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(54) **SPARK PLUG**

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Filed: **May 11, 2004**

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(51) **Int. Cl.**
H01T 13/20 (2006.01)

(52) **U.S. Cl.** **313/141**; 313/143

(58) **Field of Classification Search** 313/118, 313/137, 141, 143–145
See application file for complete search history.

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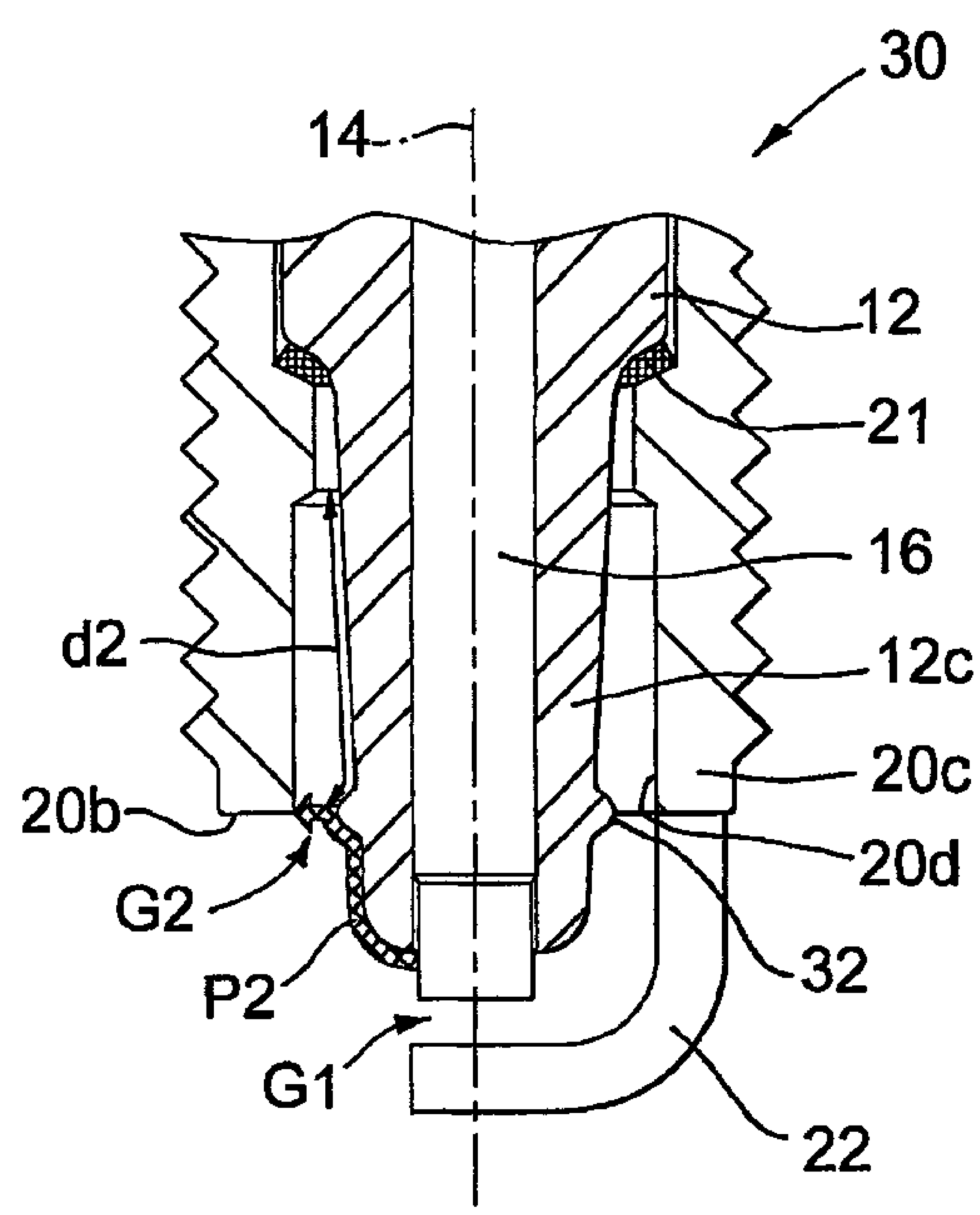
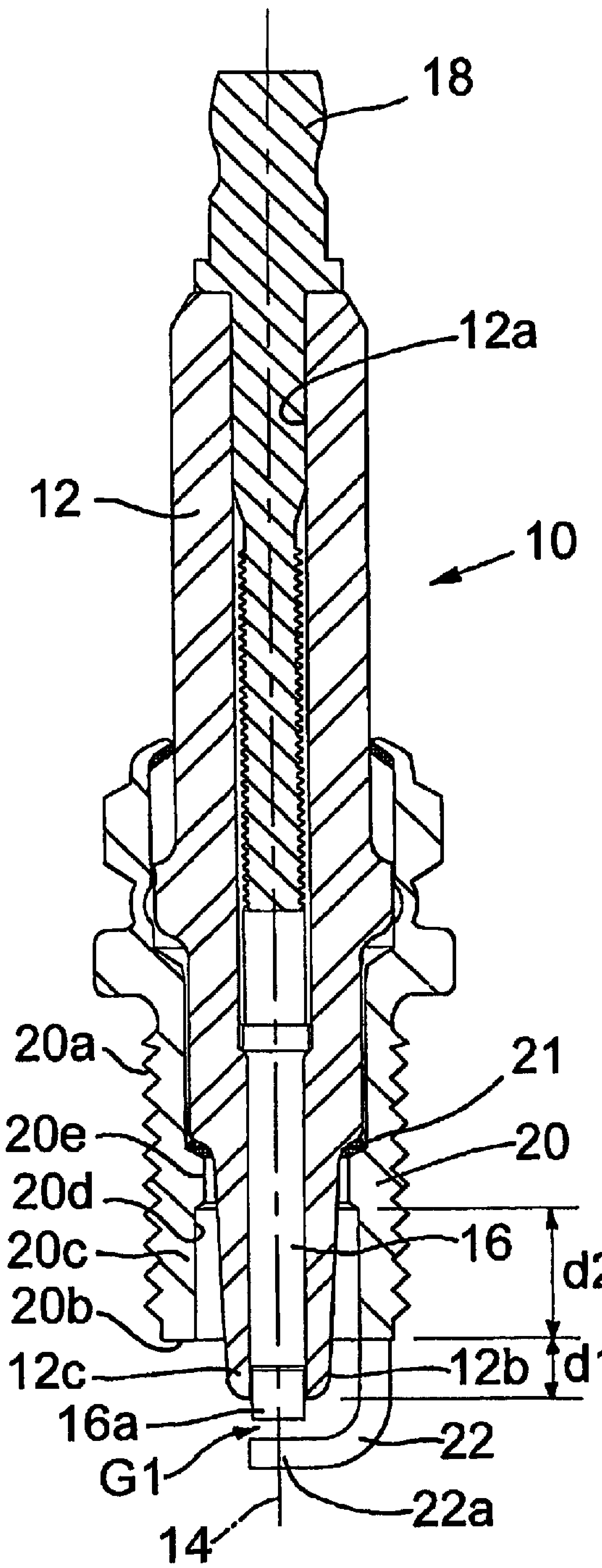
(57) **ABSTRACT**

A spark plug (**30**; **40**) comprises an electrically-insulating sleeve (**12**), a first electrode (**16**), an electrically-conducting shell (**20**) surrounding said sleeve, and a second electrode (**22**) mounted on said shell. The electrodes (**16** and **22**) define a spark gap (G**1**) of the plug. The shell (**20**) has an end portion (**20**c) terminating at an end surface (**20**b) of the shell. The sleeve (**12**) extends past said end portion (**20**c) with a clearance therebetween and extends beyond said end surface (**20**b). The sleeve (**12**) has at least one projection (**32**) which projects from the sleeve (**12**) and reduces said clearance in the region of the end surface (**20**b), thereby forming a secondary spark gap (G**2**).

8 Claims, 6 Drawing Sheets

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12a
12
10
20a
21
20e
20
20d
20c
16
d2
20b
12c
12b
d1
16a
22
G1
22a
14

