION OF DRILL RIG HYDRAULIC DRIVES****

1. INTRODUCTION

The drive technology used for drilling rigs accounts for the mechanics of driving and working machines, their design, reliability, technology, power, safety of work, environmental protection etc.

As far as machines mechanics is concerned, two basic parts can be distinguished:

1) strength of machine elements – part of strength of materials,
2) transfer of motion, forces and torques, relation between forces and motion of machines, and the definition of forces evoked by the motion (dynamics of a machine).

The transfer of mechanical power in rotary movement on the driven machine is made through the torque M at rotary velocity n, and in the translatory motion by force F at linear velocity v.

In the broader sense, all the means evoking a given motion as well as control of motion are also driving elements. Rotary and translatory motions are a basic form of transforming other type of energy on mechanical energy in the driving systems. Hence the necessity to analyze the phenomena related with it in view of the respective rules for a given type of drive.

A correct configuration of hydraulic systems is possible with the use of fundamentals of hydromechanics. These aspects decide about the design and build of the driving systems and hydraulic control. Another such element is technical feasibility, especially tightness. This factor has been a drawback in the power hydraulics applications for years. Friction losses of fluids, especially volume losses have been considerably reduced by precise ma-

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chining design of sealing elements and new sealing materials. The reliability of sealings caused a fast development of hydraulic drives. Another constant element are the advantages of drives and hydraulic control. Hydraulic drives have wide possibilities of control and transmission of drive to long distances, high efficiency, relatively simple design of control elements, possibility of making still and flexible drives as well as direct connection of the motor with the working machine or its sub-assembly [10]. These drives require qualified attendance and strict following the instructions and technical procedures.

Moreover, hydraulic drives provide two to three times bigger acceleration as compared to the respective electrical motor. The dynamic torque of hydraulic drives is considerably higher than in other types of drive, resulting in short time constants of the system. Their weight-to-power ratio is low, i.e. one to two orders lower than for e.g. electrical machines. The system is not excessively overburdened owing to the application of safety valves, step-control valves, or overflow valves, which is crucial for the safety of the system. The principle of operation of the hydraulic system is based on the Pascal law, defined in mechanics as hydraulic lever principle, on the basis of which the following relation at pressure *p* holds true for a hydraulic gear (Fig. 1)

$$\frac{x_1}{x_2} = \frac{S_2}{S_1} = \frac{F_2}{F_1} \tag{1}$$

where:

x_1, x_2 – displacements,
S_1, S_2 – piston surface areas,
F_1, F_2 – forces.

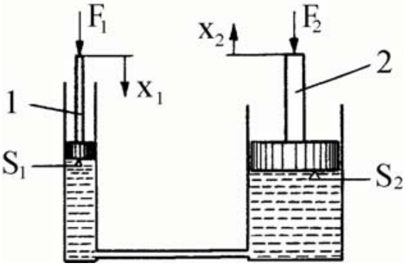

Fig. 1. Hydraulic gear

Operation of piston 1 is equal to the product of force and distance of piston

$$L_1 = F_1 \cdot x_1 \tag{2}$$

By substituting

$$F_1 = p \cdot S_1,$$

and

$$x_1 = \frac{V_1}{S_1},$$

to equation (2), equation for gear running is obtained

$$L_1 = p \cdot V_1 \tag{3}$$

Power N defined as running in a unit of time is

$$N = \frac{dL}{dt} \tag{4}$$

Knowing the derivative of equation (2) and assuming the force F_1 as constant, we obtain

$$N_1 = \frac{d}{dt}(F_1 \cdot x_1) = F\frac{dx_1}{dt} = F_1 \cdot v_1 \tag{5}$$

Introducing the notion of volumetric flow rate and using the Pascal law, the added power will be

$$N_1 = p \cdot S_1 \frac{Q_1}{S_1} = p \cdot Q_1 \tag{6}$$

These simple relations are widely applicable for designing systems in drilling rigs, where power hydraulic elements are encountered. Servo-motors belong to linear hydraulic drives, where they are the most prominent element of hydraulic systems controlling operation in the drilling rigs. They are produced in various sizes, types and designs. The servo-motors transform the pressure of fluid (hydraulic oil) to fast and controlled motion of the piston rod to shift the load.

