

Title: Pressure Containment Devices

Description of Invention

5 The invention relates to a pressure containment device, particularly but not exclusively, an annular blowout preventer for use in the drilling of a wellbore into a subterranean fluid reservoir and / or the production of fluid, typically hydrocarbon fluids, from such a reservoir.

10 The drilling of a borehole or well is typically carried out using a steel pipe known as a drill pipe or drill string with a drill bit on the lowermost end. The drill string comprises a series of tubular sections, which are connected end to end. The entire drill string is typically rotated using a rotary table or top drive mounted on top of the drill pipe, and as drilling progresses, a flow of mud is used to carry the debris and/or cuttings created by the drilling process out of the wellbore. Mud is pumped down the drill string to pass through the drill bit, 15 and returns to the surface via the annular space between the outer diameter of the drill string and the wellbore (generally referred to as the annulus). For a subsea well bore, a tubular, known as a riser, extends from the rig to the top of the wellbore and provides a continuous pathway for the drill string and the fluids emanating from the well bore. In effect, the riser extends the wellbore 20 from the sea bed to the rig, and the annulus also comprises the annular space between the outer diameter of the drill string and the riser.

The use of a blowout preventer (BOP) to seal, control and monitor oil and gas wells is well known, and these are used on both land and off-shore rigs. During drilling of a typical high-pressure wellbore, the drill string is routed 25 through a BOP stack toward a reservoir of oil and/or gas. The BOP is operable, in the event of a sudden influx of formation fluid into the wellbore (a kick) to seal around the drill string, thus closing the annulus and stopping tools and formation fluid from being blown out of the wellbore (a blowout). The BOP

stack may also be operable to sever the drill string to close the wellbore completely. Two types of BOP are in common use – ram and annular, and a BOP stack typically includes at least one of each type. The original design of annular BOP is disclosed in US 2,609,836.

- 5 A typical BOP has a sealing element and a fluid pressure operated actuator mounted in a housing. The actuator divides the interior of the housing into two chambers (an “open chamber” and a “close chamber”), and substantially prevents flow of fluid between the two chambers. The actuator is movable, by means of the supply of pressurised fluid to the close chamber, to urge the
10 sealing element into sealing engagement with a drill pipe extending through the BOP (the closed position), and, by means of the supply of pressurised fluid to the open chamber, to release the sealing element from sealing engagement with the drill pipe (the open position). Certain types of BOP are configured such that, when there is no drill pipe in the BOP, the sealing element can close
15 on itself to close completely the BOP stack, and thus also the wellbore.

The supply of pressurised fluid for actuation of the BOP typically comprises a pump which is operable to pump fluid into an accumulator via a line containing a non-return valve. Fluid flow lines are provided to connect the accumulator to the open chamber and the close chamber and at least one valve is provided to
20 control flow of fluid from the accumulator to the open or close chamber.

An example of a typical annular BOP and fluid pressure control system is shown in US 4,098,341. Alternative embodiments of BOP and their control systems are disclosed in US 3,044,481, US 3,299,957, US 4,614,148 and US 4,317,557, US 3,128,077 and US 4,317, 57.

- 25 Various configurations of seals suitable for use in mineral extraction systems are also disclosed in US 8,800,648, US 2013/0043657 and US 2014/0203516.

FIGURE 1 is a schematic illustration of a transverse cross-section through a conventional, prior art, elastomeric sealing element 10' of the type used in

conventional, prior art, blowout preventers a) in a relaxed state and b) in a compressed state. When in the relaxed state, the sealing element 10' has a generally annular transverse cross-section. When the blowout preventer is closed, the sealing element 10' is compressed so as to reduce the diameter of the space it encloses. To do this, radially inwardly directed forces are applied to the sealing element 10', either directly or by virtue of the sealing element 10' being pushed against the BOP housing by a piston which is movable generally parallel to the longitudinal axis of the BOP.

