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DOWNHOLE TOOL

Abstract

A downhole tool, comprising: an inner body, having first and second connections in a drill string to convey fluid from immediately upper to immediately lower components. The inner body defines a flow bore which communicates between the first and second connections. An outer body disposed around at least part of the inner body is axially movable with respect to the inner body, in a direction which is parallel or substantially parallel with a longitudinal axis of the tool, such that introduction of pressurised fluid into pressure chambers tends to drive the outer body axially with respect to the inner body. The tool further comprises a component which is activated or operated by axial movement of the outer body with respect to the inner body.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation of U.S. patent application Ser. No. 18/038,175, filed May 22, 2025, which is the U.S. National Stage of International Application No. PCT/GB2021/052931, filed Nov. 12, 2021, which was published in English under PCT Article 21(2), which in turn claims the benefit of Great Britain Application No. 2018337.2, filed Nov. 22, 2020, Great Britain Application No. 2018527.8, filed Nov. 25, 2020, and Great Britain Application No. 2108895.0, filed Jun. 21, 2021. The prior applications are incorporated herein in their entirety.

[0002] This application relates to a downhole tool, and in particular concerns a tool including one or more blades or other members which may be driven outwardly with respect to a tool body, for instance to perforate or split the casing of a wellbore.
[0003] Perforating tools are well-known in the fields of downhole exploration and extraction of fossil fuels. The most common reason to create perforations in a wellbore casing is to allow communication between the wellbore and a surrounding productive reservoir.
[0004] In known perforating tools, a series of axially spaced pistons are provided, such that when the pistons are activated, the forces generated by the pistons act cumulatively, to drive blades outwardly into contact with the interior surface of the casing with sufficient force to perforate or otherwise break the casing. Perforation guns, which use explosive charges to punch holes through a casing, are also used in some applications.
[0005] An example of this can be seen in EP2616625. This document discloses a tool in which a series of axially-spaced pistons are disposed within the tool body, and can be hydraulically activated to drive cutter blocks outwardly and into engagement with the casing of a wellbore.
[0006] It is an object of the invention to provide an improved tool of this type.
[0007] Accordingly, one aspect of the present invention provides a tool and method according to the independent claims. Preferred features of the tool and method are set out in the dependent claims.

Description

[0008] In order that the invention may be more readily understood, embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:
[0009] FIG. **1** shows a tool embodying the present invention in a first configuration;
[0010] FIGS. **2**, **3** and **6** are more detailed images of parts of the tool of FIG. **1**;
[0011] FIGS. **4** and **5** are cross-sectional views through the tool of FIG. **1**;
[0012] FIG. **7** shows a tool embodying the present invention in a second configuration;
[0013] FIGS. **8**, **9** and **12** are more detailed images of parts of the tool of FIG. **7**;

[0014] FIGS. **10** and **11** are cross-sectional views through the tool of FIG. **7**;
[0015] FIG. **13** shows a portion of an alternative tool in a first configuration;
[0016] FIG. **14** shows the portion of the alternative tool in a second configuration;
[0017] FIG. **15** shows a blade body suitable for use with the invention, in isolation;
[0018] FIG. **16** shows a perspective view, similar to the view shown in FIG. **9**;
[0019] FIG. **17** shows a further alternate tool embodying the invention;
[0020] FIGS. **18** and **19** are detailed views of the region indicated by I in FIG. **17**;
[0021] FIG. **20** shows a yet further tool embodying the invention in a first configuration;
[0022] FIG. **21** shows the tool of FIG. **20** in a second configuration;
[0023] FIG. **22** shows a partial close up view of the tool of FIG. **20** showing the activation shaft;
[0024] FIG. **23** shows a detailed view of the tool of FIG. **20**;
[0025] FIG. **24** shows a detailed view of the tool of FIG. **20** in a partly disassembled state; and
[0026] FIG. **25** shows a possible blade arrangement for use in the tool of FIG. **20**.
[0027] FIG. **1** shows a tool **1** embodying the present invention.
[0028] The tool **1** is elongate and is intended to be incorporated into a drill string along with other components, as is known in the art.
[0029] In the figures for this application, tools and parts of tools are generally shown with a top end thereof positioned on the left-hand side of the page, and the bottom end at the right-hand side of the page. As the skilled reader will understand, the drill string extends from the surface, and the end of the tool which is closer to the connection to the surface is referred to as the “top” end of the tool. This is by way of convenience and convention, and does not exclude orientations in which this end of the tool is not uppermost.
[0030] At the top end **2** of the tool **1**, a threaded connection **3** is provided, to connect the tool **1** to the next uppermost tool or component in the drill string. Similarly, at its bottom end **4**, the tool **1** has a lower threaded connection **31**, for connection to the next lowermost tool or component in the drill string.
[0031] FIG. **2** shows a zoomed-in view of the tool **1**, between the lines indicated by A and B in FIG. **1**. FIG. **2** therefore shows an upper part of the tool **1**.
[0032] The upper threaded connection **3** is provided in an upper connection piece **5**, which has a central bore **6** running therethrough. As can be seen in FIG. **1**, the upper connection piece has a centraliser **15** partway along its length. The centraliser **15** comprises a widened section, which is intended to fill or substantially fill the internal diameter of the casing, and assist in keeping the other components of the tool **1** centralised within the wellbore.
[0033] At its lower end, the upper connection piece **5** is connected to a first piston inner **7**. This connection is preferably made by a threaded connection. In the example shown two O-rings **8** are provided as part of this connection, to form an effective seal between these components **5**, **7**.
[0034] The first piston inner **7** is generally cylindrical, having a central flow bore **9** passing therethrough. Near its top end, the first piston inner **7** has a protruding radial flange **10**.
[0035] At its bottom end, the first piston inner **7** is connected to a second piston inner **11**, which is preferably similar in shape to the first piston inner **7**, being generally cylindrical with a protruding radial flange **10**.
[0036] Attached to the lower end of the second piston inner is a third piston inner **12**, and connected to the lower end of the third piston inner **12** is a fourth piston inner **13**.
[0037] While the first to fourth piston inners **7-13** are preferably identical or substantially identical, this need not be the case. However, in the example shown, each of the piston inners is generally cylindrical, having a protruding radial flange **10** near its top end. The first to fourth piston inners **7-13** are preferably each connected to one another by way of threaded connections, although any other suitable connection method may be used.
[0038] Each of the second to fourth piston inners **11-13** has a communication port **14** which extends radially through the body of the piston inner **11-13**, and provides communication between

the central bore **9** and the exterior of the piston inner, at a position above (i.e. closer to the top end **2** than) the radial flange **10**.
[0039] In contrast to the second to fourth piston inners **11-13**, the first piston inner **7** has a communication port **16** which is positioned below the radial flange **10**.
[0040] FIG. **3** shows a zoomed-in view of the tool **1**, showing the region between the lines indicated by C and D in FIG. **1**. The fourth piston inner **13** can be seen at the left-hand side of FIG. **3**.
[0041] At its lower end, the fourth piston inner **13** connects to a blade carrier **17**. At its upper end, the blade carrier **17** is generally solid and cylindrical. In a mid-section **18** thereof, the blade carrier **17** defines four pockets **19**, each comprising a cut-out section in the cross-sectional shape of the blade carrier **17**, which extends part of the way from the circumference of the blade carrier **17** towards the centre thereof. FIG. **4** shows a cross-sectional view of the tool, at the position indicated by G in FIG. **4**. As can be seen in FIG. **4**, the blade carrier **17** defines four radially spaced-apart pockets **19**. In the embodiment shown, the pockets **19** are equally radially spaced apart from each other, i.e. are each set at exactly or substantially 90° with respect to the adjacent pockets **19**. Embodiments of the invention may have any number of pockets, however, and it is not necessary for the pockets to be evenly radially spaced, or for a pocket to be directly radially opposite to another pocket.
[0042] The pockets **19** are elongate, and extend over a significant portion of the length of the blade carrier **17**.
[0043] The blade carrier **17** has a central flow bore **20** running along the length thereof.
[0044] At its lower end, below the pockets **19**, the blade carrier **17** comprises a stop component **21**. The stop component **21** is generally cylindrical, having an outwardly-protruding flange **22** and a further section **80** which extends downwardly below the flange **22**.
[0045] In the example shown the stop component **21** is formed integrally with the blade carrier **17**, as a single member, but in other embodiments this need not be the case.
[0046] FIG. **6** shows a zoomed-in view of the tool of FIG. **1**, extending between the lines indicated by E and F in FIG. **1**. The lower end of the stop component **21** can be seen at the left-hand end of FIG. **6**.
[0047] At its lower end, the stop component **21** is connected to a fifth piston inner **24**. The fifth piston inner **24** is, in turn, connected to a sixth piston inner **25** at its lower end.
[0048] The fifth and sixth piston inners **24**, **25** are preferably identical or substantially identical to the second to fourth piston inners **11-13** shown in FIG. **2**. Each includes an outwardly upper protruding flange **10** near its top end, a central flow bore **9** passing along its length, and a communication port **14** extending from the flow bore **9** to the exterior of the piston inner, at a level above the flange **10**.
[0049] At its lower end, the sixth piston inner **25** is connected to a lower connection body **26**. An upper region **27** of the lower connection piece **26** has a relatively small diameter, and a lower region **28** of the lower connection body **26** has a greater diameter.
[0050] At its bottom end, the lower connection body **26** is connected to a bottom connection piece **29**, which carries the threaded connection at the lower end **4** of the tool. The bottom connection piece **29** has a centraliser **77** partway along its length, similar to the upper connection piece **5**.
[0051] The lower body **26** and bottom connection piece **29** have flow bores **30** passing along their length.
[0052] All of the components described above are fixed to one another and, in use of the tool **1**, will not substantially move longitudinally with respect to one another. The distance between the upper and lower threaded connections **3**, **31** will not change during use of the tool **1**. Each of the components has a central flow bore, and these bores align with one another to form a continuous or substantially continuous flow bore passing along the length of the tool **1**, from the top end **2** to the bottom end **4** thereof.

