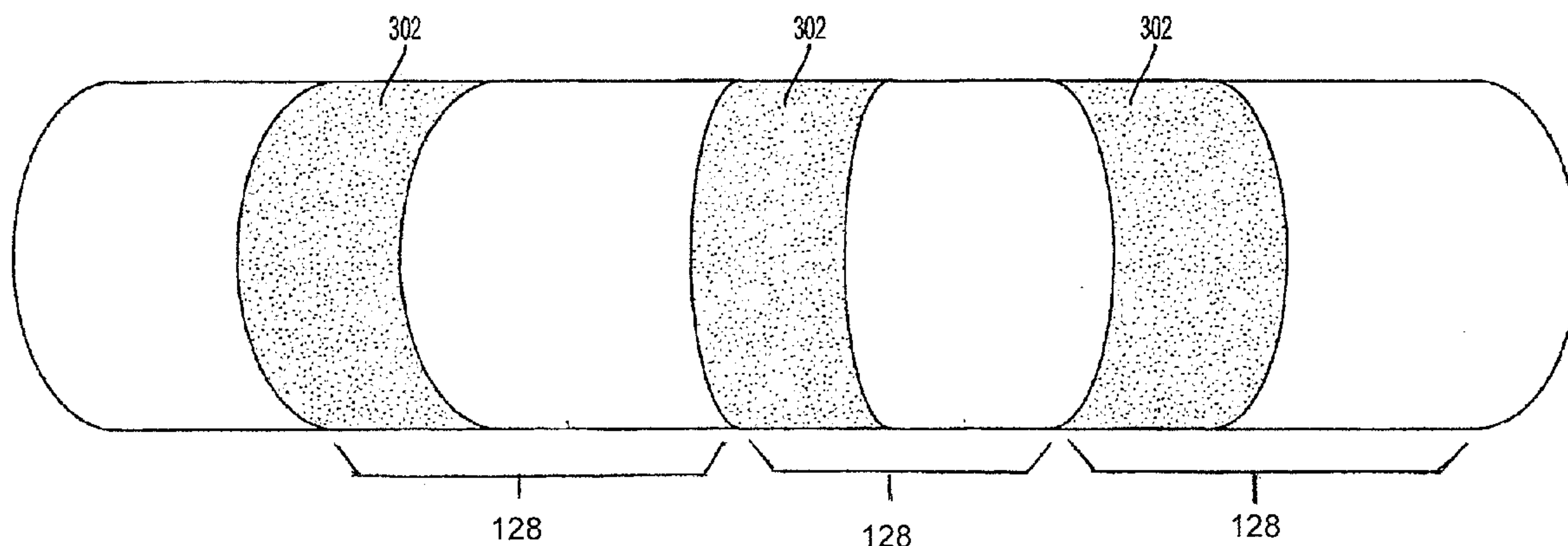




(86) Date de dépôt PCT/PCT Filing Date: 2008/02/27
 (87) Date publication PCT/PCT Publication Date: 2008/10/09
 (45) Date de délivrance/Issue Date: 2016/06/14
 (85) Entrée phase nationale/National Entry: 2009/08/26
 (86) N° demande PCT/PCT Application No.: US 2008/055156
 (87) N° publication PCT/PCT Publication No.: 2008/121466
 (30) Priorité/Priority: 2007/02/27 (US60/891,881)

(51) Cl.Int./Int.Cl. *B25J 18/06* (2006.01),
A61B 1/005 (2006.01), *B25J 17/00* (2006.01),
B25J 9/06 (2006.01)
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(54) Titre : DISPOSITIF A PLUSIEURS BIELLES AYANT UN ELEMENT DE RENFORCEMENT
 (54) Title: A MULTI-LINKED DEVICE HAVING A REINFORCING MEMBER



(57) **Abrégé/Abstract:**

A steerable multi-linked device may include a first multi-linked mechanism and a second multi-linked mechanism. At least one of the first multi-linked mechanism and the second multi-linked mechanism may include a first link, a plurality of intermediate links, a second link movably coupled to a second one of the intermediate links and a reinforcing member. A first one of the intermediate links may be movably coupled to the first link, and the reinforcing member may extend from a first end of a third one of the intermediate links toward a second end of the third one of the intermediate links.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
9 October 2008 (09.10.2008)

PCT

(10) International Publication Number
WO 2008/121466 A3(51) International Patent Classification:
B25J 17/00 (2006.01)

(21) International Application Number:

PCT/US2008/055156

(22) International Filing Date:

27 February 2008 (27.02.2008)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

60/891,881 27 February 2007 (27.02.2007) US

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Heights Drive, Pittsburgh, Pennsylvania 15215 (US).(74) Agent: **SINGER, James**; Pepper Hamilton LLP, One Mel-
lon Center, 500 Grant Street, Pittsburgh, PA 15219 (US).(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA,
CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE,
EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID,
IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC,
LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN,
MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH,
PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV,
SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN,
ZA, ZM, ZW.(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,
ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),
European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,
FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL,
NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG,
CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).**Published:**

— with international search report

(88) Date of publication of the international search report:

24 December 2008

(54) Title: A MULTI-LINKED DEVICE HAVING A REINFORCING MEMBER

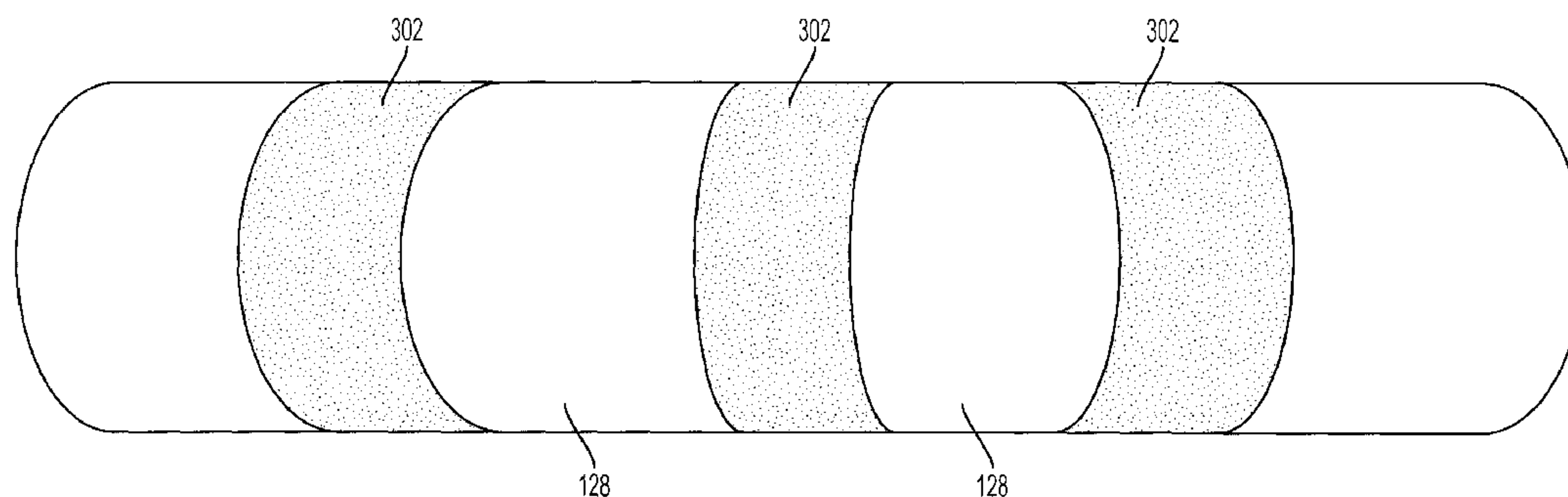


FIG. 12

(57) Abstract: A steerable multi-linked device may include a first multi-linked mechanism and a second multi-linked mechanism. At least one of the first multi-linked mechanism and the second multi-linked mechanism may include a first link, a plurality of intermediate links, a second link movably coupled to a second one of the intermediate links and a reinforcing member. A first one of the intermediate links may be movably coupled to the first link, and the reinforcing member may extend from a first end of a third one of the intermediate links toward a second end of the third one of the intermediate links.

WO 2008/121466 A3

A. TITLE – A MULTI-LINKED DEVICE HAVING A REINFORCING MEMBER

F. BACKGROUND

[0002] This application discloses an invention that is related, generally and in various embodiments, to a steerable multi-linked device having a reinforcing member.

G. SUMMARY

A steerable multi-linked device may include a first multi-linked mechanism and a second multi-linked mechanism. At least one of the first multi-linked mechanism and the second multi-linked mechanism may include a first link, a plurality of intermediate links, a second link movably coupled to a second one of the intermediate links and a reinforcing member. A first one of the intermediate links may be movably coupled to the first link, and the reinforcing member may extend from a first end of a third one of the intermediate links toward a second end of the third one of the intermediate links.

H. BRIEF DESCRIPTION OF DRAWINGS

[0003] Various embodiments of the invention are described herein by way of example in conjunction with the following figures.

[0004] FIGS. 1A and 1B illustrate various embodiments of a steerable multi-linked device;

[0005] FIG. 2 illustrates various embodiments of a core mechanism of the device of Figure 1;

[0006] FIGS. 3A-3C illustrate various embodiments of a proximal link of the core mechanism;

[0007] FIGS. 4A-4C illustrate various embodiments of an intermediate link of the core mechanism;

[0008] FIGS. 5A-5C illustrate various embodiments of a distal link of the core mechanism;

[0009] FIG. 6 illustrates various embodiments of a sleeve mechanism of the device of Figure 1;

[0010] FIGS. 7A-7C illustrate various embodiments of a proximal link of the sleeve mechanism;

[0011] FIGS. 8A-8C illustrate various embodiments of an intermediate link of the sleeve mechanism;

[0012] FIGS. 9A-9D illustrate various embodiments of a distal link of the sleeve mechanism;

[0013] FIG. 10 illustrates various embodiments of a motion sequence of the device of FIG. 1;

[0014] FIG. 11 illustrates various embodiments of a steerable multi-linked device traversing a path having tight curvatures;

[0015] FIG. 12 illustrates various embodiments of a portion of a steerable multi-linked device having one or more reinforcing members;

[0016] FIG. 13 illustrates an exemplary mechanical limit according to various embodiments;

[0017] FIG. 14 illustrates an exemplary mechanical limit according to various embodiments.

I. DETAILED DESCRIPTION

[0018] It is to be understood that at least some of the figures and descriptions of the invention have been simplified to focus on elements that are relevant for a clear understanding of the invention, while eliminating, for purposes of clarity, other elements that those of ordinary skill in the art will appreciate may also comprise a portion of the invention. However, because such elements are well known in the art, and because they do not necessarily facilitate a better understanding of the invention, a description of such elements is not provided herein.

[0019] According to various embodiments, the invention described herein may be utilized to control movement of a multi-linked device such as the steerable multi-linked device described herein. For ease of explanation purposes, the invention will be described in the context of its use with various embodiments of the steerable multi-linked device described herein. However, one skilled in the art will appreciate that the invention may be utilized with other types of multi-linked devices.

[0020] FIGS. 1A and 1B illustrate various embodiments of a steerable multi-linked device **10**. According to various embodiments, the steerable multi-linked device may be a

snake robot, a continuum robot or the like. Various embodiments of the device **10** may be utilized for medical procedures (e.g., as a robotic bore, positioning device, ablation tool, camera or instrument support, or guidance system for minimally invasive procedures), for surveillance applications, for inspection applications, for search and rescue applications, etc. For purposes of clarity only, the utility of the device **10** will be described hereinbelow in the context of its applicability to medical procedures. However, a person skilled in the art will appreciate that the device **10** can be utilized in a variety of different applications.

[0021] The device **10** comprises a first mechanism **12** and a second mechanism **14**. According to various embodiments, a mechanism may be a snake robot, a continuum robot or the like. According to various embodiments, the second mechanism **14** is structured and arranged to receive and surround the first mechanism **12** as shown in FIG. 1B. Thus, the first mechanism and second mechanism may be concentric. For such embodiments, the first mechanism **12** may be considered the inner mechanism or the core mechanism, and the second mechanism **14** may be considered the outer mechanism or the sleeve mechanism. According to other embodiments, the first and second mechanisms **12**, **14** may be structured and arranged to have a relationship other than a concentric relationship. For example, one skilled in the art will appreciate that, according to various embodiments, the first and second mechanisms **12**, **14** may be structured and arranged to operate in a side-by-side arrangement, where the first mechanism **12** operates adjacent to the second mechanism **14**. According to various embodiments, additional and/or alternate configurations may be used within the scope of this disclosure. According to various embodiments, a three-dimensional space **240** may be provided between the first and second mechanisms. This space will be described in more detail below.

[0022] As described in more detail hereinbelow, the first mechanism **12** may operate in either a rigid mode or a limp mode, the second mechanism **14** may operate in either a rigid

mode or a limp mode, and the first and second mechanisms **12**, **14** may operate independent of one another. Both the first mechanism **12** and the second mechanism **14** may be steerable mechanisms. Accordingly, it will be appreciated that the device **10** may be utilized to navigate a luminal space as well as any three-dimensional path within an intracavity space. According to various embodiments, the device **10** may advance by alternating the operation of the first mechanism **12** and the second mechanism **14** between a limp mode and a rigid mode.

