HYDRAULIC CIRCUIT CONSTRUCTION IN DOWNHOLE TOOLS

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BACKGROUND

The present invention relates generally to equipment and methods utilized in conjunction with a subterranean well and, in an embodiment described herein, more particularly provides a hydraulic circuit construction for use in downhole tools.

Many downhole tools are operated or controlled by relatively complex hydraulic circuits. These hydraulic circuits are made up of hydraulic components, such as valves, restrictors, pumps, sensors, etc., interconnected by

passages. The passages interconnecting the hydraulic components are typically formed by separate lines or tubing extending between the components, or the passages are formed through a solid body, such as a housing or mandrel to which the components are connected.

When the passages are formed in a body of a downhole tool, the passages are generally formed by drilling into the body, and cross-drilling to form intersecting passages. Specialized drilling machines must be used where the passages extend substantial distances into the body. Often, ends of the passages used to initiate the drilling must be closed off with plugs.

It will be appreciated that this method of constructing hydraulic circuits in downhole tools is expensive, labor-intensive, time-consuming and prone to error. Therefore, it would be advantageous to provide improved hydraulic circuit construction for use in downhole tools.

SUMMARY

In carrying out the principles of the present invention, in accordance with an embodiment thereof, an improved fluid circuit construction is provided which solves the above problems in the art. This circuit construction utilizes passages formed initially on a surface of a circuit layer to interconnect fluid-operative components installed on another layer. Thus, extensive drilling and cross-

drilling to form the passages and interconnect the components is eliminated, or at least substantially reduced.

In one aspect of the invention, a fluid circuit construction for use in downhole tools is provided which includes a first layer having at least one fluid-operative component installed therein and a second layer having a fluid passage formed thereon. The first and second layers are sealingly attached to each other, and the fluid-operative component is in fluid communication with the fluid passage.

In another aspect of the invention, a fluid circuit construction for use in downhole tools is provided which includes a first layer having multiple fluid-operative components received therein and a second layer having at least one fluid passage formed thereon. The fluid passage is in fluid communication with at least one of the fluid-operative components. A surface of the first layer closes off an outer side of the fluid passage on the second layer.

In yet another aspect of the invention, a fluid circuit construction for use in downhole tools is provided which includes a first layer having at least one fluid-operative component received therein and a surface, and a second layer having a fluid passage formed on a surface thereof. The fluid passage is in fluid communication with the fluid-operative component. The first layer surface and the second layer surface are sealingly attached, so that the first layer surface closes off an outer side of the fluid passage.

These and other features, advantages, benefits and objects of the present invention will become apparent to one of ordinary skill in the art upon careful consideration of the detailed description of representative embodiments of the invention hereinbelow and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a prior art hydraulic circuit construction;

FIG. 2 is a cross-sectional view of the prior art hydraulic circuit construction, taken along line 2-2 of FIG. 1;

FIG. 3 is a schematic cross-sectional view of a first fluid circuit construction embodying principles of the present invention;

FIG. 4 is a cross-sectional view of the first fluid circuit construction, taken along line 4-4 of FIG. 3;

FIG. 5 is a schematic side view of a passage layer of a second fluid circuit construction embodying principles of the present invention;

FIG. 6 is a schematic end view of a fluid-operative component layer of the second fluid circuit construction;

FIG. 7 is a cross-sectional view of the fluid-operative component layer, taken along line 7-7 of FIG. 6;

FIG. 8 is a schematic isometric view of a third fluid circuit construction embodying principles of the present invention;

FIG. 9 is a schematic isometric exploded assembly view of a fourth fluid circuit construction embodying principles of the present invention;

FIGS. 10-13 are schematic views of a fifth fluid circuit construction embodying principles of the present invention; and

FIG. 14 is a schematic isometric exploded assembly view of a sixth fluid circuit construction embodying principles of the present invention.

DETAILED DESCRIPTION

A prior art hydraulic circuit construction 10 is illustrated in FIGS. 1 & 2. An element of a downhole tool, such as a tubular mandrel 12 has a hydraulic component, such as a valve 14 installed therein. The valve 14 is installed in a hole 16, which is then closed off by installing a plug 18 in the hole.

To provide fluid communication longitudinally through the mandrel 12, another hole 20 is drilled in a sidewall of the mandrel. The hole 20 is usually relatively difficult and time-consuming to drill, due to its small diameter/length ratio and the need for it to be accurately directed to intersect the hole 16. Another plug 22 is used to close off an end of the hole 20.