[0053] The components described above together form a rigid or substantially rigid supporting stem of the tool **1**, which may be referred to as a mandrel.
[0054] A series of further components will be now be described, which, in use, are movable with respect to the mandrel.
[0055] Returning to FIG. **2**, a first piston outer **32** is positioned around the first piston inner **7**. The first piston outer **32** has an elongate sleeve portion **34**, which is preferably generally cylindrical, and has an inward-facing flange **33** at its top end. The inward-facing flange **32** is positioned above the protruding flange **10** of the first piston inner **7**. The sleeve portion **34** of the first piston outer **32** is sufficiently large that it can fit over, and slide with respect to, the radial flange **10** of the first piston inner **7**. The inward-protruding flange **33** of the first piston outer has an inner diameter which is smaller than the outer diameter of the flange **10** of the first piston inner **7**, however.
[0056] An O ring or similar seal **35** is provided between the outer surface of the radial flange **10** of the first piston inner **7** and the sleeve portion **34** of the first piston outer **32**.
[0057] A first chamber **36** is formed between the outer surface of the first piston inner **7**, in the region below the flange **10** thereof, and the inner surface of the sleeve portion **34** of the first piston outer **32**. The communication port **16** of the first piston inner **7** allows fluid flow between the flow bore **9** and the first chamber **36**.
[0058] At its lower end, the first piston outer **32** is connected to a second piston outer **37**. The second piston outer once again has a sleeve portion **38**, and an inward-facing flange **39** near its top end, which is positioned above the outward-protruding flange **10** of the second piston inner **11**.
[0059] A second chamber **40** is, in a similar manner to that described above, formed between the outer surface of the second piston inner **11**, in the region below the outwardly protruding flange **10** thereof, and the inner surface of the sleeve portion **38** of the second piston outer **37**.
[0060] Where the communication port **14** of the second piston inner **11** meets the outer surface thereof, a recess **41** is formed in the flange **39** of the second piston outer **37**.
[0061] At its lower end, the second piston outer **37** is connected to a third piston outer **42**, which is identical or generally identical to the second piston outer **37**. At its lower end, the third piston outer **42** is connected to a fourth piston outer **43**, which is once again identical or substantially identical to the second piston outer **37**.
[0062] At its lower end, the fourth piston outer **43** is connected to a blade housing **44**. The blade housing **44** can be seen at the right-hand end of FIG. **2**, and at the left-hand end of FIG. **3**. The blade housing **44** is generally hollow and cylindrical in profile, and surrounds the blade carrier **17**. With reference to FIG. **4**, as discussed above, the blade carrier **17** has four pockets **19** formed therein. The blade housing **44** similarly has pockets **45**, comprising gaps in the blade housing **44**, which align with the pockets **19** of the blade carrier **17**. The pockets **45** extend, in the example shown in the figures, along a significant portion of the length of the blade housing **44**.
[0063] At its lower end, the blade housing **44** surrounds the stop component **21**, and comprises a drive sleeve **47**, which surrounds and is connected to one or more travelling blocks **48**.
[0064] FIG. **5** shows a cross-sectional view through the tool **1**, at the position marked by H in FIG. **3**. As can be seen in FIG. **5**, the blade carrier **17** extends into regions between the travelling blocks **48**. The travelling blocks **48** are arranged in the pockets **19** in the blade carrier **17**. As can be understood from FIGS. **4** and **5**, the pockets **19** extend along the blade carrier **17** and through the positions marked by G and H in FIG. **3**. One travelling block **48** is received in each pocket **19**.
[0065] The travelling blocks **48** are joined to the drive sleeve **47**, and in the example shown this is done by the provision of inserts **49**, which pass through and are connected to both the drive sleeve **47** and the travelling blocks **48**. In the example shown, two sets of inserts **49** are provided, i.e. an upper set and a lower set. The upper and lower sets of inserts **49** are axially spaced apart from each other. In each set of inserts **49**, one insert **49** is provided to connect each travelling block **48** to the drive sleeve **47**. There are therefore eight inserts **49** altogether.
[0066] The inserts **49** are joined to the travelling blocks **48** in any suitable way. In the example

shown, a pair of screws **50** is threaded into suitable apertures which are formed in each insert **49** and each travelling block **48**.
[0067] A stop ring **51** is attached to the inner side of the drive sleeve **47** at its lower end. In the configuration shown in FIG. **3**, a gap **52** is initially present between the top end of the stop ring **51**, and the rearward-facing shoulder **53** formed by the lower side of the protruding flange **22** of the stop element **21**.
[0068] At its lower end, the drive sleeve **47** is attached to a fifth piston outer **54**. At its lower end, the fifth piston outer **54** is attached to a sixth piston outer **55**. The fourth and fifth piston outers **54**, **55** are identical or substantially identical to the second to the fourth piston outers **37**, **42**, **43**, and surround the fifth and sixth piston inners **24**, **25** respectively. Each has a sleeve portion **38**, and an inward facing flange **39**.
[0069] At its lower end, the sleeve portion **38** of the sixth piston outer **55** is attached to an intermediate sleeve portion **56**, which surrounds an upper part of the lower connection body **26**. The intermediate sleeve portion **56** is in turn attached at its lower end to a lower sleeve portion **57**, for instance by a threaded connection **58**. The lower sleeve portion **57** surrounds a middle part of the lower connection body **26**. The lower connection body **26** protrudes, in the example shown, downwardly below the lower end of the lower sleeve portion **57**.
[0070] The further components described above (i.e. the first to sixth piston outers **32**, **37**, **42**, **43**, **54**, **55**, the blade housing **44**, the intermediate sleeve portion **56** and the lower sleeve portion **57**) are connected to one another, and are movable with respect to the components that formed a mandrel. These components are referred to collectively below as the outer sleeve components, or simply the outer sleeve, of the tool **1**.
[0071] With reference to FIG. **6**, the intermediate sleeve portion **56** has an inwardly-protruding support ring **59**, which is preferably positioned towards its lower end. The support ring **59** extends towards the outer surface of the upper region **27** of the lower connection body **26**, but does not contact the lower connection body **26**, such that there is a gap between these components. A drive chamber **60** is defined between the lower surface of the support ring **59** and the upward-facing shoulder **61** which is created by the change in width between the upper and lower regions **27**, **28** of the lower connection body **26**.
[0072] A communication port **69** extends between the main flow bore **30** of the lower connection body **26** and the drive chamber **60**.
[0073] A floating piston ring **97** is positioned above the support ring **59**, and is free to move upwardly and downwardly with respect both to the lower connection body **26** and the intermediate sleeve portion **56**. The piston ring **97** preferably fills or substantially fills the space between the lower connection body **26** and the intermediate sleeve portion **56**, and has O rings or other seals to form reliable seals against these components.
[0074] In the example shown, a sleeve **98** extends upwardly from the inner side of the piston ring **97**, lying adjacent or against the outer surface of the lower connection body **26**.
[0075] A bracing ring **62** is connected to the outer surface of the top end of the upper region **27** of the lower connection body **26**. The bracing ring **62** is fixed in place with respect to lower connection body **26**, and therefore forms part of the mandrel. In the configuration of the tool **1** shown in FIGS. **1-6**, there is a gap between the top end of the sleeve **98** and the bracing ring **62**.
[0076] A spring **63** (or other suitable resilient element) is positioned between the outer surface of the upper region **27** of the lower connection body **26**, and the interior of the intermediate sleeve portion **56**. The spring **63** is braced at its upper end against the lower side of the bracing ring **62**, and its lower end against the piston ring **97**. The sleeve **98** of the piston **97** lies inside the spring **63**.
[0077] The configuration of the tool **1** shown in FIGS. **1-6** is a first configuration, in which the tool will be initially placed to be run in hole. In this configuration, the outer sleeve components are moved as far downwardly with respect to the mandrel as possible. This downward motion is, in the example shown, limited by contact between the lower side of the travelling blocks **48** and the upper