2. HYDRAULIC ACTUATORS

A typical actuator consists of: a cylindrical body, a head playing the role of a gland (front cover), foot (back cover), piston and piston rod with sealing and guide-elements for piston and piston rod (Fig. 2) [11]. Servo-motors are used for operation at various values of nominal pressure in conventional industrial applications to 21 MPa bar (continuous operation) and to 35 MPa in special machines. The available servo-motors are up to 0.80 m of diameter and step of tens of meters, e.g. rig RAMRIG® [2, 3, 8].

The lateral servo-motor has the simplest design, where the hydraulic oil is transmitted to only one side of the piston, generating force on input and motion in only one direction. The gravity force or external back-springs move the piston to the initial position, and the oil is re-pumped to the container. In the bi-lateral servo-motors the hydraulic oil is transmitted to both sides of the piston, generating force and motion both at pushing and pulling of the piston rod. The sealing between the outer diameter of the piston and the inner diameter of the body of the servo-motor should provide tight motion of the piston in both directions. A servo-motor with a bi-lateral piston is a variant of bi-lateral servo-motor; in this solution one piston rod crosses the hear cover and the other one the back cover. The bi-lateral servo-motor is the most popular hydraulic servo-motor which provides motion in two directions.

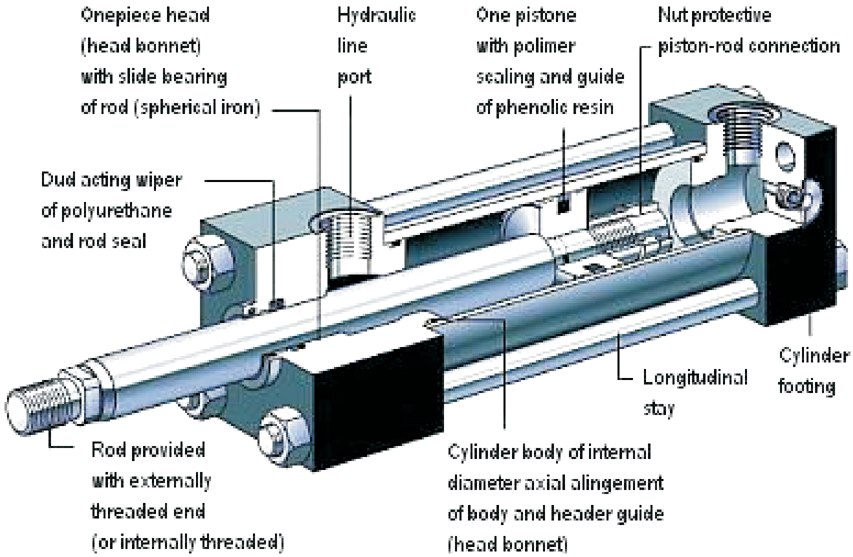

Fig. 2. Dual-acting servo-motor with one piston rod

In a typical bi-lateral servo-motor the force generated during pulling of the piston is slightly bigger than in the case of pushing the piston rod, when identical pressure is applied at both sides of the piston. This results from the difference in the effective surfaces at both sides of the piston. On the side of the piston rod, the effective surface is smaller than on the opposite side. In line with the Pascal law the force of pulling the piston rod is smaller. In the bi-lateral servo-motor the surface on both sides of the piston are almost identical, and no difference in the force of pulling and pushing the piston ro are observed.

A servo-motor with reinforced piston rod, the diameter of which is close to the diameter of the cylindrical body of the servo-motor, is a variant of the above presented servo-motors. The reinforced construction of the piston rod prevents its bending at a big step of horizontal advancement or side-bulking at a considerable vertical load on piston, e.g. in the case of various presses.

The piston is connected with the high-endurance steel piston rod. The other side of the piston rod may have various endings, e.g. outer threaded (see in the figure), inner threaded or other. Hardened or chrome-coated piston rods with a very smooth surface are fundamental for piston tightness. The outer diameter of the piston should perfectly fit in the internal diameter of the cylindrical body of the servo-motor. Both the piston and the body should be perfectly cylindrical and very smooth, to provide a fluent motion of the piston rod.