The resulting deformation/folding pattern on the elastomeric material will be based on the least resistance region of the sealing element 10' and will depend on either the buckling modes of the elastomeric ring or the defects/weak regions of the elastomer. As a consequence, there is no control over the folding pattern at the inner surface of the sealing element 10' which will create irregular folds as shown in Figure 1b. Irregular folds creates high strains in certain folds and low strains in other folds, and the highly strained regions of the elastomeric material will have a tendency for faster crack growth/lesser life due to the availability of high strain energy density on the critical folding regions. Moreover, the sealing surface generated between the sealing element 10' and a tubular string 12' extending through the BOP will be perfect in some regions and not in other regions where the sealing element 10' is still spaced from the tubular string. This variation in the sealing surface means that a very high compressive force is required to seal completely around the tubular string.

Embodiments of the present invention seek to provide an improved pressure containment device in which these problems may be reduced.

According to one aspect of the invention we provide a pressure containment device comprising a sealing element having a longitudinal axis and a cross-section perpendicular to its longitudinal axis which is generally annular, the sealing element thus having a radially inwardly facing interior surface, a radially outwardly facing exterior surface, and a first end surface and a second

end surface which extend from the interior surface to the exterior surface, wherein both the interior surface and the first end surface are provided with a plurality of discrete recesses,

- wherein the recesses provided in the interior surface form a first set of
 5 recesses in which the recesses are spaced around the circumference of the interior surface and the recesses in the first set are located exclusively in the interior surface between the first end surface and the second end surface; wherein the recesses provided in the end surface form a second set of recesses in which the recesses are spaced in a generally circular array; and
 10 wherein a centre of each of the recesses is located on an imaginary plane in which the longitudinal axis of the sealing element also lies, and the imaginary plane associated with each recess in the first set is located directly between two of the imaginary planes associated with the recesses of the second set.

- The recesses in the first set may be located generally centrally between the
 15 first end surface and the second end surface. In one embodiment, the recesses in the first set are regularly spaced around the circumference of the interior surface.

In one embodiment, the recesses in the second set are regularly spaced in a generally circular array.

- 20 In one embodiment, a centre of each of the recesses is located on an imaginary plane in which the longitudinal axis of the sealing element also lies, and the imaginary plane associated with each recess in the second set is located directly between two of the imaginary planes associated with recesses of the first set.
- 25 The imaginary plane associated with each recess in the second set may be located centrally between two of the imaginary planes associated with recesses of the first set.

The imaginary plane associated with each recess in the first set may be located centrally between two of the imaginary planes associated with the recesses of the second set.

5 In one embodiment, the angle between adjacent imaginary planes is substantially equal for all pairs of adjacent imaginary planes.

The pressure containment device may further comprise an actuator assembly which is operable to engage with the sealing element to reduce the diameter of the space enclosed by the interior surface.

10 The pressure containment device may further include a housing, the actuator assembly being operable to push the sealing element against the housing to reduce the diameter of the space enclosed by the interior surface.

The actuator assembly may comprise a piston movable by means of the supply of pressurised fluid to the pressure containment device. In one embodiment, the piston is movable generally parallel to a longitudinal axis of
15 the pressure containment device by means of the supply of pressurised fluid to the pressure containment device.

The sealing element may be made predominantly from an elastomer.

The sealing element may include a plurality of rigid inserts. In this case, the inserts may be metallic. The inserts may be spaced from one another and
20 arranged in a generally circular array around the space enclosed by the interior surface of the sealing element.