As depicted in FIG. 2, when it is necessary to provide fluid communication between the valve 14 and another region radially separated relative to the mandrel 12, a series of cross-drilled holes 24, 26 must be drilled into the mandrel sidewall. Again, these holes 24, 26 are difficult and time-consuming to drill,

since they must accurately intersect each other in the mandrel 12 sidewall, the interior of which is not visible during the drilling process. One or more plugs 28 are again used to close off open ends of the holes 24, 26.

It will be readily appreciated that, even with the relatively simple prior art hydraulic circuit construction 10 illustrated in FIGS. 1 & 2, an unduly large number of difficult and time-consuming steps are required to form the hydraulic circuit. This makes the prior art hydraulic circuit construction 10 very expensive to produce. The problem is compounded when it is necessary for a hydraulic path to deviate from a straight line, such as to extend circumferentially in the tubular mandrel 12 sidewall.

Representatively illustrated in FIGS. 3 & 4 is a fluid or hydraulic circuit construction 30 which embodies principles of the present invention. In the following description of the hydraulic circuit construction 30 and other apparatus and methods described herein, directional terms, such as "above", "below", "upper", "lower", etc., are used only for convenience in referring to the accompanying drawings. Additionally, it is to be understood that the various embodiments of the present invention described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of the present invention.

The circuit construction 30 is referred to in the description below as a "hydraulic" circuit construction as an example of a fluid circuit construction which may benefit from the invention. However, other types of fluid circuits

which are not specifically hydraulic circuits (such as pneumatic or other gas circuits) may also benefit from the invention. Thus, the principles of the invention are not limited to use in only hydraulic circuits.

The hydraulic circuit construction 30 utilizes a layered construction, wherein hydraulic passages or paths are formed on surfaces of mating layers. In this manner, little or no drilling is required to interconnect hydraulic components. The hydraulic paths may be formed, for example, by milling the paths on the layer surfaces. When the layers are attached to each other, one layer surface will close off a side of a hydraulic path formed on a surface of another layer.

In FIGS. 3 & 4, the hydraulic circuit construction 30 is demonstrated as part of a generally tubular mandrel 32 of a downhole tool. The mandrel 32 includes an inner layer 34, a middle layer 36 and an outer layer 38. However, it should be understood that the principles of the invention are not limited to the specific details of the hydraulic circuit construction 30 depicted in FIGS. 3 & 4. For example, it is not necessary for the hydraulic circuit construction 30 to be formed in a tubular member or element, and it is not necessary for the hydraulic circuit construction to include three layers 34, 36, 38. Any shape may be used, and any number of layers may be used, in keeping with the principles of the invention.

A hydraulic or fluid-operative component, such as a valve 40 is received in a sidewall of the middle layer 36. As used herein, the term "fluid-operative

component" is used to indicate an element which regulates or otherwise controls fluid flowing therethrough, which operates in response to a fluid property, or which senses a property of fluid. Thus, pumps, valves, chokes, restrictors, pistons, and pressure and temperature sensors are examples of fluid-operative components. Fluid-operative components may be mechanical, electronic, electrical, optical, thermal, magnetic or other types of devices.

As depicted in FIGS. 3 & 4, the valve 40 is installed in an end of the middle layer 36. A hole 42 drilled through the middle layer 36 provides fluid communication with the valve 40. The hole 42 extends between outer and inner external surfaces 44, 46 of the middle layer 36.

A fluid path or passage 48 is formed on an outer external surface 50 of the inner layer 34. The passage 48 extends longitudinally on the inner layer 34. The passage 48 may be fairly easily formed on the surface 50, for example, by using a mill to cut the passage onto the surface. Note that it is far easier to mill a long path, such as the passage 48, onto an external surface than it is to drill a hole of the same cross-sectional area and length.

Another fluid path or passage 52 is formed on an inner surface 54 of the outer layer 38. The passage 52 extends circumferentially in the outer layer 38. The passage 52 may be fairly easily formed on the surface 54, for example, by using a lathe to cut the passage onto the surface. Note that it is far easier to lathe-cut a circumferential path than it is to cross-drill intersecting holes to form a circumferential path.

