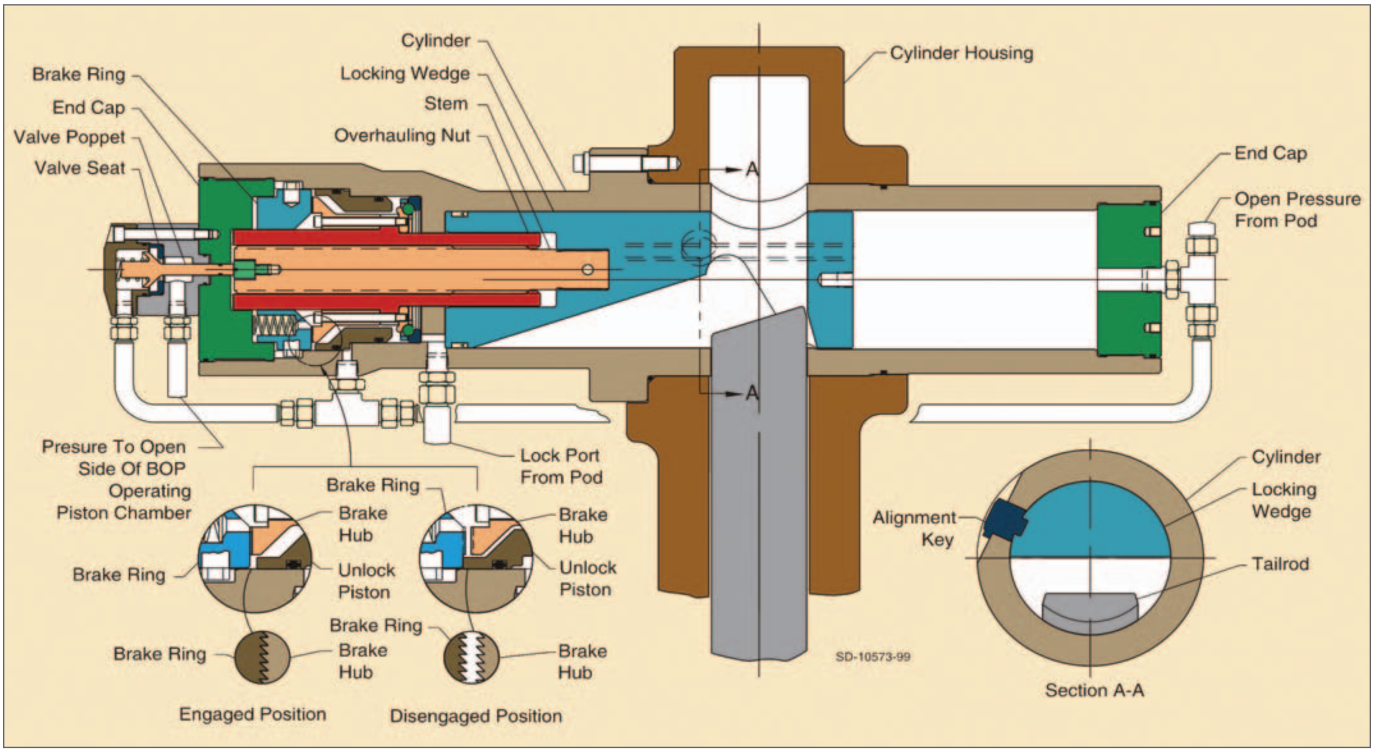


The above shows a typical BOP operating piston assembly with a transverse-mounted locking mechanism.

Design evolution of a subsea BOP

Blowout preventer requirements get tougher as drilling goes ever deeper

By Melvyn F (Mel) Whitby, Cameron's Drilling System Group

THE FIRST RAM BOP was developed in 1920, and, in the last 90 years, the principle of operation of a ram BOP has not deviated much from the original concept.

In a typical design, a set of 2 rams is mechanically or hydraulically closed either around a wellbore tubular to form a pressure-tight seal against downhole pressure or wellbore fluids. Shearing rams were introduced in the 1960s. These rams sheared the pipe in the wellbore, but an additional BOP cavity containing a set of blind rams was required to seal the bore. Later, these functions were combined into shearing blind rams, commonly known as SBRs, which reduced the number of BOP cavities required to 1.

From the 1st BOP design to the present designs, the basic mechanisms have remained constant: A BOP body is sandwiched between 2 operating systems. The rams are opened and closed mechanically either by manual intervention or by hydraulically operated pistons.

What has changed, however, and is in a constant state of flux are the operating parameters and the manner in which BOPs are used in today's drilling activities. Today, a subsea BOP can be required to operate in water depths of greater than 10,000 ft, at pressures of up to 15,000 psi and even 25,000 psi, with internal wellbore fluid temperatures up to 400° F and external immersed temperatures coming close to freezing (34° F).