FIG.1A

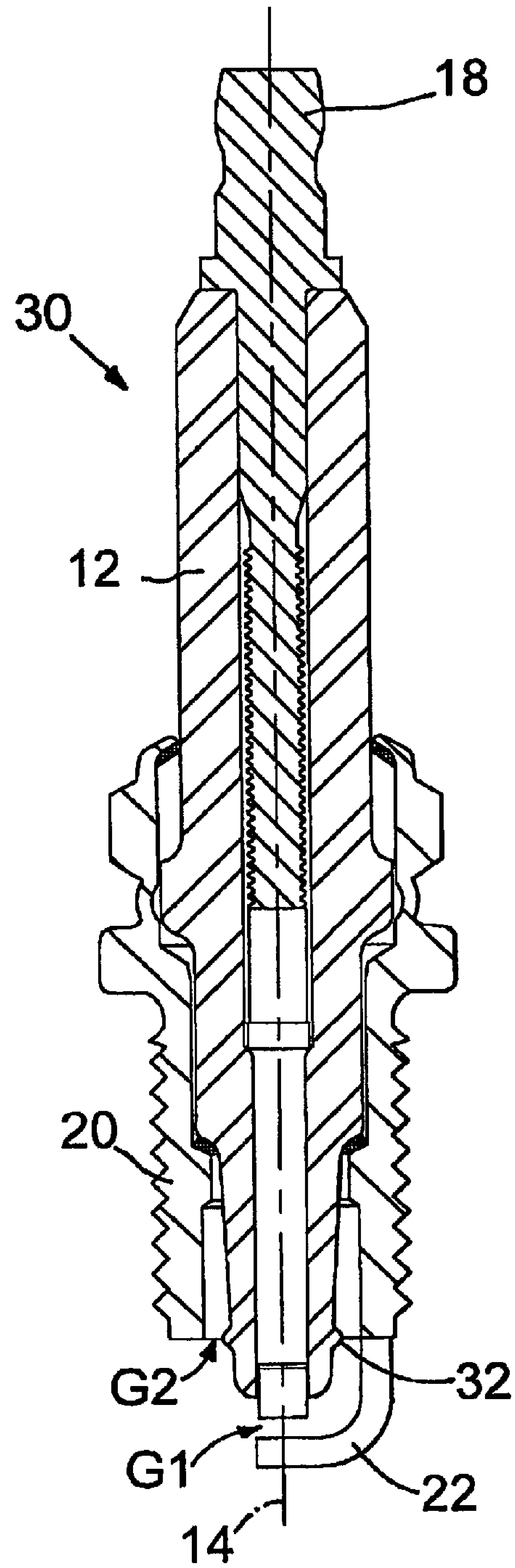
18
30
12
20
G2
32
G1
22
14

FIG.1B

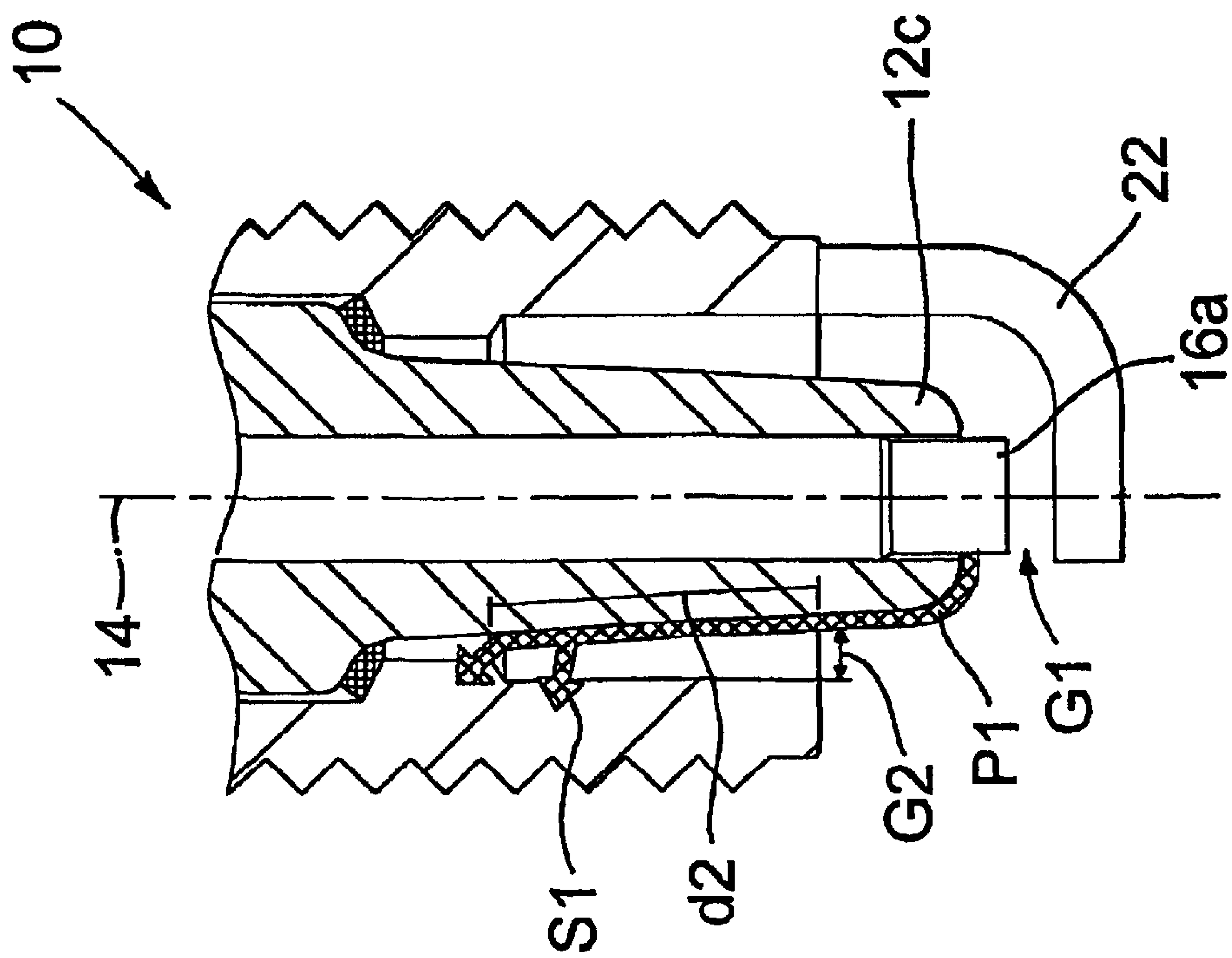
10
12c
22
16a
14
S1
d2
G2
P1
G1

FIG.2A

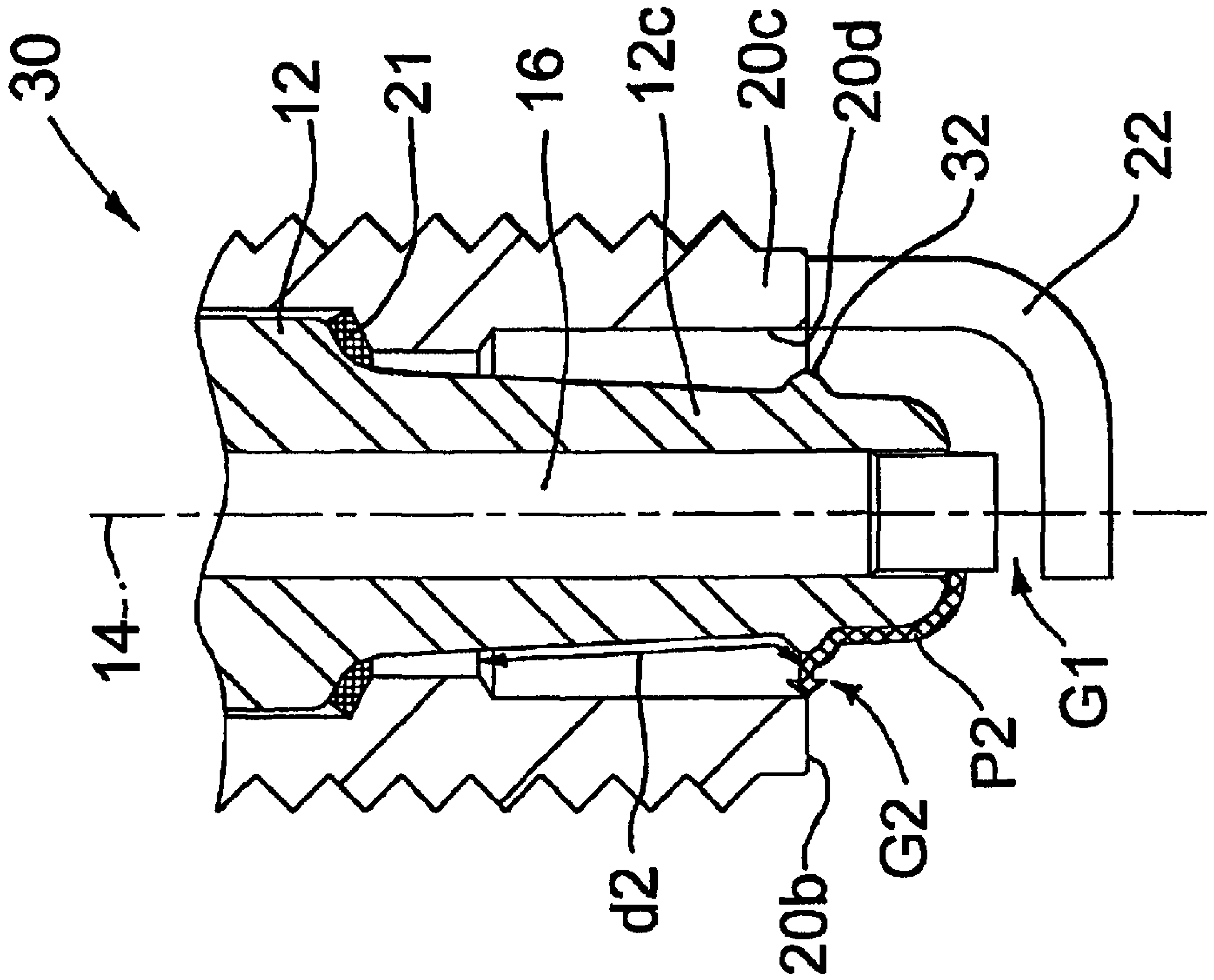
30
12
21
16
12c
20c
20d
32
22
14
d2
20b
G2
P2
G1