[0023] According to various embodiments, the device **10** may also comprise one or more cables. According to various embodiments, one or more of the cables may be steering cables and/or tensioning cables. For example, the device may include three steering cables and one tensioning cables.

[0024] FIG. 2 illustrates various embodiments of the first mechanism **12** of the device **10**. The first mechanism **12** is a multi-linked mechanism and includes a first end **24** and a second end **26**. The first end **24** may be considered the proximal end and the second end **26** may be considered the distal end. The first mechanism **12** may comprise a first link **28**, a second link **30**, and one or more intermediate links **32** between the first and second links **28**, **30**. The first link **28** may be considered the proximal link, and the second link **30** may be considered the distal link.

[0025] FIGS. 3A-3C illustrate various embodiments of the first link **28** (inner proximal link) of the first mechanism **12**. The first link **28** includes a first end **34** and a second end **36**, and defines a longitudinal axis **38** that passes through the center of the first end **34** and the center of the second end **36** as shown in FIG. 3B. The first link **28** may be fabricated from any suitable material. According to various embodiments, the first link **28** is fabricated from a fiber reinforced material such as, for example, G10/FR4 Garolite®. The

first link **28** has a generally cylindrical shaped exterior and is described in more detail hereinbelow.

[0026] The first link **28** comprises a first portion **40** and a second portion **42**. The first portion **40** may be considered the proximal portion and the second portion **42** may be considered the distal portion. The first portion **40** may be fabricated integral with the second portion **42**. The first portion **40** has a cylindrical shaped exterior, and extends from the first end **34** of the first link **28** toward the second end **36** of the first link **28**. According to various embodiments, the diameter of the first portion **40** may be on the order of approximately 6.35 millimeters. Other sizes are possible.

[0027] The second portion **42** has a generally cylindrically shaped exterior, with other features described below. The second portion **42** has a cylindrically shaped exterior where it contacts the first portion **40**, and tapers toward the second end **36** of the first link **28**. The second portion **42** may be shaped in the form of a generally segmented hemisphere at the second end **36** of the first link **28**. According to various embodiments, the diameter of the second portion **42** may be on the order of approximately 4.75 millimeters where it contacts the first portion **40**. Other sizes are possible.

[0028] The second portion **42** comprises a first surface **44**. The first surface **44** may be considered the outer surface of the second portion **42**. The second portion **42** defines a first groove **46** parallel to the longitudinal axis **38** along the first surface **44**, a second groove **48** parallel to the longitudinal axis **38** along the first surface **44**, and a third groove **50** parallel to the longitudinal axis **38** along the first surface **44**. Each of the first, second and third grooves **46**, **48**, **50** extend along the first surface **44** toward the second end **36** of the first link **28**. The first, second and third grooves **46**, **48**, **50** may be semi-tubular shaped and may be evenly spaced about the first surface **44** of the second portion **42** of the first link **28** as shown in FIG. 3C. According to various embodiments, the first, second, and third grooves **46**, **48**,

50 may be configured in the shape of a segmented cylinder. The size of each of the grooves **46, 48, 50** may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second grooves **46, 48** may be configured as segments of a cylinder having a diameter on the order of approximately 1.25 millimeters, and the third groove **50** may be configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters. The length of the first link **28** may be on the order of approximately 65 millimeters. However, one skilled in the art will appreciate that the length or diameter of the first link **28** can vary based on the application.

[0029] The first link **28** also defines a passage **52** extending from the first end **34** to the second end **36** along the longitudinal axis **38** as shown in FIG. 3B. The passage **52** is of a size sufficient to allow at least one cable to pass therethrough. According to various embodiments, the passage **52** may be of a sufficient size to allow a tensioning cable to pass therethrough. According to various embodiments, the passage **52** is generally configured as a complex shape that comprises a combination of a first cylinder **54** that extends from the first end **34** toward the second end **36**, and a second cylinder **56** that extends from the first cylinder **54** toward the second end **36**. The diameter of the first cylinder **54** is larger than the diameter of the second cylinder **56**. For example, according to various embodiments, the first cylinder **54** may have a diameter on the order of approximately 3.20 millimeters and the second cylinder **56** may have a diameter on the order of approximately 1.50 millimeters. Other sizes are possible.

[0030] FIGS. 4A-4C illustrate various embodiments of one of the intermediate links **32** (inner intermediate link) of the first mechanism **12**. The intermediate link **32** is representative of the other intermediate links **32**. The intermediate link **32** includes a first end **58** and a second end **60**, and defines a longitudinal axis **62** that passes through the center of the first end **58** and the center of the second end **60** as shown in FIG. 4B. The intermediate

link **32** may be fabricated from any suitable material. According to various embodiments, the intermediate link **32** is fabricated from a fiber reinforced material such as, for example, G10/FR4 Garolite®. The intermediate link **32** has a generally bullet-shaped exterior and is described in more detail hereinbelow.

[0031] The intermediate link **32** comprises a first portion **64** and a second portion **66**. The first portion **64** may be considered the proximal portion and the second portion **66** may be considered the distal portion. The first portion **64** may be fabricated integral with the second portion **66**. The first portion **64** has a generally cylindrical shaped exterior, and extends from the first end **58** of the intermediate link **32** toward the second end **60** of the intermediate link **32**. According to various embodiments, the second portion **66** has a generally cylindrically shaped exterior where it contacts the first portion **64**, and tapers toward the second end **60** of the intermediate link **32**. The exterior of the second portion **66** is configured in the form of a generally segmented hemisphere. According to various embodiments, the diameter of the intermediate link **32** may be on the order of approximately 4.75 millimeters at the first end **58** thereof. The length of the intermediate link **32** may be on the order of approximately 5.85 millimeters. However, one skilled in the art will appreciate that the length or diameter of the intermediate link **32** can vary based on the application.

[0032] The intermediate link **32** also comprises a first surface **68** that extends from the first end **58** of the intermediate link **32** to the second end **60** of the intermediate link **32**. The first surface **68** may be considered the outer surface of the intermediate link **32**. The intermediate link **32** also defines a first groove **70** parallel to the longitudinal axis **62** along the first surface **68**, a second groove **72** parallel to the longitudinal axis **62** along the first surface **68**, and a third groove **74** parallel to the longitudinal axis **62** along the first surface **68**. Each of the first, second and third grooves **70**, **72**, **74** extend along the first surface **68** from the first end **58** of the intermediate link **32** toward the second end **60** of the intermediate link

32. The first, second and third grooves 70, 72, 74 may be semi-tubular shaped and may be evenly spaced about the first surface 68 of the intermediate link 32 as shown in FIG. 4C. According to various embodiments, the first, second, and third grooves 70, 72, 74 may be configured in the shape of a segmented cylinder. The size of each of the grooves 70, 72, 74 may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second grooves 70, 72 are configured as segments of a cylinder having a diameter on the order of approximately 1.75 millimeters at the first end 58 of the intermediate link 32, and the third groove 74 is configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters at the first end 58 of the intermediate link 32. The first, second and third grooves 70, 72, 74 are each configured to receive and partially surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end 24 of the multi-linked device 10 to the second end 26 of the multi-linked device 10.

[0033] The intermediate link 32 also defines a passage 76 extending from the first end 58 to the second end 60 along the longitudinal axis 62 as shown in FIG. 4B. The passage 76 may be of a size sufficient to allow one or more cables to pass therethrough. According to various embodiments, the passage 76 may be of a size sufficient to allow a tensioning cable to pass therethrough. According to various embodiments, the passage 76 is generally configured as a complex shape that comprises a combination of a first segmented hemisphere 78 that extends from the first end 58 toward the second end 60, a second segmented hemisphere 80 that extends from the first segmented hemisphere 78 toward the second end 60, a cylinder 82 that extends from the second segmented hemisphere 80 toward the second end 60, and a third segmented hemisphere 84 that extends from the cylinder 82 to the second end 60 of the intermediate link 32. According to various embodiments, the first segmented hemisphere 78 represents a portion of a sphere having a diameter on the order of

approximately 4.75 millimeters, the second segmented hemisphere **80** represents a portion of a sphere having a diameter on the order of approximately 2.25 millimeters, the cylinder **82** may have a diameter on the order of approximately 1.0 millimeter, and the third segmented hemisphere **84** represents a portion of a sphere having a diameter on the order of approximately 2.25 millimeters. Other sizes are possible.

[0034] The first segmented hemisphere **78** of the passage **76** is configured to receive the second end **36** of the first link **28** when the first link **28** is coupled to the intermediate link **32**. Similarly, for a given intermediate link **32**, the first segmented hemisphere **78** of the passage **76** is configured to receive the second end **60** of another intermediate link **32** when the other intermediate link **32** is coupled to the given intermediate link **32**. The third segmented hemisphere **84** may serve to reduce the pinching or binding a cable when one intermediate link **32** moves relative to an adjacent intermediate link **32** coupled thereto. Similarly, when the second link **30** is coupled to a given intermediate link **32**, the third segmented hemisphere **84** may serve to reduce the pinching or binding of a cable when the second link **30** moves relative to the given intermediate link **32**.

[0035] With the above described structure, the first link **28** may be coupled to the intermediate link **32** by seating the second end **36** of the first link **28** in the first segmented hemisphere **78** of the passage **76** of the intermediate link **32**. As the convex configuration of the second end **36** of the first link **28** generally corresponds with the concave configuration of the first segmented hemisphere **78** of the passage **76** of the intermediate link **32**, the first link **28** may be coupled to the intermediate link **32** such that the longitudinal axis **38** and the first, second and third grooves **46**, **48**, **50** of the first link **28** are respectively aligned with the longitudinal axis **62** and the first, second and third grooves **70**, **72**, **74** of the intermediate link **32**. The intermediate link **32** may be moved relative to the first link **28** such that the longitudinal axis **62** of the intermediate link **32** is not aligned with the longitudinal axis **38** of

the first link **28**. According to various embodiments, the configuration of the first link **28** and the intermediate link **32** allows for the intermediate link **32** to be moved relative to the first link **28** coupled thereto such that the longitudinal axis **38** of the first link **28** and the longitudinal axis **62** of the intermediate link **32** are up to approximately 25° out of alignment with one another. Similarly, one intermediate link **32** may be coupled to another intermediate link **32**, and so on, by seating the second end **60** of one intermediate link **32** in the first segmented hemisphere **78** of the passage **76** of another intermediate link **32**. As the convex configuration of the second end **60** of the intermediate link **32** generally corresponds with the concave configuration of the first segmented hemisphere **78** of the passage **76** of the intermediate link **32**, the intermediate links **32** may be coupled such that the respective longitudinal axes **62** and the respective first, second and third grooves **46**, **48**, **50** of the intermediate links **32** are aligned. The coupled intermediate links **32** may be moved relative to one another such that the respective longitudinal axes **62** of the coupled intermediate links **32** are not aligned. According to various embodiments, the configuration of the coupled intermediate links **32** allows for one intermediate link **32** to be moved relative to an adjacent intermediate link **32** coupled thereto such that the respective longitudinal axes **62** are up to approximately 25° out of alignment with one another.

[0036] FIGS. 5A-5C illustrate various embodiments of the second link **30** (inner distal link) of the first mechanism **12**. The second link **30** includes a first end **86** and a second end **88**, and defines a longitudinal axis **90** that passes through the center of the first end **86** and the center of the second end **88** as shown in FIG. 5B. The second link **30** may be fabricated from any suitable material. According to various embodiments, the second link **30** is fabricated from a thermoplastic material such as, for example, Delrin®.

[0037] The second link **30** comprises a first portion **92** and a second portion **94**. The first portion **92** may be considered the proximal portion and the second portion **94** may be

considered the distal portion. The first portion **92** may be fabricated integral with the second portion **94**. The first portion **92** has a generally cylindrical shaped exterior, and extends from the first end **86** of the second link **30** toward the second end **88** of the second link **30**.

According to various embodiments, the second portion **94** has a generally cylindrically shaped exterior where it contacts the first portion **92**, and tapers toward the second end **88** of the second link **30**. The exterior of the second portion **64** is configured in the form of a generally segmented cone. According to various embodiments, the diameter of the second link **30** may be on the order of approximately 4.75 millimeters at the first end **86** thereof, and the taper of the second portion **94** may be at an angle of approximately 30° relative to the exterior of the first portion **92**. The length of the second link **30** may be on the order of approximately 5.90 millimeters. However, one skilled in the art will appreciate that the length or diameter of the second link **30** can vary based on the application.