THE CHALLENGE

The deepwater challenges being experienced by drilling contractors and oil companies alike are critical technical challenges that must be overcome if drilling is to move into deepwater environments

Today's deepwater BOPs can be required to remain subsea for extended periods of time ranging from 45 to 90 days for a single well, to more than a year in cases where drilling and completions on multiple wells are required. In all cases, however, when the BOP is called on to function in an emergency situation, it is the main barrier protecting human life, capital equipment and the environment.

Therefore, it must function without fail. One possible enhancement involves taking advantage of advances in metallurgy to use higher-strength materials in ram connecting rods or ram-shafts.

The newbuild drilling and production facilities under construction for today's market are limited for space and handling capabilities and, therefore, require that BOP stacks be lighter-weight and take up less space on the rig while providing the accustomed functionality. In addition, existing limited capacity rigs have the potential to be upgraded for use in deepwater with higher-capability equipment, but the upgrade must be accomplished within limited height and weight parameters. With deck space and load capacity of these rigs already at a premium, lighter weight BOPs can help offset distribution of alternative equipment such as subsea riser joints necessary for increased water-depth capability.

BOPs today are also being used not only in drilling and workover applications but also in completions and production environments. The industry is not just dealing with drilling mud anymore.

BOPs have traditionally evolved using conventional design methodology. Today the envelope is rapidly changing, forcing some fundamental paradigm shifts. Emerging technologies give way to new manufacturing techniques and innovation of design of operation. Sealing technology has improved radically with new materials and compounds being used to formulate sealing elements able to withstand extreme temperatures and hostile fluid environments.

RELIABILITY OF OPERATION

The increased design complexity of modern-day BOPs can come at a price. While high-tech solutions may seem desirable, the intricate mechanical components that may result must be considered, along with other factors, such as possible leak paths and redundancy of critical seals.

In addition, control system functions can be limited and, in order to save function availability, hydraulic functions are often combined. An example of this is the integrated closing and automatic locking of the BOP when the closing function is initiated. This combined function has now been discarded, in many instances, in favor of separate close and lock functions. It is now understood that the chances of a locking system problem are increased with a proliferation of locking cycles.

Many drilling contractors today are reluctant to operate the locks subsea in order to prevent unnecessary unlocking problems. The locks are tested on the surface for assurance that they will operate should the situation arise. In the performance characteristics section of API 16A, API suggest that the locks be fatigue-tested in concurrence with a 546 cycle, 78 pressure cycle API ram fatigue test.

This test initially was designed to simulate 1 closure per day and a weekly pressure test for an estimated period of 18 months' service. In combining the locking system test into this test, it was recommended that every 7th pressure cycle be conducted in locked mode. This means that during the course of an 18-month service period, the locks were expected to be used a total of 11 times.

Combining the closing and locking system function meant that the locks were being exposed to a locking operation every time the BOP was operated, requiring a complicated mechanical or hydraulic sequencing arrangement be incorporated. In addition, a locking system can be exposed to extremely high load forces during a shearing operation and is therefore required to be extremely robust by design. The complexity of such systems and their mechanical function can be impaired by the acute mechanical detail required to make them work adequately.

FLUID CONSUMPTION, ACCUMULATOR VOLUME

Fluid consumption is a double-edged sword: Less fluid typically comes at a high cost because conventional design philosophy often means that smaller pistons yield smaller force output. In deepwater applications, this force is additionally reduced by the hydrostatic column of seawater and/or drilling mud. In order to mitigate these factors, 2 things must be considered — closing ratio and piston area.

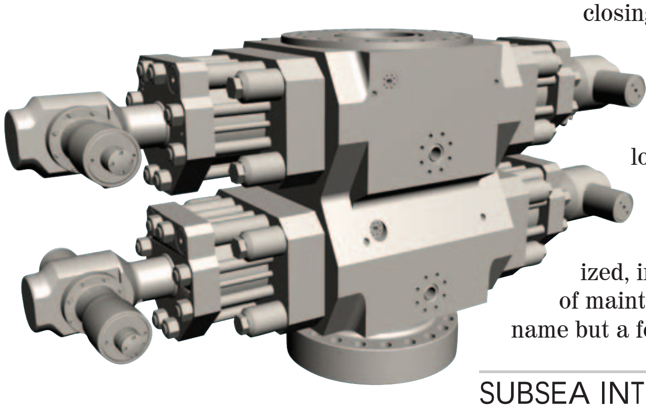
Smaller-diameter pistons mean that wellbore-exposed areas are minimized and, therefore, will not "rob" the operating system of much-needed power. However, the piston area must be large enough to provide sufficient power for ram seal energizing and rubber feed, and must provide the power to shear high-strength, ductile tubulars when necessary.

The downside of traditional design philosophy is that a piston large enough to provide the much-needed power is almost the same area in opening as it is in closing. Ergo, a BOP that requires 22 gallons of fluid to close will require approximately 18 gallons to open, a factor that can affect the surface and subsea accumulator bottle count.