FIG.2B

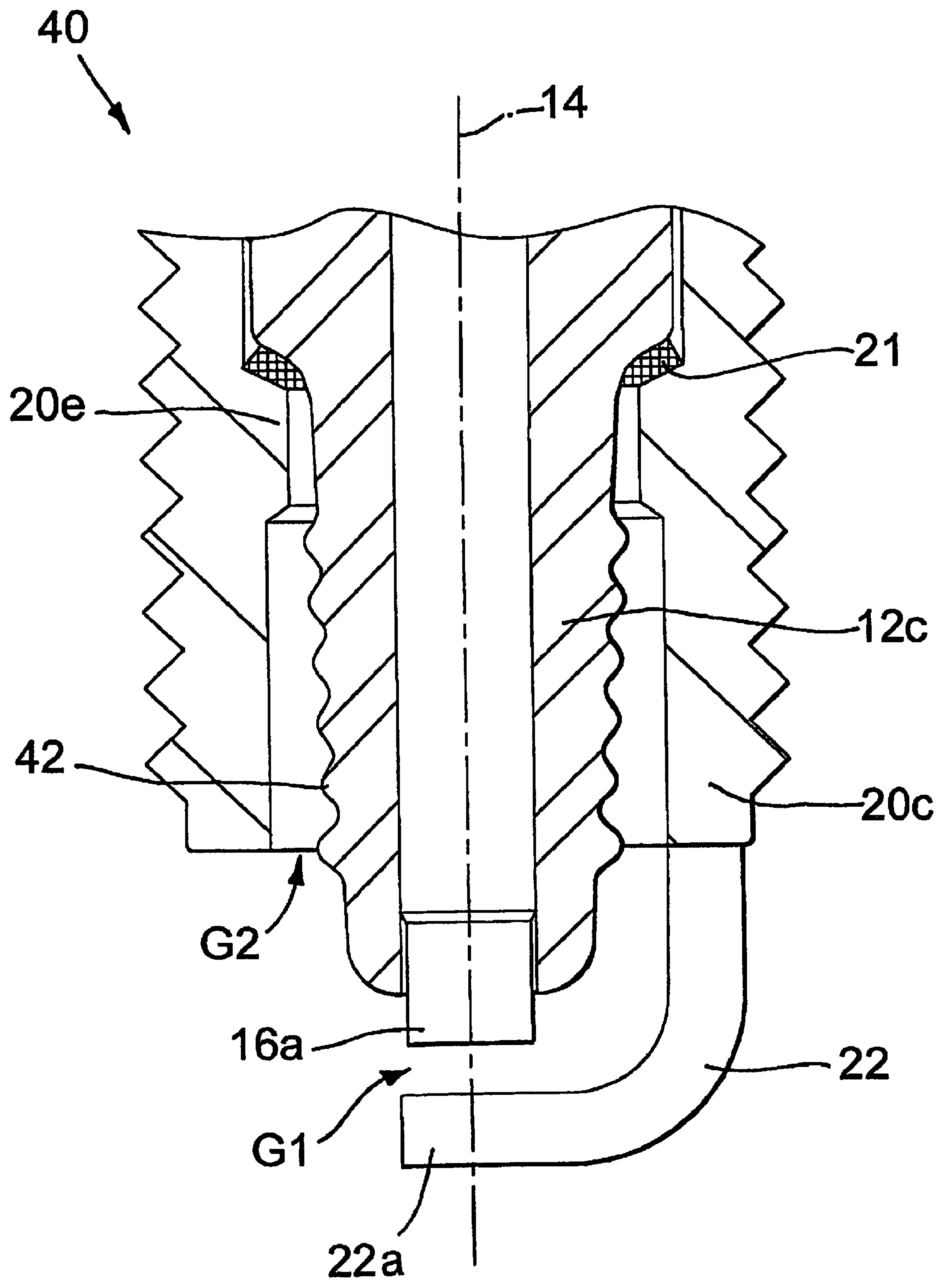

FIG.3

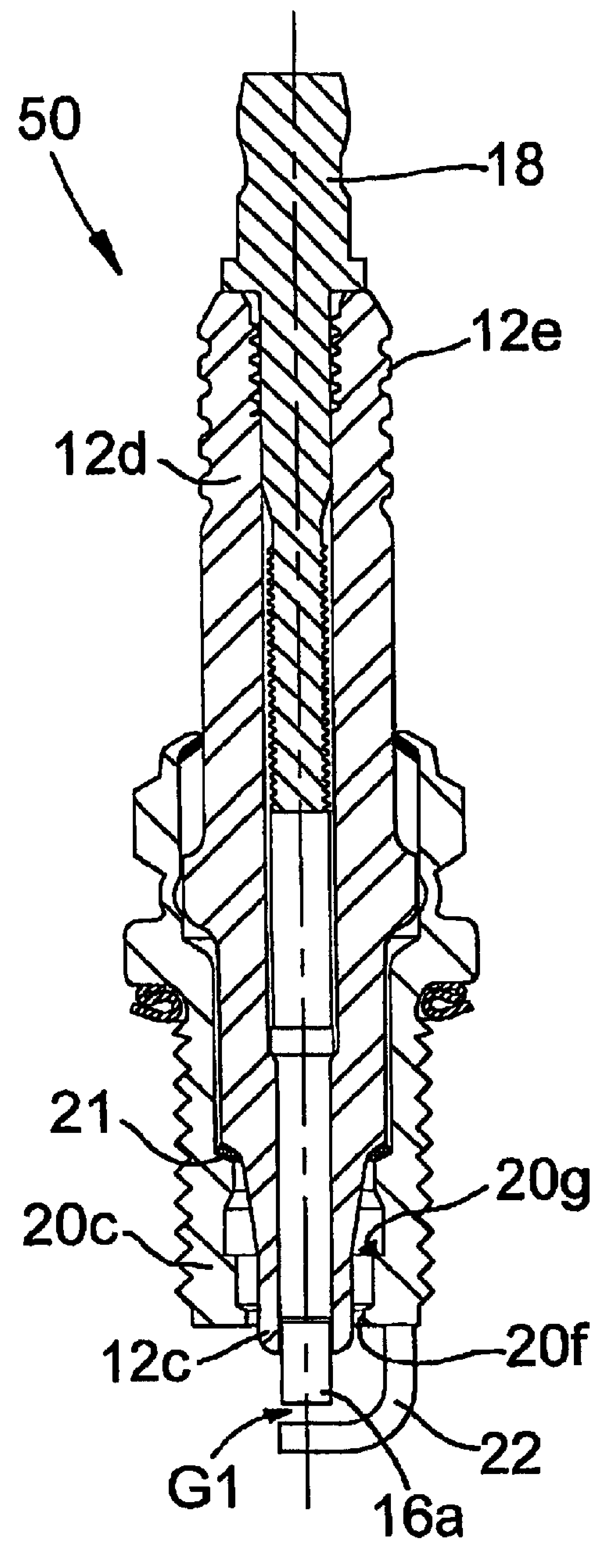

FIG.4A

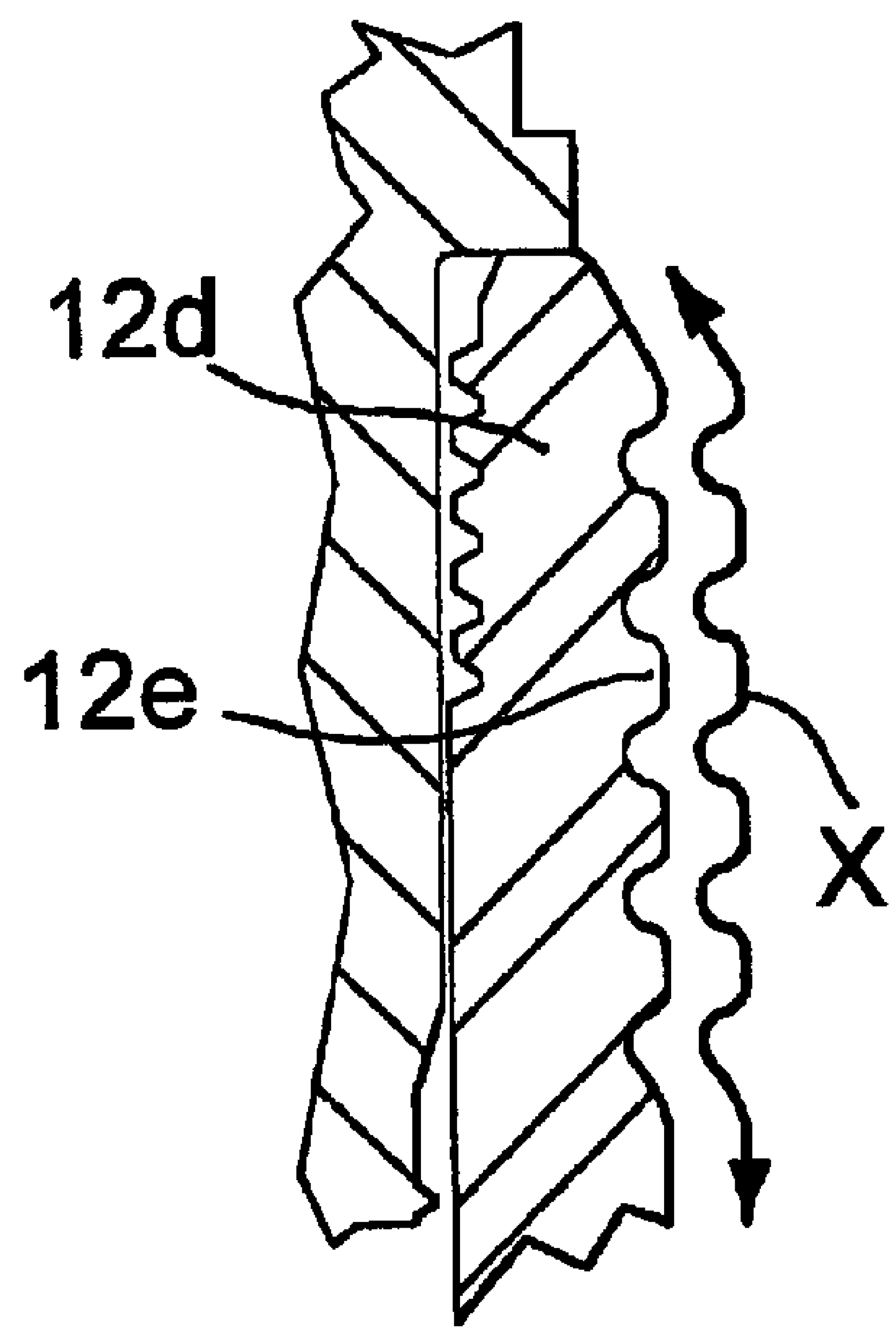

FIG.4B

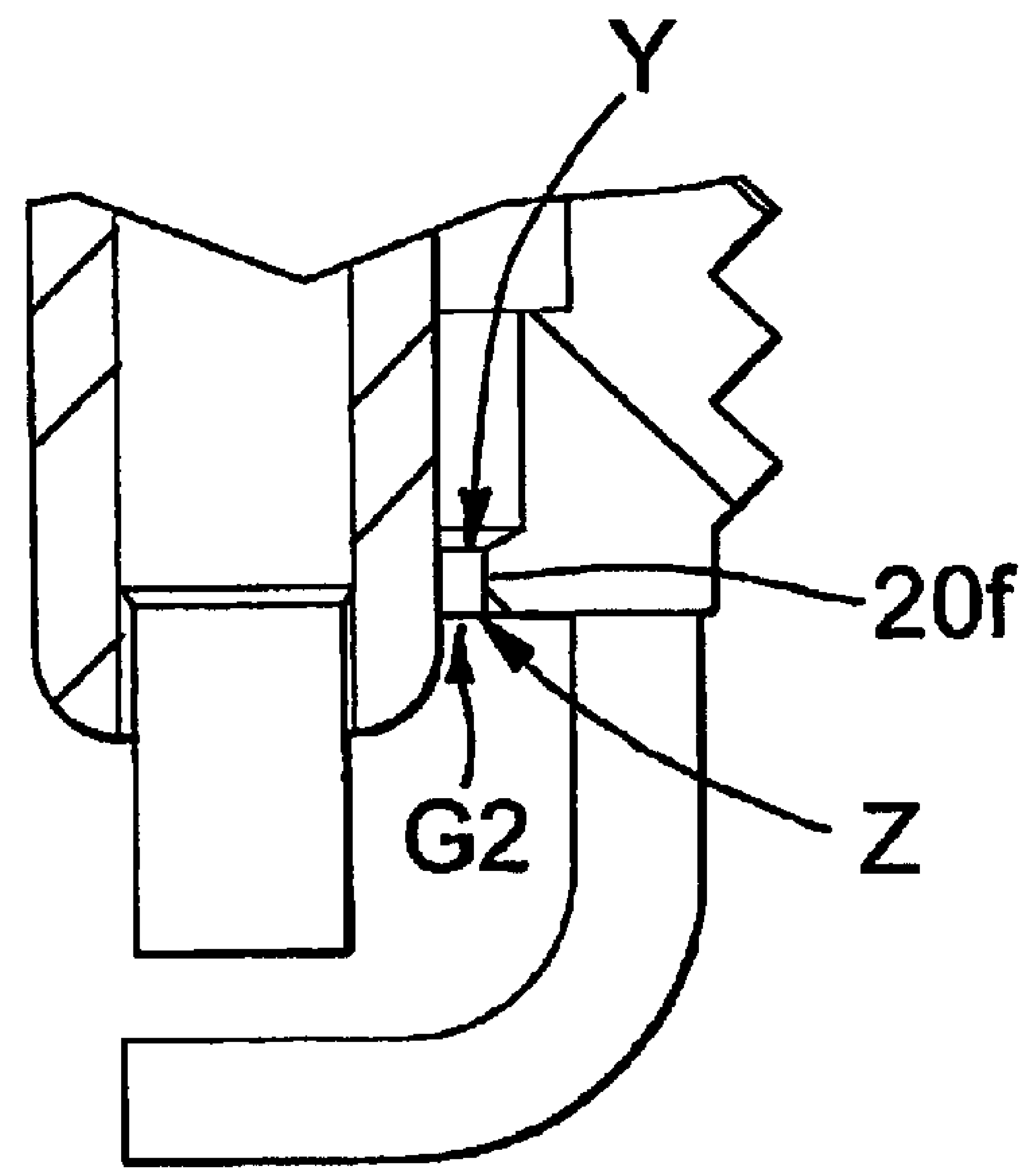

FIG.4C

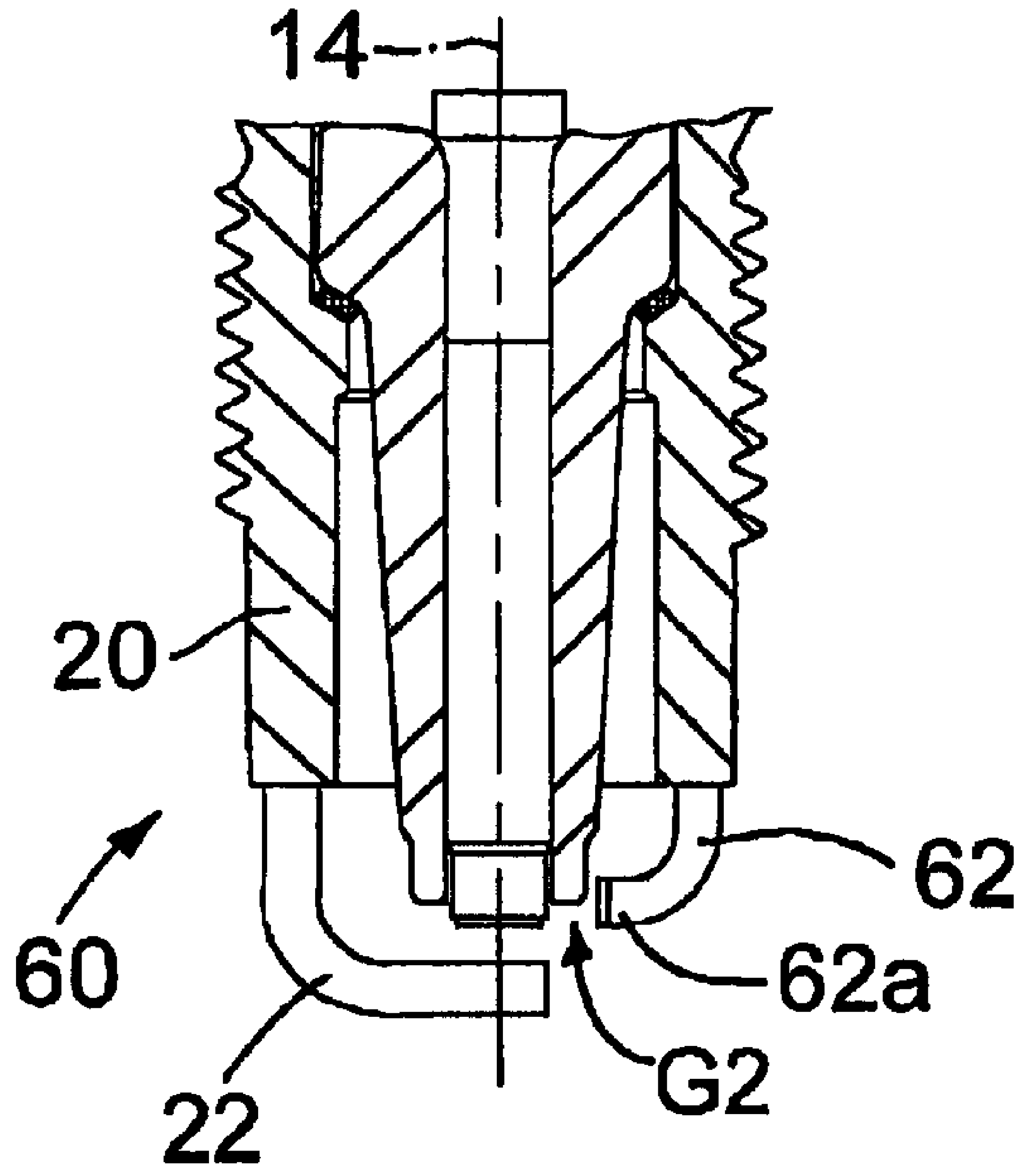