Hydraulic servo-motors are equipped with a location sensor (feedback) and electrical-hydraulic servo-valve for controlling the rate and location of the piston rod and the load (not only moving the object at a certain step of distance). The applicability of the latter is especially wide in the contemporary drilling rigs. Servo-motors provide stability of the carrying frame of the rig, elevation, lowering, protrusion and sliding the masts, and are the main design element in the system levelling out the vertical displacement of the platform or ship, are a basic force element of the machine tongs for screwing and unscrewing pipes and casing [1, 5], control the high-pressure cycles of drilling manifolds, production wellheads and other valves in the exploitation systems.

They are basic during pipe handling operations [4, 9], construction of driving heads etc. Only some examples of their application have been presented. The role and significance of his small construction element in the contemporary rigs designs can be observed. Attention should be paid to the design of the following rigs: Sense [6, 7], Huisman-Itrec and HH by Drillmec. The configuration of servo-motors for pipe maneuvering operation and the results of their application are presented on the example of rigs HH by Drillmec. New development trends converge to universal fully hydraulic drilling equipment.

3. HH SERIES – HYDRAULIC RIGS

Drillmec started the design of this new-concept rigs in 1990 producing the first unit called G-75 – 667 kN (75 T) pulling capacity – in 1993 that has been successfully used in deep water well drilling in the south of Italy and, after twelve years, is still operating for Coal Bed Methane gas drilling in Ukraine.

In 1994 Drillmec supplied a winterised G-100 rig – 890 kN (100 T) capacity – to a gas drilling company operating in Siberia. An hydraulic rig operating in a –40°C environment was an important goal.

After a three-year testing, the Italian oil company AGIP got involved in screening this new technology and asked for a package of new-concept rigs to develop marginal oil field with features of: small footprint, fast moving, reduced transport loads, environmental orientation, reduced number of crew personnel. In 1996 Drillmec delivered a G-125 rig – 1335 kN, (150 T) pulling capacity, which has operated in the north of Italy close to urban areas (near cities like Milan and Piacenza) for natural gas researches, in Puglia (south-east of Italy) and in Sicily around the Etna volcano area. This rig is now operating in Egypt in oil research.

Drillmec rigs have been supplied for different applications (oil, gas, geothermal and water researches) and tested in any field conditions confirming the flexibility, reliability and good performance of this idea.

At present there are about 50 HH rig units operating all around the world and there are expectations to become 100 within the end of 2008 thanks to orders already in the portfolio. The main parameters of HH models rigs are presented in Table 1.

"Fast" moving – all equipment is on trailer (Fig. 3) or can be "trailer integrated" to avoid the need of gin pole or rented cranes to load flat bed trailers with consequent reductions in: moving time, cost of rented equipment, assembling/disassembling time, moving crew. Mast, top drive, casing beams and lifting cylinder can be moved with rig trailer.

Table 1

Range and main features of HH drilling rigs

Model	Static hook load		Max Pull down		Rated input power		Top drive torque		Top drive stroke		Approx. mass	
	kN	lbs	kN	lbs	kW	HP	daNm	lbs.ft	m	ft	kg	lbs
HH-100	890	200000	196	44000	403	540	3530	26035	15	49 ¼	43000	94800
HH-102	979	220000	196	44000	418	560	3530	26035	16	52 ½	45000	99200
HH-150	1335	300000	196	44000	522	700	3530	26035	16	52 ½	50000	110230
HH-200	1779	400000	196	44000	1000	1340	3530	26035	16	52 ½	55000	121250
HH-220	1962	441000	196	44000	1000	1340	3530	26035	16	52 ½	60000	132280
HH-300	2669	600000	294	66000	1150	1542	4900	36141	16	52 ½	90000	198420

