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(54) **Methods and apparatus for expanding tubular members**

(57) A tool (10) for expanding a tubular member in a well, comprises: a locating device for locating the tool in the tubular member to be expanded; and an expanding device for expanding the tubular member beyond its starting diameter, the expanding device comprising a radial array of expanding elements (40), each element, in use, acting on the tubular member to deform it radially outwardly; wherein each element is moveable in an axial direction independently of the other elements in the array. A method of expanding a tubular member in a well, comprises: positioning an expansion tool in the tubular mem-

ber in the well, the expansion tool comprising a radial array of expanding elements; and moving the elements in an axial direction to act on the tubular and deform it in a radial direction, each at least on element moving in an axial direction independently of others in the array. A system comprises a tool suspended on a wireline cable and connected to control equipment located at the surface so as to be operable in a well to expand tubular members located therein.

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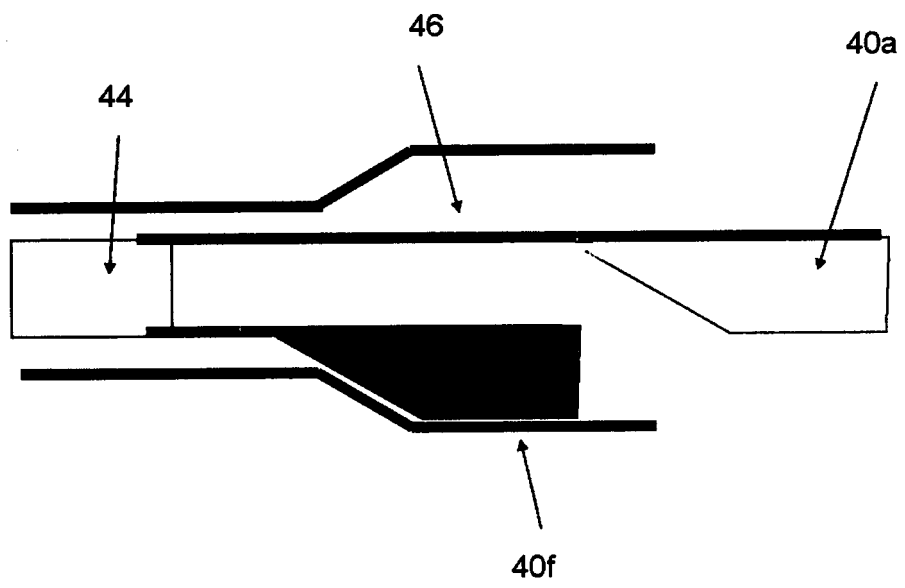


Fig. 9

Description

Technical field

[0001] This invention relates to methods and apparatus for use in the expansion of tubular members. The invention find particular application to such operations conducted in underground well or boreholes such as are found in the oil and gas industry.

Background art

[0002] The use of expandable tubular members to seal or isolate portions of wells has been widely proposed. In one version, a simple tubular member is expanded against the borehole by stretching the wall of the tubular using an expanding tool. In another, the tubular member is positioned in the borehole in a vertically corrugated form and then expanded back to a circular cross-section against the borehole.

[0003] Where expansion is achieved by simple stretching, the thickness of the material forming the tubular decreases and there is typically a limit of 20-30% expansion before plastic deformation of the material causes the tubular to become weakened (and failure occurs). For practical purposes, an upper limit of 10% expansion is used.

[0004] Where the tubular is vertically corrugated, much greater expansion ratios can be achieved. However, effective sealing against the borehole can be an issue.

[0005] A number of techniques and tools have been proposed for expanding the tubular. These include inflation with a pressurised fluid such that the tubular 'balloons' against the borehole, forcing a tapered, oversize mandrel through the tubular, either by using a cable or using fluid pressure, or by use of a rotating system of rollers urged radially outwardly against the tubular (see for example US 2002185274 A and WO 2005003511 A).

[0006] The expanding tools typically comprise a device for locating the tool in the tubular to be expanded and an expanding device that is moved axially through the tubular to expand it to the desired diameter. The expanding device can comprise a tapered, cone-like mandrel, or a radial array of expanding elements that are urged against the tubular to expand it. The array may also rotate to expand the tubular and the array can be moved axially through the tubular to increase the axial extent of the expanded portion.

[0007] Disclosure of the invention

[0008] A first aspect of the invention comprises a tool for expanding a tubular member in a well, comprising:

- a locating device for locating the tool in the tubular member to be expanded; and
- an expanding device for expanding the tubular member beyond its starting diameter, the expanding device comprising a radial array of expanding elements, each element, in use, acting on the tubular member to deform it radially outwardly;

wherein each element is moveable in an axial direction independently of the other elements in the array.

[0009] Preferably each element is tapered inwardly at one end. Consequently, the array can comprise a sector cone-like structure when all of the elements are positioned at the same axial location in the member.

[0010] Each element can be moveable radially outwardly independent of the other elements in the array. The elements can also be rotatable about a longitudinal axis. In such a case each element can be rotatable in use between a first position in which axial movement of the element causes no radial deformation of the tubular, and a second position in which axial movement causes radial deformation.

[0011] The array is preferably configurable such that the elements are axially distributed so multiple elements of the array can be rotated into the first position at the same time. The array can then be configured for expansion by rotation of the elements into the respective second position.

[0012] In one embodiment of the invention, the elements comprise rollers.

[0013] In this embodiment, the tool preferably further comprises a mandrel over which the rollers move during expansion of the tubular. The rollers move axially over the surface of the mandrel from one end to the other as the mandrel is moved through the tubular, the rollers being returned to the one end through the interior of the mandrel. The mandrel preferably has a cone-like shape.

[0014] Power for operation of the tool can comprise electrical power provided over a wireline cable.

[0015] The tool can also comprise at least one sensor capable of making measurements during the deformation operation.

[0016] In one preferred embodiment, the locating device comprises a cone-like member that is forced into the tubular member to counteract the force required to move the expanding elements axially while deforming the tubular member. Preferably, the cone-like member deforms the tubular member radially outwardly.

[0017] The cone angle of the cone-like member can be different to the corresponding angle on the expanding elements. Also, more than one cone-like member can be provided. When a single cone-like member is used, the cone angle may be larger, when more than one is used, the angle may be smaller.

[0018] A second aspect of the invention comprises a method of expanding a tubular member in a well, comprising:

- positioning an expansion tool in the tubular member in the well, the expansion tool comprising a radial array of expanding elements ; and
- moving the elements in an axial direction to act on the tubular and deform it in a radial direction, each at least on element moving in an axial direction independently of others in the array.

[0019] The method preferably further comprises positioning the tool in the tubular with the elements of the array positioned in a first position in which axial movement causes no radial deformation of the tubular, the elements of the array being moved to a second position such that axial movement causes deformation once the tool is in position.

[0020] The movement between the first and second positions can be achieved by rotation of each element about a longitudinal axis.

[0021] The method according to the second aspect of the invention is preferably performed using a tool according to the first aspect of the invention.

[0022] The elements can be moved so as to deform the tubular member in a non-axisymmetrical manner. It is particularly preferred that the geometry of the well is measured and the expanding elements configured so as to provide a corresponding geometry in the deformed tubular member.

[0023] A swelling material can be introduced between the tubular member and the well wall so as to fill voids remaining after deformation of the tubular member.

Brief description of the drawings

[0024] Figure 1 shows one embodiment of a tool according to the invention;

Figure 2 shows a corrugated sleeve prior to expansion;

Figure 3 shows a more detailed view of the tool of Figure 1;

Figure 4 shows the steps in a multi-stage operation;

Figure 5 shows a schematic side view of an expansion tool;

Figure 6 shows a schematic plan view of a tool according to an embodiment of the invention;

Figure 7 shows a schematic side view of the tool of Figure 6;

Figure 8 shows a schematic side view of an embodiment of the tool of Figure 7 with an actuator;

Figure 9 shows a schematic side view of another embodiment of the tool of Figure 7;

Figure 10 shows the tool of Figure 9 when installed prior to expansion;

Figure 11 shows the use of a tool according to an embodiment of the invention in an irregular borehole;

Figure 12 shows a tool according to another embodiment of the invention;

Figure 13 shows a plan view of the tool of Figure 12; and

Figure 14 shows details of an embodiment of a tool with a modified anchoring unit.

Mode(s) for carrying out the invention

[0025] The fundamentals of expandable tubular in wells are well-known and will not be described in detail

here. One such application comprises the expansion of a sleeve inside a casing to close off perforations that might be producing water. The use of an embodiment of the invention in such an application is shown schematically in Figure 1. In use, a tool 10 according to one embodiment of the invention, is positioned in a well 12 through production tubing 16 located in the well 12 by means of a packer 14 and extending to the surface (not shown). The tool 10 is lowered through the tubing 16 by means of a wireline cable 18 which provides electric power and data to the tool 10. An expandable sleeve 20 is positioned on the tool 10 with a mandrel 22 positioned below the sleeve 20 and connected to the tool 10 through the centre thereof. In this example, the sleeve 20 is vertically corrugated as is shown in Figure 2 so as to reduce its outer diameter and allow its installation through tubing. Other forms of expandable tubular can also be used. To expand the sleeve 20, the mandrel is drawn upwardly by the tool 10 through the sleeve where it forces the sleeve outwardly.

[0026] Figure 3 shows more detail of the tool in use. In this preferred embodiment, the tool 10 is suspended on the wireline cable 18 and comprises a number of functional elements.

[0027] A control unit 24 is connected to the upper part of the tool and providing electrical and mechanical connection to the cable 18 and a proper operational interface with the cable 18 for sending and receiving commands and data. This unit provides for the management of the electrical power transmitted by the cable 18 to the down-hole tool 10. In particular, power supplies provide energy to control electronics (such as a microprocessor (not shown)). This section includes also control systems for high levels of electrical power which will be required to perform the expansion of the tubular sleeve. This power control preferably allows smooth starting of expansion functions.

[0028] The control unit 24 also performs monitoring of the expansion process and transmits this information to the surface, so that the operator may adapt operational parameters for the optimum expansion process.