FIG.5A

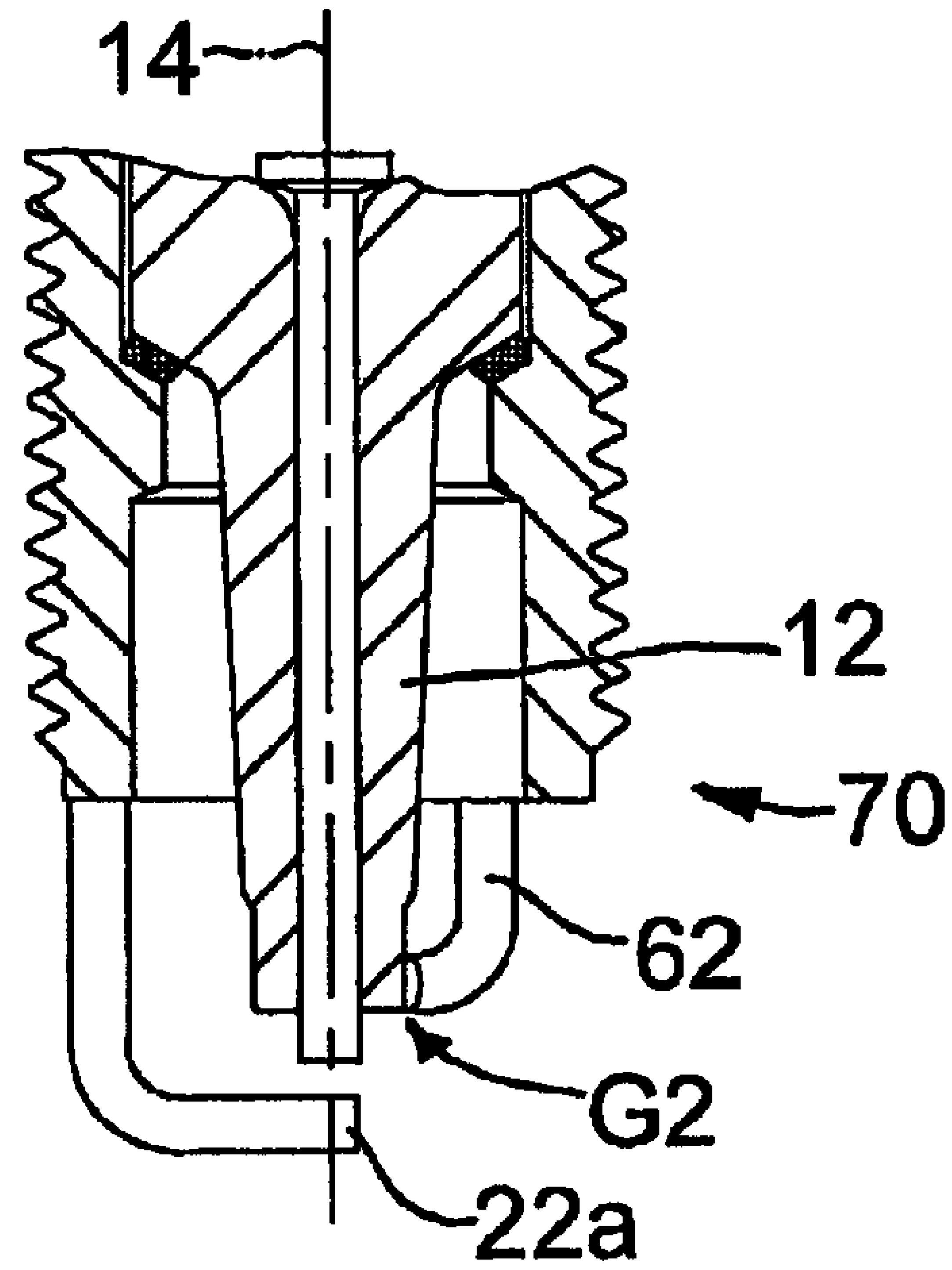

FIG.5C

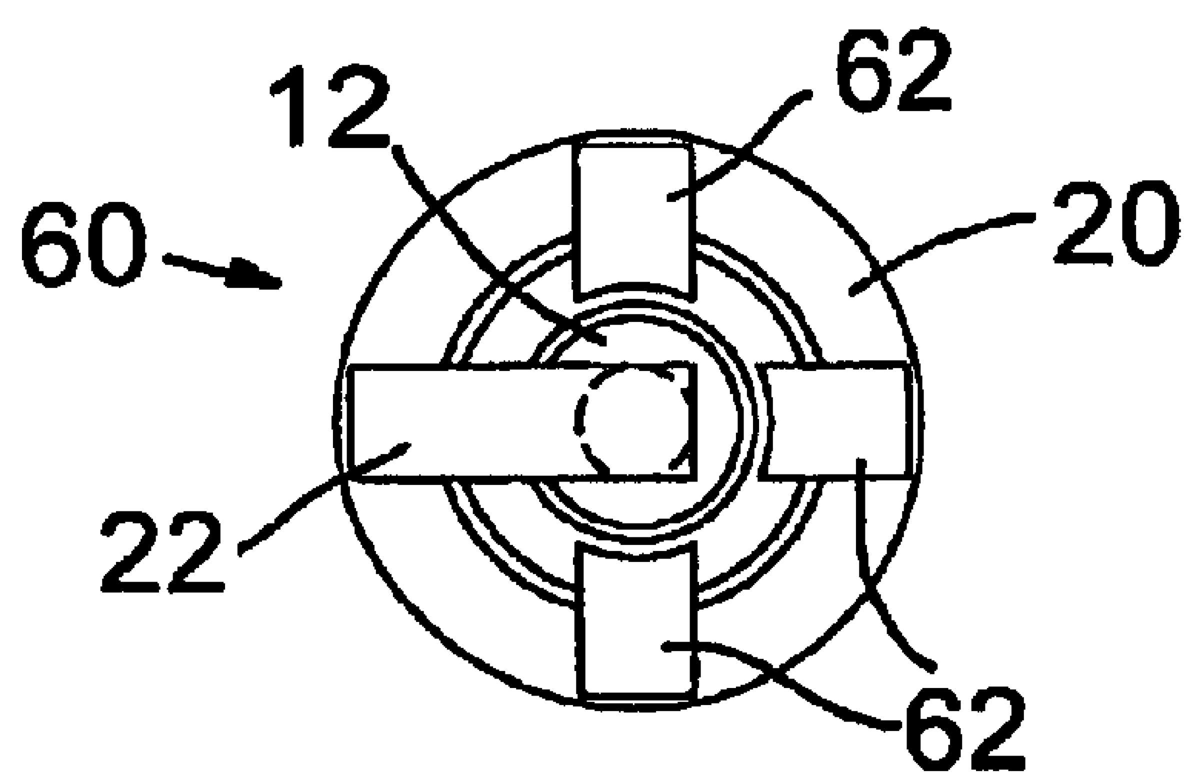

FIG.5B

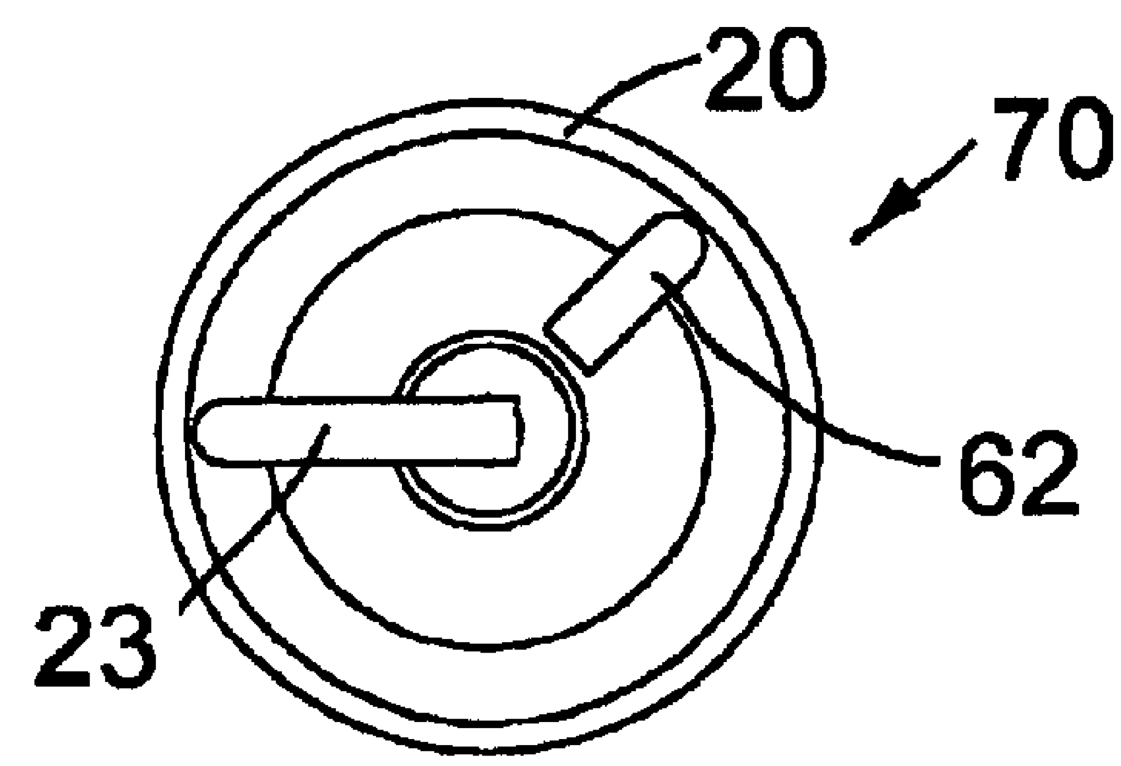

FIG.5D

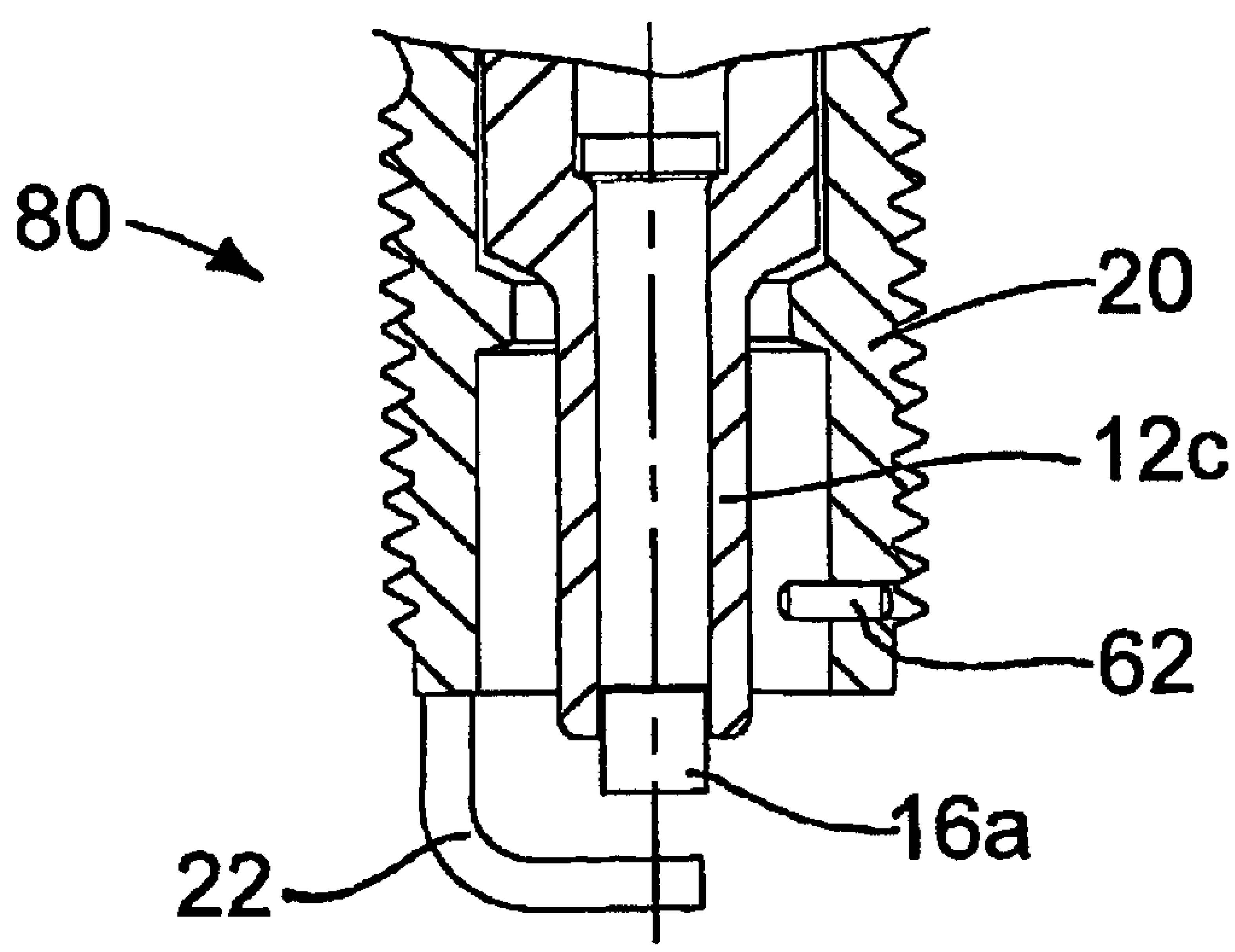

FIG.5E

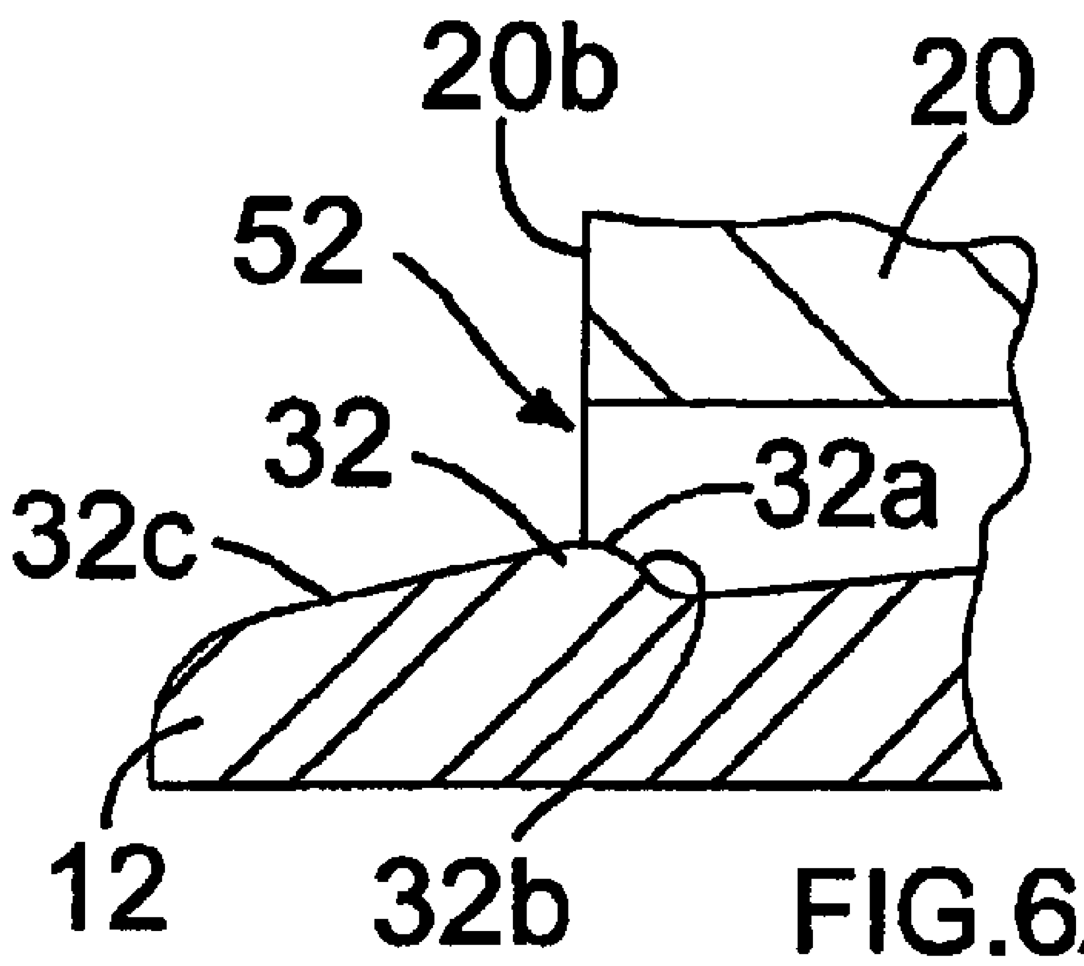

FIG.6A

