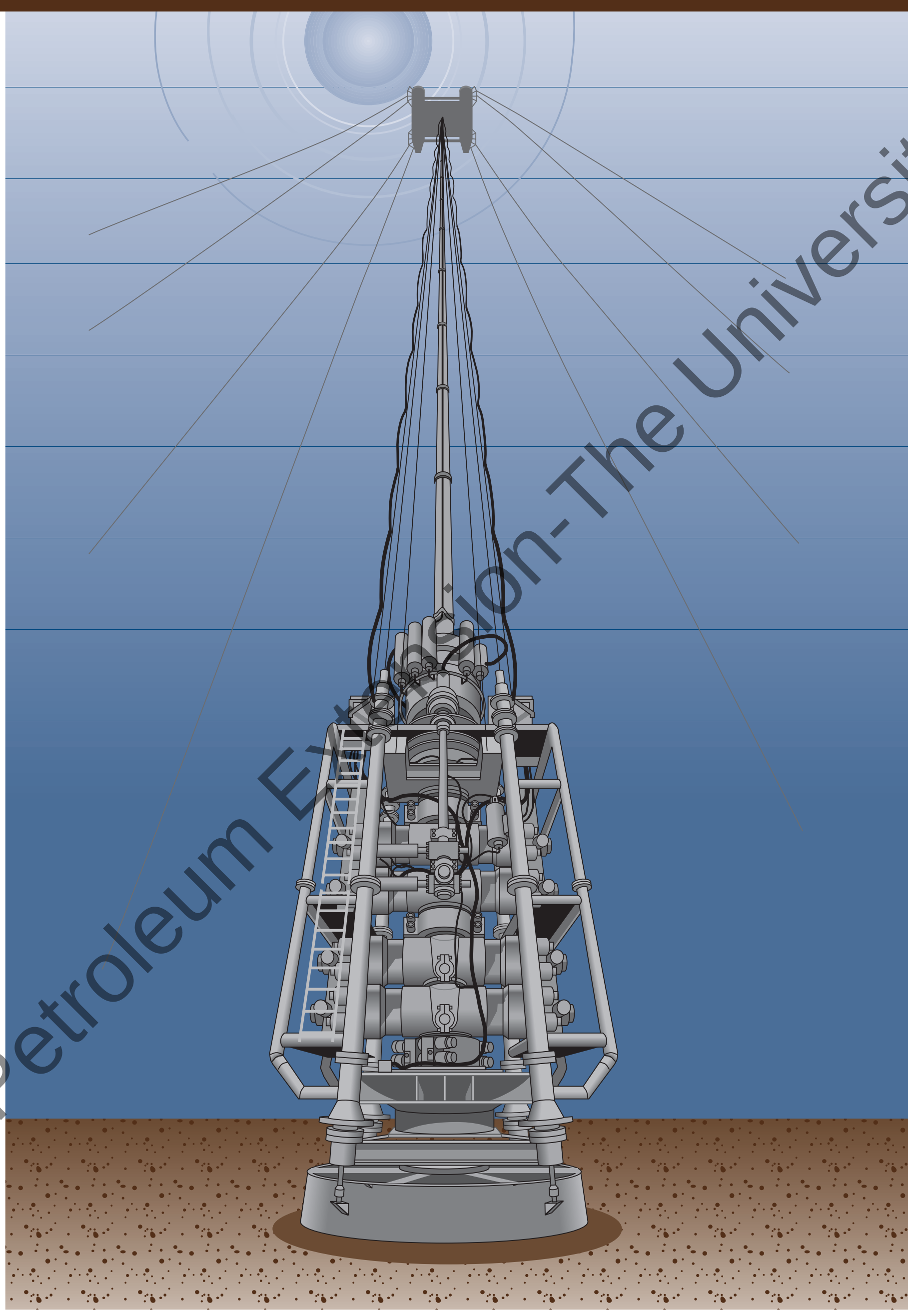
ROTARY DRILLING

MARINE RISER SYSTEMS AND SUBSEA BLOWOUT PREVENTERS



First Edition

UNIT V • LESSON 10

ROTARY DRILLING SERIES

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Units of Measurement

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Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is almost the only country that employs the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, for example, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the Système International (SI) d'Unités. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The *Rotary Drilling Series* gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is *metre*, not *meter*. (Note, however, that the unit of weight is *gram*, not *gramme*.)