[0038] The second link **30** also comprises a first surface **96** that extends from the first end **86** of the second link **30** to the second end **88** of the second link **30**. The first surface **96** may be considered the outer surface of the second link **30**. The second link **30** also defines a first groove **98** parallel to the longitudinal axis **90** along the first surface **96**, a second groove **100** parallel to the longitudinal axis **90** along the first surface **96**, and a third groove **102** parallel to the longitudinal axis **90** along the first surface **96**. Each of the first, second and third grooves **98**, **100**, **102** extend along the first surface **96** from the first end **86** of the second link **30** toward the second end **88** of the second link **30**. The first, second and third grooves **98**, **100**, **102** may be semi-tubular shaped and may be evenly spaced about the first surface **96** of the second link **30** as shown in FIG. 5C. According to various embodiments, the first, second, and third grooves **98**, **100**, **102** may be configured in the shape of a segmented cylinder. The size of each of the grooves **98**, **100**, **102** may be identical to one another or may be different from one another. For example, according to various

embodiments, the first and second grooves **98**, **100** are configured as segments of a cylinder having a diameter on the order of approximately 1.25 millimeters at the first end **86** of the second link **30**, and the third groove **102** is configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters at the first end **86** of the second link **30**. The first, second and third grooves **98**, **100**, **102** are each configured to receive and partially surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**.

[0039] The second link **30** also defines a passage **104** extending from the first end **86** to the second end **88** along the longitudinal axis **90** as shown in FIG. 5B. The passage **104** may be of a size sufficient to allow at least one cable to pass therethrough. According to various embodiments, the passage **104** may be of a size sufficient to allow a tensioning cable to pass therethrough. According to various embodiments, the passage **104** is generally configured as a complex shape that comprises a combination of a first segmented hemisphere **106** that extends from the first end **86** toward the second end **88**, a second segmented hemisphere **108** that extends from the first segmented hemisphere **106** toward the second end **88**, and a cylinder **110** that extends from the second segmented hemisphere **108** to the second end **88** of the second link **30**. According to various embodiments, the first segmented hemisphere **106** represents a portion of a sphere having a diameter on the order of approximately 4.75 millimeters, the second segmented hemisphere **108** represents a portion of a sphere having a diameter on the order of approximately 2.50 millimeters, and the cylinder **110** may have a diameter on the order of approximately 1.0 millimeter. The first segmented hemisphere **106** of the passage **104** may be configured to receive the second end **60** of an intermediate link **32** when the intermediate link **32** is coupled to the second link **30**.

[0040] With the above described structure, an intermediate link **32** may be coupled to the second link **30** by seating the second end **60** of the intermediate link **32** in the first segmented hemisphere **106** of the passage **104** of the second link **30**. As the convex configuration of the second end **60** of the intermediate link **32** generally corresponds with the concave configuration of the first segmented hemisphere **106** of the passage **104** of the second link **30**, the intermediate link **32** may be coupled to the second link **30** such that the longitudinal axis **62** and the first, second and third grooves **70**, **72**, **74** of the intermediate link **32** are respectively aligned with the longitudinal axis **90** and the first, second and third grooves **98**, **100**, **102** of the second link **30**. The second link **30** may be moved relative to the intermediate link **32** coupled thereto such that the respective longitudinal axes **62**, **90** are not aligned. According to various embodiments, the configuration of the second link **30** allows for an intermediate link **32** coupled thereto to be moved relative to the second link **30** such that the respective longitudinal axes **62**, **90** are up to approximately 25° out of alignment with one another.

[0041] FIG. 6 illustrates various embodiments of the second mechanism **14** of the device **10**. The second mechanism **14** is a multi-linked mechanism and includes a first end **120** and a second end **122**. The first end **120** may be considered the proximal end and the second end **122** may be considered the distal end. The second mechanism **14** comprises a first link **124**, a second link **126**, and any number of intermediate links **128** between the first and second links **124**, **126**. The first link **124** may be considered the proximal link, and the second link **126** may be considered the distal link.

[0042] FIGS. 7A-7C illustrate various embodiments of the first link **124** (outer proximal link) of the second mechanism **14**. The first link **124** includes a first end **130** and a second end **132**, and defines a longitudinal axis **134** that passes through the center of the first end **130** and the center of the second end **132** as shown in FIG. 7B. The first link **124** may be

fabricated from any suitable material. According to various embodiments, the first link **124** is fabricated from a stainless steel material such as, for example, **316** stainless steel. The first link **124** has a generally bullet-shaped exterior and is described in more detail hereinbelow.

[0043] The first link **124** comprises a first portion **136** and a second portion **138**. The first portion **136** may be considered the proximal portion and the second portion **138** may be considered the distal portion. The first portion **136** may be fabricated integral with the second portion **138**. The first portion **136** has a cylindrical shaped exterior, and extends from the first end **130** of the first link **124** toward the second end **132** of the first link **124**. According to various embodiments, the diameter of the first portion **136** may be on the order of approximately 12.70 millimeters. Other sizes are possible.

[0044] The second portion **138** has a generally cylindrically shaped exterior. The second portion **138** has a cylindrically shaped exterior where it contacts the first portion **136**, and tapers toward the second end **132** of the first link **124**. The second portion **138** may be shaped in the form of a generally segmented hemisphere at the second end **132** of the first link **124**. According to various embodiments, the diameter of the second portion **138** may be on the order of approximately 9.50 millimeters where it contacts the first portion **136**. Other sizes and shapes are possible.

[0045] The second portion **138** comprises a first surface **140**. The first surface **140** may be considered the outer surface of the second portion **138**. The second portion **138** defines a first groove **142** along the first surface **140**, a second groove **144** along the first surface **140**, and a third groove **146** along the first surface **140**. Each of the first, second and third grooves **142**, **144**, **146** are oblique relative to the longitudinal axis **134** and extend along the first surface **140** toward the second end **132** of the first link **124**. According to various embodiments, each of the grooves **142**, **144**, **146** are oriented at an angle on the order of approximately 15° relative to the longitudinal axis **134**. As shown in FIG. 7C, the first,

second and third grooves **142**, **144**, **146** may be evenly spaced about the first surface **140** of the first link **124**. According to various embodiments, the first, second, and third grooves **142**, **144**, **146** may be configured in the shape of a segmented cylinder. The size of each of the grooves **142**, **144**, **146** may be identical to one another or may be different from one another. For example, according to various embodiments, each of the grooves **142**, **144**, **146** are configured as segments of respective cylinders having diameters on the order of approximately 3.0 millimeters. The first, second and third grooves **142**, **144**, **146** are each configured to facilitate the introduction of various tools or instruments (e.g., ablation tools) into the multi-linked device **10**. The length of the first link **124** may be on the order of approximately 18.5 millimeters. However, one skilled in the art will appreciate that the length or diameter of the first link **124** can vary based on the application.

[0046] The first link **124** also defines a passage **148** extending from the first end **130** to the second end **132** along the longitudinal axis **134** as shown in FIG. 7B. The passage **148** is of a size sufficient to allow the first mechanism **12** to pass therethrough. According to various embodiments, the passage **148** is generally configured as a complex shape that comprises a combination of a segmented cone **150** that extends from the first end **130** toward the second end **132**, and a cylinder **152** that extends from the segmented cone **150** to the second end **132** of the first link **124**. According to various embodiments, the segmented cone **150** has a diameter on the order of approximately 7.0 millimeters at the first end **130** of the first link **124**, and may be tapered at an angle on the order of approximately 45° relative to the longitudinal axis **134**. The cylinder **152** may have a diameter on the order of approximately 5.50 millimeters. Other dimensions are possible.

[0047] The first link **124** also defines a first through-hole **154**, a second through-hole **156**, and a third through-hole **158**. (See FIG. 7C). The first through-hole **154** is substantially parallel to the longitudinal axis **134**, extends from the first portion **136** toward the second end

132, and is positioned between the passage **148** and the first surface **140**. The second through-hole **156** is substantially parallel to the longitudinal axis **134**, extends from the first portion **136** to the second end **132**, and is positioned between the passage **148** and the first surface **140**. The third through-hole **158** is substantially parallel to the longitudinal axis **134**, extends from the first portion **136** to the second end **132**, and is positioned between the passage **148** and the first surface **140**. The first, second and third through-holes **154**, **156**, **158** are generally cylindrically shaped. According to various embodiments, the through-holes **154**, **156**, **158** are evenly spaced from one another as shown in FIG. 7C. The size of each of the through-holes **154**, **156**, **158** may be identical to one another or may be different from one another. For example, according to various embodiments, the respective diameters associated with the through-holes **154**, **156**, **158** may each be on the order of approximately 1.20 millimeters. The first through-hole **154** is configured to receive and surround a cable. The second through-hole **156** is configured to receive and surround a cable. The third through-hole **158** is configured to receive and surround a cable. The first, second and third through-holes **154**, **156**, **158** may serve as guidepaths for movement of the cables.

[0048] FIGS. 8A-8C illustrate various embodiments of one of the intermediate links **128** (outer intermediate link) of the second mechanism **14**. The intermediate link **128** is representative of the other intermediate links **128**. The intermediate link **128** includes a first end **160** and a second end **162**, and defines a longitudinal axis **164** that passes through the center of the first end **160** and the center of the second end **162** as shown in FIG. 8C. The intermediate link **128** may be fabricated from any suitable material. According to various embodiments, the intermediate link **128** is fabricated from a polymer thermosplastic material such as, for example, polysulfone. The intermediate link **128** has a generally bullet-shaped exterior and is described in more detail hereinbelow.

[0049] The intermediate link **128** comprises a first portion **166** and a second portion **168**. The first portion **166** may be considered the proximal portion and the second portion **168** may be considered the distal portion. The first portion **166** may be fabricated integral with the second portion **168**. The first portion **166** has a generally cylindrical shaped exterior, and extends from the first end **160** of the intermediate link **128** toward the second end **162** of the intermediate link **128**. According to various embodiments, the second portion **168** has a generally cylindrically shaped exterior where it contacts the first portion **166**, and tapers toward the second end **162** of the intermediate link **128**. The exterior of the second portion **168** is configured in the form of a generally segmented hemisphere. According to various embodiments, the diameter of the intermediate link **128** is on the order of approximately 9.65 millimeters at the first end **160** thereof. The length of the intermediate link **128** may be on the order of approximately 8.40 millimeters. However, one skilled in the art will appreciate that the dimensions of the intermediate link **128** can vary based on the application.

[0050] The intermediate link **128** also comprises a first surface **170** that extends from the first end **160** of the intermediate link **128** to the second end **162** of the intermediate link **128**, and a second surface **172** that extends from the first end **160** of the intermediate link **128** to the second end **162** of the intermediate link **128**. The first surface **170** may be considered the outer surface of the intermediate link **128**, and the second surface **172** may be considered the inner surface of the intermediate link **128**. The intermediate link **128** also defines a first groove **174** substantially parallel to the longitudinal axis **164** along the second surface **172**, a second groove **176** substantially parallel to the longitudinal axis **164** along the second surface **172**, and a third groove **178** substantially parallel to the longitudinal axis **164** along the second surface **172**. Each of the first, second and third grooves **174**, **176**, **178** extend along the second surface **172** toward the second end **162** of the intermediate link **128**. The first,

second and third grooves **174**, **176**, **178** may be semi-tubular shaped and may be evenly spaced about the second surface **172** of the intermediate link **128** as shown in FIG. 8C. According to various embodiments, the first, second, and third grooves **174**, **176**, **178** may be configured in the shape of a segmented cylinder. The size of each of the grooves **174**, **176**, **178** may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second grooves **174**, **176** are configured as segments of cylinders having diameters on the order of approximately 1.75 millimeters at the first end **160** of the intermediate link **128**, and the third groove **178** is configured as a segment of a cylinder having a diameter on the order of approximately 2.50 millimeters at the first end **160** of the intermediate link **128**. The first, second and third grooves **174**, **176**, **178** are each configured to receive and partially surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**.

[0051] The intermediate link **128** also defines a passage **180** extending from the first end **160** to the second end **162** along the longitudinal axis **164** as shown in FIG. 8B. The passage **180** is of a size sufficient to allow the first mechanism **12** to pass therethrough. According to various embodiments, the passage **180** is generally configured as a complex shape that comprises a combination of a segmented hemisphere **182** that extends from the first end **160** toward the second end **162**, a first segmented cone **184** that extends from the segmented hemisphere **182** toward the second end **162**, a cylinder **186** that extends from the first segmented cone **184** toward the second end **162**, and a second segmented cone **188** that extends from the cylinder **186** to the second end **162** of the intermediate link **128**. According to various embodiments, the segmented hemisphere **182** represents a portion of a sphere having a diameter on the order of approximately 9.65 millimeters, the first segmented cone **184** is tapered at an angle on the order of approximately 15° relative to the longitudinal axis

164, the cylinder **186** has a diameter on the order of approximately 5.50 millimeters, and the second segmented cone **188** is tapered at an angle on the order of approximately 15° relative to the longitudinal axis **164**. The segmented hemisphere **182** of the passage **180** is configured to receive the second end **132** of the first link **124** when the first link **124** is coupled to the intermediate link **128**. Similarly, for a given intermediate link **128**, the segmented hemisphere **182** of the passage **180** is configured to receive the second end **162** of another intermediate link **128** when the other intermediate link **128** is coupled to the given intermediate link **128**.