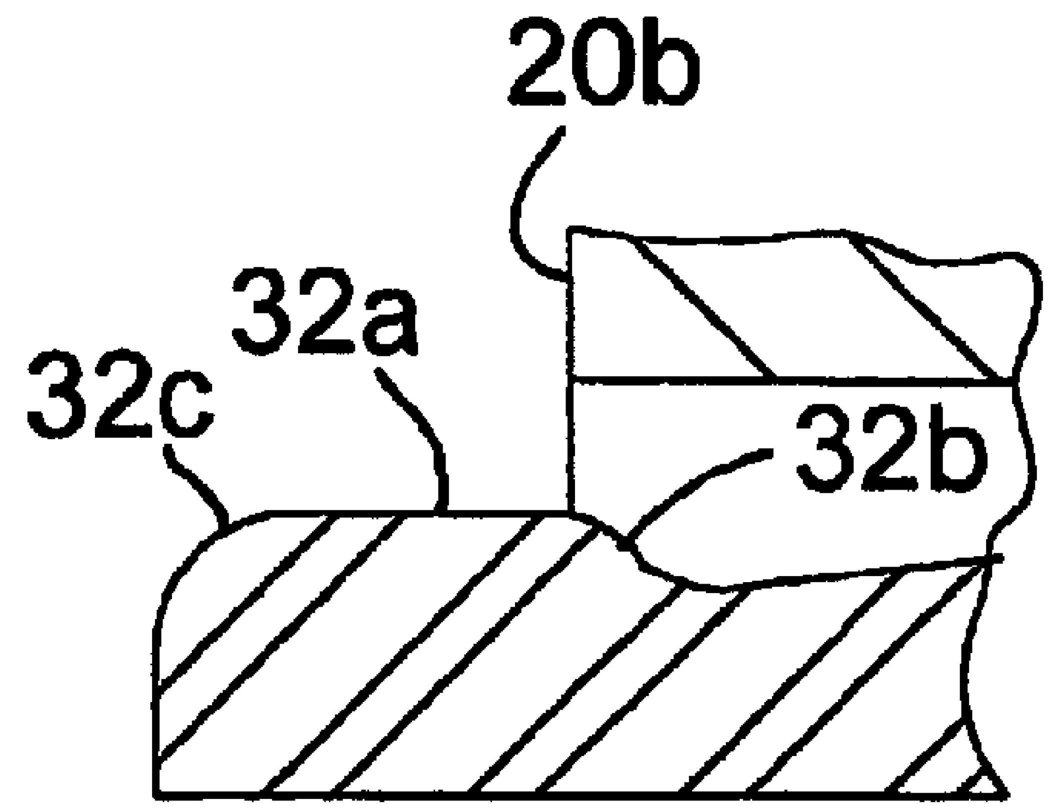

FIG.6B

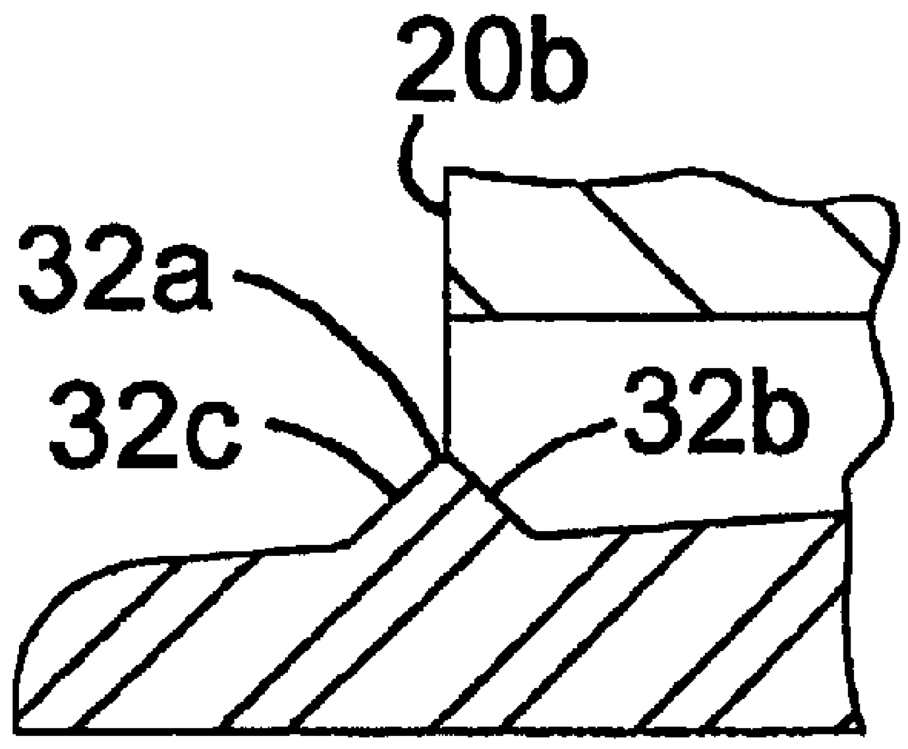

FIG.6C

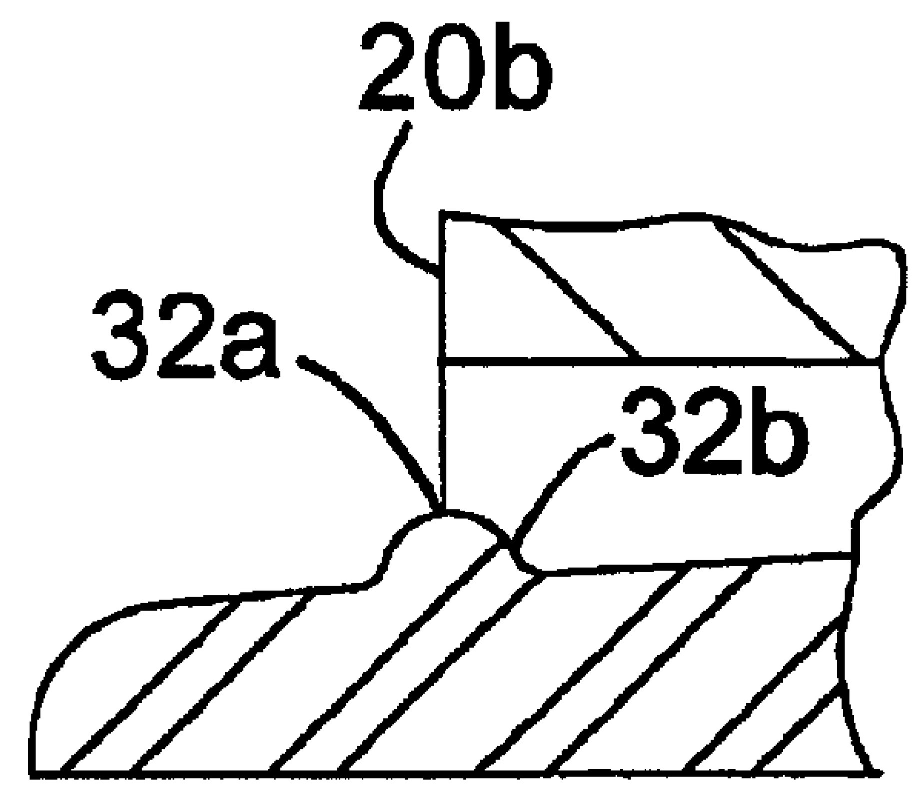

FIG.6D

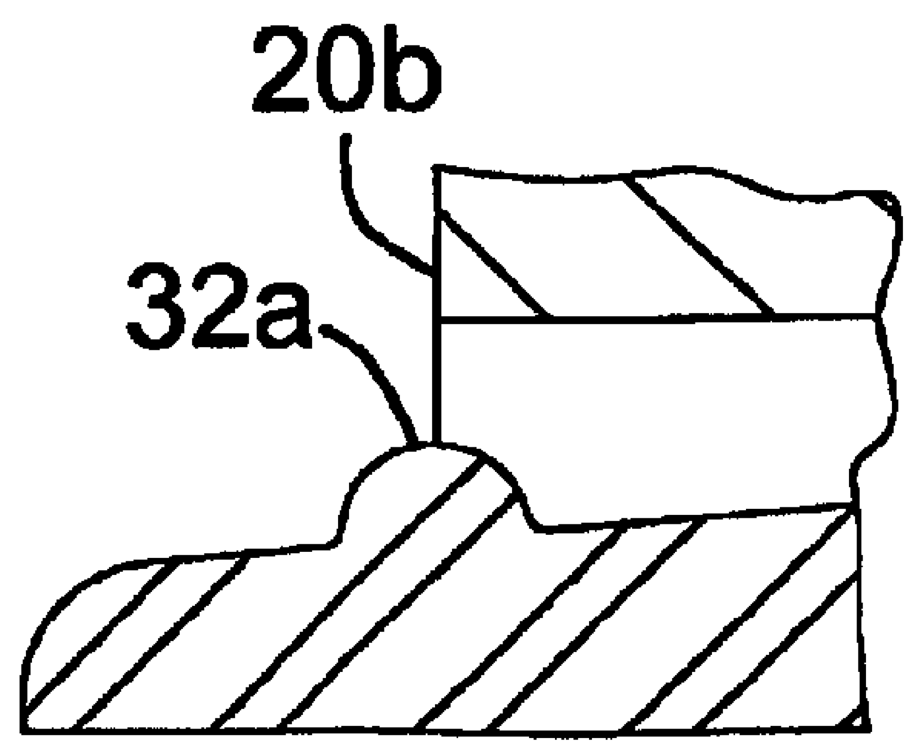

FIG.6E

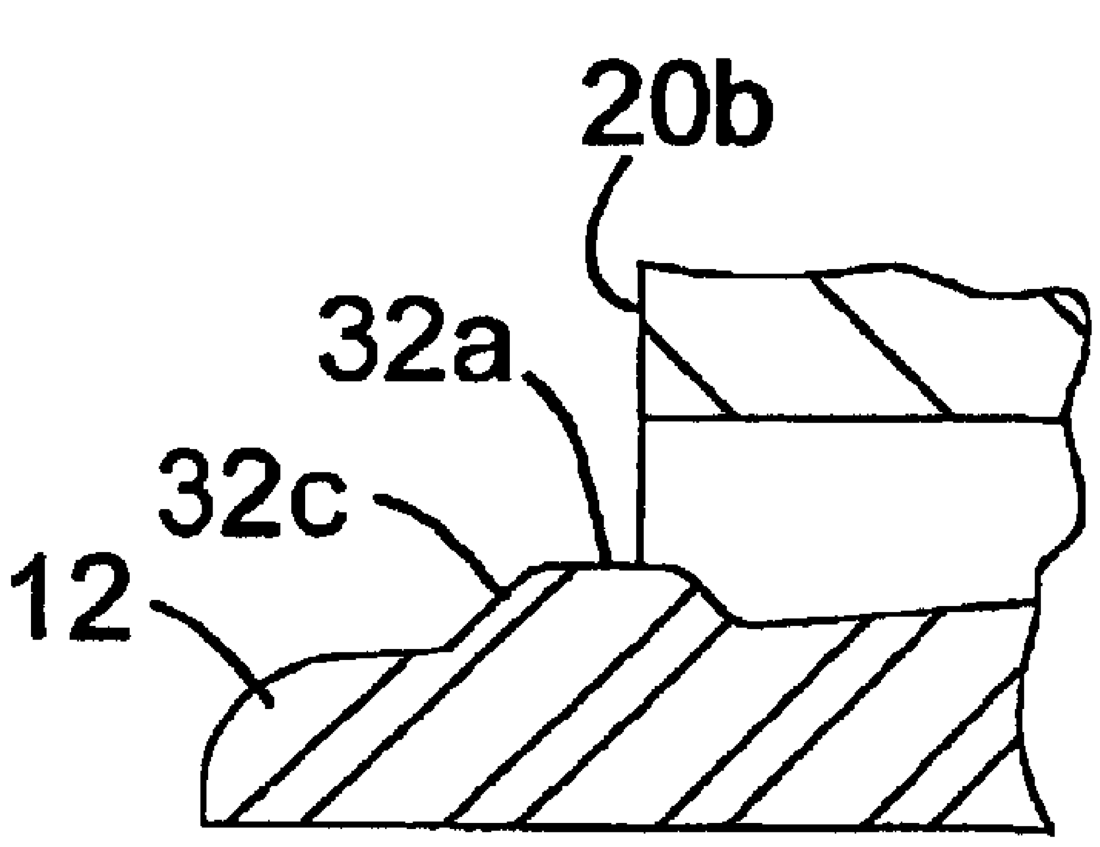

FIG.6F