To aid U.S. readers in making and understanding the conversion to the SI system, we include the following table.

English-Units-to-SI-Units Conversion Factors

Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m^3)
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m^3/stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches ($in.^3$)	16.387	cubic centimetres (cm^3)
	cubic feet (ft^3)	28.3169	litres (L)
		0.0283	cubic metres (m^3)
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m^3)
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m^3)
	barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m^3/t)
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m^3/min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m^3/h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m^3/stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m^3/min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{°F - 32}{1.8}$	degrees Celsius (°C)
Thermal gradient	1°F per 60 feet	—	1°C per 33 metres
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m^3)
	pounds per cubic foot (lb/ft^3)	16.0	kilograms per cubic metre (kg/m^3)
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.7	kilowatts (kW)
Area	square inches ($in.^2$)	6.45	square centimetres (cm^2)
	square feet (ft^2)	0.0929	square metres (m^2)
	square yards (yd^2)	0.8361	square metres (m^2)
	square miles (mi^2)	2.59	square kilometres (km^2)
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

Introduction

During normal drilling operations, the column of drilling fluid—the mud—in the well creates hydrostatic pressure to counterbalance formation pressures. As long as the rig crew maintains the mud's hydrostatic pressure at a value greater than the formation pressure, formation fluids cannot flow into the well. In short, the mud column is the primary means of well control.

In the English, or conventional, system of measurement, where mud weight is in pounds per gallon (ppg), hole depth is in feet (ft), and pressure is in pounds per square inch (psi), the following equation can be used to calculate the hydrostatic pressure created by the mud column at the bottom of the well.

$$HP = 0.052 \times MW \times TVD \qquad \text{(Eq. 1)}$$

where

HP = hydrostatic pressure, psi
MW = mud weight, ppg
TVD = true vertical depth, ft.

The number 0.052 is a constant—that is, its value does not change as long as the other units of measure in the equation, such as ft, ppg, and psi, do not change. The constant 0.052 is derived from the pressure in psi created by a 1-ft high column of fluid that has a weight of 1 ppg.

As an example of determining hydrostatic pressure in psi, suppose a well is full of mud that weighs 12.0 ppg and that the well's *TVD* is 12,500 ft. What is the hydrostatic pressure at the bottom of the well? Using equation 1—

$$\begin{aligned} HP &= 0.052 \times 12.0 \times 12{,}500 \\ &= 0.624 \times 12{,}500 \\ HP &= 7{,}800 \text{ psi.} \end{aligned}$$

Marine Riser Systems

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A marine riser system provides a fluid conduit to and from the wellbore—that is, it extends the wellbore from the subsea BOP to the drilling rig. It also supports auxiliary lines, such as high-pressure choke and kill lines, mud booster lines, and hydraulic conduits. Further, the marine riser system guides the drill stem and other tools from the drilling rig to the wellhead on the seabed. Finally, it provides a means of running and retrieving the BOP assembly from the surface to the wellhead on the seafloor.

Marine riser systems are critical equipment; therefore, if a system fails, catastrophic losses can result. Consequently, the overall design of the system is of paramount importance. Generally, system design begins with an assessment of expected operating conditions and an engineering analysis to establish such factors as tensile loads, bending stresses, maximum operational water depth, buoyancy requirements, surface tension, and vessel response to motion.

Additional factors that affect riser system design include—

- dynamic and axial loads while running and retrieving the riser system and BOP assembly;
- lateral forces from currents and vessel offset;
- cyclic forces from wave and vessel motion;
- vortex induced vibrations (VIVs);
- axial loads created by the weight of the riser system itself, the weight of the drilling fluid inside the riser, and the additional weight of freestanding pipe within the riser;
- axial tension from the tensioning system at the surface;

Diverters

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A diverter system (fig. 22) protects personnel and equipment by diverting the flow from shallow gas kicks overboard. Such gas flows can occur before a BOP stack can be installed because no casing is set in the well. A diverter does not shut in or halt well flow; rather, it diverts flow away from the rig. During normal drilling operations, the diverter directs the flow of mud returning from the marine riser into the rig's return flow line.