[0029] An anchorage mechanism 26 is provided that can be expanded into the sleeve 20 to lock the tool 10 and sleeve 20 together. Typically this locking is performed by hydraulic slips 27 which can be pushed radially against the sleeve 20. This mechanism holds the tool in place while the expansion is being performed. For the proper operation, this mechanism has to transmit the reaction forces of the expansion process. In some application, this is only an axial force, but it can also be torque.

[0030] A retraction system 28 which operates to move the expansion system 29 (corresponding to the mandrel 22 described above) through the sleeve 20 over a pre-determined length. The expansion/retraction section of the tool generates the mechanical movement for the expansion process. This section contains typically high power and high torque systems to generate these expansion movement.

[0031] A retraction and expansion transmission system 30 for transmitting the drive from the retraction system 28 to the expansion system 29.

[0032] The expansion system 29 is the device in direct contact with the sleeve 20 to cause it to expand. This device transmits the high contact force to the sleeve 20 to deform it. It is driven by an expansion and retraction transmission 30. The expansion system may include a cone-shaped mandrel (as will be described in more detail below). In this case, the mandrel is pulled towards the wireline tool 10 by the retraction transmission 30.

[0033] The expansion of a sleeve 20 over lengths longer than the maximum stroke of the retraction mechanism is feasible. However, expansion using the tool of Figure 3 has to be performed in multiple steps of short expansion as is shown in Figure 4. A short tubular section is expanded as previously explained (Steps 1 and 2). Then the slips 27 are removed, the wireline tool 24, 26, 28 is pulled upwards while the retraction mechanism 30 is expanded (Step 3). After these operations, the wireline tool is in a new upwards position inside the tubular 20 to be expanded, with its expansion cone 29 still in contact with the upper part of tubular section already expanded in the previous stroke. The slips 27 can then be reopened (Step 4). The next section of tubular can be the expanded (Step 5).

[0034] The tool 10 may be provided with sensors to perform several measurements relating to the expansion process, including:

- calliper information to track the shape of the expanded tubular;
- expanding force;
- thickness of tubular after expansion;
- loss of diameter (relaxation) after unloading of tool following expansion;
- contact quality with formation (and layer behind metal structure);
- presence of cracks and surface quality; and
- change of length of the tubular.

[0035] The expanding tooling 29 (such as a mandrel 22) can take a number of forms. For smooth tubular at the end of the job, one option is to perform the expansion by axial displacement of a cone. This process can be considered as forcing a too-large cone 22 in the sleeve 20. Figure 5 shows schematically this process and is known in the art. An embodiment of the present invention based on this process comprises the use of a sector cone as a mandrel. This is shown generally in Figures 6 and 7 which show the mandrel in the form of an eight sector hollow mandrel (40a-40h). The sector cone support high hoop stresses which press the sectors (or parts) of the cone together. These high stresses are generated by the contact force with the tubular during the expansion process.

[0036] The instantaneous axial force to displace the whole cone may be important, depending on the sleeve

thickness and diameter. To limit this instantaneous axial force requirement, the sector cone can be moved one sector at a time. Figure 8 shows one embodiment of such a system. Each conical sector 40 is dragged by a hook 42 pulled by the control unit 44. The tip of the hook 42 is a right angle turn which is applied against only one sector 40 at a time. Before pulling a sector 40, the hook 42 is rotated to apply its tip onto the proper sector.

[0037] In Figure 8, the hook 42 is represented as a small bar. The hook may also consist of a cylinder running inside the sector cone and equipped with a solid (relatively high-strength) pin extending out of the cylinder. This pin corresponds to the finger of the hook 42.

[0038] In some applications, each sector has its own dragging hook. In this case, the wireline control unit maintains a direct link to each sector and the hook may be physically attached to the sector itself.

[0039] The sector cone allows the expansion to start with the whole system inside the none-expanded tubular. This is can be important when only a certain defined length of the tubular has to be expanded to a larger diameter. For example, multiple short lengths of tubular inside a long completion could be expanded: the expanded lengths acting as annular seals (and replacing the ECP function).

[0040] To start inside the unexpanded tubular, the cone is initially assembled with missing sectors, so that the circumference of this initial assembly is smaller than in complete assembly. Then, the missing sectors are axially forced between sectors of the initial assembly cone. When these sectors are added, the circumference of the assembled cone increases and grows to its final size. During this growth, the tubular is also formed to a larger diameter. When the cone is completely assembled to final shape, it can then be dragged over some distance to perform the tubular expansion.

[0041] To ease the insertion of the missing sectors, these sectors may be machined with major chamfer (corresponding to half of the width of the sector). Other special cuts can also be considered.

[0042] With the design of the sector cone, sector can be added or removed so that the overall cone diameter can either be increase or reduced. Above an expanded zone in the well, the tubular may be left at its initial size.

[0043] Another major advantage offered by the use of sector cone is to allow the expanding tool to be passed through narrow section. For this purpose, the cone sectors can be installed one below each other in a long string. In this configuration, the global radial dimension of the system is small (in the range of the sector lateral dimension). This can be important in order to pass through production tubing. When reaching the proper location, the control unit rebuilds the cone in one plane before starting the expansion job. This reconstruction of the cone from the in-line setting of the sectors can be achieved with limited manipulation. Figure 9 shows such a tool with parts omitted for clarity. Each sector 40 is mounted on its own connecting rod 46. In Figure 9, two sectors are

shown, 40a which is in its in-line position, and 40f which is in its operating position. The sectors conserve their radial array position between their operating and in-line positions. To pass from the in-line position to the operating position, the sectors are first rotated radially towards the tubular, then they are moved to the same depth location. For the reverse transition, the sectors are first spread in depth. Then they are rotated towards the centre of the borehole to be positioned in-line. Figure 10 shows three sectors 40a, 40b, 40c each in the in-line position at different depths. This function can be implemented as already explained above: each sector 40 is attached to the wireline control unit 44 with its own connecting rod 46 in a permanent fashion. Each connecting rod 46 can be independently extended and rotated by the control unit 44. When required by the control unit 44, the connecting rod 46 can be extended each at a different length to stagger the sectors 40 in depth so that each sector is held at a different depth. Then each connecting rod and sector is rotated by 180 degrees, bringing the sector to the centre of the system (as is shown in Figure 10). In this configuration, all the sectors are in-line and centralized into a minimum-sized overall dimension.

[0044] The reverse process is performed to prepare the tool for expansion.

[0045] If the sectored cone has a hollow centre (as shown) when assembled from all of its sectors, the system can then provide a sleeve expansion of nearly three fold (the hollow centre being one third of the final diameter, making each sector width equal to one third of the final diameter).

[0046] The use of a cone mandrel is compatible with the expansion of a corrugated sleeve. The cone is in contact with the internal part of the corrugated sleeve at an earlier position than the part closer to the outside diameter, making the opening of the corrugated surface quite smooth. The cone can also have a shape matching the sleeve corrugated shape to help smooth the process.

[0047] This proposed technique allows also the expansion of multiple sections of non-successive tubulars in a single run in the well-bore. In this case, only critical zones of the completion can be expanded for a pre-defined purpose. For example with long completion of slotted liner, slotted liner elements can be separated by solid tubulars which can be expanded against the formation to act as external sealing (and replace ECPs). The present invention is well-suited to this application. The expansion cone (or sectored cone) can be used over long length of tubular to expand without undue wear. The sectored cone allows expansion to be started from the initial size of the tubular. The sectored cone can be easily moved to the next section to be expanded by removal of some sectors to allow the overall diameter to be reduced for this move. The expansion process can be started even in front of a non-sealing tubular (such as screen, slotted liner, or perforated structure).

[0048] The overall shape of the mandrel does not have to be circular but can have a different shape than cylin-

drical over its large section. With such a section, the tubular may have non-circular cross-section after expansion. In particular, the tubular can be deformed to oval shape which can be critical in some cases such as in the connection zone for multi-lateral well with two legs.

[0049] In some applications, it is critical to perform the tubular expansion so that the expanded tubular is against the bore-hole (or the already installed tubular). This is particularly true for the case of liner hanger expansions. In this situation, the liner has to be in solid contact with the previous casing to be able to hang onto the casing. It can also be important for expansion of completion for the largest internal bore for easy internal flow and for sleeve for sealing against the well-bore.

[0050] In such situations, it is important that the tubular is expanded at maximum diameter allowed by the hole, and not a pre-defined diameter.

[0051] With the initial design of the sectored cone described above, and by dragging the cone over the tubular length, the tubular is expanded to a constant diameter. To achieve the new requirement of variable expansion against the external structure (i.e. the formation or a pre-installed casing), the system has been adapted. One solution is to use the concept of using sectors with large entry chamfers and moving one sector per unit of time. By moving each sector individually, the overall cone diameter grows. During that growth, the overall diameter of the tubular also grows as the sector chamfers engage and make the overall cone diameter larger. The circumferential growth is sustained until an external event stops it, for example:

- The resistance to circumferential growth is too large, indicating that the tubular is expanded against the formation.
- The maximum engagement of all sectors is reached, ensuring the maximum expansion size.
- The material of the tubular is at its limit for circumferential expansion such that cracking may appear if more expansion is applied.

[0052] When this point has been reached, one (or more) sectors are backed-off slightly from the assembled cone. The rest of the cone is moved slightly forwards and then the missing sectors are reinserted to expand the next zone of the tubular.

[0053] Only small displacement of the assembled cone is performed when the sectors are missing to avoid creating an irregular (wavy) surface on the tubular.

[0054] This latest technique can be slightly modified to ensure that the tubular is expanded against the well-bore, while ensuring proper contact over the full perimeter. The tubular therefore has a variable diameter with depth and but also its shape also conforms to the well. This may be important for proper sealing at the outside face of the expanded tubular (which is vital for sealing sleeves and tubular).