[0052] The intermediate link **128** also defines a first through-hole **190**, a second through-hole **192**, and a third through-hole **194**. (See FIG. 8C). The first through-hole **190** is substantially parallel to the longitudinal axis **164**, extends from the first portion **166** toward the second end **162**, and is positioned between the passage **180** and the first surface **170**. The second through-hole **192** is substantially parallel to the longitudinal axis **164**, extends from the first portion **166** to the second end **162**, and is positioned between the passage **180** and the first surface **170**. The third through-hole **194** is substantially parallel to the longitudinal axis **164**, extends from the first portion **166** to the second end **162**, and is positioned between the passage **180** and the first surface **170**. The first, second and third through-holes **190**, **192**, **194** are generally cylindrically shaped. According to various embodiments, the through-holes **190**, **192**, **194** are evenly spaced from one another. The size of each of the through-holes **190**, **192**, **194** may be identical to one another or may be different from one another. For example, according to various embodiments, the respective diameters associated with the through-holes **190**, **192**, **194** may each be on the order of approximately 1.25 millimeters. The first through-hole **190** is configured to receive and surround a cable. The second through-hole **192** is configured to receive and surround a cable. The third through-hole **194**

is configured to receive and surround a cable. The first, second and third through-holes **190**, **192**, **194** may serve as guidepaths for movement of the cables.

[0053] As shown in FIG. 8C, the intermediate link **128** also defines first, second and third indents **196**, **198**, **200** at the second end **162** thereof resulting, in part, from the combination of the taper associated with the second portion **168** and the configuration and orientation of the first, second, and third grooves **174**, **176**, **178**. The first, second and third indents **196**, **198**, **200** may be evenly spaced about the second end **162** of the intermediate link **128** as shown in FIG. 8C. The first, second and third indents **196**, **198**, **200** may serve to reduce the pinching or binding of various tools or instruments (e.g., ablation tools) when one intermediate link **128** of the second mechanism **14** is moved relative to another intermediate link **128** coupled thereto.

[0054] The intermediate link **128** also defines fourth, fifth and sixth indents **202**, **204**, **206** at the second end **162** thereof resulting from the combination of the taper associated with the second portion **168** and the configuration and orientation of the first, second, and third through-holes **190**, **192**, **194**. The fourth, fifth and sixth indents **202**, **204**, **206** may be evenly spaced about the second end **162** of the intermediate link **128**, and may be evenly spaced from the first, second and third indents **196**, **198**, **200** as shown in FIG. 8C. The fourth, fifth and sixth indents **202**, **204**, **206** may serve to reduce the pinching or binding of the cables when one intermediate link **128** of the second mechanism **14** is moved relative to another intermediate link **128** coupled thereto.

[0055] According to various embodiments, an intermediate link **128** may also define an opening (not shown) that extends from the second surface **172** or from one of the grooves **174**, **176**, **178** to the first surface **170** of the intermediate link **128**. The intermediate link **128** may have any number of such openings, and any number of the intermediate links **128** may have such openings. Referring to FIGs. 2 and 4, the opening may be utilized as an exit point

for a tool or instrument which may pass from the first end **24** of the multi-linked device **10** toward the second end **26** of the multi-linked device **10**. For such embodiments, the respective intermediate link **128** may be positioned proximate to the second link **126** of the second mechanism **14**. The opening may be oriented at any angle relative to the longitudinal axis **134** of the intermediate link **128**. When the first mechanism **12** is removed from the second mechanism **14**, and a relatively large tool or instrument is advanced from the first end **120** of the second mechanism **14** to the second end **122** of the second mechanism **14**, sufficient room may not exist for a second tool or instrument (e.g., fiber optic cable) to pass through the second end **122** of the second mechanism **14**. For such instances, the second tool or instrument may exit through an opening of one of the intermediate links **128**.

[0056] With the above described structure, the first link **124** may be coupled to the intermediate link **128** by seating the second end **132** of the first link **124** in the segmented hemisphere **182** of the passage **180** of the intermediate link **128**. As the convex configuration of the second end **132** of the first link **124** generally corresponds with the concave configuration of the segmented hemisphere **182** of the passage **180** of the intermediate link **128**, the first link **124** may be coupled to the intermediate link **128** such that the longitudinal axis **134**, the first, second and third grooves **142**, **144**, **146**, and the first, second and third through-holes **154**, **156**, **158** of the first link **124** are respectively aligned with the longitudinal axis **164**, the first, second and third grooves **174**, **176**, **178**, and the first, second and third through-holes **190**, **192**, **194** of the intermediate link **128**. The intermediate link **128** may be moved relative to the first link **124** such that the longitudinal axis **164** of the intermediate link **128** is not aligned with the longitudinal axis **134** of the first link **124**. According to various embodiments, the configuration of the first link **124** and the intermediate link **128** allows for the intermediate link **128** to be moved relative to the first link **124** coupled thereto such that the longitudinal axis **134** of the first link **124** and the longitudinal axis **164** of the intermediate

link **128** are up to approximately 10° out of alignment with one another. Similarly, one intermediate link **128** may be coupled to another intermediate link **128**, and so on, by seating the second end **162** of one intermediate link **128** in the segmented hemisphere **182** of the passage **180** of another intermediate link **128**. As the convex configuration of the second end **162** of the intermediate link **128** generally corresponds with the concave configuration of the segmented hemisphere **182** of the passage **180** of the intermediate link **128**, the intermediate links **128** may be coupled such that the respective longitudinal axes **164**, the respective first, second and third grooves **174**, **176**, **178**, and the respective first, second and third through-holes **190**, **192**, **194** of the intermediate links **128** are aligned. The coupled intermediate links **128** may be moved relative to one another such that the respective longitudinal axes **164** of the coupled intermediate links **128** are not aligned. According to various embodiments, the configuration of the coupled intermediate links **128** allows for one intermediate link **128** to be moved relative to another intermediate link **128** coupled thereto such that the respective longitudinal axes **164** are up to approximately 10° out of alignment with one another.

[0057] FIGS. 9A-9D illustrate various embodiments of the second link **126** (outer distal link) of the second mechanism **14**. The second link **126** includes a first end **208** and a second end **210**, and defines a longitudinal axis **212** that passes through the center of the first end **208** and the center of the second end **210** as shown in FIG. 9C. The second link **126** may be fabricated from any suitable material. According to various embodiments, the second link **126** is fabricated from a thermoplastic material such as, for example, Delrin®.

[0058] The second link **126** comprises a first portion **214** and a second portion **216**. The first portion **214** may be considered the proximal portion and the second portion **216** may be considered the distal portion. The first portion **214** may be fabricated integral with the second portion **216**. The first portion **214** has a generally cylindrical shaped exterior, and extends from the first end **208** of the second link **126** toward the second end **210** of the

second link **126**. According to various embodiments, the diameter of the first portion **214** is on the order of approximately 4.80 millimeters.

[0059] According to various embodiments, the second portion **216** has a generally cylindrically shaped exterior where it contacts the first portion **214**, and tapers toward the second end **210** of the second link **126**. The exterior of the second portion **216** is configured in the form of a generally segmented cone. According to various embodiments, the exterior of the second portion **216** tapers from the first portion **214** to the second end **210** of the second link **126** at an angle on the order of approximately 20° relative to the exterior of the first portion **214**. The length of the second link **126** may be on the order of approximately 15 millimeters. However, one skilled in the art will appreciate that the length of the second link **126** can vary based on the application.

[0060] The second link **126** also comprises a first surface **218** that extends from the first end **208** of the second link **126** to the second end **210** of the second link **126**, and a second surface **220** that extends from the first end **208** of the second link **126** toward the second end **210** of the second link **126**. The first surface **218** may be considered the outer surface of the second link **126**, and the second surface **220** may be considered the inner surface of the second link **126**.

[0061] The second link **126** also defines a first port **222**, a second port **224**, and a third port **226**. (See FIG. 9B). The first port **222** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The second port **224** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The third port **226** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The first, second and third ports **222**, **224**, **226** may be cylindrical shaped and may be evenly spaced about the longitudinal axis **212** of the second link **126** as shown in FIG. 9D. The size of each of the

ports **222**, **224**, **226** may be identical to one another or may be different from one another. For example, according to various embodiments, the first and second ports **222**, **224** are configured as cylinders having diameters on the order of approximately 1.50 millimeters, and the third port **226** is configured as a cylinder having a diameter on the order of approximately 2.50 millimeters. Other dimensions are possible. The first, second and third ports **222**, **224**, **226** are each configured to receive and surround any of a variety of tools or instruments (e.g., ablation tools) which may pass from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**.

[0062] The second link **126** also defines a first through-hole **228**, a second through-hole **230**, and a third through-hole **232**. (See FIG. 9B). The first through-hole **228** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The second through-hole **230** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The third through-hole **232** extends from the second surface **220** to the first surface **218** and is substantially parallel to the longitudinal axis **212**. The first, second and third through-holes **228**, **230**, **232** are generally cylindrically shaped. According to various embodiments, the through-holes **228**, **230**, **232** are evenly spaced from one another as shown in FIG 9D. The size of each of the through-holes **228**, **230**, **232** may be identical to one another or may be different from one another. For example, according to various embodiments, the respective diameters associated with the through-holes **228**, **230**, **232** may each be on the order of approximately 1.25 millimeters. The first through-hole **228** is configured to receive and surround a cable. The second through-hole **230** is configured to receive and surround a cable. The third through-hole **232** is configured to receive and surround a cable.

[0063] The second link **126** also defines a recess **234** that extends from the first end **208** toward the second end **210** along the longitudinal axis **212** as shown in FIG. 9C.

According to various embodiments, the recess **234** is generally configured as a complex shape that comprises a combination of a first segmented hemisphere **236** that extends from the first end **208** toward the second end **210**, and a second segmented hemisphere **238** that extends from the first segmented hemisphere **236** toward the second end **210** of the second link **126**. According to various embodiments, the first segmented hemisphere **236** represents a portion of a sphere having a diameter on the order of approximately 9.50 millimeters, and the second segmented hemisphere **238** represents a portion of a sphere having a diameter on the order of approximately 7.0 millimeters. The first segmented hemisphere **236** of the recess **234** is configured to receive the second end **162** of an intermediate link **128** when the intermediate link **128** is coupled to the second link **126**.

[0064] With the above described structure, an intermediate link **128** may be coupled to the second link **126** by seating the second end **162** of the intermediate link **128** in the first segmented hemisphere **236** of the recess **234** of the second link **126**. As the convex configuration of the second end **162** of the intermediate link **128** generally corresponds with the concave configuration of the first segmented hemisphere **236** of the recess **234** of the second link **126**, the intermediate link **128** may be coupled to the second link **126** such that the longitudinal axis **164**, the first, second and third grooves **174**, **176**, **178**, and the first, second and third through-holes **190**, **192**, **194** of the intermediate link **128** are respectively aligned with the longitudinal axis **212**, the first, second and third ports **222**, **224**, **226**, and the first, second and third through-holes **228**, **230**, **232** of the second link **126**. The second link **126** may be moved relative to the intermediate link **128** coupled thereto such that the respective longitudinal axes **164**, **212** are not aligned. According to various embodiments, the configuration of the second link **126** allows for an intermediate link **128** coupled thereto to be moved relative to the second link **126** such that the respective longitudinal axes **164**, **212** are up to approximately 10° out of alignment with one another.

[0065] When the first mechanism **12** is inserted into the second mechanism **14**, the first second and third grooves **70, 72, 74** of the intermediate links **32** of the first mechanism **12** may be substantially aligned with the first, second and third grooves **174, 176, 178** of the intermediate links **128** of the second mechanism **14**, and the first, second and third grooves **98, 100, 102** of the second link **30** of the first mechanism **12** may be substantially aligned with the first, second and third ports **222, 224, 226** of the second link **126** of the second mechanism **14**. The combination of the first grooves **70** of the intermediate links **32** of the first mechanism **12** aligned with the first grooves **174** of the intermediate links **128** of the second mechanism **14** allows the respective first grooves **70, 174** to collectively serve as a first working port that is substantially aligned with the first port **222** of the second link **126** of the second mechanism **14**. The first groove **70** may be considered the inner portion of the first working port and the first groove **174** may be considered the outer portion of the first working port.

[0066] Similarly, the combination of the second grooves **72** of the intermediate links **32** of the first mechanism **12** aligned with the second grooves **176** of the intermediate links **128** of the second mechanism **14** allows the respective second grooves **72, 176** to collectively serve as a second working port that is substantially aligned with the second port **224** of the second link **126** of the second mechanism **14**, and the combination of the third grooves **74** of the intermediate links **32** of the first mechanism **12** aligned with the third grooves **178** of the intermediate links **128** of the second mechanism **14** allows the respective third grooves **74, 178** to collectively serve as a third working port that is substantially aligned with the third port **226** of the second link **126** of the second mechanism **14**. The second groove **72** may be considered the inner portion of the second working port and the second groove **176** may be considered the outer portion of the second working port. The third groove **74** may be considered the inner portion of the third working port and the third groove **178** may be

considered the outer portion of the third working port. The first, second and third working ports may be utilized to pass various tools or instruments (e.g., ablation tools) from the first end **24** of the multi-linked device **10** to the second end **26** of the multi-linked device **10**. For the exemplary sizes described hereinabove, the third working port is larger than the first and second working ports. Accordingly, the third working port may be utilized to carry a particular tool or instrument that is too large to be carried by the first or second working ports.