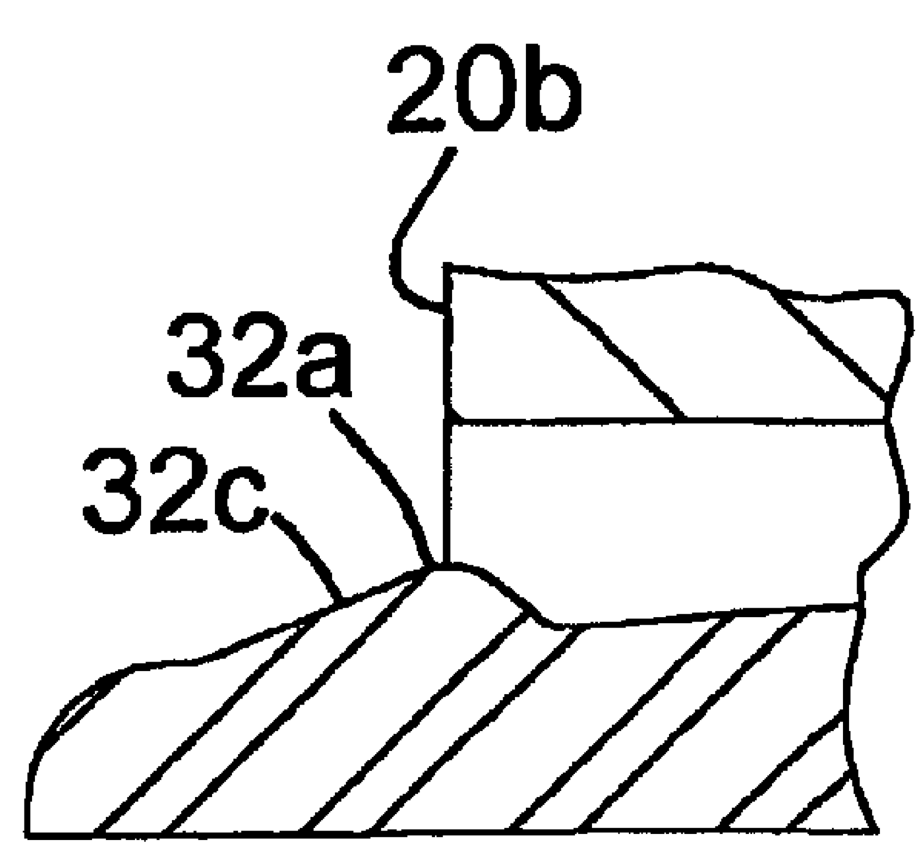

FIG.6G

SPARK PLUG

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This invention is concerned with a spark plug for use in providing an ignition spark to ignite the fuel of an internal combustion engine.