side of the stop component **21**. This need not be the case, and in other embodiments downward motion could be limited by contact between, for example, the upper surfaces of the radial flanges **10** of the first to sixth piston inners **7**, **11-13**, **24**, **25**, and the lower surfaces of the inward-facing flanges **39** of the first to sixth piston outers **32**, **37**, **42**, **43**, **54**, **55**. In the example shown, when the outer sleeve is at the limit of its downward motion with respect to the mandrel, a small gap is present between the flanges of the piston inners and outers, and this allows for some manufacturing tolerance in these components.

[0078] The outer sleeve components may move upwardly with respect to the mandrel, and the extent of this motion is, in preferred embodiments, limited by the stop component **21**. As the outer sleeve components move upwardly with respect to the mandrel, the top end of the stop ring **51** will contact the downward-facing shoulder **53** of the flange of the stop element **21**. The movement of the outer sleeve components with respect to the mandrel is therefore limited in both the upward and downward directions.

[0079] First to fourth blades **64** are carried by the blade carrier **17**. Each blade **64** is received in one of the pockets **19** of the blade carrier **17**, but is not attached to the blade carrier **17**, and is able to move both axially and radially with respect to the blade carrier **17**.

[0080] At least a part of the inward-facing walls **65** of each pocket **19** have slanting ribs **66** formed thereon, as can be seen in FIGS. **3** and **4**.

[0081] Each blade **64** comprises a blade body **67**, shown in isolation in FIG. **15**, which preferably takes the form of a block received between the inward-facing walls **65** of the respective pocket **19**. The outer side surfaces **100** of the blade body **67** have slanting grooves **101** formed on them, into which the ribs **66** are received.

[0082] The slant of the ribs **66** and grooves **101** is such that, as the ribs **66** slide along the grooves **101**, the blade **64** moves radially outwardly with respect to the mandrel, and also upwardly towards the top end **2** of the tool **1**.

[0083] Each blade **64** further comprises a cutting portion **68**, which is fixed to the outward-facing side of the blade body **67**. The cutting portion **68** may have a relatively sharp cutting edge, although this need not be the case. In the view shown in FIG. **15** the cutting portion **68** is not present, and an aperture **103** can be seen in the top of the blade body **67**, in which the cutting portion **68** is received when it is attached.

[0084] In the example shown, the cutting portion **68** of each blade **64** is removably attached to the respective blade body **67**. This means that, if a cutting portion **68** is damaged or worn, it can be removed and replaced without the blade body **67** also needing to be replaced. This arrangement also allows the blade body **67** and cutting portion **68** to be formed from different materials which are best suited to their tasks. In other embodiments this need not be the case, and for example the body **67** and cutting portion **68** of each blade **64** may be integrally formed as a single unit.

[0085] At their lower ends, the blade bodies **67** are attached to the top end of the respective travelling blocks **48**. In preferred embodiments, the lower end of each blade body **67** has a T-shaped protrusion **102**, which can be seen in FIG. **15**, and cooperating T-slots are formed in the top sides of the travelling blocks, and also optionally in the upper set of inserts **49**. As the skilled reader will understand, this arrangement will allow the blade bodies **67** to slide radially inwardly and outwardly with respect to the travelling blocks **48**, but will also fix the blade bodies **67** to the travelling blocks **48** in the axial direction.

[0086] As mentioned above, the configuration shown in FIGS. **1-6** is a first configuration, in which the blades **64** of the tool **1** are retracted. As can be seen in FIG. **4**, in this configuration the outer tips of the cutting portions **68** of the blade **64** do not protrude outwardly beyond the cross-section of the blade housing **44**.

[0087] Operation of the tool **1** will now be described.

[0088] As discussed above, the tool **1** comprises first to sixth piston inners **7**, **11-13**, **24**, **25**, and respective first to sixth piston outers **32**, **37**, **42**, **43**, **54**, **55**. Each piston inner and respective piston outer together form a piston, and for convenience these pistons will be referred to below as the first to sixth pistons. It should be understood that the first piston is composed of the first piston inner **7** and the first piston outer **32**, and so on.

[0089] The tool **1** is incorporated into a drill string, and will be connected to other tools in the drill string via the upper and lower threaded connections **3**, **31**. The tool **1** is initially in the first configuration, as shown in FIGS. **1-6**.

[0090] Once the tool **1** is at the required depth in the well bore, the tool **1** may be activated, to move into a second configuration, which is shown in FIGS. **7** to **12**. The views in FIGS. **7** to **12** correspond generally to the views shown in FIGS. **1** to **6**, respectively.

[0091] In the example shown in the figures, activation is initiated by increasing the fluid pressure in the flow bore passing along the centre of the tool **1**.

[0092] With reference to FIG. **6**, one consequence of this will be that pressurised fluid flows through the communication port **69** and into the drive chamber **60**. This fluid pressure will be communicated through the gap between the support ring **59** and the lower connection body **26**, and tend to drive against the lower side of the floating piston ring **97**, and hence push the piston ring **97** upwardly with respect to the mandrel. This will have the effect of compressing the spring **63**, which is positioned between the bracing ring **62** and the piston ring **97**. At this stage there will be a gap between the floating piston ring **97** and the support ring **59**. The effect of the spring **63** is to drive the outer sleeve downwardly with respect to the mandrel, i.e. to retain the tool **1** in the first configuration, and introducing pressurised fluid into the drive chamber **60** in this way helps to stop the spring **63** from preventing the tool **1** from moving into its activated configuration.

[0093] The upward motion of the piston ring **97** is halted when the top of the sleeve **98** contacts the bracing ring **62**. The length of the sleeve **98** is chosen so that the spring **63** is not over-compressed as the tool is activated.

[0094] With reference to the second piston, as can be seen most clearly in FIG. **8**, a drive chamber **70** is defined on its inner side by the outer surface of the second piston inner **11**, above the protruding flange **10**, on its outer side by the inner side of the sleeve portion **38** of the second piston outer **37**, on its upper side by the lower side of the inward-protruding flange **39** of the second piston outer **37**, and on its lower side by the upper side of the outward-protruding flange **10** of the second piston inner **11**. The communication port **14** of the second piston inner allows pressurised fluid to flow from the central flow bore **9** into the drive chamber **70**.

[0095] As pressurised fluid enters the drive chamber **70**, the effect will be to force the second piston outer **37** upwardly with respect to the second piston inner **11**. As this happens, the volume of the second chamber **40** will decrease, and fluid will flow from the second chamber **40** into the annulus through one or more vent ports **78**. In the example shown, the vent ports **78** are formed in an upper part of the sleeve portion **38** of the third piston outer **42**.

[0096] The skilled reader will understand that each of the third to sixth pistons will likewise form a drive chamber **70**, into which pressurised fluid will flow from the main flow bore **9**, and which will also generate a force to drive the respective piston outer upwardly with respect to the piston inner.

[0097] As pressurised fluid is introduced into the tool **1**, the overall effect of the second to sixth pistons will be to drive the outer sleeve components upwardly with respect to the mandrel.

[0098] With regard to FIG. **9**, the travelling blocks **48**, which are connected to the drive sleeve **47** by the inserts **49**, will also be driven upwardly. As discussed above, the travelling blocks **48** are attached to the blade bodies **67** of the blades **64**, and so the blades **64** are driven upwardly with respect to the blade carrier **17**. As this occurs, the ribs **66** will cause the blades **64** to move radially outwardly with respect to the longitudinal axis of the tool **1**, as can be seen in FIG. **9**.

[0099] FIG. **16** shows similar components to FIG. **9**, but is a perspective view.

[0100] With reference to FIG. **10**, it can be seen that the cutting portions **68** of the blades **64** protrude outwardly beyond the blade housing **44**.