[0055] For this purpose, the sectored cone is modified

as is shown in Figure 11, so that the sectors 40 do not have flat faces for their contact area. In this case, they are in contact only following a line. This can be achieved by the use of axial small interface cylinders 47. Thanks to this local linear contact, each sector can pivot slightly versus the neighbour sector.

Thanks to this pivoting, the overall shape is not exactly circular (as is shown in Figure 6), but is an assembly of broken segments of a circle. This irregular perimeter allows adequate adjustment to the shape of the external surface 48 (bore-hole or already installed tubular). Alternatively, the geometry of the hole can be measured prior to installation of the tubular and the expanding elements configured to provide a corresponding geometry in the expanded tubular. A swelling material can be introduced between the tubular member and the borehole wall to fill any voids remaining after expansion.

[0056] In certain cases, the radius of the hole may vary from depth to depth. In such a case, it is desirable that the diameter of the expanded tubular should vary correspondingly. This can be achieved by providing each segment of the split cone with large chamfer. Thanks to these chamfers, the global circumference of the assembled cone will grow by engaging more the segments together. In order to maintain an overall cylindrical shape, the segments are partially engaged, with all the "even" segments at one axial position (or depth), while the "odd" segments are slightly shifted in axial position (depth). The global circumference of the expansion mandrel is depends directly on the axial shift of the chamfered split segments.

[0057] The shape of the expansion mandrel can be modified from a cylindrical shape to other shapes (such as oval, ellipse, egg shape, tri-angular rounded...) by setting the proper axial shift for each segment. For example for oval shape some segments (a quarter of the total number) are fully engaged at the extremity of the small axis of the oval (this defines the arc of large radius), and some segments (a quarter of the total number) are partially engaged (high variation of axial shift from segment to segment) to defined the arc of the small radius of the oval.

[0058] The control unit maintains the proper axial shift of the elements while displacing the segment in sequential fashion. The shift is selected from the target local expansion diameter. It can be also based on real-time measurement outputs (such as required force for expansion or contact detection with the formation).

[0059] The various expansion devices described above can be combined with a wireline tool for effective control for all required functions. In particular the proper setting sequence for installation the sectors in the proper position can be performed.

[0060] It should also be noted that the tubular to expand may be lowered in the well in advance of the expansion system. In some cases, the tubular to be expanded may have been previously lowered with the completion (in case of screens and slotted liner). In other

applications, the tubular to be expanded may be a sleeve of limited length (e.g. 10 meters). In these applications, the sleeve can be lowered by the wireline tool itself with a consequent saving rig time.

[0061] A further embodiment of the present invention incorporating a cone system for expanding the sleeve involves the introduction of rollers between the cone and the sleeve, for friction reduction. An example of this is shown in Figures 12 and 13. The rollers 50 are injected at least in three rows, as the circumference 52 at the point of injection is smaller, allowing that only a limited number of rollers can be installed at once at a given circumference. As soon as the rollers have moved, a second layer is injected with a small angular offset (and so on for the third and further layers). Three layers can achieve a expansion ratio of nearly three fold.

[0062] This technique allows expansion above the diameter of a pipe through which the cone can pass, as the total internal diameter of the expanded sleeve 54 is larger than (cone diameter + 2 x roller diameters).

[0063] The rollers 50 are similar to the rollers of roller bearing. Their curvature can correspond to the final internal diameter of the expanded sleeve 54. The cone 56 can also be made of sectors as is described above.

[0064] The rollers are re-circulated from the end of the stroke between the cone 56 and the tubular 54. This re-circulation consists of catching the rollers and returning them 58 to the upper end of the cone 56.

[0065] In the embodiments described above, the expansion is performed by a wireline tool which is lowered in the well-bore. This tool pulls the expanding elements upwards in the form of a cone which performs the expansion of the tubular. The displacement of these elements may require a relatively large force, depending on the shape and material of the tubular to expand. In some cases, this force may be tens of tons. Consequently, the tool needs to anchor itself in the tubular outside the section that is to be expanded. In many cases, the tool creates a displacement of the cone over a stroke in the range of less than a few meters. When the cone is displaced over this stroke, the tool has to be moved to the next position to allow the expansion of the next section. It is therefore necessary that any anchoring can be easily released to allow movement of the tool.

[0066] In most case, the expansion process proceeds in a bottom to top direction (with respect to the well). In this situation, a tool that operates by pulling must anchor itself in a tubular section which is not yet expanded.

[0067] The anchors have to be able to resist forces which generate the tubular expansion. In a particularly preferred form of anchor, the anchoring effect is obtained by plastic deformation of the tubular itself. The tool is equipped with a similar set of slipped cone elements installed on top of the tool. This cone works in the same way as the expansion cone, but it is facing downwards. The tool installs this cone at the desired location and deforms the tubular. After this installation, the tool locks itself in this cone and can then pull the expansion cone

upwards. To ensure that the anchor does not move downwards during the expansion, the anchor is set with a higher plastic deformation force for it to move. To achieve this, the anchoring cone is provided with a more aggressive cone angle so that the axial force for its displacement is higher.

[0068] Another embodiment comprises two (or more) cones spaced axially by a small distance, an example of which is shown in Figure 13. Each of these cones 60 is installed by plastic deformation of the tubular 62 (as described above). The total axial force to displace this anchor corresponds to the sum of the anchoring force of each anchor. With this technique, each anchor does not need to be expanded final diameter of the expanded tubular, and the cone of each anchor 60 is smaller than the cone use for the tubular expansion 29. While the maximum load supportable by each anchor 60 is lower than the force to move the expansion cone 29, the sum of the anchoring forces is higher. As the deformation 62 of the tubular by the anchoring cone(s) 60 is smaller than the final expansion, the expansion process will ensure a smooth surface even at the depth of anchoring.

[0069] The load is shared between the anchoring cones 60, each cone supports a certain axial load before starting tubular expansion while sliding. The sliding of the anchors will stop when an even force distribution is achieved due to the axial plastic deformation below each cone of the anchor.

[0070] The anchoring cones can be constructed in a similar design as the expansion cone. They can be made of splitted cones which can allow each cone segment to be moved axially as well as rotated. This construction allows to install the cone segment of the anchors in line to insure small overall diameter: this small overall diameter allows to pass through narrow well section (such as the production tubing).

[0071] The expansion of the final section of the limited length tubular may need particular attention, as the process described above requires that the tool is anchored into the tubular to expand. In the final upper section of the tubular, the expansion can be performed in the opposite direction (downwards). For this to occur, an expansion cone is provided in the tool system to be pulled downwards and an anchoring mechanism is positioned at the bottom of the tool system. The previously described slip mechanism based on split cone, allowing anchoring by plastic deformation of the tubular can be modified to become the "upper" expansion cone.

This can work particularly well with the system equipped with the pair of split cones for slips. In this case, one cone is left contracted so that it plays no effect in the process, while the other cone is fully opened imposing the full size deformation of the tubular. Furthermore, the lower split cone which is the expanding tool for the normal expanding process becomes the anchoring system for this downwards expansion. For this operation, this lower split cone is opened at extremely high opening force. This opening force is counter-balanced by the simultaneous strength

of the expanded tubular and the pre-existing structure (behind the expanded tubular). Thanks to this combined resisting force, the anchor is capable of supporting a larger force than the force for the downwards expansion.

[0072] Another tool configuration can have two sets of pairs of split cones (one on top and one at the bottom of the tool). With this symmetrical tool design, the expansion process can be fully symmetrical (upwards or downwards). When anchoring on one side, both cones of the relevant set are expanded at limited forces, while the expansion process at the other extremity requires the opening on only one cone.

[0073] The expansion of the upper part of the tubular starts with the upper cone outside the tubular (just in contact with the tubular upper end).

[0074] When expanding downwards, slack can be provided in the wireline cable so that the cable is not stretched by the downwards expanding process.

[0075] As will be appreciated from the above description, making the expanding elements (cone sectors, rollers, etc,) moveable axially independently of each other allows an expansion tool and method that addresses problems associated with the previously proposed systems.

Claims

1. A tool for expanding a tubular member in a well, comprising:
 - a locating device for locating the tool in the tubular member to be expanded; and
 - an expanding device for expanding the tubular member beyond its starting diameter, the expanding device comprising a radial array of expanding elements, each element, in use, acting on the tubular member to deform it radially outwardly;
 wherein each element is moveable in an axial direction independently of the other elements in the array
2. A tool as claimed in claim 1, wherein each element is tapered inwardly at one end.
3. A tool as claimed in claim 2, wherein the array comprises a sectorized cone-like structure when all of the elements are positioned at the same axial location in the member.
4. A tool as claimed in any preceding claim, wherein each element is moveable radially outwardly independent of the other elements in the array.
5. A tool as claimed in any preceding claim, wherein each element is rotatable about a longitudinal axis.