[0067] When the respective grooves **70, 72, 74, 174, 176, 178** of the respective intermediate links **32, 128** are aligned and collectively surround the various tools and instruments, the combination of the grooves **70, 72, 74, 174, 176, 178** and the tools and instruments may serve to limit or prevent the rotation of the first mechanism **12** relative to the second mechanism **14**.

[0068] As the diameter of the passage **180** of the intermediate link **128** of the second mechanism **14** is larger than the diameter of any portion of the first mechanism **12**, a three-dimensional space **240** exists between the first mechanism **12** and the second mechanism **14** when the first mechanism **12** is received by the second mechanism **14** (See FIG. 1B). According to various embodiments, the space **240** may be utilized to carry wiring, tools, instruments, etc. from the first end **24** of the multi-linked device **10** toward the second end **26** of the multi-linked device **10**.

[0069] According to various embodiments, one or more steering cables may be fabricated from any suitable material. For example, according to various embodiments, the steering cables may be fabricated from a polyethylene fiber cable such as, for example, Spectra®. The steering cables may be utilized to control the movement of the multi-linked device **10**. For example, by applying a substantially equal tension to each of the steering cables, the first mechanism **12** and/or second mechanism **14** may be steered in a direction

such that the respective longitudinal axes **38, 62, 90, 134, 164, 212** of each of the links **28, 30, 32, 124, 126, 128** are all aligned. By applying a different tension to one or more of the steering cables, the first mechanism **12** and/or the second mechanism **14** may be steered in a direction such that the respective longitudinal axes **38, 62, 90, 134, 164, 212** of each of the links **28, 30, 32, 124, 126, 128** are not all aligned. The cables **16, 18, 20** may also be utilized to control the relative state of the second mechanism **14**. For example, when a uniform tension is applied to the steering cables, the second mechanism **14** may be placed in a "rigid" state, and when a tension is removed from the steering cables, the second mechanism **14** may be placed in a "limp" state. According to various embodiments, one or more of the steering cables may be attached at the first end **130** of the first link **124** of the second mechanism **14** to respective pullies (not shown) by, for example, respective stopper knots. The steering cables may be attached to the second end **132** of the second link **126** of the second mechanism **14** by, for example, respective stopper knots. One skilled in the art will appreciate that, according to other embodiments, the "rigid" and "limp" states may be achieved by subjecting the first and/or second mechanisms **12, 14** to a twisting force, or by any other manner known in the art.

[0070] According to various embodiments, one or more tensioning cables may be fabricated from any suitable material. For example, according to various embodiments, the tensioning cables may be fabricated from a polyethylene fiber cable such as, for example, Spectra®. The tensioning cables may be utilized to control the relative state of the first mechanism **12**. For example, when the tensioning cable is drawn tight, the first mechanism **12** may be placed in a "rigid" state, whereas when the tensioning cable is let loose, the first mechanism **12** may be placed in a "limp" state. According to various embodiments, the tensioning cable may be attached at the first end **34** of the first link **28** of the first mechanism **12** to a pully (not shown) by, for example, a stopper knot. The tensioning cable may be

attached to the second end **88** of the second link **30** of the first mechanism **12** by, for example, a stopper knot.

[0071] FIG. 10 illustrates various embodiments of a motion sequence of the steerable multi-linked device **10**. At the start of the sequence, the second mechanism **14** surrounds the first mechanism **12** as shown in step "a" of FIG. 10, the longitudinal axes **38**, **62**, **90** of the links **28**, **30**, **32** of the first mechanism **12** are substantially aligned with the respective longitudinal axes **134**, **164**, **212** of the links **124**, **126**, **128** of the second mechanism, and the second end **26** of the first mechanism **12** is at substantially the same position as the second end **122** of the second mechanism **14**. A tensioning cable is pulled tight, thereby placing the first mechanism **12** in the rigid mode. The steering cables are not pulled tight, thereby placing the second mechanism **14** in the limp mode.

[0072] The second mechanism **14** is then advanced so that its second link **126** is positioned approximately one link ahead of the second end **24** of the first mechanism **12** as shown in step "b" of FIG. 10. The cables **16**, **18**, **20** may be utilized to orient the second link **126** to a particular orientation, where the longitudinal axis **134** of the first link **124** is no longer aligned with the longitudinal axes **164** of the intermediate links **128** of the second mechanism **14** or the longitudinal axis **90** of the second link **30** of the first mechanism **12**. After the second link **126** is in the desired position and orientation, the steering cables are pulled with identical force in order to place the second mechanism **14** in the rigid mode, thereby preserving the position and orientation of the second mechanism **14**.

[0073] The pulling force of the tensioning cable is then released to place the first mechanism **12** in the limp mode. After the first mechanism **12** is placed in the limp mode, the first mechanism **12** is advanced so that its second link **30** is at substantially the same position as the second end **122** of the second mechanism **14** as shown in step "c" of FIG. 10. After the second link **30** of the first mechanism **12** is in the desired position and orientation,

the tensioning cable is pulled tight to place the first mechanism **12** back in the rigid mode, thereby preserving the position and orientation of the first mechanism **12**.

[0074] The pulling forces of the steering cables are then released to place the second mechanism **14** back in the limp mode. After the second mechanism **14** is placed back in the limp mode, the second mechanism **14** is advanced so that its second link **126** is once again positioned approximately one link ahead of the second end **26** of the first mechanism **12** as shown in step “d” of FIG. 10. After the second link **126** is in the desired position and orientation, the steering cables are pulled with identical force in order to place the second mechanism **14** in the rigid mode, thereby preserving the position and orientation of the second mechanism **14**.

[0075] The pulling force of the tensioning cable is then released to place the first mechanism **12** back in the limp mode. After the first mechanism **12** is placed back in the limp mode, the first mechanism **12** is advanced so that its second link **30** is once again at substantially the same position as the second end **122** of the second mechanism **14** as shown in step “e” of FIG. 10. After the second link **30** of the first mechanism **12** is in the desired position and orientation, the tensioning cable is pulled tight to place the first mechanism **12** back in the rigid mode, thereby preserving the position and orientation of the first mechanism **12**. The general motion sequence described hereinabove, may be repeated any number of times, and the second link **126** of the second mechanism **14** may be advancing in any direction and orientation. One skilled in the art will appreciate that any number of motion sequences may be utilized with the multi-linked device **10**. For example, according to various embodiments, the second mechanism **14** may advance any number of links ahead of the first mechanism **12**.

[0076] The exemplary sizes described hereinabove are generally relative to each other, and one skilled in the art will appreciate that the multi-linked device **10** can be scaled

up or scaled down. For example, although the diameter at the largest portion of the intermediate link **128** of the multi-linked device **10** is on the order of approximately 9.65 millimeters for the embodiments described hereinabove, one skilled in the art will appreciate that, for other embodiments, the intermediate link **128** can be scaled down such that the diameter at the largest portion of the intermediate link **128** of the multi-linked device **10** is on the order of approximately 1.0 millimeter. For such embodiments, each of the other components of the multi-linked device **10** would also be proportionally scaled down.

[0077] The combination of the unique configuration of the respective links **28**, **30**, **32** which comprise the first mechanism **12** and the unique configuration of the respective links **124**, **126**, **128** which comprise the second mechanism **14** provides the multi-linked device **10** with the ability to traverse a path defined by the circumference of a circle having a relatively small radius. For example, for the exemplary sizes described hereinabove, the multi-linked device **10** can traverse a path defined by the circumference of a circle having a radius on the order of approximately 45 millimeters. An example of the multi-linked device **10** navigating such tight curvatures is shown in FIG. 11. For embodiments, where the largest portion of the intermediate link **128** of the multi-linked device **10** is on the order of approximately 1.0 millimeter, the multi-linked device **10** can traverse a path defined by the circumference of a circle having a radius significantly smaller than 45 millimeters. One skilled in the art will appreciate that the ability to navigate such tight curvatures makes the multi-linked device **10** suitable for use in a number of different minimally invasive procedures, both in luminal spaces and in intracavity spaces.

[0078] FIG. 12 illustrates various embodiments of a portion of a steerable multi-linked device **10**. The device **10** may include one or more reinforcing members **302** in contact with at least a portion of one or more respective intermediate links **128** (outer intermediate link) of the second mechanism **14**. According to various embodiments, the first

link **28** may include one or more reinforcing members **302** in contact with at least a portion of the first link **28**. Similarly, the second link **30** may include one or more reinforcing members **302** in contact with at least a portion of the second link **30**. In various embodiments, the reinforcing member **302** may be a circumferentially reinforcing member.

[0079] In various embodiments, the reinforcing member **302** may be fabricated from any suitable material. For example, a reinforcing member **302** may be fabricated from a polymer thermoplastic material, a mesh, a shrink tubing, a metal, a fiber, etc. According to various embodiments, the reinforcing member **302** may be fabricated from a material comprising a plurality of fibers that may be laminated or otherwise embedded in the material. The fibers may be aligned such that they lie in a substantially circumferential configuration. In various embodiments, the fiber may include a glass, a nylon, etc.

[0080] The reinforcing member **302** may be connected to an intermediate link **128**, a first link **28** and/or a second link **30** in any suitable manner. According to various embodiments, the reinforcing member **302** may be press-fit to a first surface **170** of an intermediate link **128** proximate the first end **160** thereof. According to other embodiments, the reinforcing member **302** may be formed integral with the intermediate link **128** proximate the first end **160** thereof. According to various embodiments, the reinforcing member may be press-fit to a first surface **44** of the first link **28**. The reinforcing member may be formed integral with the first link **28**. Similarly, the reinforcing member **302** may be press-fit to a surface of the second link **30**. Alternatively, the reinforcing member **302** may be formed integral with the second link **30**.

[0081] The reinforcing member **302** may be of any suitable size, and may operate to reduce stresses experienced by one or more links when forces are applied to the cables.

[0082] In various embodiments, a reinforcing member **302** may extend from the first end **160** of an intermediate link **128** toward the second end **162** of the intermediate link **128**.

The height of a reinforcing member **302** and the surface area of the intermediate link that is surrounded by the reinforcing member **302** may be dependent on one or more of the thickness of the reinforcing member **302** and the diameter of the device **10**. For example, a reinforcing member **302** having a certain thickness may surround less surface area of an intermediate link **128** than a reinforcing member **302** having a smaller thickness. In an embodiment, a reinforcing member **302** may surround at least ten percent of the surface area of an intermediate link **128**. According to various embodiments, reinforcing members **302** on the first link **28** and/or the second link **30** may have similar configurations.

[0083] According to various embodiments, one or more reinforcing members **302** may interfere with the range of motion of a joint. A joint may be the point where two adjacent links meet. As such, the one or more reinforcing members **302** may mechanically limit the range of motion of a joint. FIG. 13 illustrates an exemplary mechanical limit according to various embodiments. As illustrated, the wall thickness **1300** of the reinforcing member **302** may be held constant while the longitudinal length **1305** of the reinforcing member **302** may be increased to the point where the reinforcing member **302** interferes with the motion of the adjacent link **1310**.

[0084] As illustrated by FIG. 14, a similar result may be achieved by increasing the wall thickness **1400** of a reinforcing member **302** while keeping the longitudinal length **1405** of the reinforcing member **302** constant. As illustrated, the wall thickness **1400** may be increased to the point that the reinforcing member may interfere with the motion of adjacent links **1410**.

[0085] According to various embodiments, one or more reinforcing members **302** may mechanically limit the range of motion of a joint by increasing both the wall thickness of the reinforcing member and the longitudinal length of the reinforcing member **302**.

[0086] According to various embodiments, one or more reinforcing members similar to the reinforcing member **302** may surround and be in contact with one or more of the respective intermediate links **32** (inner intermediate link) of the first mechanism **12**.

[0087] According to various embodiments, one or more reinforcing members similar to the reinforcing member **302** may surround and be in contact with one or more of the respective intermediate links **128** (outer intermediate link) of the second mechanism **14** and the respective intermediate links **32** (inner intermediate link) of the first mechanism **12**.

[0088] While several embodiments of the invention have been described herein by way of example, those skilled in the art will appreciate that various modifications, alterations, and adaptations to the described embodiments may be realized. Accordingly, the scope of the claims should not be limited by the specific embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

J. CLAIMS

What Is Claimed Is:

1. A steerable multi-linked device, comprising:
 - a first multi-linked mechanism;
 - a second multi-linked mechanism; and
 - a plurality of steering cables connected to the second multi-linked mechanism, wherein the second multi-linked mechanism concentrically surrounds the first multi-linked mechanism, and
 - wherein the second multi-linked mechanism comprises a plurality of links, wherein at least one of the plurality of links comprises a reinforcing member that surrounds at least a portion of the at least one of the plurality of links, wherein at least a portion of the reinforcing member extends from a first end of the at least one of the plurality of links toward a joint positioned between the at least one of the plurality of links and an adjacent link, wherein the reinforcing member has a wall thickness that limits a range of motion of the joint.
2. The device of claim 1, wherein the reinforcing member is connected to a first surface of the at least one of the plurality of links.
3. The device of claim 1, wherein the reinforcing member is formed integral with the at least one of the plurality of links.
4. The device of claim 1, wherein the reinforcing member is comprised of metal.
5. The device of claim 1, wherein a longitudinal length associated with the reinforcing member is such that the reinforcing member interferes with the range of motion of the joint.
6. The device of claim 1, wherein the reinforcing member surrounds at least ten percent of the at least one of the plurality of links.
7. The device of claim 1, wherein the reinforcing member is comprised of at least one of the following:
 - a polymer thermoplastic material;
 - a fiber; and

a mesh.