[0101] The cumulative force generated by the second to sixth pistons therefore acts to drive the blades **64** outwardly from the tool **1**, so that they can perforate a casing (not shown) surrounding the tool **1**. A large outward radial force will therefore be imparted to the blades **64**, enabling them to break a relatively thick and strong casing.

[0102] As can be seen in FIGS. **3** and **9**, at its top end each blade body **67** has an inclined face, which slopes radially outwardly and upwardly. At the top end of each pocket **19**, a corresponding inclined face **82** is formed, and this inclined face **82** is preferably set at the same, or substantially the same, angle as the inclined face **81** at the top end of the corresponding blade body **67**. These inclined faces **81**, **82** are also preferably set at the same, or substantially the same, angle as the slanting ribs **66** of the blade carrier **17** and cooperating slanting grooves formed on the blade bodies **67**.

[0103] As the blades are expanded and brought into contact with the casing, the inclined face **81** of the blade body **67** slides over the inclined face **82** at the top of the pocket **19**. This provides a large bearing surface area between these components, and helps to guide the blades **64** outwardly in a sturdy and reliable manner.

[0104] The upward motion of the outer sleeve components with respect to the mandrel is halted by the stop ring **51** contacting the downward-facing shoulder **53** of the flange **22** of the stop component **21**.

[0105] During activation of the tool **1**, applying a downward force on the drill string from the surface (or fully or partially releasing the drill string so that downward forces act through gravity) may help to dig the blades further into the casing, as this will lead to further relative downward motion of the mandrel with respect to the outer sleeve. If this technique is to be used, it may be beneficial to shape the leading edge of each blade so that the downward force applied to the mandrel does not act to retract the blades. The skilled reader will appreciate how this may be achieved.

[0106] A further effect of the second to sixth pistons driving the outer sleeve upwardly with respect to the mandrel will be that the intermediate sleeve portion **56** will move upwardly, and the support ring **59** will therefore also move upwardly. The support ring **59** may abut against the lower side of the piston ring **97**.

[0107] The skilled reader will note that, in the example shown in the figures, the first piston works in opposition to the motion generated by the second to sixth pistons. When pressurised fluid is introduced in the flow bore of the tool **1**, it will flow through the communication port **16** of the first piston inner **7**, and into the first chamber **36**, which is best seen in FIGS. **2** and **8**. The first chamber **36** is bounded at its top side by the bottom side of the flange **10** of the first piston inner **7**, and at its bottom side by the top side of the inward-protruding flange **39** of the second piston outer **37**. As pressurised fluid is introduced into the first chamber **36**, the effect will tend to be to drive the outer sleeve components downwardly with respect to the mandrel.

[0108] During activation of the tool **1**, the first piston will at least partly counteract the effect of the second piston. In this embodiment, therefore, the upward motion of the outer sleeve components with respect to the mandrel will effectively be driven by the third to sixth pistons.

[0109] However, the first piston may be used in the deactivation of the tool **1**, i.e. in moving the tool **1** from the second or activated configuration back to the first configuration, in which the blades **64** are retracted.

[0110] With reference to FIG. **2**, a ball seat **71**, which in the illustrated example takes the form of a narrowed portion of the flow bore **9**, is provided in the first piston inner **7**. The ball seat **71** is positioned below the communication port **16** of the first piston inner **7**.

[0111] When operators wish to move the tool from the second configuration back to the first configuration, in the first instance the supply of pressurised fluid to the tool may be stopped. Once this has occurred, two separate forces will tend to return the tool to the first configuration. Firstly, since tool **1** is likely to be used with the top end **2** uppermost, the weight of the outer sleeve components will tend to drop under gravity with respect to the mandrel, thus returning the tool to

the first configuration. Secondly, the spring **63** will tend to drive the sleeve components downwardly with respect to the mandrel, once again returning the tool to the first configuration.
[0112] As discussed above the blade bodies **67** are axially connected to the respective travelling blocks **48**, through the T-shaped protrusions **102** and the corresponding T-shaped slots. As the travelling blocks **48** move downwardly with respect to the mandrel, therefore, this will act to pull the blades **64** downwardly, into their retracted positions.
[0113] In some circumstances, however this combination of forces may not be sufficient to retract the blades **64**. If the blades **64** have been driven forcefully into a wellbore casing, the blades **64** may be held relatively firmly in place with respect to the casing, and the effects discussed above may not generate sufficient force to retract the blades **64**.
[0114] A further action that can be taken to retract the blades **64** is to pull the drill string upwardly with respect to the casing. If the blades **64** are stuck in the casing, then the blades **64** will remain substantially axially fixed with respect to the casing, while the mandrel (which is rigidly connected to the other components of the drill string) moves upwardly. This will tend to cause the blades **64** to be retracted, due to the slanting cooperating ribs **66** and grooves **101** of the pockets **19** and blades **64**.
[0115] Where one or more blades **64** are very firmly stuck in the casing, this may be not sufficient to cause the blades **64** to retract.
[0116] In this case, a ball (not shown) may be dropped through the drill string and into the top end **2** of the tool **1**, and come to rest on the ball seat **71**. The effect of this will be to block fluid flow through the main flow bore of the tool **1**, below the level of the ball seat **71**.
[0117] Once the ball has been dropped and received in the ball seat **71**, pressurised fluid may be introduced into the tool **1**. As the skilled reader will appreciate, the pressurised fluid will be able to flow through the communication port **16** of the first piston inner **7**, and into the first chamber **36**. As can be understood from FIG. **8**, the effect of this will be to drive the outer sleeve components downwardly with respect to the mandrel.
[0118] Because of the presence of the ball in the ball seat **71**, the pressurised fluid will not be received by any of the second to sixth pistons. Therefore, the force generated by the first piston will not be opposed by any of the other pistons.
[0119] The result of introducing pressurised fluid to the first piston only will provide a large force to return the tool to the first configuration, and withdraw the blades **64** from a casing in which they may be embedded.
[0120] While the first piston counteracts the effects of the second to sixth pistons during the activation process, the return effect provided by the first piston may be very valuable in some applications, and will justify the effect of the first piston during the activation process.
[0121] Once the tool **1** has been returned to the first configuration, the ball may be removed from the seat **71**, for instance by increasing the pressure until the ball is extruded through the seat **71**. The ball may be caught by a suitable ball catcher (not shown) provided in the tool **1** or in another component of the drill string, or may simply pass out of the bottom of the tool **1**. The tool **1** is then ready to be activated again, if necessary.
[0122] In other embodiments, the first piston may be omitted, and all of the pistons which are formed as part of the tool **1** may generate a force, when pressurised fluid is introduced into the tool **1**, that tends to move the sleeve components upwardly with respect to the mandrel.
[0123] With reference to FIGS. **6** and **12**, some further details of the lower end of the tool **1** will now be described.
[0124] As can be seen in FIG. **6**, two vent passages **72** extend downwardly from the drive chamber **60** that is defined partly by the lower connection body **26**. The vent passages **22** extend from the drive chamber **60** along an outer surface of the lower connection body **26**, and preferably each takes the form of a groove or trough on the outer surface of the lower connection body **26**.
[0125] In the first configuration, shown in FIG. **6**, the vent passages **72** do not axially align with

any further flow passages. The vent passages **72** therefore terminate in dead ends. When pressurised fluid is first introduced into the drive chamber **60**, when the tool **1** is in the first configuration, the pressurised fluid will enter the vent passages **72**, but will not be communicated further from the vent passages **72**.

[0126] A communication groove (not shown in FIG. **6**) runs around the exterior of the lower connection body **26**. Two vent ports **73** are formed through the lower sleeve portion **57**, and are axially aligned with, and in fluid communication with, the communication groove.

[0127] However, in the first configuration shown in FIG. **6**, the vent ports **73** are lower than the vent passages **72**.

[0128] While two vent passages **72** and two vent ports **73** are shown in the figures, further vent passages and vent ports may be provided. In alternative embodiments, only one vent passage and vent port may be included.

[0129] When the tool **1** is activated, and fully moved into the second configuration (i.e. to the end of its range of motion), as seen in FIG. **12**, the communication groove aligns with the end of the respective vent passages **72**, and pressurised fluid may then flow from the drive chamber **60**, through the vent passages **72** and the vent ports **73**, to the annulus. The formation of a communication groove which extends around the exterior of the lower connection body **26** means that the vent passages **72** do not need to be radially aligned with the vent ports **73**.

[0130] As the tool **1** reaches its full stroke, i.e. the sleeve components have moved upwardly by their maximum extent with respect to the mandrel, this will lead to a distinct and measurable drop in pressure within the tool **1**, which can be detected from the surface and can let operators at the surface know that the tool **1** is fully activated.