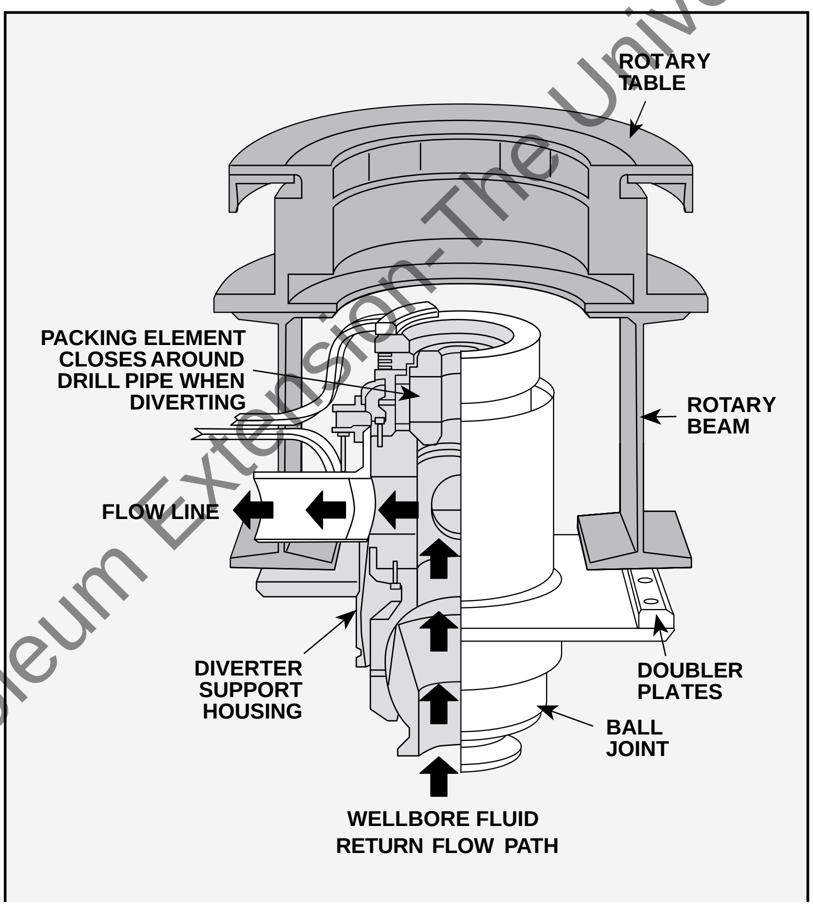

Figure 22. Diverter (Courtesy of ABB Vetco Gray)

Riser Tensioning Systems

The weight of the marine riser system must be supported while it is deployed. Otherwise, the weight of the joints at the top of the string can crush the joints below. If not supported, a conventional marine riser buckles in water depths greater than 200 to 300 ft (60 to 90 m).

A riser tensioning system (fig. 25) must support the weight of the longest riser string at the rig's deepest operating water depth.