6. A tool as claimed in claim 5, wherein each element is rotatable in use between a first position in which axial movement of the element causes no radial deformation of the tubular, and a second position in which axial movement causes radial deformation. 5
7. A tool as claimed in claim 6, wherein the array is configurable such that the elements are axially distributed so multiple elements of the array can be rotated into the first position at the same time. 10
8. A tool as claimed in claim 7, wherein the array is configurable for expansion by rotation of the elements into the respective second position. 15
9. A tool as claimed in claim 1, wherein the elements comprise rollers.
10. A tool as claimed in claim 9, wherein the tool further comprises a mandrel over which the rollers move during expansion of the tubular. 20
11. A tool as claimed in claim 10, wherein the rollers move axially over the surface of the mandrel from one end to the other as the mandrel is moved through the tubular, the rollers being returned to the one end through the interior of the mandrel. 25
12. A tool as claimed in claim 10 or 11, wherein the mandrel has a cone-like shape. 30
13. A tool as claimed in any preceding claim, wherein electrical power and control signals for operation of the tool provided over a wireline cable. 35
14. A tool as claimed in any preceding claim, wherein the locating device comprises a cone-like member that is forced into the tubular member to counteract the force required to move the expanding elements axially while deforming the tubular member. 40
15. A tool as claimed in claim 14, wherein the cone-like member deforms the tubular member radially outwardly. 45
16. A tool as claimed in claim 15, wherein the cone angle of the cone-like member is different to the corresponding angle on the expanding elements.
17. A tool as claimed in any of claims 14-16, comprising more than one cone-like member. 50
18. A tool as claimed in any of claims 14-17, wherein the expanding device and the cone-like member can each be operated as a locating device or as an expanding member so as to allow expansion to proceed in either direction. 55
19. A method of expanding a tubular member in a well, comprising:
- positioning an expansion tool in the tubular member in the well, the expansion tool comprising a radial array of expanding elements ; and
 - moving the elements in an axial direction to act on the tubular and deform it in a radial direction, each at least one element moving in an axial direction independently of others in the array.
20. A method as claimed in claim 19, further comprising positioning the tool in the tubular with the elements of the array positioned in a first position in which axial movement causes no radial deformation of the tubular, the elements of the array being moved to a second position such that axial movement causes deformation once the tool is in position.
21. A method as claimed in claim 20, wherein the movement between the first and second positions is achieved by rotation of each element about a longitudinal axis.
22. A method as claimed in any of claims 19, 20 or 21, when performed using a tool as claimed in any of claims 1-18.
23. A method as claimed in any of claims 19-22, comprising moving the elements so as to deform the tubular member in a non-axisymmetrical manner.
24. A method as claimed in any of claims 19-23, comprising deforming the tubular member against the wall of the well or a structure located therein.
25. A method as claimed in claim 24, wherein deformation is performed so as to seal the annulus after expansion.
26. A method as claimed in claim 25, when performed in open hole.
27. A method as claimed in any of claims 19-23, further comprising introducing a swelling material between the tubular member and the well wall so as to fill voids remaining after deformation of the tubular member.
28. A system comprising a tool as claimed in any of claims 1-18 suspended on a wireline cable and connected to control equipment located at the surface so as to be operable in a well to expand tubular members located therein.