The layers 34, 36, 38 are sealingly attached to each other to make up the mandrel 32. When the outer surface 44 of the middle layer 36 is attached to the inner surface 54 of the outer layer 38, the outer surface 44 closes off an inner side of the passage 52, except for where the hole 42 provides fluid communication with the valve 40. When the inner surface 46 of the middle layer 36 is attached to the outer surface 50 of the inner layer 34, the inner surface 46 closes off an outer side of the passage 48, except for where the hole 42 provides fluid communication with the valve 40. Thus, the valve 40 can control fluid flow between the passages 48, 52 in the hydraulic circuit construction 30.

The surfaces 44, 46, 50, 54 of the layers 34, 36, 38 may be attached to each other using any appropriate means. For example, the surfaces 44, 46, 50, 54 may be adhered or bonded to each other using an epoxy, such as a thermoset epoxy. As another alternative, the surfaces 44, 46, 50, 54 could be furnace brazed or welded to each other.

It may now be fully appreciated that the hydraulic circuit construction 30 illustrated in FIGS. 3 & 4 is far superior to the prior art hydraulic circuit construction 10. These advantages become even more apparent when more complex hydraulic circuits are needed in downhole tools. In these situations, it becomes infeasible, or at least extremely difficult, to drill and cross-drill a large number of holes to form the hydraulic circuit. However, it remains fairly easy to form complex hydraulic passages on external surfaces, for example, by milling the passages.

Turning now to FIGS. 5-7, another hydraulic circuit construction 60 embodying principles of the present invention is representatively and schematically illustrated. In FIG. 5 it may be seen that a relatively complex arrangement of fluid passages 62 has been cut into an external surface 64 of a tubular layer 66.

The passages 62 are used to provide fluid communication between multiple fluid-operative components 68 installed in another tubular layer 70 of the hydraulic circuit construction 60 depicted in FIG. 6. The components 68 are radially spaced apart in the layer 70, and so portions of the passages 62 extend circumferentially on the layer 66. As viewed in FIG. 7, some of the components 68 may also be longitudinally spaced apart in the layer 70, and so portions of the passages 62 also extend longitudinally on the layer 66.

In assembly, the outer surface 64 of the layer 66 is sealingly attached to an inner surface 72 of the layer 70. Any method may be used for this sealing attachment, such as bonding, welding, brazing, etc. When so attached, the inner surface 72 closes off an outer side of the passages 62.

An example of a similar hydraulic circuit construction 80 being assembled is depicted in FIG. 8. An inner tubular layer 82 having fluid passages 84 formed thereon is being inserted into a tubular middle layer 86 having fluid-operative components 88 installed therein. Once assembled, the layers 82, 86 are sealingly attached to each other, and the passages 84 then provide fluid communication

between the components 88, or between the components and other portions of the downhole tool.

An outer tubular layer 90 may be used to externally close off passages or holes in the middle layer 86, although use of such an outer layer is not necessary in keeping with the principles of the invention. It should also be understood that it is not necessary for the components 88 to be installed in the middle layer 86, or for the passages 84 to be formed on the inner layer 82. The components 88 could instead, or in addition, be installed in the inner or outer layers 82, 90, and the passages 84 could be formed on the middle or outer layers 86, 90.

Referring additionally now to FIG. 9, another hydraulic circuit construction 100 embodying principles of the present invention is representatively illustrated. Instead of a tubular shape as depicted in FIGS. 3-8, the hydraulic circuit construction 100 has a planar shape. Thus, it may be appreciated that the principles of the invention may be incorporated into downhole tools in any shape of hydraulic circuit construction.

As depicted in FIG. 9, multiple fluid-operative components 102 are installed in a middle layer 104. Fluid paths or passages 106 are formed on an external surface 108 of an outer layer 110. When the layers 104, 110 are sealingly attached to each other, the passages 106 provide fluid communication between the components 102, and the layer 104 closes off a side of the passages 106.

The passages 106 are depicted in dashed lines on the middle layer 104, so that it may be seen how the passages interconnect holes 112 drilled through the

middle layer. Another layer 114 may be sealingly attached to the middle layer 104, for example, to close off upper ends of the holes 112. Alternatively, or in addition, the upper layer 114 may have passages, such as the passages 106, formed thereon to provide further paths for fluid communication between the components 102 or other portions of a downhole tool.

Referring additionally now to FIGS. 10-13, another hydraulic circuit construction 120 embodying principles of the invention is representatively illustrated. In this circuit construction 120, a generally tubular member 122 of a downhole tool has a portion or segment 124 cut from the member. For example, the segment 124 could be cut from the member 122 using wire EDM methods well known to those skilled in the art.