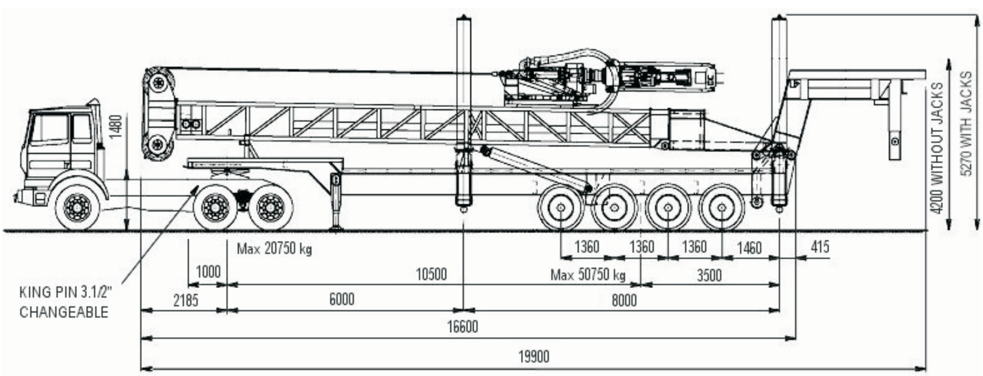

Fig. 3. HH-220 drilling rig moving layout

Fast rig-up – the preparation of the rig for drilling operations can be done without generators and SCR/VFD. An independent hydraulic power pack assembled on rig trailer allows: rig lifting, mast rising and pipe handling system assembling (Fig. 4).

There is a big advantage in the rig-up and rig-down time because these operations can be done while disconnecting all main electric equipment; the result is: no waste of time. In addition there is no need to load or unload pipes from monkey board and mast or top drive assembling and disassembling for moving. Moving time of HH-220 rig is shown in the Figure 5. Moving time progress has been achieved tanks to fast and easy crew training.

Enhanced drilling – perfect weight-on-bit setting and automatic adjustment during drilling operations are ensured. The components of this system are the hydraulically operated telescopic mast, the hydraulic hoist (no drawworks is needed) and the hydraulic top drive (no rotary table is needed). The core of Drillmec design is the perfect and automatic control of weight on tools given by hydraulic system that controls and reacts to the load in-formation received from the well: based on the drilling tool (bits, DHT motors etc.) the operator sets the optimal weight and the rig keeps this weight constant during the drilling also when the formation changes.

Fig. 4. HH-300 drilling rig

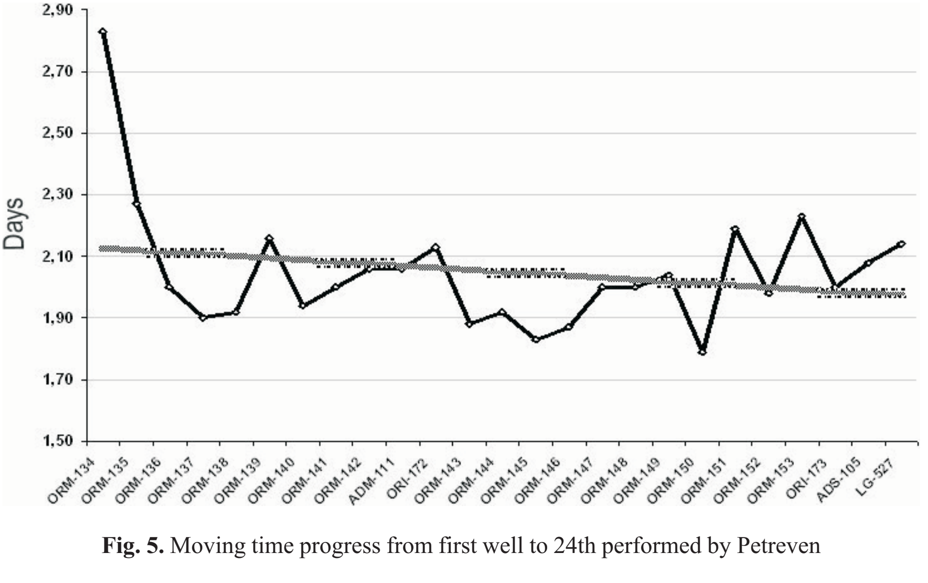

Fig. 5. Moving time progress from first well to 24th performed by Petreven

The results are: the faster possible drilling, performance and wearing of drilling tools optimisation, reduction of stacking risk, better quality of the job for operators (Tab. 2).