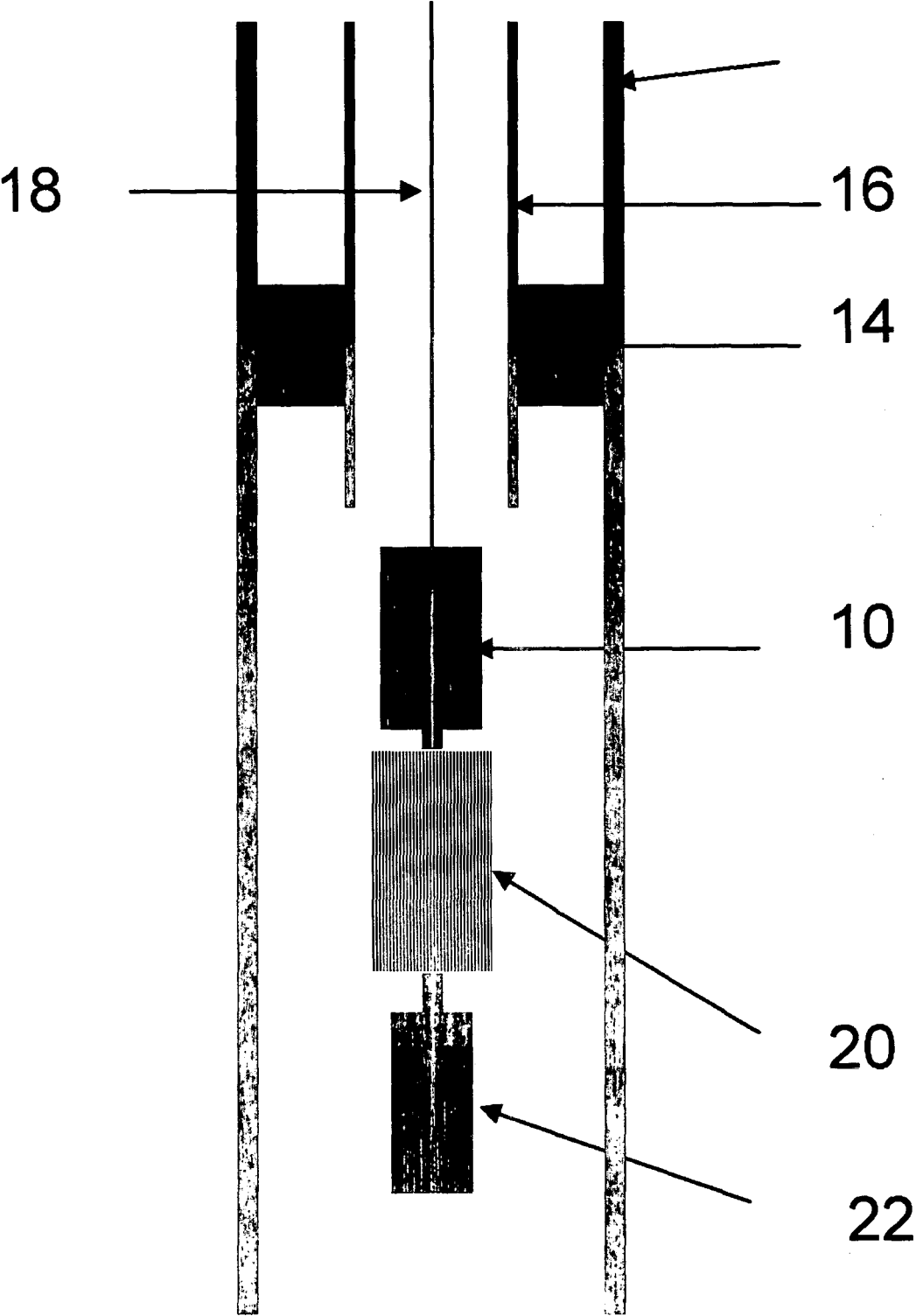


Fig. 1

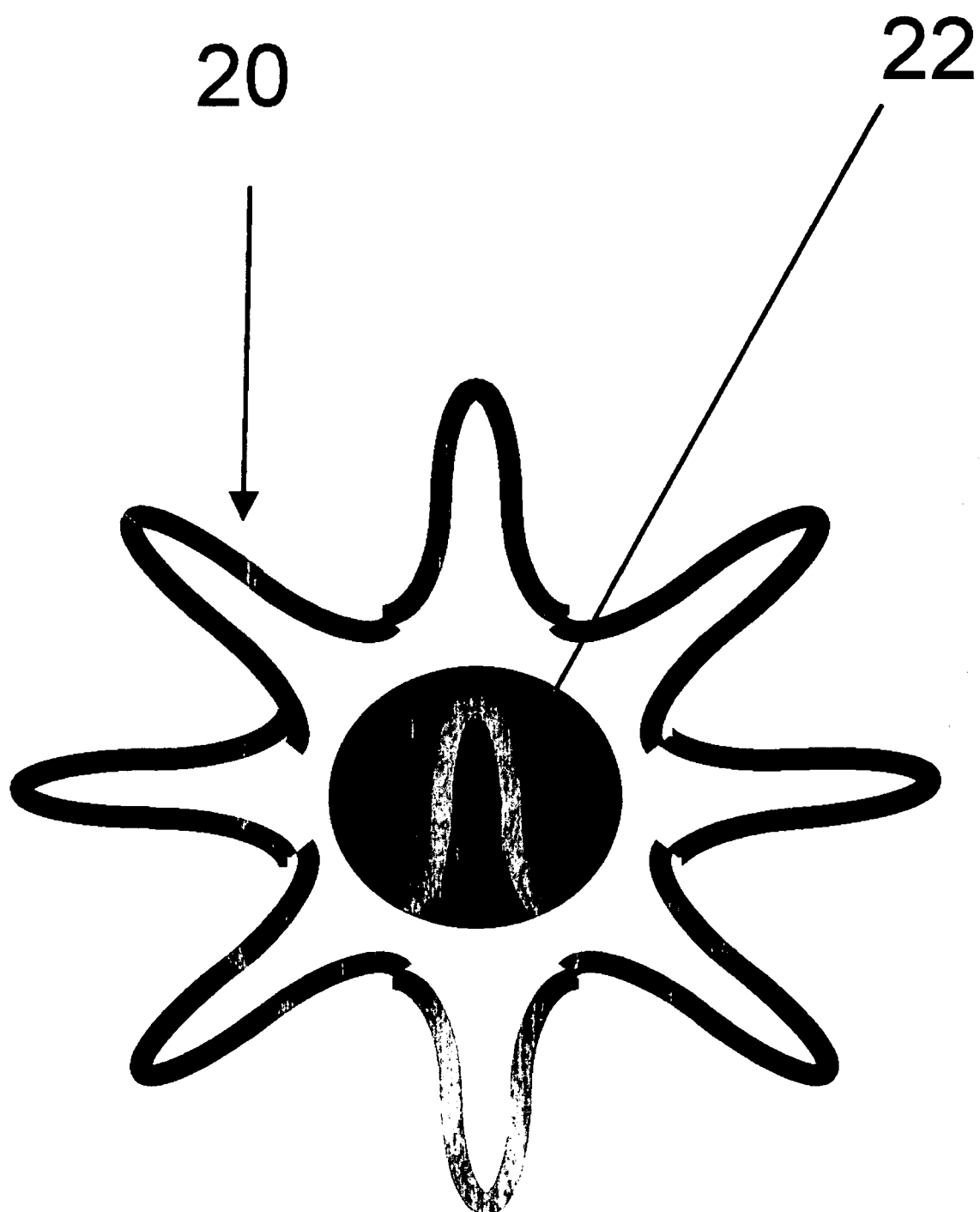


Fig. 2

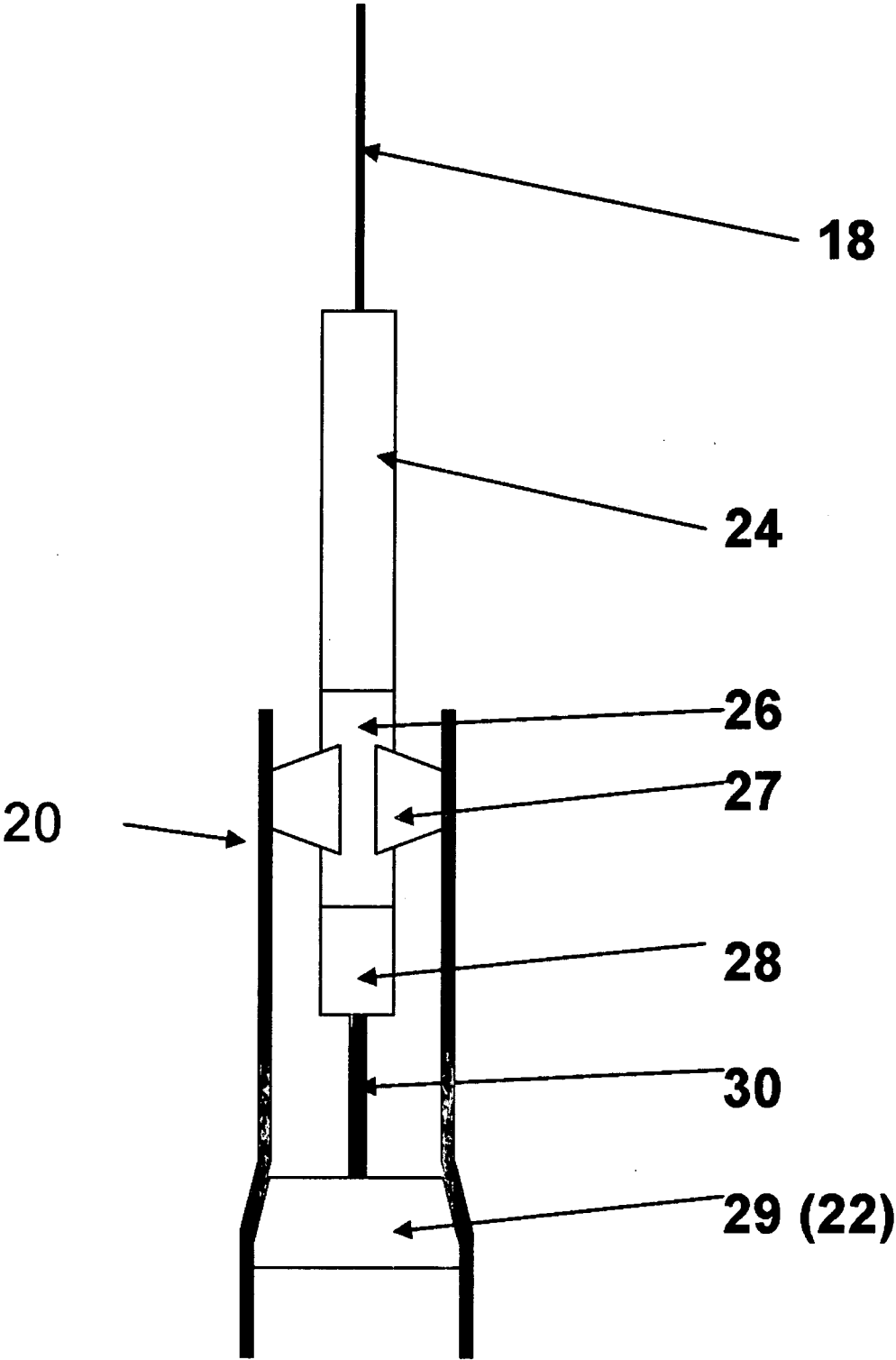


Fig. 3

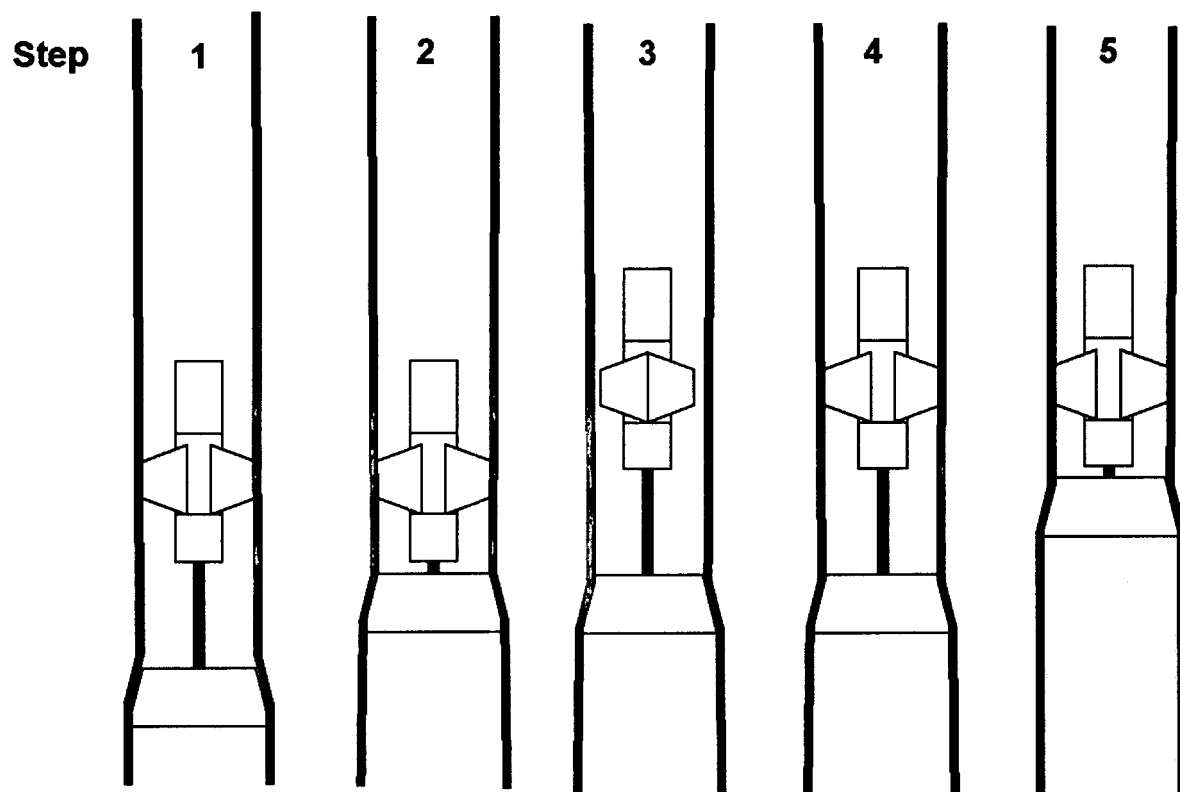