As depicted in FIG. 10, the segment 124 has parallel lateral surfaces 126 and a radiused inner surface 128. It should be clearly understood, however, that the invention is not limited to any particular shape or configuration of the member 122 or the segment 124. For example, the member 122 could be planar or otherwise shaped. The segment 124 could be wedge-shaped, in which case the sides 126 would not be parallel, and the inner surface 128 could be flat, without departing from the principles of the invention.

In FIG. 11, the segment 124 has been cut into overlapping layers 130, 132, for example, using wire EDM methods. A fluid passage 134 has been formed on an upper surface 142 of the inner layer 132, for example, by milling. Note that the surface 142 is severed from the outer layer 130 when the layers 130, 132 are cut

apart. Thus, the surface 142 should precisely match an inner surface 144 of the outer layer 130. Fluid-operative components 136 are installed in each of the layers 130, 132.

The layers 130, 132 are then reassembled with the remainder of the member 122, as depicted in FIG. 12. The layers 130, 132 and the remainder of the member 122 are then attached to each other, for example, by bonding, brazing or welding. If desired, the components 136 may be installed after the attaching step, to prevent damage to the components from the brazing or welding processes. The outer layer 130 now closes off an upper side of the passage 134. At this point, the fluid-operative components 136 are in fluid communication with each other, and/or with other portions of the well tool, via the passage 134.

An alternate construction is shown in FIG. 13, wherein the segment 124 is divided into four layers 138. It will be readily appreciated that, no matter the number of layers 138, fluid communication between the layers can be readily achieved by simply forming an opening 140 between the layers.

Referring additionally now to FIG. 14, another hydraulic circuit construction 150 is representatively illustrated. This circuit construction 150 demonstrates another method whereby circumferentially separated fluid-operative components may be placed in fluid communication using the principles of the invention.

Piston bores 152 are formed longitudinally in the wall of a generally tubular member 154 of a downhole tool. For example, the downhole tool could be

a subsurface safety valve, in which case the bores 152 could be for rod pistons (not shown) of the type well known to those skilled in the safety valve art. The bores 152 are radially spaced apart, for example, by 180°, and it is desired to provide fluid communication between the bores.

To accomplish this result, a segment or portion 156 is cut from an end of the member 154. As depicted in FIG. 14, the segment 156 is cut from the member 154 after the bores 152 have been formed in the member. However, if it is desired to use the segment 156 to close off ends of the bores 152, the segment 156 could be cut from the member 154 prior to forming the bores.

With the segment 156 removed, a hydraulic passage 158 is formed on an end surface 160 of the member 154. For example, the circumferentially extending passage 158 could be milled on the surface 160 between the bores 152. Alternatively, the passage 158 could extend in a complete circle on the surface 160, in which case the passage could be lathe-cut on the surface.

After the passage 158 is formed, the segment 156 is attached to the remainder of the member 154, for example, by bonding, welding or brazing. The segment 156 then closes off an outer side of the passage 158, so that the passage forms an enclosed fluid communication path between the piston bores 152.

Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the invention, readily appreciate that many modifications, additions, substitutions, deletions, and other

changes may be made to these specific embodiments, and such changes are contemplated by the principles of the present invention. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the present invention being limited solely by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A fluid circuit construction for use in downhole tools, comprising:

a first layer having at least one fluid-operative component installed therein; and

a second layer having a fluid passage formed thereon, the first and second layers being sealingly attached to each other, and the fluid-operative component being in fluid communication with the passage.

2. The fluid circuit construction according to claim 1, wherein multiple fluid-operative components are installed in the first layer.

3. The fluid circuit construction according to claim 2, wherein the fluid-operative components are in fluid communication with each other via the passage on the second layer.

4. The fluid circuit construction according to claim 1, wherein the fluid passage is formed on an external surface of the second layer.

5. The fluid circuit construction according to claim 1, wherein the fluid passage extends circumferentially on the second layer.

6. The fluid circuit construction according to claim 1, wherein the fluid passage provides fluid communication between multiple radially separated ones of the fluid-operative components in the first layer.

7. The fluid circuit construction according to claim 1, wherein each of the first and second layers is generally tubular shaped.

8. The fluid circuit construction according to claim 1, wherein each of the first and second layers is generally planar shaped.