Embodiments of the invention will now be described with reference to the accompanying drawings of which

FIGURE 2 is an illustration of a longitudinal cross section through a pressure
25 containment device according to the invention,

FIGURE 3 is an isometric view of the longitudinal cross section through a pressure containment device illustrated in Figure 2

FIGURE 4 is an isometric view of the longitudinal cross section through a pressure containment device illustrated in Figure 2 with a portion of a drill
5 string extending through the pressure containment device,

FIGURE 5 is an illustration of a longitudinal cross-section through the sealing element of the pressure containment device illustrated in Figures 2 and 3,

FIGURE 6 is an isometric view of the longitudinal cross-section through the sealing element illustrated in Figure 5,

10 FIGURE 7 is a schematic illustration of a transverse cross-section through the sealing element illustrated in Figures 5 and 6 a) in a relaxed state and b) in a compressed state,

FIGURE 8 is an illustration of a longitudinal cross-section through an alternative embodiment of sealing element,

15 FIGURE 9 is an isometric view of the longitudinal cross-section through the sealing element illustrated in Figure 8,

FIGURE 10 is an illustration of a longitudinal cross-section through a further alternative embodiment of sealing element, and

FIGURE 11 is an isometric view of the longitudinal cross-section through the
20 sealing element illustrated in Figure 10.

Referring now to Figures 2 and 3, there is shown a blowout preventer 14 having a housing 16 in which is located a sealing element 10 and an actuator assembly 18. The sealing element 10 has a longitudinal axis A and a cross-section perpendicular to its longitudinal axis A which is generally annular. The
25 sealing element 10 thus has a radially inwardly facing interior surface 10a, a

radially outwardly facing exterior surface 10b, and a first end surface 10c and a second end surface 10d which extend from the interior surface 10a to the exterior surface 10c, at opposite ends of the sealing element 10. Both the interior surface 10a and the first end surface 10c are provided with a plurality of discrete recesses 20.

In this example, the end surfaces 10c, 10d of the sealing element 10 extend generally perpendicular to the interior surface 10a.

The actuator assembly 18 is operable to engage with the sealing element 10 to reduce the diameter of the space enclosed by its interior surface 10a.

In one embodiment, the actuator assembly 18 is operable to push the sealing element 10 against the housing 16 to reduce the diameter of the space enclosed by the interior surface 10a.

In the example illustrated in Figures 2 and 3, the actuator assembly 18 comprises a piston movable by means of the supply of pressurised fluid to the pressure containment device. In this embodiment, the piston is movable generally parallel to a longitudinal axis A by means of the supply of pressurised fluid to an activation chamber provided in the housing 16 of the pressure containment device.

In one embodiment, the housing 16 is provided in two parts 16a, 16b, the first part 16a having a curved interior surface which is intended to engage with the sealing element and to cause the sealing element 10 to constrict when the sealing element 10 is pushed against the housing 16 by the actuator assembly 18.

It should be appreciated, however, that the invention is not restricted to this type of actuator assembly 18. The actuator assembly may, for example, comprise a ram/piston or plurality of rams/pistons which is/are movable perpendicular to the longitudinal axis A and radially inwardly of the sealing

element 10. Alternatively, the actuator assembly may comprise a supply of pressurised fluid and means to direct the pressurised fluid to act directly on the exterior surface 10b of the sealing element 10 to compress the sealing element 10 and thus reduce the diameter of the space enclosed by the interior surface 10a.

Figure 4 shows a tubular drill string 12 extending through the blowout preventer 14. In this example, the drill string 12 extends along the longitudinal axis A of the sealing element 10.

The sealing element 10 is illustrated in more detail in Figures 5 and 6.

The recesses 20 provided in the interior surface 10a of the form a first set of recesses 20a in which the recesses are located exclusively in the interior surface 10a between the first end surface 10c and the second end surface 10d, spaced around the circumference of the interior surface 10a. In this example, the recesses in the first set 20a are located generally centrally between the first end surface 10c and the second end surface 10d, and are regularly spaced around the circumference of the interior surface 10a.

The recesses 20 provided in the end surface 10c form a second set of recesses 20b in which the recesses are spaced in a generally circular array. In this example, the recesses in the second set 20b are regularly spaced in a generally circular array.

In this example, each set 20a, 20b has 6 recesses.