Fig. 4

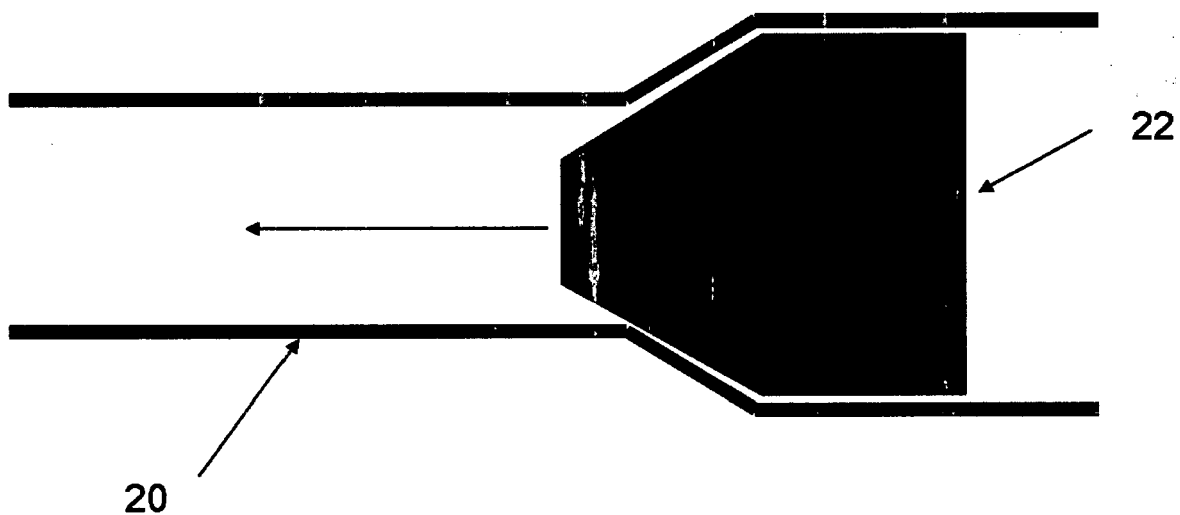


Fig. 5

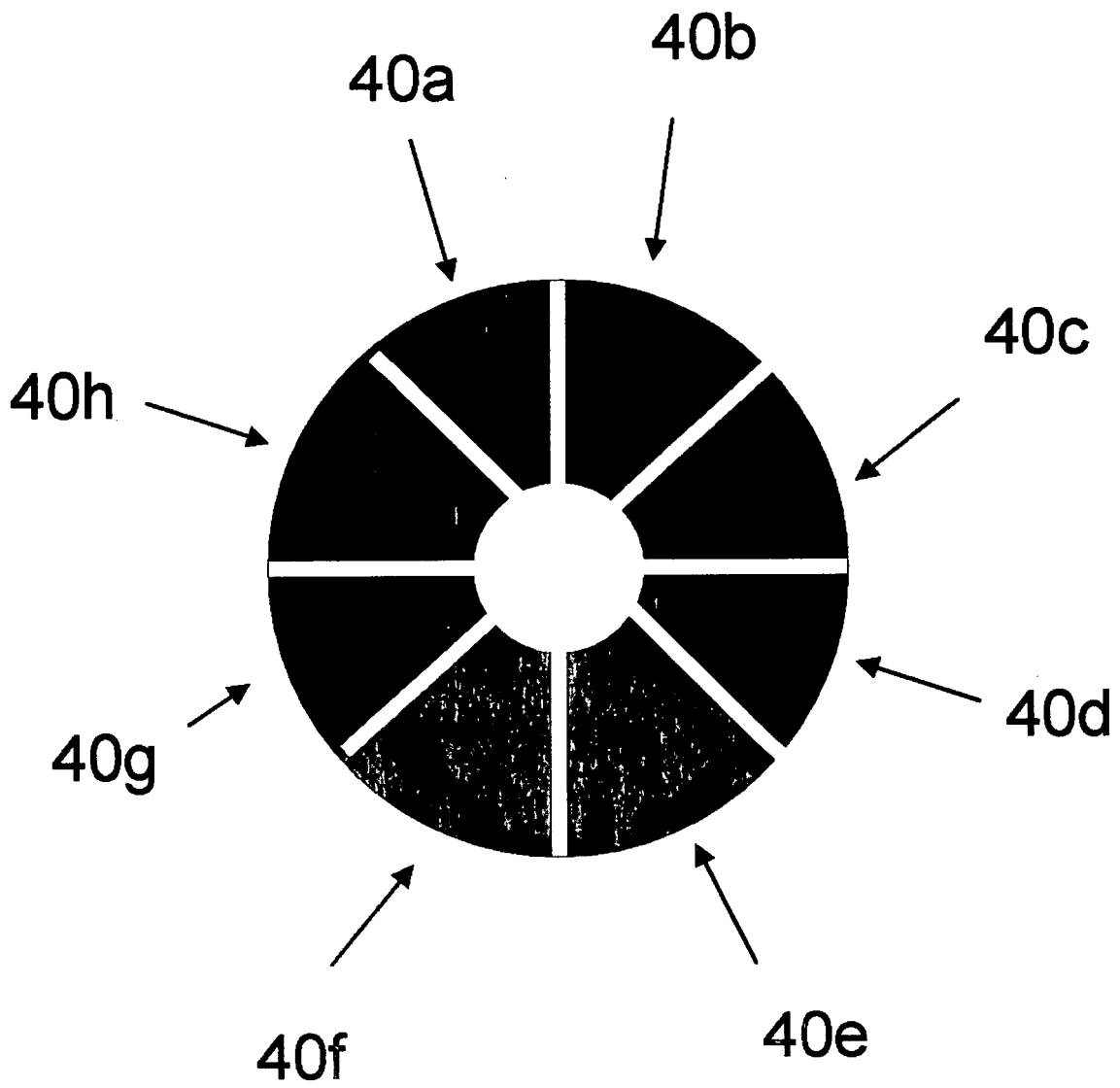


Fig. 6

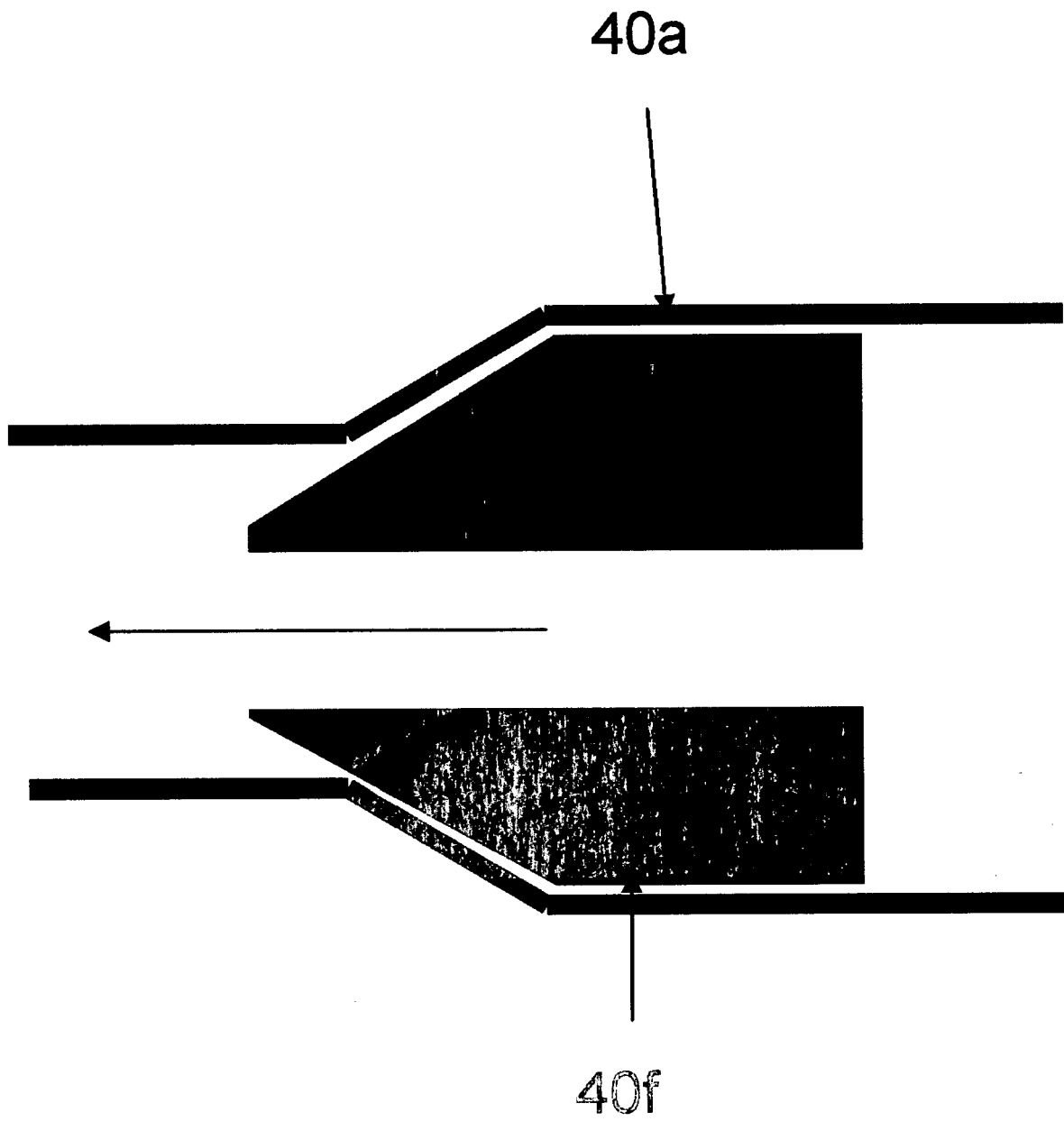


Fig. 7