9. The fluid circuit construction according to claim 1, further comprising a third layer having at least one fluid path formed thereon, the path being in fluid communication with the fluid-operative component.

10. The fluid circuit construction according to claim 9, wherein the third layer is sealingly attached to the first layer.

11. The fluid circuit construction according to claim 9, wherein the first layer is positioned between the second and third layers.

12. The fluid circuit construction according to claim 1, wherein the first and second layers are parts of a segment cut from a member of a downhole tool.

13. The fluid circuit construction according to claim 12, wherein an opening formed through at least one of the first and second layers provides fluid communication between the first and second layers.

14. The fluid circuit construction according to claim 12, wherein the passage is formed on a surface of the second layer severed from the first layer.

15. A fluid circuit construction for use in downhole tools, comprising:

a first layer having multiple fluid-operative components received therein; and

a second layer having at least one fluid passage formed thereon, the passage being in fluid communication with at least one of the fluid-operative components, and a first surface of the first layer closing off a side of the passage.

16. The fluid circuit construction according to claim 15, further comprising a third layer having at least one fluid path formed externally thereon, the path being in fluid communication with at least one of the fluid-operative components, and a second surface of the first layer closing off a side of the path.

17. The fluid circuit construction according to claim 16, wherein the first layer is sealingly attached to each of the second and third layers.

18. The fluid circuit construction according to claim 17, wherein the first layer is positioned between the second and third layers.

19. The fluid circuit construction according to claim 15, wherein the first surface is bonded to the second layer.

20. The fluid circuit construction according to claim 15, wherein the first surface is brazed to the second layer.

21. The fluid circuit construction according to claim 15, wherein the first surface is welded to the second layer.

22. The fluid circuit construction according to claim 15, wherein each of the first and second layers is generally tubular shaped.

23. The fluid circuit construction according to claim 15, wherein each of the first and second layers is generally planar shaped.

24. The fluid circuit construction according to claim 15, wherein there are multiple fluid-operative components in the first layer, and wherein the fluid-operative components are radially spaced apart.

25. The fluid circuit construction according to claim 24, wherein the passage is in fluid communication with each of the radially spaced apart fluid-operative components.

26. A fluid circuit construction for use in downhole tools, comprising:

a first layer having a surface; and

a second layer having a fluid passage formed on a surface thereof, the first layer surface and the second layer surface being sealingly attached, so that the first layer surface closes off a side of the passage.

27. The fluid circuit construction according to claim 26, wherein the first layer surface is bonded to the second layer surface.

28. The fluid circuit construction according to claim 26, wherein the first layer surface is brazed to the second layer surface.

29. The fluid circuit construction according to claim 26, wherein the first layer surface is welded to the second layer surface.

30. The fluid circuit construction according to claim 26, wherein multiple fluid-operative components are installed in the first layer, and wherein the passage provides fluid communication between the fluid-operative components.

31. The fluid circuit construction according to claim 26, wherein the fluid passage extends circumferentially on the second layer.

32. The fluid circuit construction according to claim 26, wherein the fluid passage is formed on the second layer without use of holes intersecting in the second layer.

33. The fluid circuit construction according to claim 26, wherein the fluid passage is formed on the second layer without cross-drilling holes in the second layer.

34. The fluid circuit construction according to claim 26, wherein the second layer is generally tubular shaped and the fluid passage is formed externally on the second layer, and wherein the first layer outwardly overlies the second layer.

35. The fluid circuit construction according to claim 26, wherein the second layer is generally tubular shaped and the second layer surface is an internal surface, and wherein the second layer outwardly overlies the first layer.

36. The fluid circuit construction according to claim 26, wherein the first layer further has at least one fluid-operative component received therein, and the passage is in fluid communication with the fluid-operative component.

37. The fluid circuit construction according to claim 26, wherein the first and second layers are parts of a segment cut from a member of a downhole tool.

38. The fluid circuit construction according to claim 37, wherein an opening formed through at least one of the first and second layers provides fluid communication between the first and second layers.

39. The fluid circuit construction according to claim 37, wherein the second layer surface is severed from the first layer surface.

40. The fluid circuit construction according to claim 26, wherein the first layer is an end cut from a generally tubular member of a downhole tool.

41. The fluid circuit construction according to claim 40, wherein the passage provides fluid communication between radially separated bores formed in the member.