In this example, the recesses in the second set 20b are located at the interface between the end surface 10c and the interior surface 10a.

The centre of each recesses is located on an imaginary plane in which the longitudinal axis A of the sealing element 10 also lies, and in this example, the imaginary plane associated with each recess in the first set 20a is located directly between two of the imaginary planes associated with recesses of the

second set 20b, whilst the imaginary plane associated with each recess in the second set 20b is located directly between two of the imaginary planes associated with the recesses of the first set 20a. In other words, when viewed from a direction generally parallel to the longitudinal axis A, each recess in the first set 20a is located between two recesses from the second set 20b and vice versa.

In this case, the angle between adjacent imaginary planes is substantially equal for all pairs of adjacent imaginary planes.

The sealing element may be made predominantly from an elastomer such as hydrogenated nitrile butadiene rubber (HNBR), nitrile rubber (NBR), polyurethanes or a combination thereof. Rubbers and elastomers having a durometer range between 50 Shore A and 100 Shore A may be used. Composite materials which include elastomers, polymers and fibre reinforced elastomers or fluorocarbons may also be used. The elastomeric material may further be modified by the addition of friction reducers.

In this example, the sealing element includes a plurality of rigid inserts 22. Preferably these are metallic.

In this example, the inserts are regularly spaced from one another and arranged in a generally circular array around the space enclosed by the interior surface 10a of the sealing element 10.

A transverse cross-section (in a plane perpendicular to the longitudinal axis A) through the sealing element 10 and associated drill string 12 is illustrated schematically in Figures 7a and 7b. Figure 7a shows the sealing element 10 in its undeformed, relaxed, state in which the interior surface 10a of the sealing element is spaced from the drill string 12. Figure 7b shows the sealing element 10 in its deformed state in which the actuator assembly has acted on the sealing element 10 to cause it to constrict about the drill string 12.

As mentioned earlier in relation to prior art blowout preventers, the deformation/folding pattern on the elastomeric material on the sealing element 10 depends on either the buckling modes or the defects/weak regions of the elastomer ring. The recesses 20 at the inner surface regions provide the least
5 resistance for material folding, and hence the material will fold at each recess 20. As a result, the folding pattern will be more regular at the inner surface of the elastomer as shown in Figure 7b. These regular folds create the same level of strain in all the folds. This may increase the life of the elastomeric component of the sealing element 10 due to the reduction in the available
10 strain energy density at the critical folding regions. This regular folding pattern distributes the sealing surface evenly around the circumference of the drill string 12, and the radial compressive force required to seal around the drill string 12 may be reduced.

The exact shape of the recesses 20 may be varied. Alternative embodiments
15 of sealing elements are illustrated in Figures 8, 9, 10 and 11. In the example illustrated in Figures 8 and 9, the recesses are generally elliptical with the recesses in the first set 20a have the shape of roughly half of an ellipsoid (cut longitudinally), whilst the recesses in the second set 20b have the shape of roughly one quarter of an ellipsoid. In the example illustrated in Figures 10
20 and 11, the recesses in the first set 20a have the shape of a longitudinal cross-section through a cylinder, whilst the recesses in the second set 20b have the shape of a portion of an ovoid. The recesses in the second set 20b could, of course, have the shape of a quarter of a cylinder.

Whilst in the examples described above, it is specified that recesses are
25 provided only the interior surface 10a and the end surface 10b of the sealing element 10, it should be appreciated that the sealing element 10 has a further end surface 10d which also extends between the interior surface 10a and the exterior surface 10b at an opposite end of the sealing element 10 to the end surface 10c. A third set of recesses 20c may also be provided in this further
30 end surface 10d as illustrated in Figures 8 and 9. In this example, the

recesses in the second 20b and third set 20c are arranged such that on each imaginary plane (containing the longitudinal axis A) associated with a recess in either of the end surfaces 10c, 10d there is either a recess in the second set 20b or a recess in the third set 20c, not both. Also in this example, the
5 recesses in the second 20b and third 20c set alternate moving around the longitudinal axis A of the sealing element 10. It should be appreciated, however, that this need not be the case, and recesses in both the second 20b and third 20c set may be provided in the same imaginary plane.