[0131] In the example shown in the figures, a number of O rings are provided between the lower connection body **26** and the lower sleeve portion **57**, to help form an effective seal between these components. One of these O rings **74** is positioned such that, during the movement of the tool **1** from the first configuration to the second configuration, the vent port **73** will pass directly over the O ring **74**, thus exposing the O ring **74** to fluid from the annulus. It is possible that, in the course of this process, the O ring **74** may be damaged.

[0132] Positioned between the lower connection body **26** and the lower sleeve portion **57**, in a recess **75** formed in the outer surface of the lower connection body **26**, is a supply of further O rings **76**. In use of the tool **1**, these O rings **76** need not provide a sealing function. However, when the tool **1** has been recovered from the well bore after a trip into the wellbore, the lower sleeve portion **57** may be disconnected from the intermediate sleeve portion **56** (in the example shown, by undoing a threaded connection between these components) and slid downwardly with respect to the mandrel. This will allow operators to access the further O rings **76** in the recess **75**, and use one of these O rings **76** to replace the O ring **74** which may have been damaged during activation or deactivation of the tool **1**.

[0133] The further O rings **76** are positioned such that they can be accessed once a single component of the tool **1** has been disconnected and moved, where this procedure is relatively straightforward.

[0134] Once the O ring **74** has been replaced by one of the further O rings **76**, the lower sleeve portion **56** may be re-attached to the tool **1**.

[0135] One or more shear pins or other frangible components may be provided to hold the mandrel and the outer sleeve components in place with respect to each other before the tool **1** is ready to be activated. In the example shown, shear pins **79** are initially provided to form a connection between the lower sleeve portion **57** and the lower connection body **26**, as can be seen in FIG. **6**. When the tool is to be activated, and fluid above an activation pressure is introduced into the tool **1**, the resulting forces will break the shear pins **79** (as can be seen in FIG. **12**) to allow operation of the tool **1**.

[0136] With reference to FIGS. **13** and **14**, a modified version of the tool is shown. FIGS. **13** and

14 show a region of the tool in the region of the bottom end of the spring **63**, corresponding to a part of the view that can be seen in FIGS. **6** and **12**.

[0137] As can be seen in these figures, the support ring **59** protrudes inwardly from the intermediate sleeve portion **56**. In this embodiment, the support ring **59** has a longer axial extension than in the example shown in FIGS. **1-12**. With reference to the lower side of FIG. **13**, the support ring **59** presents a drive surface **83** at its top end, which faces generally upwardly towards the top end **2** of the tool **1**. As in the example shown in FIGS. **1-12**, a gap **84** is present between the inner side of the drive surface **83** and the outer surface of the lower connection body **26**.

[0138] Below the drive surface **83**, the support ring **59** comprises an elongate holding section **85**. The holding section **85** does not protrude inwardly as far towards the lower connection body **26** as the drive surface **83**.

[0139] The holding section **85** has an inward-facing recess **86** formed part way along its length.

[0140] A modified floating piston ring **87** is positioned between the drive surface **83** of the support ring **59** and the lower end of the spring **63**. The piston ring **87** generally takes the form of a ring, presenting an upward-facing surface **88** on which the lower end of the spring **63** rests, and a downward facing surface **89** which abuts against the drive surface **83**. In the example shown the piston ring **87** has inner and outer O rings **90** or similar seals so that its inner and outer surfaces seal effectively against the inner side of the intermediate sleeve portion **56** and the outer side of the lower connection body **26**. As explained in connection with the previous embodiment, the piston ring **87** has a sleeve **98** extending upwardly from the inner side thereof, lying on the inner side of the spring **63**.

[0141] In this example, the piston ring **87** also has a protrusion **91** which extends downwardly from an inner side of the main part of the piston ring **87**. The protrusion **91** passes through the gap **84** between the lower connection body **26** and the drive face **83** of the support ring **59**, and terminates in a position which is aligned with the recess **86** formed in the holding section **85** of the support ring **59**.

[0142] The drive chamber **60** can also be seen in FIG. **13**. As described above, a lower side of the drive chamber **60** is formed by the shoulder **61** formed where the upper and lower regions **27**, **28** of the lower connection body **26** meet each other. On an inner side of the drive chamber **60**, near this shoulder **61**, a raised support is formed on the outer side of the upper section **27** of the lower connection body **26**. The support **92** protrudes further towards the inner side of the intermediate sleeve portion **56**.

[0143] A collet **93** takes the form of a generally cylindrical, hollow sleeve. A lower end **94** of the collet is positioned around the support **92**, and is preferably axially fixed in place with respect to the support **92**. An upper end **95** of the collet **93** protrudes upwardly beyond the support **92**. As can be seen in FIGS. **13** and **14**, there is a space between the inner side of the upper part **95** of the collet **93** and the outer surface of the lower connection body **26**. The outer side of the upper part **95** of the collet **93** has a protruding shape, which generally matches the interior shape of at least part of, and optionally all or substantially all of, the recess **86** formed in the holding section **85** of the support ring **59**.

[0144] The collet **93** is resilient, so the upper part **95** can deflect inwardly with respect to the lower part. To allow this to happen, the upper part **95** may be formed as a series of parallel fingers, with breaks between the fingers. The lower part **94** may be formed as a continuous ring, with each of the fingers being inwardly deflectable with respect to the ring.

[0145] FIG. **13** shows the first configuration of the tool, in which the outer sleeve is moved downwardly with respect to the mandrel as far as possible, and the blades are retracted. In this configuration, the upper part **95** of the collet **93** fits into the recess **85**. As can also be seen in FIG. **13**, the protrusion **91** of the piston ring **87** is positioned between the upper end **95** of the collet **93** and the outer surface of the lower connection body **26**.

[0146] In this configuration, the collet **93** will prevent the outer sleeve from moving upwardly with respect to the mandrel. Forces may act on the outer sleeve which would tend to drive it upwardly with respect to the mandrel if, for instance, a part of the outer sleeve drags or snags against the interior of the wellbore as the tool is lowered downwardly through the wellbore.

[0147] If an upward force acts on the outer sleeve, the outer sleeve will not be able to move upwardly because the protruding shape of the upper part **95** of the collet **93** is fitted into the recess **86**, and the abutting walls of the upper part **95** of the collet **93** and of the recess **86** will prevent the support ring **59** from moving upwardly with respect to the lower connection body **26**.

[0148] Moreover, the upper part **95** of the collet **93** is prevented from deflecting inwardly, towards the lower connection body **26**, by the presence of the protrusion **91** of the piston ring **87**.

[0149] The collet **93** will therefore effectively lock the outer sleeve and mandrel together in the axial direction, in this configuration.

[0150] When the tool is activated, pressurised fluid flows from the flow bore **30** into the drive chamber **60**, through the communication port **69**. In preferred embodiments the collet **93** has apertures **96** formed there through, to ensure that pressurised fluid can flow effectively around the collet **93** and into the drive chamber **60**.

[0151] As discussed above, the effect of pressurised fluid being introduced into the drive chamber **60** is to push the piston ring **87** upwardly with respect to the lower connection body **26**, and compress the spring **63**.

[0152] As this occurs the protrusion **91** will be withdrawn from the gap **84** between the support ring **59** and the lower connection body **26**. The upper part **95** of the collet **93** will then no longer be prevented from deflecting inwardly towards the lower connection body **26**. When the outer sleeve is driven upwardly with respect to the mandrel by the second to sixth pistons, the collet **93** can therefore deflect inwardly, out of the recess **86**, allowing the support ring **59** to move upwardly past the upper part **95** of the collet **93**. This is shown in FIG. **14**.

[0153] To assist in this inward deflection, a downward-facing surface of the upper part **95** of the collet **93**, and an upward-facing surface of the recess **86**, may have cooperating bevelled surfaces (set, for example at 45° to the longitudinal axis of the tool).

[0154] When the tool is activated through the introduction of pressurised fluid, the collet **93** will therefore not prevent this activation.

[0155] When the tool is deactivated, to return it from the second configuration to the first configuration, the reverse process will occur. The intermediate sleeve portion **56** and the support ring **59** will move downwardly, and as the lower edge of the support ring **59** contacts the upper part **95** of the collet **93**, the upper part **95** will deflect inwardly. To assist in this, the edges of these components that first contact each other may have bevelled edges, so that the upper part **95** of the collet **93** is deflected inwardly as the edges meet.

[0156] As the support ring **59** moves further downwardly, the protruding upper part **95** of the collet **93** will align with the recess **86**, and the collet **93** will deflect so that the upper part **95** thereof is received in the recess **86**.