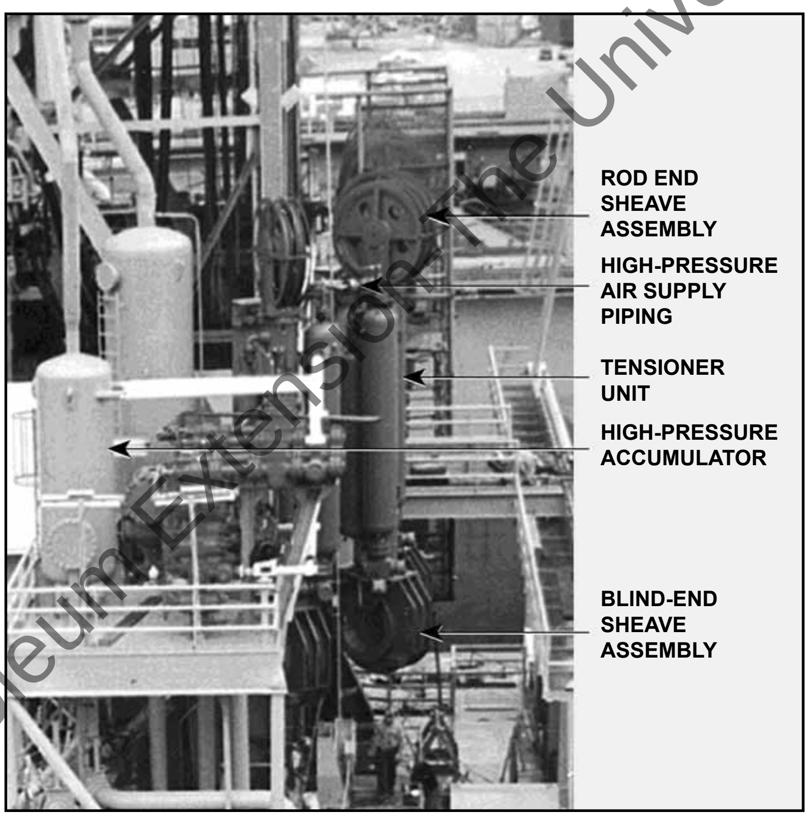

Figure 25. Riser tensioning system (Courtesy of Shaffer)

Guideline Tensioners

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In water depths no greater than about 5,000 ft (1,500 m), guidelines may be used to guide the BOP and LMRP assembly to the wellhead on the seabed. Four wire-rope guidelines form the corners of a square that extend from the vessel to guideposts on a guide base at the seabed. Each wire rope is attached to a guideline tensioner through double sheaves on the piston rod and cylinder's blind end. The guideposts on the guide base are 6 ft (2 m) from the center of the wellbore, and form a square whose sides are about 8½ ft (2.5 m) long. Guidelines are inserted into funnels at each corner of the BOP and LMRP frames.

When the BOP and LMRP are run, the guidelines are tensioned sufficiently to (1) prevent rotation of the BOP and LMRP assembly, (2) overcome the lateral loads imposed on the guidelines by vessel movement and current forces, and (3) provide alignment with the guideposts on the guide base.

Once the BOP assembly has been lowered over the guideposts and landed on the wellhead, the guideline tension can be reduced to a point sufficient just to support the weight of the wire rope.

If the LMRP has to be disconnected from the BOP, the guideline tensioners are used to guide the LMRP back over the BOP guideposts.

The guideline tensioners may also be used to guide other equipment to and from the seabed. For example, they may guide TV cameras to monitor riser angle or to see whether hydrates are forming. Guideline tensioners may also be used to guide control pods to and from the LMRP. Experience has shown that even the heaviest loads can be guided with guideline tension at the surface set at 6,000 to 12,000 lb (2,670 to 5,340 dN).

Subsea Wellheads and Casing

The subsea wellhead and casing are a system—a system that forms the foundation for drilling a successful well. This system also links the well to the BOP equipment. A structural casing string is set and cemented in place to support the BOP assembly at the seabed. This structural casing also supports subsequent casing strings that are run in the well.

As the well is drilled, crew members run casing that is smaller in diameter and has higher pressure ratings than previous casing strings. Table 2 gives a typical casing program.