Another negative impact is that a larger BOP opening area can actually put the equipment and the environment at risk. If opening pressure is inadvertently applied to a BOP that is retaining wellbore pressure or residual pressure, damage can result to the connecting rod and/or the ram to connecting rod interface. This damage can result in the loss of sealing integrity or ram control, leaving the rig at risk and increasing the potential for environmental harm, not to mention the associated downtime necessary for repair.

By separating the closing function from the opening function and reducing the opening area, a number of benefits can be realized:

• Reduced operating volume. More closing power can be achieved by using



An example of a 18 ¾-in. 15M subsea BOP with 18-in. operating pistons.

a large closing piston diameter and a second smaller piston diameter for the opening function. For example a closing area of 224 sq in. and an opening area of 41 sq in. results in 22 gallons to close but only 8 gallons to open.

• Reduced opening area. Smaller operating piston diameter reduces the effective opening ratio of the BOP, thereby protecting against accidental operation with wellbore or residual pressure in the BOP bore. In the event that opening pressure is applied in this case, the operating piston would stall, preventing potential damage to the connecting rod or ram.

• The closing piston and opening piston seals may be separated, preventing possible leak communication. Additionally, in the unlikely —but not impossible — event that wellbore pressure was to bypass the connecting rod seals, the structural integrity of the BOP bonnet would not be at risk.

LOCKING OPERATION, RELIABILITY

Over the course of BOP development, mechanical locking systems have by nature become more and more complex. Considerable BOP downtime has been attributed to errant operation or inability to unlock when required. These events typically involve possible milling through closed rams and eventual tripping of the BOP back to the surface for repair or remedial work. A lock should ultimately be reliable, but with complexity comes risk. Multiple parts must interface for proper operation.

Taking a step back in time, surface BOPs have utilized a simple but effective form of mechanical lock — a simple rotating threaded locking screw placed behind the operating piston after hydraulically closing the BOP. With recent subsea advancements in hydraulic gear motors for torque applications, it may be time to look down this path for a simple, reliable locking operation. A number of benefits could be realized, including simplicity, ease of maintenance and reliability, to name but a few.

SUBSEA INTERVENTION CAPABILITY

A simple, mechanical-type locking system for subsea BOPs may open up opportunities for intervention by a remote-operated vehicle (ROV), thereby allowing for intervention subsea. ROVs are already doing this work in other applications that require mechanical intervention, such as on subsea trees that require manual override and the torque-up of API Class 1 – 4 flange connections.

HEIGHT AND WEIGHT

The height and weight of a BOP body is determined by factors such as ram cavity height and geometry, and the operating system or bonnet design. Minimal cavity height can realize height savings but at the sacrifice of ram packer volume, which is important for the longevity of the sealing mechanisms in operation subsea. Large operating systems require excess distances between the cavities of double and triple BOP bodies.

By careful redesign of the operating system, cavity height can be increased for effectiveness while minimizing height impact. In one such case, using an 11.5-in. tall cavity, the height of a double BOP body was reduced from 83 in. tall to 72 in. tall while maintaining a large operating system area. This could be achieved either by using a binocular-style operating piston arrangement or an oval-shaped piston instead of the traditional circular style piston. Shortening the height of the BOP components in a subsea stack either allows for a shorter drilling substructure arrangement or allows for the incorporation of BOP cavities within existing substructure height envelopes.

MAINTENANCE, OPERABILITY

Ease of use and simplicity of operation and maintenance are key components to BOP design. In order to achieve these goals, several factors should be considered:

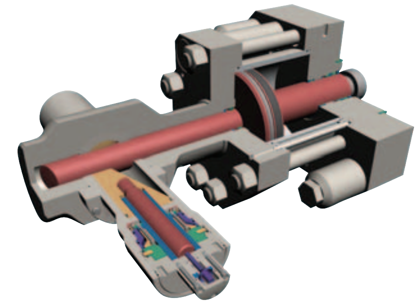
• Leak paths between critical functions should be minimized.

• Redundancy of seals should be utilized wherever possible.

• A means of isolating hydraulic functions to the BOP should be employed, if possible, to minimize personnel risk while conducting maintenance operations with the bonnets open.

• Provision should be made to allow safe handling of the bonnets should removal for repair or maintenance be required.

• Efforts should be made to minimize the handling of components weighing more than 20 lbs, or lifting arrangements should be provided to assist in their safe removal.



A 3D view of a BOP operating piston assembly with transverse mounted locking mechanism.

While efforts within the industry have been made to reduce or even remove the bonnet securing bolting, the benefits have been offset by the associative complexity and thereby increasing the risk of serious mechanical problems. These problems can cause excessive downtime when the BOPs are finally pulled back to the surface, not to mention the possibility of debris and cement causing problems with internal bore style bonnet retaining mechanisms. The complexity of these arrangements, while appearing to be high-tech, do little to enhance the subsea performance and surface maintainability of the equipment.

One reasons that BOPs have changed very little over the years is that it is extremely difficult to improve on simplicity without sacrificing reliability.

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