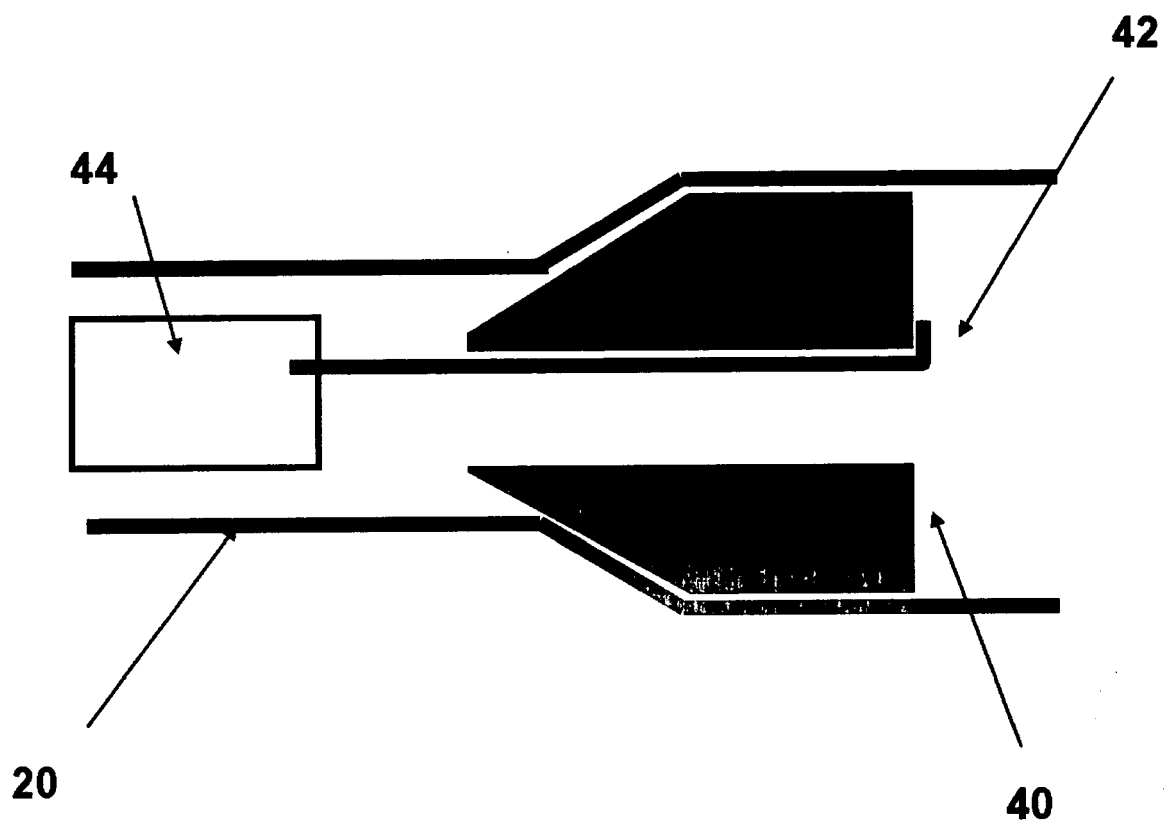


Fig. 8

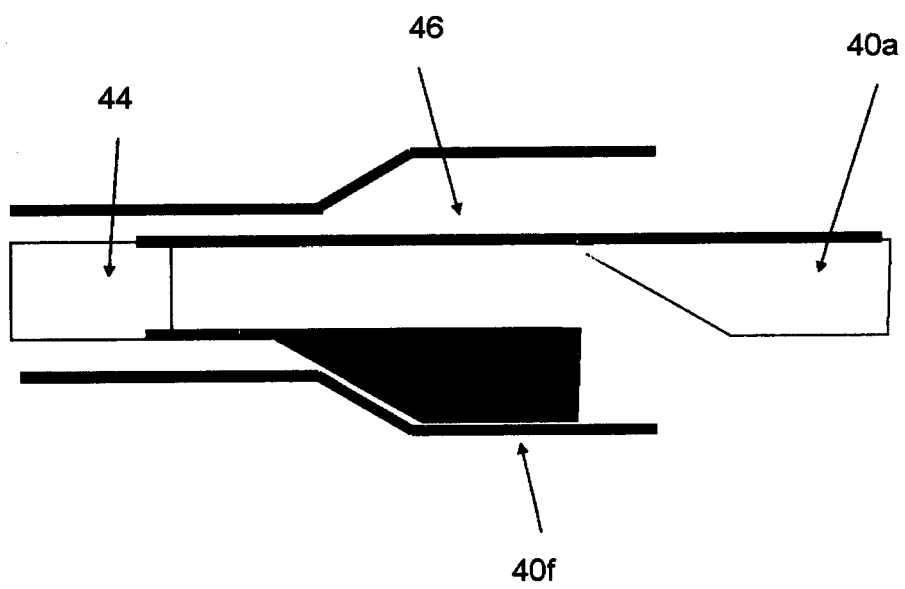
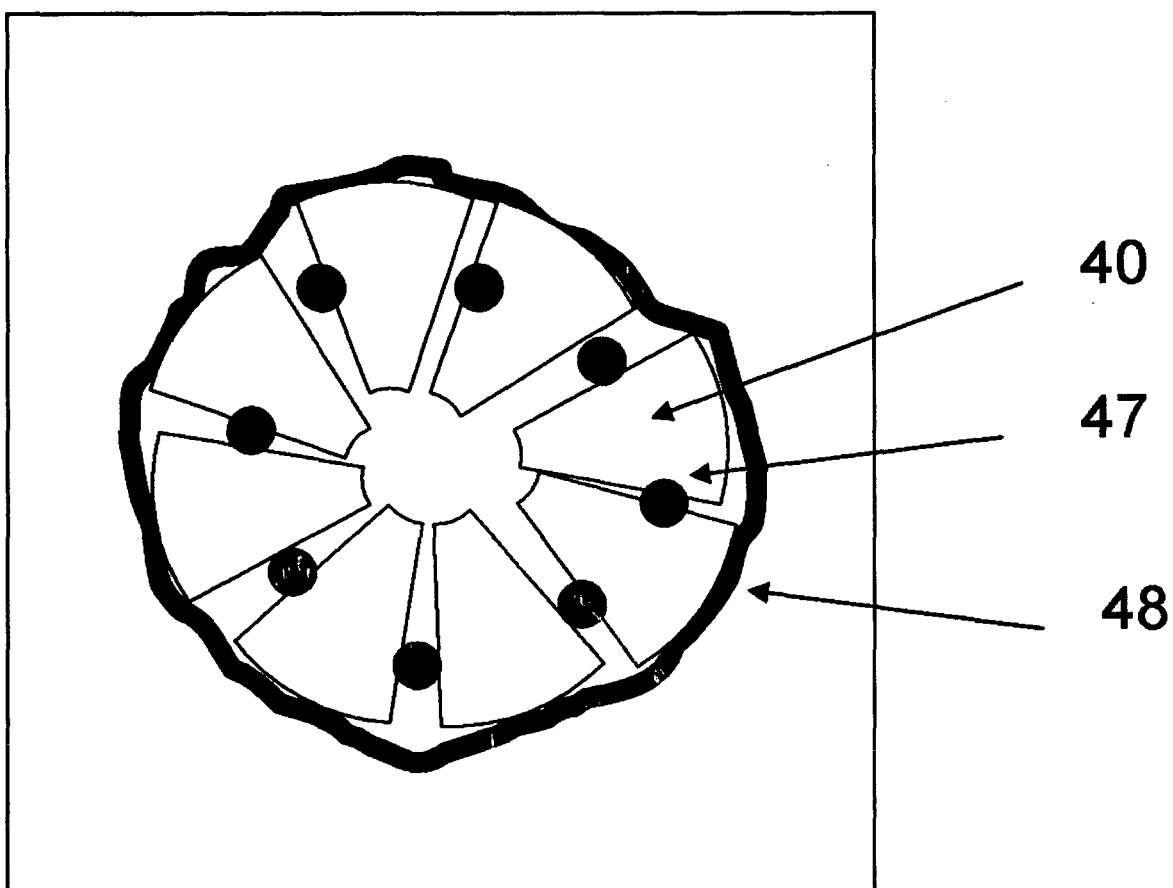
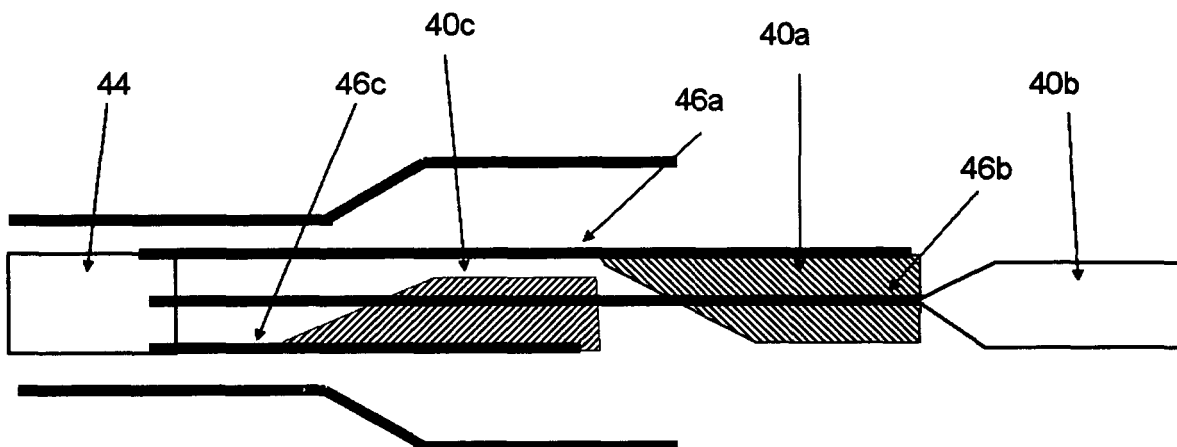