Table 2

Days per well. Average of about 100 wells drilled between 1999 and 2005 in Venezuela

Days per well	Conventional rig	G-200 – Semi automatic pipe handling system	HH-200 – Fully automatic pipe handling system	Gained days per well HH-200 *vs* conventional rig
Vertical	10.6	8.22	7.06	3.54
Directional	13.6	11.18	6.98	6.62
Horizontal	60.5	30.07	14.12	46.38

Casing operation – would you circulate mud during casing running? Now it is possible with our casing make-up device directly connected with top drive and mud manifold. This tool grips and seals the top of the casing, lifts it on centre well, performs the make-up at settled and recordable torque and makes the mud circulate during casing running (Tab. 3). An integrated top drive and hydraulically operated IBOP valve controls the process.

Table 3

Casing running time. Average of about 100 wells drilled between 1999 and 2005 in Venezuela

Casing diameter	Average depth	Average running time [hour]
9 ⅝″	0.56 m (1.848 ft)	3.25
7″	2.45 m (8.018 ft)	10.2

Fully automatic (FA) pipe handling – that's the real revolution on land rigs granting a high safety level, anti-pollution orientation, time saving, drilling string optimisation, reduction of personnel on drill floor, cost cutting, quality of work for operators.

The system is composed of: pipe racks to store single length range 3 drill pipe (DP) both during operation and moving (no need to handle drill pipes); spillage free sub base to support the pipe racks and to collect any fluid from drill floor or pipes to avoid ground pollution; a robotic handling tower hydro-electric driven to perform automatic drill pipe handling (any diameter) from racks to mouse hole, drill collar and casing handling; a remote control room (that could be integrated in the SCR/VFD container) with cubicle, computer and software to control and program the pipe handling tower; a touch screen in the dog house for driller's control and setting of the operation; hydraulic power tong (iron roughneck); automatic power slips for drill pipes (any diameter); top drive swing-out-system to spin and handle the drill pipe from mouse hole to well.

Basically the robotic tower performs all the pipe handling operation during tripping (Tab. 4) and drilling without human intervention; the power tong, remotely controlled by the driller, performs all operations of pipe and collar make-up and break-out by itself; the power slips, hydraulically remotely operated by the driller, do not need any human intervention.

This system optimises the drilling string life because it is possible to control and measure the feet drilled by each pipe. Practically the 80% of the drilling program can be performed by the driller himself.

Table 4
Pipe handling operation during tripping

With FA pipe handling system	Pipe/hour	m/hour [feet/hour]
Trip out Operation	40	488 (1600)
Run in Operation	40	488 (1600)

Integration of system – the HH Series rigs, with suitable optional to be choose inside a complete list, performs the following operations: drilling, casing running, cementing, logging, parameter recording, workover, well service, waste treatment. Thanks to this the drilling company increases its know-how and becomes more competitive and flexible to meet the market enquiries quoting a wider range of services.

Petrobras Colombia addresses profit in operations: 13 well/year · \$38,608/well = \$501,904; profit for yearly production: 13 wells/year · 4.5 days/well · 200 bpd · 60 \$/bl = \$702,000 and total estimated profit: \$1,203,904/year.

The HH Series is prepared to meet requirements of workover operations. No data submitted yet to ascertain whether these rigs are acceptable for service in workover operations.

4. CONCLUSIONS

1) The drilling company offers a turn-key well at higher but, at the same time, more competitive day rate *vs.* the competitors having conventional rigs that need more rented equipment and service companies to perform all the operations.
2) The oil company can increase the income per well thanks to reduction of drilling time and integration of services.
3) Hydraulic systems have a number of technical advantages enabling their application in automation of a number of technological operations.
4) High requirements on repair quality should be considered. It shall be indicated on requirement of well preparation of crew and proper supervision on maintaining and operation of these systems.

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