Table 2
Casing Strings Run into a Well From Start to Finish with Typical Hole and Casing Sizes

Casing String	Hole Size, in. (mm)	Casing Size, in. (mm)
Structural	36 (914.4)	30 (762.0)
Conductor	26 (660.4)	20 (508.0)
Surface	13⅜ (339.7)	17½ (444.5)
Intermediate	12¼ (311.2)	9⅝ (244.5)
Production	8½ (215.9)	7 (177.8)

Mud- and Gas-Handling Equipment

A mud-gas separator is an essential item of rig equipment to handle the mud and gas flow from the choke manifold during a gas kick. It provides a method of separating the gas from the mud and venting the gas at a safe distance from the drill floor. Once separated from the gas, the mud can be returned to the active system. Various types of separator are available, but a bottom opening to enable fluid return to the mud system and an opening to allow gas to vent from the top are essential. The gas vent line's ID should be 6 to 8 in. (150 to 200 mm) to minimize back-pressure on the separator. The vent line is normally routed up the derrick where the gas can vent safely above the crown. Usually, a bypass to an emergency overboard line is provided should the separator become overloaded or fail. Prior to returning to the active system, the mud passes through vacuum degassers to separate any small gas accumulations that were left in the mud after it passed through the mud-gas separator. Finally, the active mud tanks have large surface areas and an agitation system. The large surface areas expose the mud to the atmosphere and the agitators stir the mud. In this manner, even smaller quantities of gas that may still be left in the mud can be removed.

Since correctly weighted mud is the primary means of well control, bulk mud mixing devices, including storage tanks with a transfer system and mixing hoppers, are required to quickly raise the mud weight.

Adequate volumes of conditioned mud should be maintained in the tanks at all times, taking into consideration the possibility of lost circulation. Further, tank space should be available to allow for expansion if it becomes necessary to circulate out a gas kick.

Auxiliary Surface Well-Control Equipment

Auxiliary surface well-control equipment includes equipment for the drill string and various surface devices. Equipment needed for the drill string include drill pipe safety valves, upper and lower kelly cocks, inside BOP valves, and drill pipe float valves. Additional surface equipment includes a trip tank, mud pit volume measuring and recording devices, a flow-line mounted flow-line sensor, and safety valves for the top drive.

Drill Pipe Safety Valve

A full-opening drill pipe safety valve with the same pressure rating as the ram preventers should be available on the rig floor at all times, complete with its closing wrench. The required crossover subs should also be available to allow the valve to be connected to any section of the drill string, casing, or tubing in use. The drill pipe safety valve's OD should be of a size that allows it to be run in the hole. Furthermore, it should have a top connection that allows it to be connected to the top drive or kelly.

Inside Blowout Preventers

An inside blowout preventer is a drop-in check valve that the floor crew installs on the surface. It is also called a Gray valve after one of the manufacturers of such valves. It should be available on the drill floor at all times. If the drop-in type is used, a landing sub is positioned in the drill string at the drill collars. A dart of the correct size to match the landing sub is kept on the rig floor at all times. Note that the dart must pass through all components of the drill string above the landing sub.

Hydraulic Control Systems

Every component in the subsea BOP assembly is hydraulically operated and a control system is used to operate them. The BOP control system must deliver, on command, hydraulic fluid at the correct pressure to operate the BOP components. Further, when a component is operated, the system must also vent hydraulic fluid from the opposite side of the operated component. Subsea BOP control systems are indirect pilot-operated systems. That is, hydraulic pilot signals from the surface operate various valves and regulators mounted in the subsea control pods that then supply the operating fluid to the BOP components. Two types of indirect pilot system are the straight hydraulic type and the multiplexed type. The straight hydraulic system (fig. 61) is rated to 3,000 psi (21,000 kPa) working pressure and delivers the hydraulic pilot signals from the surface through pilot hoses to the valves and regulators mounted in the subsea control pods.

The multiplexed system is usually rated to 5,000 psi (35,000 kPa) working pressure and sends electronic signals from the surface to subsea-mounted solenoid valves that then send the pilot signals to the valves and regulators.

Straight Hydraulic Control Systems

BOP control system manufacturers include Koomey, Shaffer, Hydril, ABB Systems, and Cameron. Basically, all straight hydraulic systems operate the same way, although different manufacturers may use slightly different valves and regulators to achieve the same result.

The control system can be separated into four individual sections—

1. the surface accumulator unit, or HPU;
2. the hose bundles, hose reels, and hose reel control panels;
3. the subsea control pods; and
4. the remote electric panels.

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