The exact location, number, size, pattern of distribution (regular/irregular),
10 number of sets in each surface and shape of the recesses 20 may, of course, be varied to achieve a desired folding pattern. The exact location, number, size and shape of the recesses 20 required will depend on the mechanical properties of the elastomeric material from which the sealing element 10 is made, the absence / presence of rigid inserts and their number, the
15 dimensions of the sealing element 10, the actuation mechanism, and the degree of constriction required.

Preferably at least 3 recesses are provided in each set.

When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or
20 integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or components.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for
25 attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS

- 1 A pressure containment device comprising a sealing element having a longitudinal axis and a cross-section perpendicular to its longitudinal axis which is generally annular, the sealing element thus having a radially inwardly
5 facing interior surface, a radially outwardly facing exterior surface, and a first end surface and a second end surface which extend from the interior surface to the exterior surface at opposite ends of the sealing element, wherein both the interior surface and the first end surface are provided with a plurality of discrete recesses,
- 10 wherein the recesses provided in the interior surface form a first set of recesses in which the recesses are spaced around the circumference of the interior surface and the recesses in the first set are located exclusively in the interior surface between the first end surface and the second end surface;
- wherein the recesses provided in the end surface form a second set of
15 recesses in which the recesses are spaced in a generally circular array; and
- wherein a centre of each of the recesses is located on an imaginary plane in which the longitudinal axis of the sealing element also lies, and the imaginary plane associated with each recess in the first set is located directly between two of the imaginary planes associated with the recesses of the second set.
- 20 2. A pressure containment device according to claim 1 wherein the recesses in the first set are located generally centrally between the first end surface and the second end surface.
3. A pressure containment device according to any preceding claim wherein the recesses in the first set are regularly spaced around the
25 circumference of the interior surface.

4. A pressure containment device according to any preceding claim wherein the recesses in the second set are regularly spaced in a generally circular array.

5. A pressure containment device according to any preceding claim
5 wherein a centre of each of the recesses is located on an imaginary plane in which the longitudinal axis of the sealing element also lies, and the imaginary plane associated with each recess in the second set is located directly between two of the imaginary planes associated with recesses of the first set.

10 6. A pressure containment device according to claim 5 wherein the imaginary plane associated with each recess in the second set is located centrally between two of the imaginary planes associated with recesses of the first set.

15 7. A pressure containment device according to any preceding claim wherein the imaginary plane associated with each recess in the first set is located centrally between two of the imaginary planes associated with the recesses of the second set.

20 8. A pressure containment device according to any preceding claim wherein the angle between adjacent imaginary planes is substantially equal for all pairs of adjacent imaginary planes.

9. A pressure containment device according to any preceding claim further comprising an actuator assembly which is operable to engage with the sealing element to reduce the diameter of the space enclosed by the interior surface.

25 10. A pressure containment device according to claim 9 further including a housing, the actuator assembly being operable to push the sealing element against the housing to reduce the diameter of the space enclosed by the interior surface.

11. A pressure containment device according to claim 9 or 10 wherein the actuator assembly comprises a piston movable by means of the supply of pressurised fluid to the pressure containment device.

5 12. A pressure containment device according to claim 11 wherein the piston is movable generally parallel to a longitudinal axis of the pressure containment device by means of the supply of pressurised fluid to the pressure containment device.

13. A pressure containment device according to any preceding claim wherein the sealing element is made predominantly from an elastomer.

10 14. A pressure containment device according to any preceding claim wherein the sealing element includes a plurality of rigid inserts.

15. A pressure containment device according to claim 14 wherein the inserts are spaced from one another and arranged in a generally circular array around the space enclosed by the interior surface of the sealing element.