A typical conventional spark plug is shown in FIGS. **1**A and **2**A and is described in detail below. This plug comprises an electrically-insulating sleeve which extends along a central axis of the plug. Such sleeves are made of ceramic material, usually alumina. The plug also comprises a first electrode mounted within the sleeve and having a tip projecting axially beyond an end portion of the sleeve. The electrode extends centrally within the sleeve and is electrically connected to a terminal projecting from the other end of the sleeve. The connection between the terminal and the first electrode may include a resistor also contained within the sleeve which serves to control to peak current. In the operation of the plug, a high tension lead is applied to the terminal so that a high voltage can be applied to the first electrode. The plug also comprises an electrically-conducting shell surrounding said sleeve. The shell is fixed, normally by a screw thread, into the head of an engine so that the tip of the first electrode projects into the combustion chamber of a cylinder of the engine. The plug also comprises a second electrode mounted on the shell, normally by welding, and electrically-connected to the shell. The second electrode has a tip which is positioned within the combustion chamber so that a spark gap is formed between the tips of the two electrodes. The shell has a generally hollow cylindrical end portion which terminates at a generally annular end surface of the shell. The insulating sleeve extends through said end portion of the shell with a clearance therebetween. The end portion of the sleeve passes through said end surface of the shell. Usually, the end portion of the insulating sleeve tapers so that its diameter reduces in a direction towards the tip of the first electrode. Thus, the clearance between the end portions of the shell and the sleeve is greatest where the end portion of the sleeve passes through the end surface of the shell.

In the typical conventional spark plug described above, under normal working conditions, the spark jumps across the spark gap defined by the tips of the first and the second electrodes and goes to ground through the shell and the engine head. However, in operation, the spark plug often becomes fouled by carbon which is deposited on the portion of the insulating sleeve which is exposed to the combustion chamber. This makes the surface of the insulating sleeve conductive, creating a potential alternative path to ground avoiding the spark gap. Eventually, the resistance of the alternative path to ground becomes comparable with or less than that across the spark gap. If this occurs, the electricity ceases jumping the spark gap and “runs” along the surface of the insulating sleeve. In this case, the electricity may jump across the clearance between the end portions of the insulating sleeve and the shell, ie the spark occurs “within the plug”. The spark within the plug may cause ignition of the fuel but ignition may not occur because the spark is less favourably positioned than at the spark gap as it is to some extent masked by the end portions of the shell and the sleeve. The further that the spark occurs from the end surface of the shell, the greater the masking is. A spark jumping said clearance does have the beneficial effect of burning the carbon deposit off the surface of the sleeve, thereby increasing the electrical resistance and increasing the chance of the next spark occurring at the spark gap. Thus, if a spark occurs away from the spark gap, it is not desirable but may result in ignition and tends to return the plug to normal operation. However, if the electricity runs along the surface of the sleeve all the way to the sleeve’s junction with the shell, no spark occurs and ignition is impossible. Furthermore, this situation is likely to be sustained. These factors lead make it desirable that a plug has a long length of exposed insulating sleeve and that the firing end of the plug operates at high temperature in order to assist in cleaning carbon off the insulating sleeve. These considerations limit the range of applications for a particular plug, complicate manufacture, and reduce the durability of the plug.

In the known spark plugs described as being of “the closed bore type”, one of which is illustrated in FIGS. **4**A to **4**C and others are disclosed in U.S. Pat. Nos. 4,209,990 and 5,244,188, in order to ensure that the electricity does jump to form a spark, the shell of the plug is provided with an internal flange in the region of its end surface. This flange reduces the clearance between the shell and the sleeve (typically to about 0.5 mm). The flange acts to shield the end portion of the sleeve within the shell against receiving carbon deposits and also provides a small gap (a “secondary spark gap”) for the electricity to jump to the flange where it is only masked from the fuel mixture to a limited extent. In some cases, the length of the path along the surface of the sleeve is increased by providing undulations in the external surface of the insulating sleeve on the portion thereof which is within the shell (see FIG. 3 of U.S. Pat. No. 4,289,990). However, the provision of a flange on the shell does not eliminate the masking of the spark since the spark may jump to any point of the flange, including the inner face thereof. Furthermore, the provision of a flange on the shell shortens the distance from the tip of the first electrode to the shell, and, by reducing the clearance, reduces the electrical resistance in the region of the flange. Both these factors increase the chance that sparking away from the intended spark gap will occur. In addition, the flange greatly restricts access to a volume within the plug in which unburned hydrocarbons and fuel droplets may collect and possibly bridge the secondary spark gap which would render the plug inoperative.

Another approach is to provide one or more additional electrodes on the shell of the plug. Three known designs are shown in FIGS. **5**A and B, FIGS. **5**c and D, and in FIG. **5**E, respectively. The additional electrodes provide secondary spark gaps at relatively unmasked locations. However, such electrodes are difficult and expensive to provide, only cause cleaning of the shell opposite the additional electrode so that carbon deposits can build up elsewhere, and limit the width of the intended spark gap, as it is necessary to avoid the additional electrode becoming the primary path for the electricity which may occur especially as the plug wears.

It is an object of the present invention to provide an improved spark plug in which the chance of the spark occurring away from the intended spark gap is reduced without reducing the chance of no spark occurring.

The invention provides spark plug comprising an electrically-insulating sleeve extending along a central axis of the plug, a first electrode mounted within the sleeve and having a tip projecting axially beyond an end portion of said sleeve, an electrically-conducting shell surrounding said sleeve, and a second electrode mounted on and electrically-connected to said shell, the second electrode having a tip positioned so that with the tip of said first electrode it defines a spark gap of the plug, the shell having an end portion terminating at an end surface of the shell, the sleeve extending past said end portion of the shell with a clearance therebetween and extending beyond said end surface of the shell, characterised in that the plug also comprises at least one projection formed from insulating material, the projection being positioned on the sleeve and projecting from the sleeve so that it reduces said clearance in the region of the end surface of the shell thereby forming a secondary spark gap.

In a spark plug according to the invention, the shell is not altered, thereby avoiding reducing the electrical resistance, avoiding reducing the distance to the tip of the first electrode, and simplifying manufacture, but the sparks which occur away from the spark gap are encouraged to occur between the projection and the end surface region of the shell which is the least masked position. A spark plug according to the invention gives improved cold foul resistance without requiring the plug to operate at a higher temperature during normal operation. This gives the advantages that the plug has greater durability, that it can be more easily manufactured, that the plug can have an increased safety margin during operation, and that one design of plug can be used for an increased range of operating conditions.

In a spark plug according to the invention, the projection may be integral with the sleeve or may be secured to the sleeve, being either a coating deposited on the sleeve or a separate piece attached to the sleeve. Where the projection is not integral with the sleeve, it may be formed from a different insulating material to the sleeve.

The projection may extend as an annular rib around the sleeve. This gives the advantages of increasing the length of the path to ground along the surface of the sleeve and of partially shielding the portion of the end portion of the sleeve which is within the shell from carbon deposits. Alternatively, there may be a series of projections distributed around the external surface of the sleeve. Each projection may have a domed shape in cross-section axially of the plug or may have a pointed crest. Preferably, each projection is aligned so that its crest is at least approximately co-planar with the end surface of the shell. The portion of the end portion of the sleeve which is within the shell may be provided with path-lengthening undulations.

Normally, the secondary spark plug will be wider than the intended spark gap, when the plug is new. The actual width of the secondary gap depends on the intended use but 0.5 to 1.1 mm is preferred.

There now follow detailed descriptions to be read with the accompanying drawings of some known spark plugs and of spark plugs which are illustrative of the invention

IN THE DRAWINGS

FIG. **1**A is a longitudinal cross-sectional view taken through a known spark plug;

FIG. **1**B is a similar view to FIG. **1**A but showing a first illustrative spark plug according to the invention;

FIGS. **2**A and **2**B are enlarged views of portions of FIGS. **1**A and **1**B, respectively;

FIG. **3** is a similar view to FIG. **2**B but of a second illustrative spark plug according to the invention;

FIG. **4**A is a similar view to FIG. **1** but shows a further known spark plug;

FIGS. **4**B and **4**C are enlarged views of portions of FIG. **4**A;

FIG. **5**A is a view similar to FIG. **3** but of a further known spark plug;

FIG. **5**B is an end view of the plug shown in FIG. **5**A;

FIGS. **5**C and **5**D are similar views to FIGS. **5**A and **5**B but of a further known spark plug;

FIG. **5**E is a view similar to FIGS. **5**A and **5**C but of a further known spark plug;

FIG. **6**A to FIG. **6**G are enlarged views of alternative projections which may be used in spark plugs according to the invention.

The known spark plug **10** shown in FIG. **1**A comprises an electrically-insulating sleeve **12** extending along a central axis **14** of the plug **10**. The sleeve **12**, which is formed from alumina, defines a space **12**a extending along the axis **14**. The plug **10** also comprises a first electrode **16** mounted within the space **12**a and having a tip **16**a projecting beyond said sleeve **12**. The plug **10** also comprises a terminal **18** mounted within the space **12**a and projecting beyond the sleeve **12** at the other end thereof to the tip **16**a of the electrode **16**. Within the space **12**a, the electrode **16** and the terminal **18** are in electrically-conductive contact with one another.

The plug **10** also comprises an electrically-conducting shell **20** surrounding a portion of said sleeve **12**, the sleeve **12** being mounted in the shell **20**. The shell **20** has an external threaded portion **20**a by which the plug **10** can be mounted on an engine head. The shell **20** has an end surface **20**b formed on an end portion **20**c of the shell **20**, which is generally annular. The end surface **20**b extends radially of the axis **14**. The end portion **20**c is generally in the form of a hollow cylinder, having an internal surface **20**d. The end portion **20**c extends over an axial distance designated "d**2**" from the surface **20**b to an inwardly-projecting flange **20**e of the shell **20**. The flange **20**e projects into close proximity to the external surface **12**b of an end portion **12**c of the sleeve **12**. A seal **21** seals the gap between the flange **20**e and the sleeve **12**. Between the flange **20**e and the end surface **20**b of the shell **20**, there is a clearance between the internal surface **20**d of the end portion **20**c of the shell **20** and the external surface **12**b of the end portion **12**c of the sleeve **12**. The external surface **12**b is generally frusto-conical so that the clearance increases in width in the direction towards the tip **16**a. The end portion **12**c extends past the end portion **20**c of the shell **20** with a clearance therebetween, and extends beyond the surface **20**b, having passed through the surface **20**b. The end portion **12**c projects beyond the surface **20**b by a distance designated "d**1**".

The plug **10** also comprises a second electrode **22** mounted on and electrically-connected to said shell **20**. Specifically, the second electrode **22** is welded to the surface **20**b and projects in a "J" shape to a tip **22**a thereof positioned in opposed relationship with the tip **16**a so that the tips **16**a and **22**a together define a spark gap designated "G**1**".