[0157] The protrusion **91** of the piston ring **87** will then pass through the gap **84** between the support ring **59** and the lower connection body **26**, and once again be positioned between the upper part **95** of the collet **93** and the outer surface of the lower connection body **26**. The tool will then have returned to the first configuration shown in FIG. **13**, and the outer sleeve and mandrel will once again be axially locked with respect to each other.

[0158] The skilled reader will appreciate how this arrangement effectively acts as a latch, locking the outer sleeve and mandrel together axially when the tool is in the first configuration, and allowing axial movement of the outer sleeve and mandrel when the tool is activated. Once the tool has been activated for a first time, any shear pins or the like will have been broken, and will no longer hold the sleeve in place with respect to the mandrel before subsequent activations. In some embodiments, the presence of a latch mechanism of this type may allow shear pins to be dispensed with altogether.

[0159] It is envisaged that is some embodiments, the collet **93** may have sufficient stiffness that the protrusion **91** which blocks inward motion of the upper part **95** of the collet **93** may be unnecessary. In these embodiments, a certain level of axial force acting on the outer sleeve is needed for the collet **93** to deflect inwardly and allow axial movement between the outer sleeve and the mandrel. The level of force is chosen to be such that, during movement of the tool within the wellbore the level of force is unlikely to be exceeded.
[0160] However, when the tool is to be activated and pressurised fluid is introduced into the second to sixth pistons the level of force is exceeded and the collet **93** deflects inwardly to allow the outer sleeve to move axially with respect to the mandrel.
[0161] The communication groove **99** (discussed above) can also be seen in FIGS. **13** and **14**.
[0162] Referring to FIGS. **17-19**, a further tool **104** embodying the invention is shown. The further tool **104** has many features in common with the tools described above, and only the different features will be described below.
[0163] FIG. **17** shows the entire tool **104**. FIGS. **18** and **19** show zoomed-in views of the region indicated by I in FIG. **17**.
[0164] Turning firstly to FIG. **18**, this figure shows the components when the tool **104** is in the first configuration, with the blades retracted. A blade carrier **105** forms part of the mandrel of the tool **104**, and again has pockets formed therein in which blades **106** are received. In this embodiment, the blade carrier **105** resembles the blade carrier **17** of the previous examples, but is arranged the other way up, so that it has an inclined face **107** formed below the blades **106**. The travelling blocks are not present in this embodiment, and support blocks **108** are positioned above the blades **106**. Each blade **106** is axially linked at its upper end to one of the support blocks **108**, for instance through each blade **106** having a T-shaped protrusion (not shown), and corresponding T-shaped radial grooves being formed in the blade carrier **105** and/or in the support blocks **108**. In this example the support blocks **108** are fixed in place with respect to the mandrel.
[0165] As before, each blade **106** comprises a blade body **109** and a cutting portion **110**. At its lower end, each blade body **109** has an inclined face **115**, which slants downwardly and outwardly with respect to the longitudinal axis of the tool **104**. The slant of this inclined face **115** preferably matches that of the inclined face **107** of the blade carrier **105**.
[0166] In this example the blade carrier **105** does not have grooves or ribs formed thereon. Instead, raised ribs **111** are formed on the inner sides of the pockets of the blade housing **112**. In the example shown, the ribs **111** slant downwardly and outwardly, relative to the longitudinal axis of the tool **104**. It can be seen in FIG. **18** that, in the region of the blades **106**, the thickness of the blade housing **112** is greater than in previous embodiments.
[0167] The blades **106** have corresponding slanted grooves (not shown) formed on their outer surfaces. In the example shown the grooves are formed on the blade bodies **109** of the blades **106**.
[0168] The tool **104** is activated in the same manner as described above. As this occurs, the outer sleeve, including the blade housing **112**, is driven upwardly with respect to the mandrel. As the blade housing **112** moves upwardly, the blades **106** will be driven outwardly with respect to the mandrel, through the interaction of the ribs **111** and grooves. FIG. **19** shows the second configuration, in which the blades **106** are fully expanded.
[0169] In this example, as the blades **106** are expanded, they move radially or substantially radially outwardly with respect to the mandrel. The blades **106** preferably do not, or substantially do not, move axially with respect to the mandrel as this occurs.
[0170] It is envisaged that this will assist in breaking through a casing, as the outward force imparted to the blades **106** will act to cut directly through the casing, without also driving the blades axially with respect to the casing. The blades **106** will, in effect, need to cut though a smaller thickness of the material of the casing, because they move in a direction which is substantially perpendicular to the thickness of the casing.
[0171] At the lower end of each pocket in the blade housing **112**, the blade housing **112** presents an

inclined face **114**, which is preferably set at exactly or substantially the same angle as the inclined face **115** of the blade bodies **109**. As can be seen in FIG. **19**, as the blades are expanded these inclined faces **114**, **115** bear against each other, and as with the previous examples this increases the area available to transfer force to the blades **106**.

[0172] The support blocks **108** allow the blades **106** to slide radially outwardly with respect thereto, with the T-shape protrusions of the blades **106** moving within the T-shaped grooves.

[0173] In this embodiment the stop component **21** had been omitted, and instead the upward travel of the outer sleeve is limited by contact between an upward-facing shoulder **115** of the blade housing **112** with the support blocks **108**. However, this need not be the case.

[0174] The present invention also covers other techniques for driving a component such as a blade or cutter outwardly with respect to a mandrel of a tool, in such a way that the component moves radially outwardly, with no or substantially no axial movement, with respect to the mandrel. This can be achieved in any manner, and not just by relative axial movement of a mandrel and outer sleeve, as is the case in the examples disclosed above. For instance, a piston could be provided as part of the mandrel, or connected to the mandrel, such that a drive axis of the piston is perpendicular to the longitudinal axis of the mandrel. When the piston is activated, the component is driven radially outwardly with respect to the mandrel.

[0175] Aspects of the present invention therefore provide a downhole tool, comprising: a body, having a first connection to connect the tool to an immediately upper component in a drill string and to receive fluid from the immediately upper component, and a second connection to connect the tool to an immediately lower component in a drill string and to deliver fluid to the immediately lower component; a drive mechanism; and a component which is operable to be driven radially outwardly with respect to the body by the drive mechanism, such that the component does not or substantially does not move axially relative to the body during this motion. Preferably, the component is a blade or cutter.

[0176] Referring to FIGS. **20-24**, a further tool **1000** embodying the invention is shown. The further tool **1000** has many features in common with the tools described above, and the description here will focus on the different features.

[0177] The arrangement discussed with reference to FIGS. **20-24** differs from the above described arrangements primarily in respect of the construction of the rigid or substantially rigid supporting stem of the tool, which as discussed may be referred to as a mandrel.

[0178] It is important to note that any of the above described arrangements may be modified to replace their disclosed mandrels with a mandrel according to the present arrangement. Moreover, features of the present arrangement may be modified in accordance with the teachings of the above arrangements.

[0179] In the above described arrangements, the mandrels each comprise a plurality of piston inners. In the present arrangement, in contrast, a plurality of the piston inners are replaced by a continuous element. In comparison, for example, to the tool of FIG. **1**, the tool of the present arrangement comprises a single continuous element **1007** in place of the first to fourth piston inners **7-13**. (In the present arrangement there are six pistons in place of the four pistons formed in part by the first to fourth piston inners **7-13**, however, as discussed below, the present invention is in no way limited to the number of pistons provided). The single continuous element **1007** preferably takes the form of an activation shaft.

[0180] Considering the activation shaft **1007**, this is generally cylindrical and provided with a central flow bore **1009**, which passes therethrough. In place of the protruding radial flanges **10** of the piston inners **7-13** of the arrangement of FIG. **1**, the activation shaft is provided with piston members **1010**, which form the plurality of first protrusions extending outwardly from the inner body of the tool **1000**. The piston members **1010**, which may, as shown, take the form of rings attached to an outer surface of the activation shaft **1007**, are described in further detail below. The activation shaft is provided with a plurality of communication ports **1014**, which extend radially through the body of the activation shaft, and provide communication between the central bore **1009** and the exterior of the activation shaft **1007**. The communication ports **1014** are provided at appropriate positions with respect to the piston members **1010**. As can be seen in FIGS. **20** and **21**, they are provided at positions above (i.e. closer to a top end of the tool **1000** than) the piston members **1010**. Their positions may clearly be modified in accordance with modifications to the tool **1000**.

[0181] In the present arrangement, in a region of a first piston outer **1032**, the activation shaft **1007** is provided with a protruding radial flange **1011**. It should be appreciated that in alternative arrangements this flange could be replaced with a piston member **1010**, of similar construction to those provided lower down the activation shaft **1007** and described further below.