8. The device of claim 1, wherein at least one of the first multi-linked mechanism and the second multi-linked mechanism comprises a plurality of reinforcing members.
9. The device of claim 1, wherein the reinforcing member is a circumferentially reinforcing member.
10. The device of claim 1, wherein the first multi-linked mechanism comprises a plurality of links, wherein at least one of the plurality of links of the first multi-linked mechanism comprises a reinforcing member that surrounds at least a portion of the link.

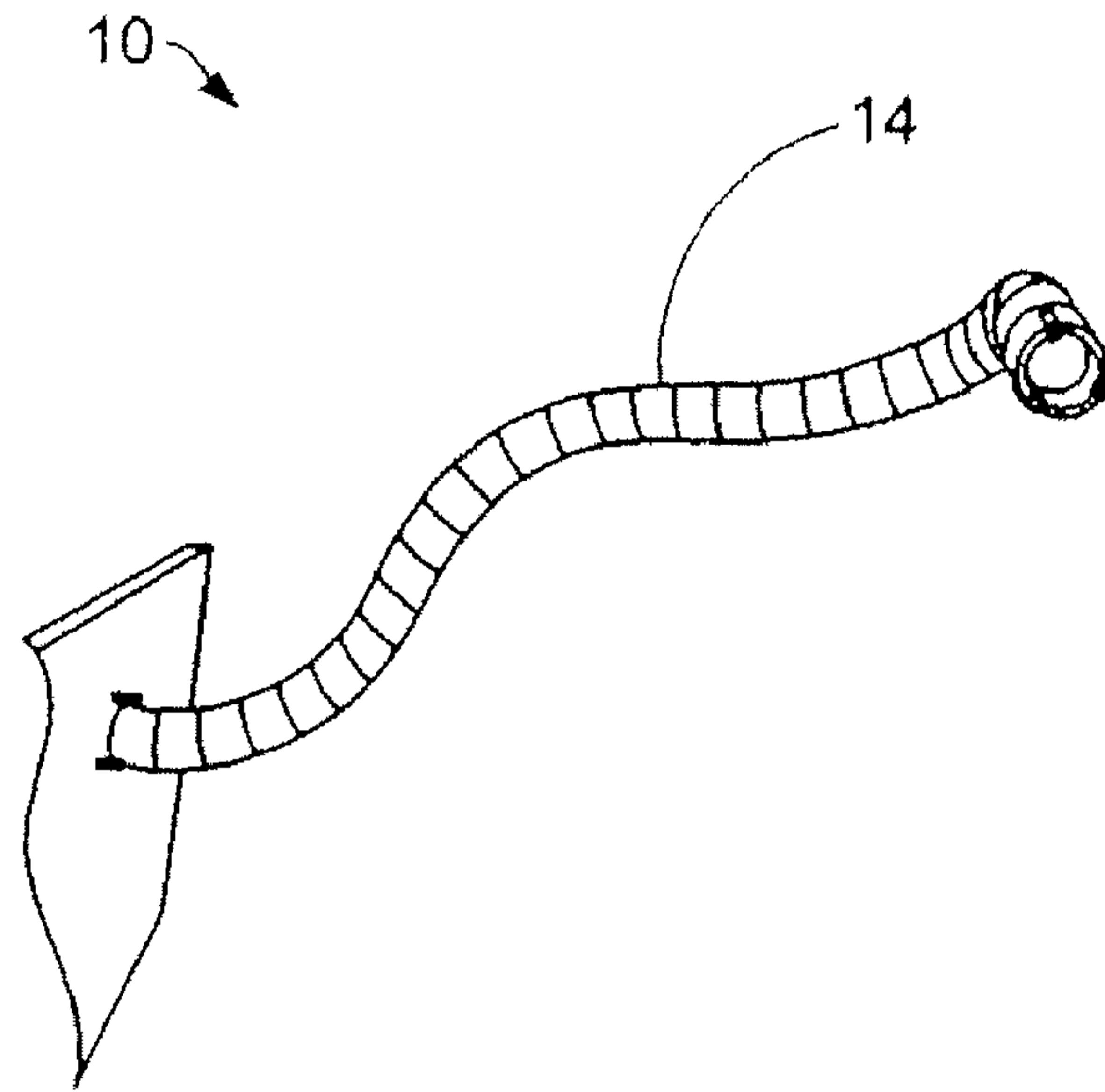


FIG. 1A

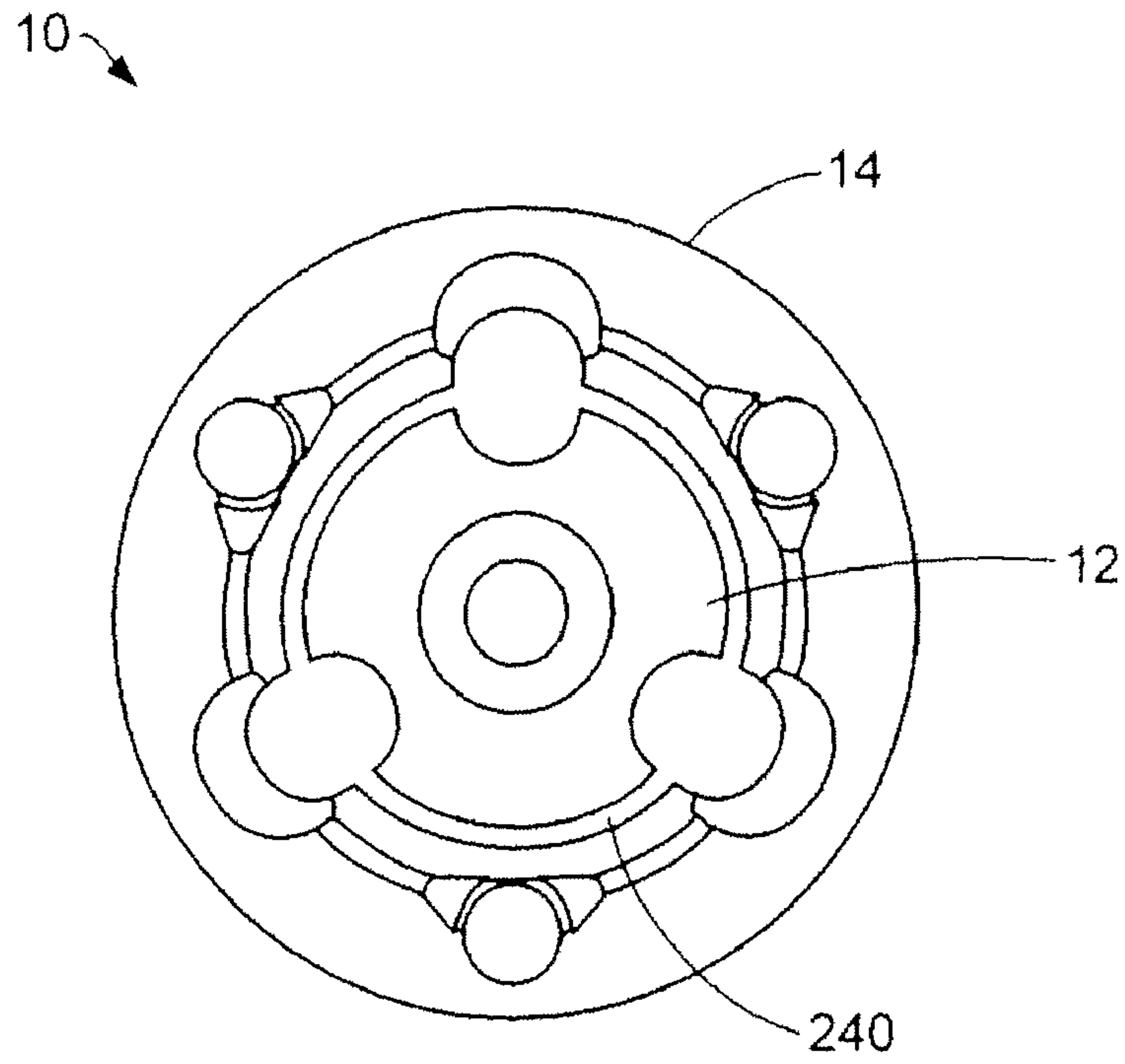


FIG. 1B

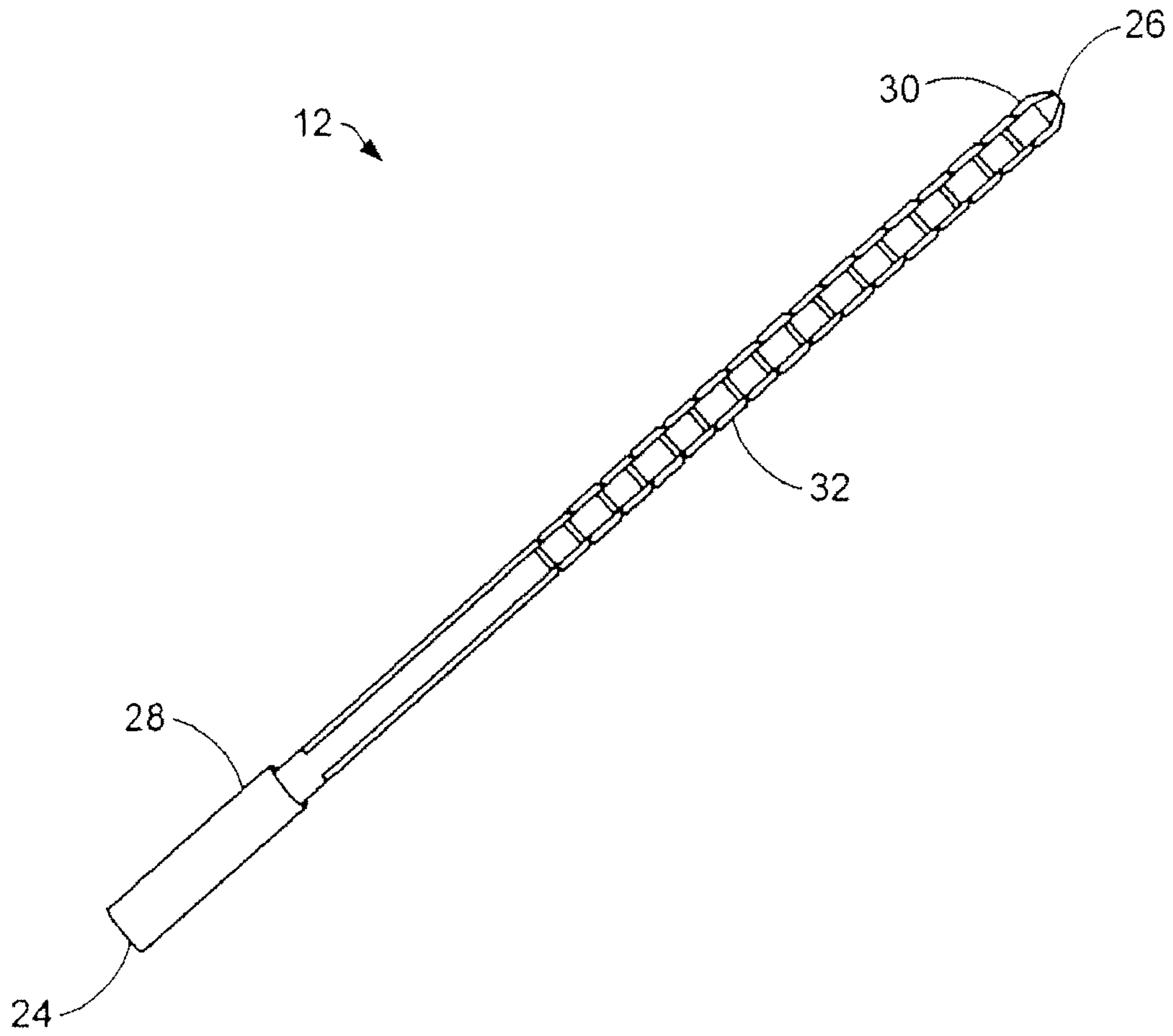


FIG. 2