Fig. 9



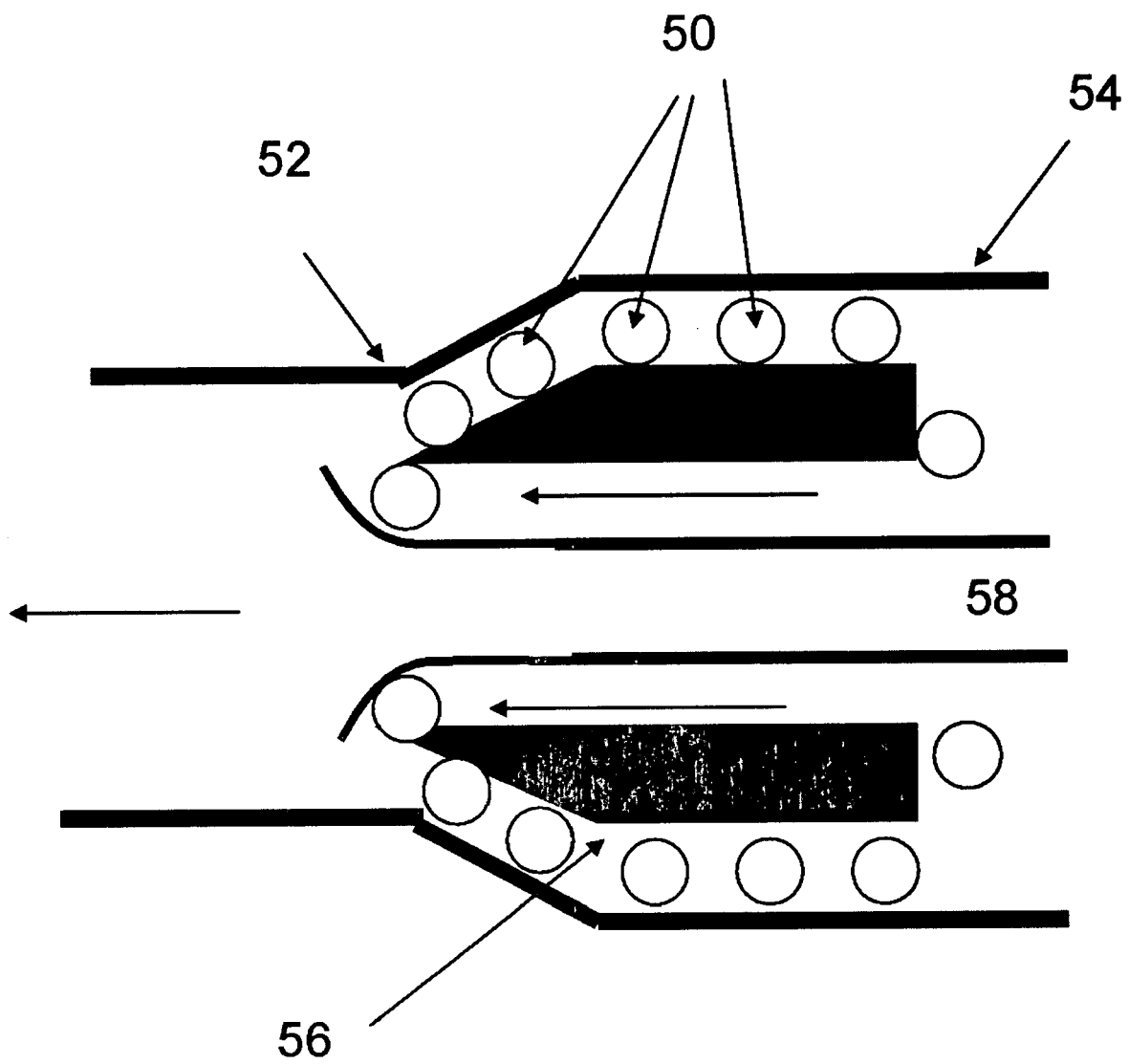


Fig. 12

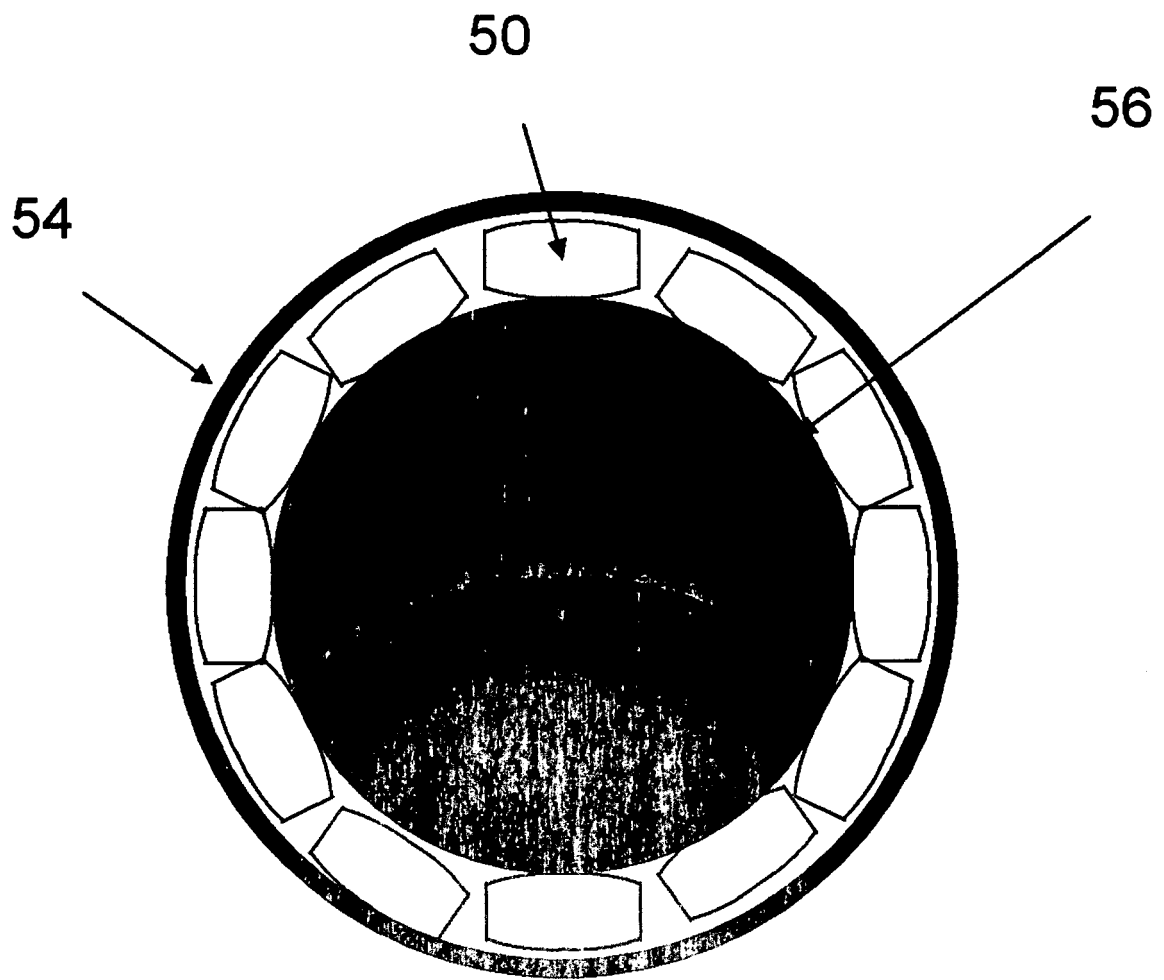


Fig. 13

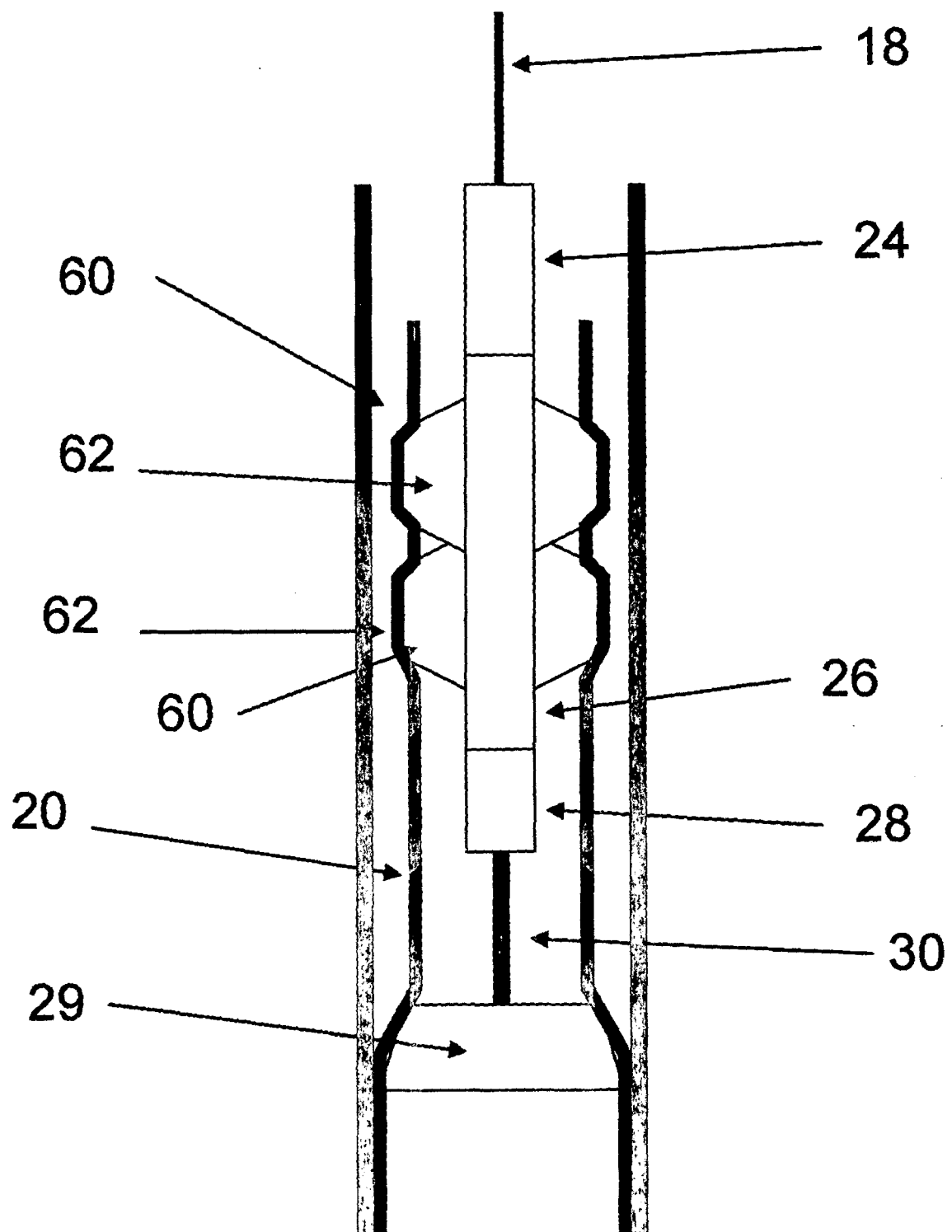


Fig. 14



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EUROPEAN SEARCH REPORT

Application Number
EP 05 29 0939

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2003/111234 A1 (MCCLURKIN JOEL ET AL) 19 June 2003 (2003-06-19)	1-4,13, 19,20, 22-26,28 27	E21B43/10
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A	WO 2004/079157 A (BAKER HUGHES INCORPORATED) 16 September 2004 (2004-09-16) * sentence 2, paragraph 5; figure 4 *	1-8,13, 19-28	
A	US 6 460 615 B1 (HEIJNEN WILHELMUS HUBERTUS PAULUS MARIA) 8 October 2002 (2002-10-08) * column 2, lines 26-28,46,47; figure 1 *	1-8,13, 19-28	TECHNICAL FIELDS SEARCHED (IPC)
X	US 2003/019638 A1 (SIMPSON NEIL ANDREW ABERCROMBIE) 30 January 2003 (2003-01-30) * paragraphs '0086!, '0098!; figures 26,29a,29b *	1,9,10, 12,19	E21B
A	US 2003/127774 A1 (STEPHENSON DAVID ET AL) 10 July 2003 (2003-07-10) * sentence 1, paragraph 17; figures 2,3 * * paragraph '0018! *	9-12	
A	US 2003/183395 A1 (JONES GARY W) 2 October 2003 (2003-10-02) * paragraph '0012!; figures 5,6 * * last sentence , paragraph 39 *	14-18	
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 16 November 2005	Examiner Georgescu, M
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)



European Patent
Office

Application Number
EP 05 29 0939

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- ☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- ☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:
- ☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:



The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-8, 13, 19-28

Apparatus and method for expanding a tubular member in a well by positioning and expanding a device comprising a radial array of expanding elements, wherein each element is movable in an axial direction independently of the other elements in the array, and wherein (claim 5) each element is rotatable about a longitudinal axis.

2. claims: 9-12

Apparatus and method for expanding a tubular member in a well by positioning and expanding a device comprising a radial array of expanding elements, wherein each element is movable in an axial direction independently of the other elements in the array, wherein (claim 9) the elements comprise rollers.

3. claims: 14-18

Apparatus and method for expanding a tubular member in a well by positioning and expanding a device comprising a radial array of expanding elements, wherein each element is movable in an axial direction independently of the other elements in the array, wherein (claim 14) the locating device comprises a cone-like member that is forced into the tubular member to counteract the force required to move the expanding elements axially while deforming the tubular member.

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 05 29 0939

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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16-11-2005

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