[0182] At its upper end, the activation shaft is provided with an upper threaded connection **1003** for connecting the tool **1000** to the next uppermost tool or component **1090** in the drill string. At its lower end, the activation shaft **1007** connects to a blade carrier **1017**, which forms part of the component which is activated or operated by axial movement of the outer body of the tool **1000**. The activation shaft **1007** thereby preferably extends continuously between the upper threaded connection **1003** and the component. It is preferably unitarily formed. The blade carrier **1017**, and the component more generally, may be arranged in accordance with any of the above described arrangements.

[0183] The piston members **1010** of the present arrangement comprise rings that are attached to the activation shaft. The piston members **1010** are appropriately axially spaced from one another along the activation shaft **1007**. The rings are each arranged to sealingly engage with the outer surface of the activation shaft **1007** and an inner surface of the outer body of the tool, as defined in the present arrangement by an inner surface of a respective one of the piston outers **1037**. For such purposes the rings are preferably provided with suitable sealing elements **1060**, which may comprise O-rings provided in suitable grooves provided in the rings, or otherwise.

[0184] The rings may be fixed in place using any suitable means, for example they may each be fixed in place using a circlip, by use of radially inwardly extending fasteners, or otherwise. In the present arrangement, however, the rings are fixed in place by load collars **1050**, which are received by corresponding grooves **1051** in the activation shaft **1007**, and are fastened to the faces of the rings, using bolts **1052** or other fasteners. In the present arrangement, the load collars are formed in two parts, which is preferable for ease of attachment. The present arrangement is not to be limited as such, however.

[0185] The second protrusions extending inwardly from the outer body of the tool **1000**, which in the present arrangement are defined by the inward facing flanges **1039** of the piston outers **1037**, sealingly engage the outer surface of the activation shaft **1007**. For such purposes, the second protrusions are preferably provided with suitable sealing elements **1070**, which may comprise O-rings provided in suitable grooves provided second protrusions, as shown, or otherwise. In an alternative arrangement, the activation shaft **1007** may instead be provided with the sealing elements. This alternative arrangement, is likely preferable. In such case, the outer surface of the activation shaft **1007** will be provided with suitable grooves for receiving the sealing elements, which again, may comprise O-rings.

[0186] Referring to FIG. **25**, there is shown a detailed view of the blade **1064** of the arrangement of FIGS. **20** to **24**. The main load bearing face is the broad face incorporated into the ramp/drive teeth profiles, in combination with the drive teeth. This end face is preferably combined with the drive teeth at this location to provide more surface area for load bearing on the end face than if the drive teeth are organised offset one pitch, or otherwise, i.e. the teeth are set back or removed from the blade end. The T-shape at the other end of the blade floats radially in the mating slot in the drive block which is moved axially by the outer housings and which allows the blade to float up/down the drive teeth ramps according to the direction of axial movement. The outer profile is substantially the opposite of that previously shown in respect of the other described arrangements.

[0187] It should be noted that the arrangement of FIGS. **20** to **24** is not to be limited to the use of blade as shown in FIG. **25** and may, for example, incorporate a blade of alternative form, such as a bade of a form previously discussed with respect to any of the other described arrangements. Correspondingly, any of the other arrangements, including those discussed with reference to FIGS. **1** to **19** may be adapted to incorporate a blade in accordance with that shown in FIG. **25**.
[0188] In the examples discussed above, the tool has six or eight pistons. However, the invention is not limited as such, and any suitable number of pistons may be used. In some arrangements, for example there may be twelve or more pistons.
[0189] In one example above, five of the six pistons generate an activation force, i.e. a force that would tend to move the tool from the first configuration, in which the blades are retracted, into the second configuration, in which the blades are deployed, and one of the pistons generates a deactivation force, which would tend to move the tool from the second configuration to the first configuration.
[0190] As discussed above, in other embodiments all of the pistons of the tool may generate an activation force, with no pistons generating a deactivation force. In such embodiments, there is likely to be no need for a ball seat to be formed in the tool.
[0191] In yet further embodiments, more than one piston may generate a deactivation force. For instance, where a casing is relatively thick, or otherwise expected to be difficult to perforate (and also difficult to remove the blades from after the perforation takes place), the tool may have twelve pistons, ten of which generate an activation force and two of which generate a deactivation force.
[0192] Use of an activation shaft in place of a number of piston inners will generally increase the total number of pistons possible by reducing the number of mechanical connections between components.
[0193] In the examples above, slanted ribs are provided on the internal walls of the pockets of the blade carrier, and corresponding grooves are formed on the outer sides of the blades. However, this may be reversed, so that the blades have outwardly-protruding ribs, which are received in corresponding grooves formed in the walls of the pockets.
[0194] In the example discussed above, the outer sleeve is moved upwardly with respect to the mandrel to activate the tool. However, in alternative embodiments the outer sleeve may move downwardly with respect to the mandrel to activate the tool. The skilled reader will readily understand how the design of the tool may be adapted in these cases.
[0195] Compared to conventional perforators, such as shown in EP2616625, embodiments of the invention have drive pistons having components which form part of the outer housing of the tool and which move, with respect to a central mandrel of the tool, to activate and deactivate the tool, and which form part of the outer surface of the tool. As this occurs the mandrel will remain fixed in place with respect to the other components of the drill string.
[0196] One advantage of this is that gravity will, if the tool is (as will usually be the case) in an orientation with the top end **2** above the bottom end **4**, assist more fully in returning the tool from the second position to the first (deactivated) position, as the outer sleeve components will drop downwardly once the drive pistons are deactivated.
[0197] In the examples discussed above, some of the drive pistons are positioned above the blades, and some are positioned below the blades. This arrangement helps with the distribution of forces within the tool as a whole.
[0198] When the tool is activated, and the blades encounter resistance when perforating a casing, components of the pistons above the blades will be placed under tension, and this effect will be cumulative. The greater the number of pistons above the blades, therefore, the greater the strain that will be applied to the weakest parts of the pistons, and the connections between the pistons. This effect may place an effective limit on the number of drive pistons that can reliably be positioned above the blades in the tool.
[0199] Similarly, during activation components of the pistons below the blades will be placed

under compression, and this effect will once again be cumulative. This may also place an effective limit on the number of drive pistons that can be positioned below the blades.

[0200] Dividing the pistons so that some are positioned above the blades and others are positioned below the blades increases the overall number of pistons that can be provided as part of the tool, and also (for a given number of pistons) reduces the maximum forces experienced by certain components of the pistons during use.

[0201] However, in other embodiments of the invention all of the pistons may be above the blades, or all of the pistons may be below the blades.

[0202] In the embodiments shown in the figures, the upper surfaces of the travelling blocks **48** are generally perpendicular to the longitudinal axis of the tool **1**. In other embodiments, these upper surfaces may be set at an angle to the longitudinal axis of the tool **1**. In particular these surfaces may be set at exactly or substantially a right angle to the angle of the ribs **66** that are formed on the inner surfaces of the pockets **19**. This will increase the bearing area available as the blades **64** are expanded, and hence increase the force that can be transferred to the casing during this process.

[0203] In the examples shown, slanting ribs **66** are provided in the inward-facing walls of the pockets **19** formed in the blade carrier **17**, which is a component of the mandrel. However, in other embodiments the ribs may instead be provided on the blade housing **44**, which is a component of the outer sleeve. In these embodiments ribs formed on the outer sleeve may be received in cooperating grooves formed on the outer sides of the blade body **67** of each blade **64**. The skilled reader will understand that, in these embodiments, the blades **64** will be driven downwardly and outwardly with respect to the mandrel when the tool **1** is activated.

[0204] In these embodiments, the thickness of the blade housing **44**, at least in the region where the ribs are formed, may need to be increased.

[0205] The blades of any arrangements described may be arranged so that the leading edge of the blade comprises a rounded edge as seen, for example, in FIGS. **21** and **22**. It may otherwise be sharp. The likely outcome of a rounded leading edge is that the perforation opening can be made using less mechanical force, which may be beneficial.

[0206] Tools embodying the invention may be used in downhole operations where more than one tool in a drill string is activated in the course of a single trip into the wellbore. For example, a drill string may be assembled including a tool according to the above, and a casing cutter. The tool is preferably positioned below the casing cutter, but this need not be the case. Operators can activate the tool to perforate the casing, either before or after the casing cutter has been used to cut the casing. In an example, the tool may be used first, to weaken the casing at a desired location, before the casing cutter is activated.