The plug **10** is mounted in an engine head by means of the threaded portion **20**a of the shell **20** so that the tip **16**a of the first electrode **16**, the end portion of the sleeve **12** adjacent to the tip **16**a, and the second electrode **22** project into a combustion chamber of the engine. When a high voltage is applied to the terminal **18**, in normal operation of the plug **10**, a spark is created which ignites fuel mixture in the combustion chamber. It is intended that the spark will cross the gap G**1**. However, in service, fouling (depositing of carbon) occurs on the end portion **12**c of the insulating sleeve **12**. This leads to the possibility that, instead of jumping the gap G**1**, the electricity may run along the surface **12**b of the sleeve **12** into the clearance between the surfaces **12**b and **20**d. In this case, a spark may jump to the shell **20** anywhere along the distance d**2**. Unless the spark jumps near the surface **20**b, the spark is at least to some extent masked from the fuel mixture by the shell **20** and the sleeve **12**, making ignition uncertain. Indeed, it is possible for the electricity to travel along the end portion **12**c all the way to the flange **20**e and no spark may occur. To reduce this possibility, it is desirable if the distance d**1** and d**2** are made relatively long, d**1** to discourage sparking away from the gap G**1**, and both d**1** and d**2** to reduce the possibility of no spark occurring. However, in practice, d**1** is usually determined by other considerations so that the clearance between the surfaces **12**b and **20**d may have to be increased instead.

The first illustrative spark plug **30** according to the invention is illustrated in FIGS. **1**B and **2**B. The plug **30** differs from the plug **10** described above only in the form of its insulating sleeve so that the same reference numerals are used in relation to the parts of the plug **30** as have been used in relation to the like parts of the plug **10** without repeating the descriptions thereof. The insulating sleeve **12** of the plug **30** is also identical to the sleeve **12** of the plug **10** except that the end portion **12**c thereof is provided with a projection **32**. This projection **32** is integral with the sleeve **12** and projects from the end portion **12**c so that, in the region of the end surface **20**b of the shell **20**, it reduces the clearance between the end portion **12**c and the end portion **20**c of the shell **20** to a gap which is designated "G**2**" since it provides a secondary spark gap where sparks are most likely to jump if they do not jump at the intended gap G**1**. The projection **32** extends as an annular rib around the sleeve **12** so that the clearance between the projection **32** and the surface **20**d is substantially equal around the sleeve **12**, being 0.8 mm.

In cross-section, axially of the plug **30**, the projection **32** has a domed sinusoidal shape with the crest of the dome substantially co-planar with the surface **20**b. In other words, the projection **32** is aligned with its centre line co-planar with the end surface **20**b of the sleeve **20**.

In FIGS. **1**A and **2**A and in FIGS. **1**B and **2**B, respectively, the distances d**1** and d**2** of the plugs **10** and **30** are shown as equal, for comparison purposes but, in practice, the distances d**1** and d**2** of the plug **30** can be reduced compared with those of the plug **10** for the same operating conditions.

The plug **30** operates, in normal conditions, in the same way as the plug **10**, ie the spark occurs at the gap G**1**. However, in the event of fouling the projection **32** changes the situation. In FIG. **2**A, the line P**1** shows a possible alternative path for the electricity to travel to the shell **20** from the tip **16**a. The arrow S**1** illustrates one possible position for a spark to form but a spark may form anywhere along the distance d**2** as previously described. In contrast, in FIG. **2**B, the line P**2** shows the probable alternative path for the electricity. It is unlikely that the electricity will pass the projection **32** so that the probability is that a spark will occur across the gap G**2**.

In FIG. **3**, there is shown the second illustrative spark plug **40** according to the invention. The plug **40** differs from the plug **30** only in that the portion of the end portion **12**c of the sleeve **12** which is within the shell **20** is provided with path-lengthening undulations **42** which are in the form of annular ribs. These undulations **42** are integral with the remainder of the sleeve **12** and make it even more likely that a spark will occur at the gap G**2** rather than the electricity will travel to the flange **20**e without a spark forming.

FIGS. **4**A, **4**B and **4**C illustrate a further known spark plug **50**. The spark plug **50** differs from the plug **10** only in the respects mentioned below so that the same reference numerals are used in relation to the parts in the plug **50** as have been used in relation to the plug **10** without repeating the descriptions thereof. The plug **50** differs from the plug **10** in that the end portion **20**c of the shell **20** thereof has a different shape, in that the end portion **12**c of the sleeve **12** thereof has a different shape, and in that the portion **12**d of the sleeve **12** thereof which is adjacent to the terminal **18** has a different shape.

Specifically, the end portion **20**c of the shell **20** is provided with an internal flange **20**f which extends from the end surface **20**b, and also has a step **20**g therein. The shape of the end portion **12**c is generally cylindrical between its end adjacent to its tip **16**a and the step **20**g and then tapers outwardly in a frusto-conical shape to the seal **21**. The portion **12**d is provided with path-lengthening undulations **12**e which reduce the possibility of a short circuit on the length X between the terminal **18** and the shell **20**.

In the operation of the plug **50**, in normal conditions, the spark occurs at the gap G**1**. However, in the event of fouling on the sleeve **12**, the electricity may run along the surface of the sleeve and jump to the flange **20**f which thereby provides a secondary spark gap G**2**. However, the gap G**2** has a considerable axial length between the points Y and Z shown in FIG. **4**C and the spark may occur anywhere along this distance. Furthermore, the flange **20**f approaches the tip **16**a closer than the remainder of the shell, thereby increasing the possibility of sparking at the gap G**2** in preference to the gap G**1**.

FIGS. **5**A and **5**B, FIGS. **5**C and **5**D, and FIG. **5**E show, respectively, three known designs of plugs which are provided with one or more additional electrodes. The same reference numerals are again used for like parts as are used in relation to the plug **10** without repeating the description thereof. In FIGS. **5**A and **5**B, a plug **60** is shown which has three additional electrodes **62** which are all welded to the shell **20** and, including the second electrode **22**, the four electrodes are evenly distributed about the axis **14**. The electrodes **62** are arranged so that the project to tips **62**a which are further from the tips **16**a than the tip **22**a of the second electrode **22**. Specifically, the electrodes **62** extend to points which are in opposed relationship with the end of the sleeve **12**. In the operation of the plug **60**, the three electrodes **62** provide three alternative secondary spark gaps G**2** which come in to operation in the event of fouling, when the electricity runs over the end of the sleeve **12** and jumps to the electrode **62**.

FIGS. **5**C and **5**D show a known plug **70** which is similar to the plug **60** but is provided with only one additional electrode **62** which has its tip in opposed relationship with the side surface of the end of the sleeve **12**.

FIG. **5**E illustrates a known plug **80** which is similar to the plugs **60** and **70** but has its additional electrode **62** provided by a pin mounted on the shell **20** and projecting inwardly towards the surface of the end portion **12**c which is cylindrical.

FIG. **6**A to **6**G show alternative forms for the projection **32** which may be used instead of the projection illustrated in FIGS. **1**B and **2**B or instead of the projection **32** illustrated in FIG. **3**. In FIG. **6**A, the projection **32** is asymmetrical having a crest **32**a which is co-planar with the surface **20**b, an inner (furthest from the tip **16**a) side surface **32**b which is approximately sinusoidal, and an outer (nearest to the tip **16**a) side surface **32**c which is inclined at a constant angle to the axis **14** of the plug. In FIG. **6**B, the projection is symmetrical having a flat crest **32**a extending between two sinusoidal side surfaces **32**b and **32**c, the crest **32**a being arranged so that most of it is outwardly positioned relative to the surface **20**c but adjacent to the surface **32**b extending through the surface **20**b. In FIG. **6**C, the projection **32** has a pointed crest **32**a which is co-planar with the surface **20**b and the side surfaces **32**b and **32**c are inclined at opposite angles relative to the axis **14** creating a symmetrical projection. In FIG. **6**D, the projection **32** has the same form, ie sinusoidal, as in FIGS. **1**B, **2**B and **3** with its crest **32**a co-planar with the surface **20**b. In FIG. **6**E, the projection **32** has a semi-circular form with its crest **32**a co-planar with the surface **20**b. In FIG. **6**F, the projection **32** has a form similar to that shown in FIG. **6**B but the projection does not extend as far towards the tip **16**a. In FIG. **6**G, the projection has a form similar to that shown in FIG. **6**A but the side surface **32c** is more steeply inclined.

It is preferred that the side surfaces **32**b and **32**c of the projection **32** should be inclined at angles up to 60 degrees relative to the axis **14**. Angles above 30 degrees are preferred to reduce sparks occurring low down in the plug.

The known plugs **10** and **50** and the plug according to the invention **30** were subjected to cold foul tests. These tests involved cooling a vehicle down to minus ten degrees C., starting the engine, immediately accelerating hard through first, second and third gears up to 50 km/h, holding this speed for 2 seconds, turning off the engine, waiting for the temperature to fall again, repeating the starting, driving and cooling stages until the car will not start again or misfires such that the speed mentioned cannot be achieved. This test is designed to cause cold fouling on the plugs, without allowing the temperature to rise sufficiently for any cleaning to occur. Clearly, the more times that the test procedure can be repeated (cycles), the better is the performance of the plug. In these tests, the lug **10** achieved an average of 11.8 cycles, the plug **50** achieved an average of 9.0 cycles and the plug **30** according to the invention achieved 26.7 cycles.

The invention claimed is:

1. A spark plug comprising an electrically-insulating sleeve extending along a central axis of the plug, a first electrode mounted within the sleeve and having a tip projecting axially beyond an end portion of said sleeve, an electrically-conducting shell surrounding said sleeve, and a second electrode mounted on and electrically-connected to said shell, the second electrode having a tip positioned so that with the tip of said first electrode it defines a spark gap of the plug, the shell having an end portion terminating at an end surface of the shell, the sleeve extending past the end portion of the shell with a clearance therebetween and extending beyond said end surface of the shell, wherein the plug also comprises at least one projection formed from insulating material, the projection being positioned on the sleeve and extending circumferentially of the sleeve, the projection having a shape, in cross-section axially of the plug, such that a crest of the projection is located in the region of the end surface of the shell and reduces said clearance to lie in the range 0.5 to 1.1 mm, thereby forming a secondary spark gap**[.]**; *and*

wherein the crest of the projection is bounded in the direction away from the first electrode by a projection side surface and the boundary between that crest and said projection side surface is substantially co-planar with the end surface of the shell.

2. A spark plug according to claim **1**, wherein the projection is integral with the sleeve.

3. A spark plug according to claim **1**, wherein the projection extends as an annular rib around the sleeve.

4. A spark plug according to claim **1**, wherein the projection has a domed shape in cross-section axially of the plug.

5. A spark plug according to claim **1**, wherein the projection has at least one of its side surfaces inclined at an angle of between 60 and 30 degrees relative to the axis.

6. A spark plug according to claim **1**, wherein the projection has a flat crest.

[7. A spark plug according to claim **1**, wherein the crest of the projection is bounded in the direction away from the first electrode by a projection side surface and the boundary between that crest and said projection side surface is co-planar with the end surface of the shell.**]**

8. A spark plug according to claim **1**, wherein the portion of the end portion of the sleeve which is within the shell is provided with path-lengthening undulations.

9. A spark plug according to claim **8**, wherein the crest of the projection is bounded in the direction towards the first electrode by a projection side surface and the boundary between that crest and said projection side surface is co-planar with the end surface of the shell.

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