[0207] The construction of the tool, having a sturdy and robust set of inner components comprising the mandrel of the tool, means that the tool is well-suited to withstanding and transmitting rotational motion of the drill string as the casing cutter is used to cut the casing.

[0208] In examples where the tool is positioned below the casing cutter, a circulating sub may be positioned below the casing cutter and above the tool. When the casing cutter is to be activated, the circulating sub is operated to open one or more ports to the annulus. The circulating sub may also block flow to components below it, for instance through a ball being dropped to set the circulating sub. A high rate of flow through the casing cutter is likely to be needed while the casing cutter is being used, and the presence of the circulating sub means that this high flow can be diverted to the annulus without passing through the tool.

[0209] It is also envisaged that the tool may be used in examples where cement is pumped through the drill string, for instance to set a cement plug in the wellbore. In such examples, it will be preferable to block, initially, the communication ports that allow fluid to flow from the central flow bore of the tool to the various chambers thereof, so that cement does not enter these chambers as the cement passes through the flow bore. Once the cement has been displaced through the drill string, a suitable spacer (for instance comprising a sponge wiper and/or a quantity of fluid) may be pumped through the drill string, and the communication ports may then be opened so that the tool is ready for use. The initial closure, and subsequent opening, of the communication ports may be achieved, for example, through the use of burst discs or plugs, as the skilled reader will readily understand.

[0210] In other processes that may be carried out using a tool embodying the invention, the tool may be included in a drill string that includes a washing component, which is configured to direct jets of fluid radially outwardly. The tool may be activated to form perforations in the wellbore casing, as discussed above. The tool may then be deactivated, and the drill string raised or lowered within the wellbore so that the washing component is substantially level with the perforations that have been formed. The washing component is then activated to direct jets of fluid radially outwardly and through at least some of the perforations.

[0211] This may be done, for example, by dropping a ball or other object through the drill string to be received in a seat in or below the washing component, so that the flow of fluid below the washing component is at least substantially blocked. Fluid flowing down the drill string will then be directed outwardly through apertures in the washing component. The casing above the washing component may be isolated using a packoff, or other annular closing device.

[0212] Tools embodying the invention may also be used in plug and abandonment applications, where a bridge plug is initially set, and then the tool is activated to perforate the casing (or alternatively the casing may be perforated before the bridge plug is set). The perforation of the casing allows circulation to occur outside the casing. A cement plug can then be formed on top of the bridge plug, by pumping cement through the drill string.

[0213] In some processes carried out using tools embodying the invention, the drill string is held stationary or substantially stationary with respect to the wellbore as the blades are driven outwardly to perforate the casing. However, in other processes, the drill string (and hence the mandrel of the tool) may be moved axially with respect to the wellbore as the blades are expanded, to create longer cuts or scores in the casing. It is envisaged that the drill string may be moved repeatedly upwardly and downwardly, in a reciprocating motion, as the blades are expanded, so that the blades create elongated cuts or scores in the casing, and progressively cut deeper into the casing along these cuts or scores as the process goes on.

[0214] The tools discussed above contain blades or other cutters which are deployed when the tool is activated. However, the invention is not limited to this, and the skilled reader will appreciate that the drive system disclosed in this application may be used with other types of tool, in which components other than blades or cutters are deployed when the tool is activated. Methods are generally disclosed of providing a tool embodying the invention, including one or more components which are activated or operated by axial movement of the outer sleeve with respect to the mandrel, running the tool into a wellbore as part of a drill string, and then activating the tool to operate the component(s).

[0215] Tools embodying the present invention may provide significant advantages with respect to conventional tools of this type.

[0216] When used in this specification and claims, the terms “comprises” and “comprising” and variations thereof mean that the specified features, steps or integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or components.

[0217] 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 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 tool, comprising: an inner body, having a first connection to connect the tool to an upper component in a drill string and to receive fluid from the upper component, and a second connection to connect the tool to an lower component in a drill string and to deliver fluid to the lower component, the inner body defining a flow bore therealong which communicates between the first connection and the second connection; an outer body disposed around at least a part of the inner body; a plurality of first protrusions extending outwardly from the inner body; a plurality of second protrusions extending inwardly from the outer body; a plurality of pressure chambers, each pressure chamber at least partly defined on an inner side by the inner body and on an outer side by the outer body, and at least partly defined on upper and lower sides by one of the first protrusions and one of the second protrusions; and a plurality of first flow ports, each of the first flow ports allowing fluid communication between the flow bore and one of the pressure chambers, wherein: the outer body is axially movable with respect to the inner body, in a direction which is parallel or substantially parallel with a longitudinal axis of the tool, such that introduction of pressurised fluid into the pressure chambers tends to drive the outer body axially with respect to the inner body; the first connection, the second connection and the plurality of first protrusions are fixed to one another and, in use of the tool, will not substantially move axially relative to one another; and the tool further comprises a component which is activated or operated by axial movement of the outer body with respect to the inner body.
2. A tool according to claim 1, wherein at least one of the pressure chambers is below the component, and at least one of the pressure chambers is above the component.
3. A tool according to claim 1, wherein the inner body comprises a plurality of piston inners, and the outer body comprises a plurality of corresponding piston outers, each piston outer at least partially surrounding the corresponding piston inner to form a piston which includes one of the pressure chambers.
4. A tool according to claim 3, wherein each piston inner includes an outwardly-protruding flange, which comprises one of the first protrusions.
5. A tool according to claim 3, wherein each piston outer includes an inwardly-protruding flange, which comprises one of the second protrusions.
6. A tool according to claim 1, wherein the inner body comprises a shaft, which extends continuously between the first connection and the component.
7. A tool according to claim 6, wherein the first protrusions comprise piston members that are attached to the shaft.
8. A tool according to claim 6, wherein the outer body comprises a plurality of piston outers, each piston outer at least partially surrounding a corresponding one of the first protrusions to form a piston which includes one of the pressure chambers.
9. A tool according to claim 8, wherein each piston outer includes an inwardly-protruding flange, which comprises one of the second protrusions.
10. A tool according to claim 1, wherein the component comprises one or more elements which are driven radially inwardly or outwardly with respect to the inner body by axial movement of the outer body with respect to the inner body.
11. A tool according to claim 10, wherein the elements comprise blades or cutters.
12. A tool according to claim 10, wherein: the tool has a first configuration, in which the elements are retracted; the tool has a second configuration, in which the elements are activated, and protrude radially outwardly to a greater extent from a longitudinal axis of the tool than in the first configuration.
13. A tool according to claim 1, wherein the pressure chambers comprise at least one first pressure chamber, communicating with the flow bore, wherein the introduction of pressurised fluid into the first pressure chamber tends to drive the outer body axially with respect to the inner body in a first direction, and at least one second pressure chamber, communicating with the flow bore, wherein

the introduction of pressurised fluid into the second pressure chamber tends to drive the outer body axially with respect to the inner body in a second direction, which is opposite or substantially opposite to the first.

14. A tool according to claim 13, further comprising an isolation arrangement, wherein when the isolation arrangement is activated fluid flow from the first connection to the or each first pressure chamber is blocked or substantially blocked, and fluid may flow from the first connection to the or each second pressure chamber.

15. A tool according to claim 1, further comprising a vent allowing fluid flow from the flow bore to an exterior of the tool, and wherein the vent is open at or near the limit of the motion of the outer body with respect to the inner body in a first direction, and closed during other relative positions between the inner and outer body.

16. A tool according to claim 1, comprising a latch arrangement which may be moved between an engaged state and a disengaged state, and where when the latch arrangement is in the engaged state, the latch arrangement substantially prevents relative axial movement of the inner body and the outer body.

17. A tool according to claim 16, wherein the latch arrangement comprises: a latch element having a resilient part, the latch element being carried by or fixed in relation to one of the inner body and the outer body; a receiver having a recess in which a part of the latch element is received, the receiver being carried by, or fixed in relation to, the other one of the inner body and the outer body.

18. A tool according to claim 17, wherein the latch arrangement further comprises a blocking component which, in a first position, prevents the resilient part of the latch element from deforming to allow the part of the latch to be removed from the recess, and in a second position does not prevent the resilient part of the latch element from deforming to allow the part of the latch to be removed from the recess.

19. A method of perforating a wellbore casing, comprising the steps of: providing a drill string including a tool according to claim 10; running the drill string into a wellbore having a casing, to a desired depth; and activating the tool to drive the elements outwardly into engagement with the casing.

20. A method according to claim 19, further comprising the steps of: including the tool in a drill string; further including a casing cutter in the drill string; and cutting the casing of the wellbore using the casing cutter during the same trip into the wellbore.