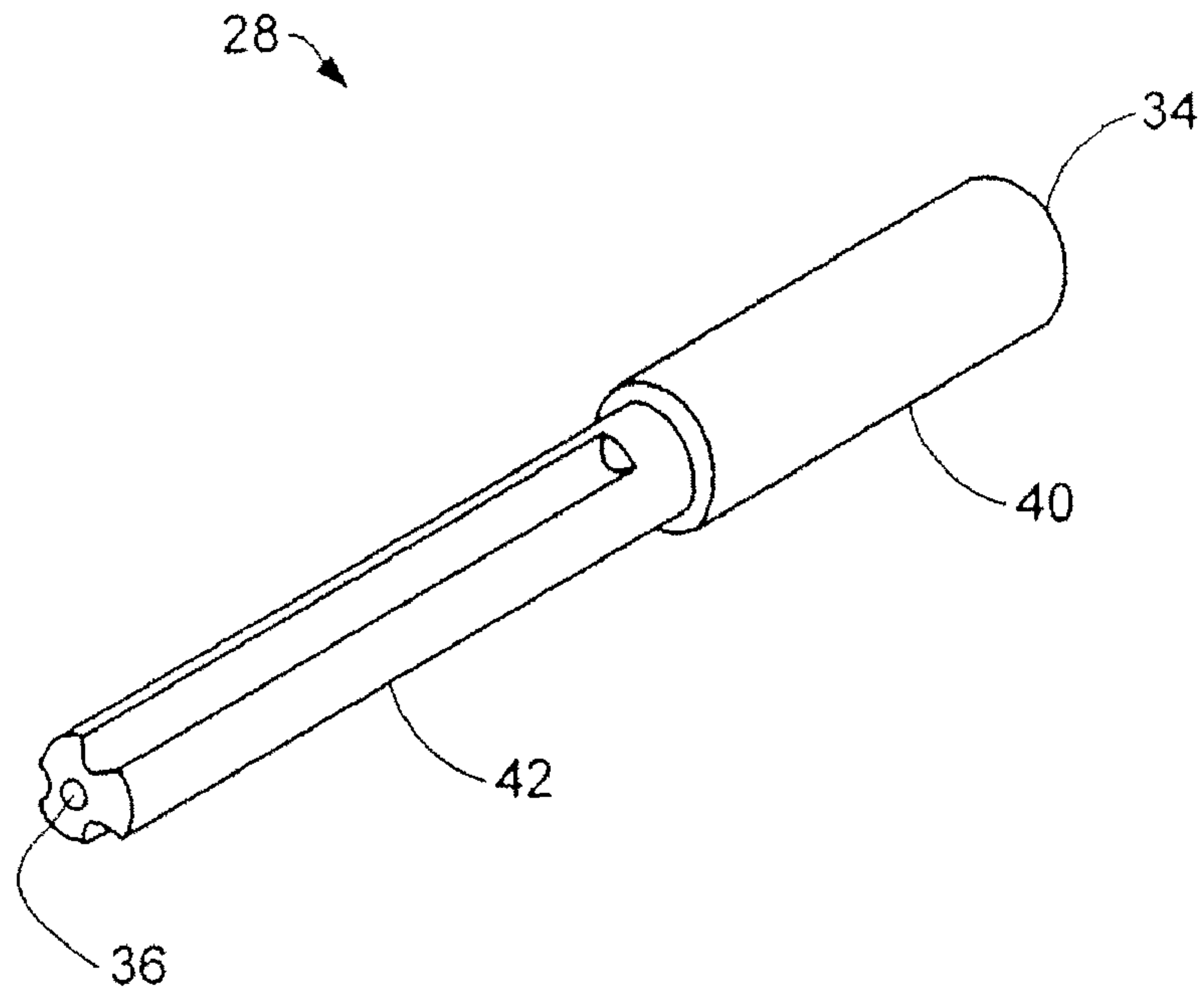


FIG. 3A

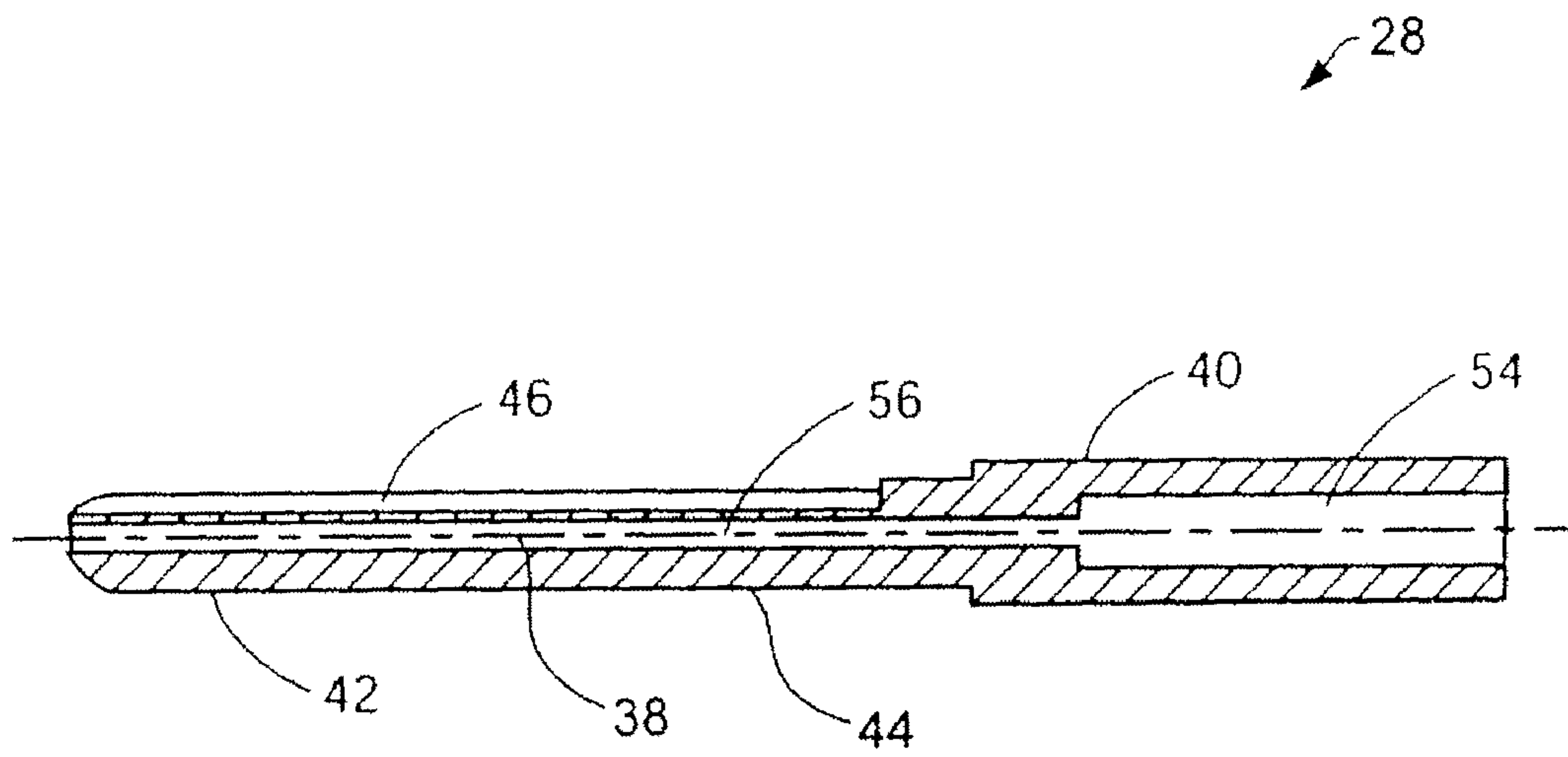


FIG. 3B

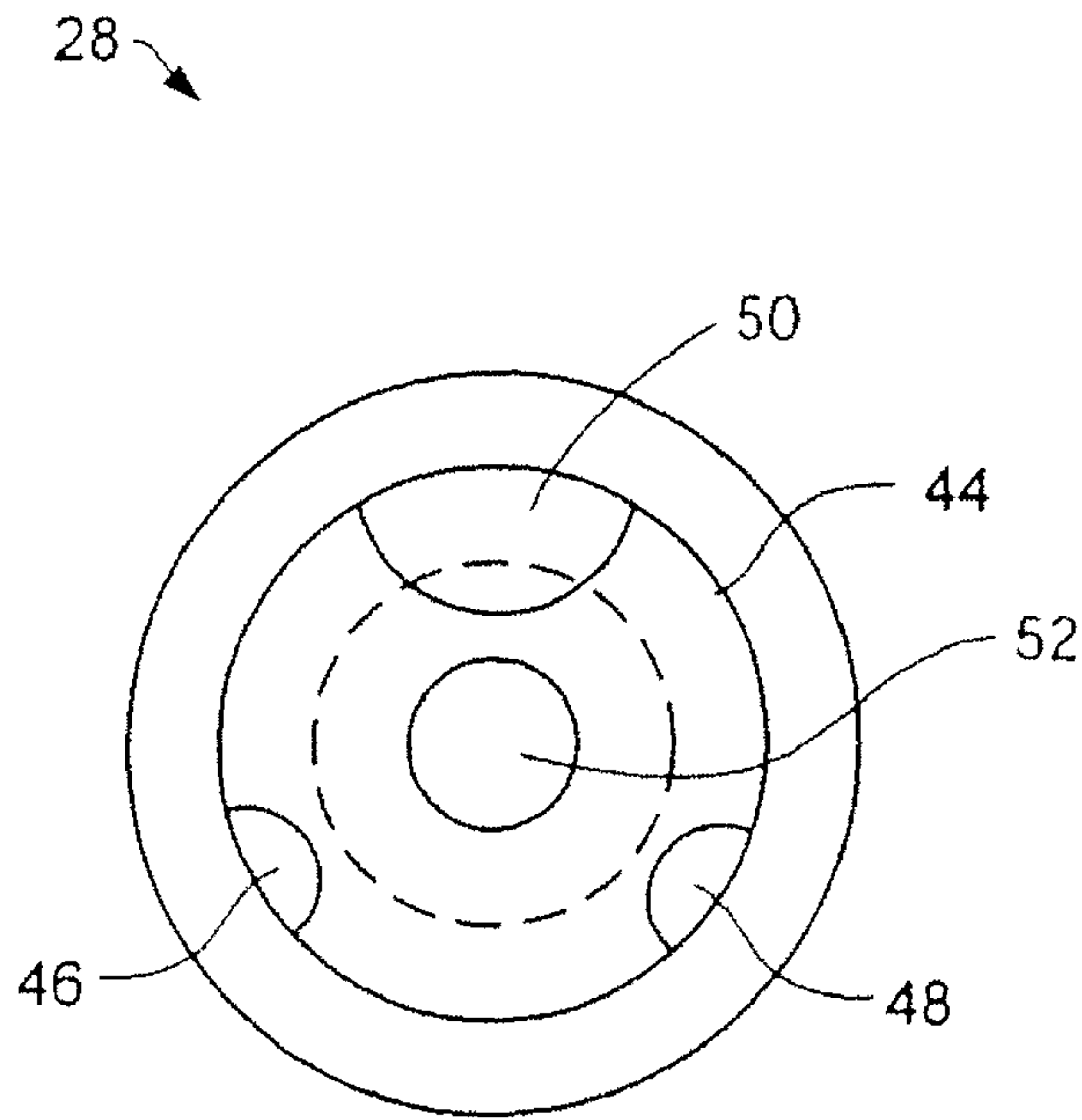


FIG. 3C

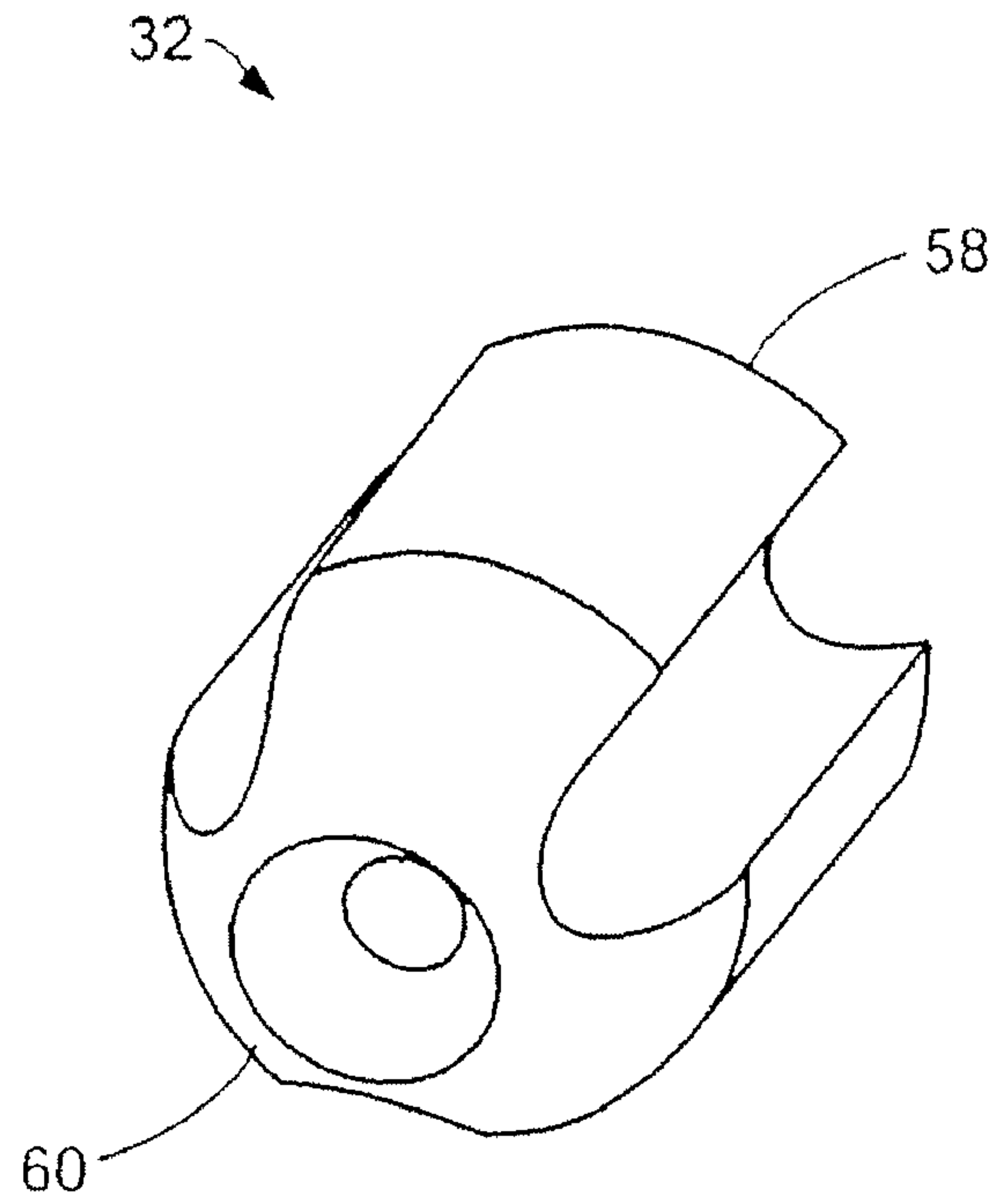


FIG. 4A

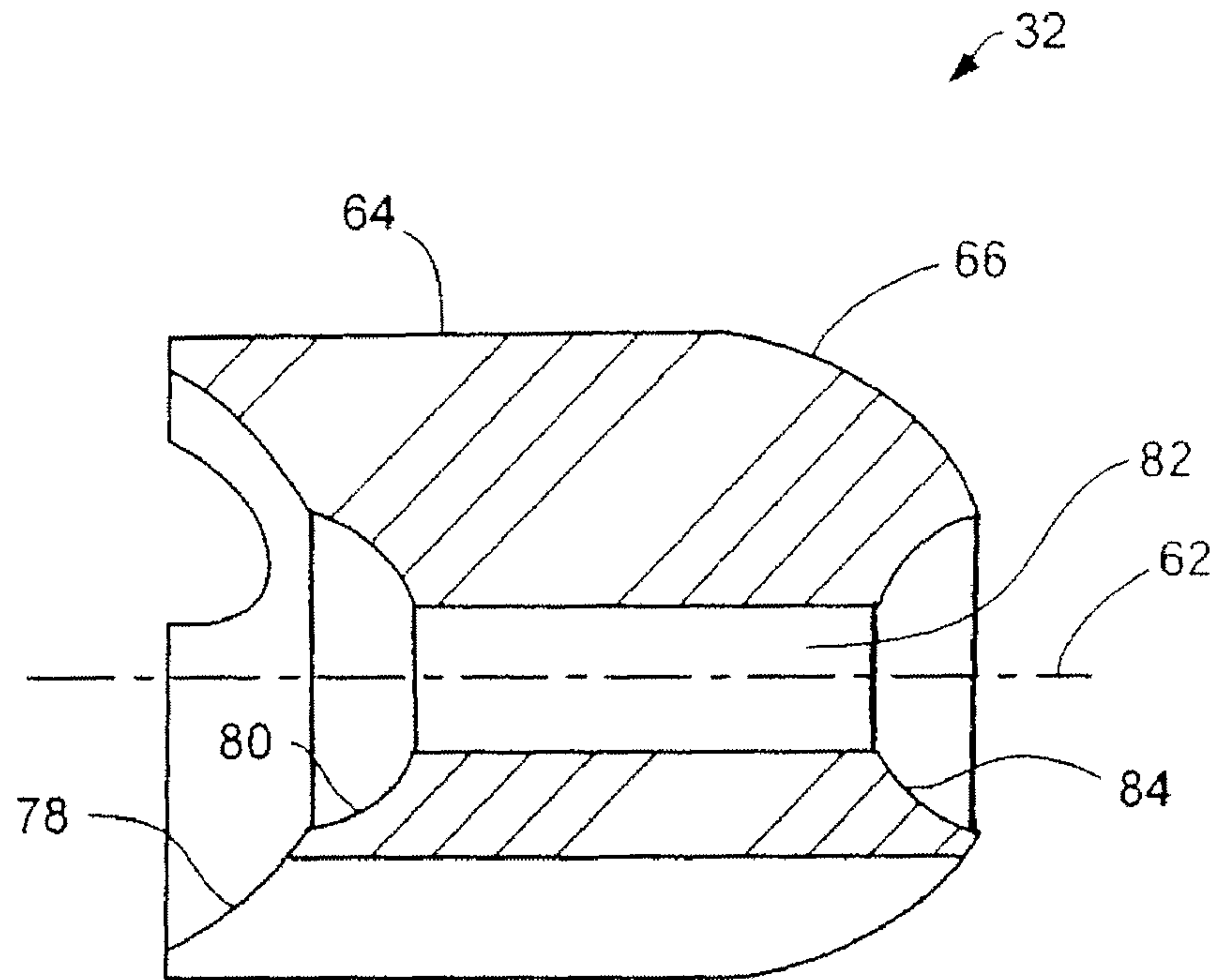


FIG. 4B

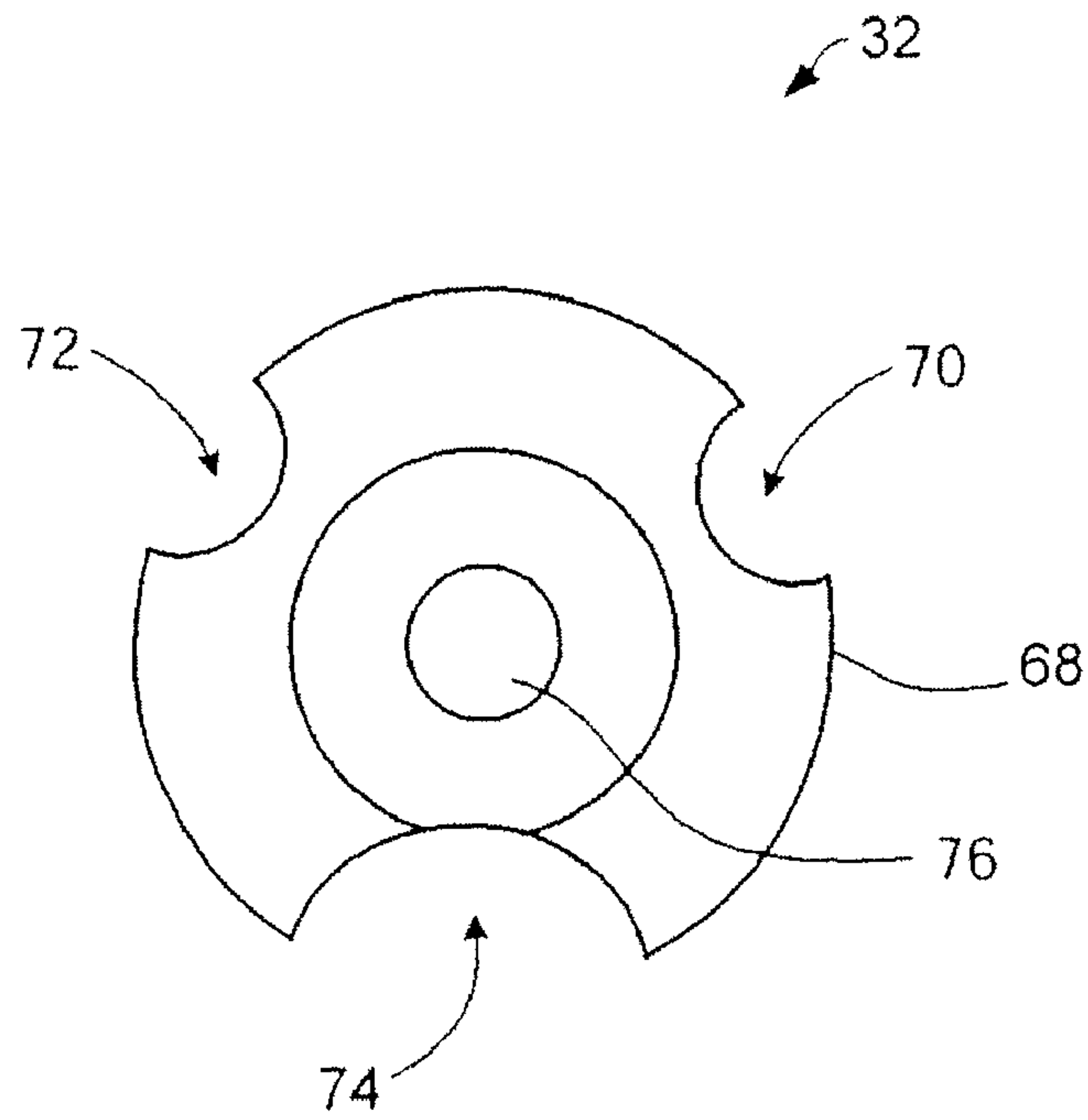


FIG. 4C

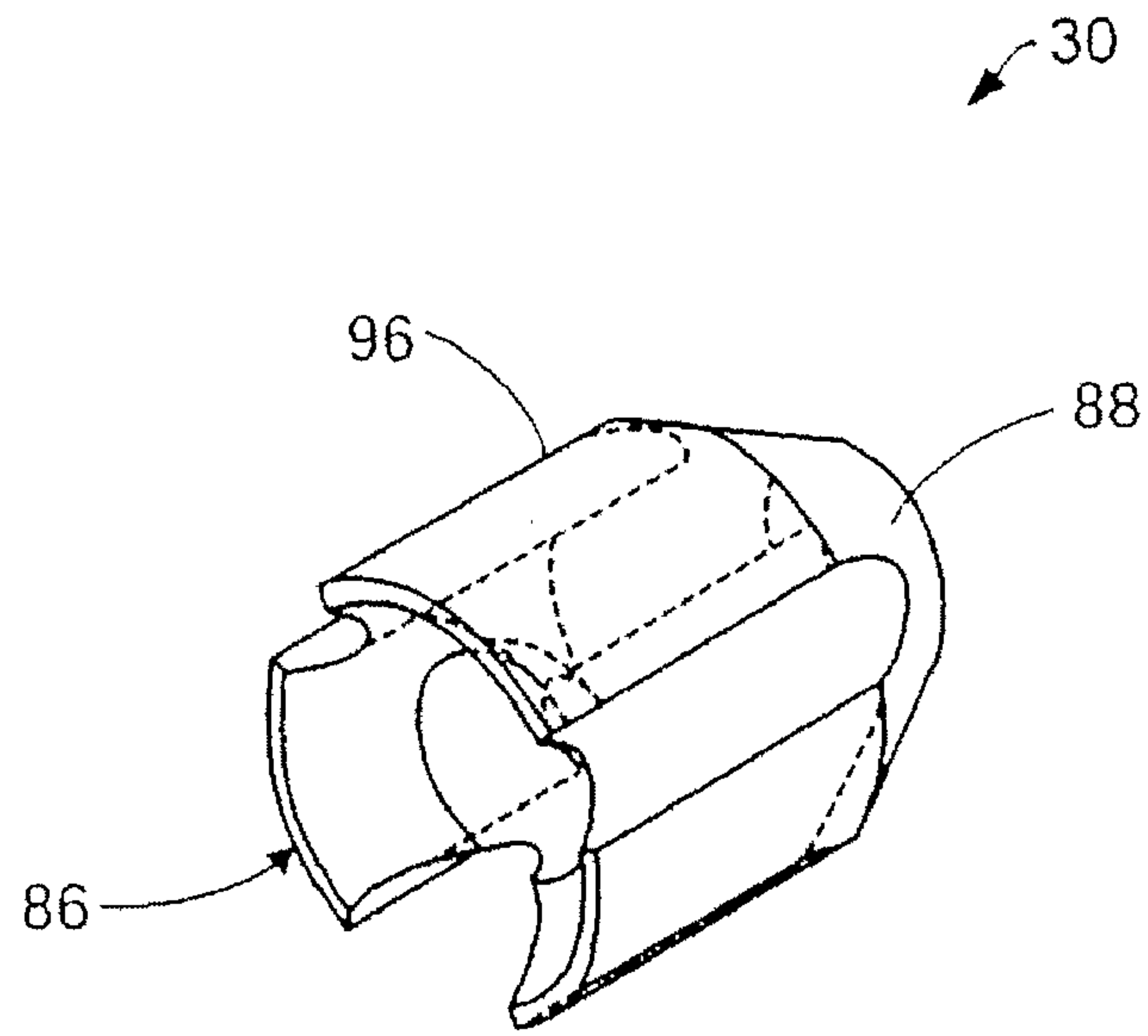


FIG. 5A

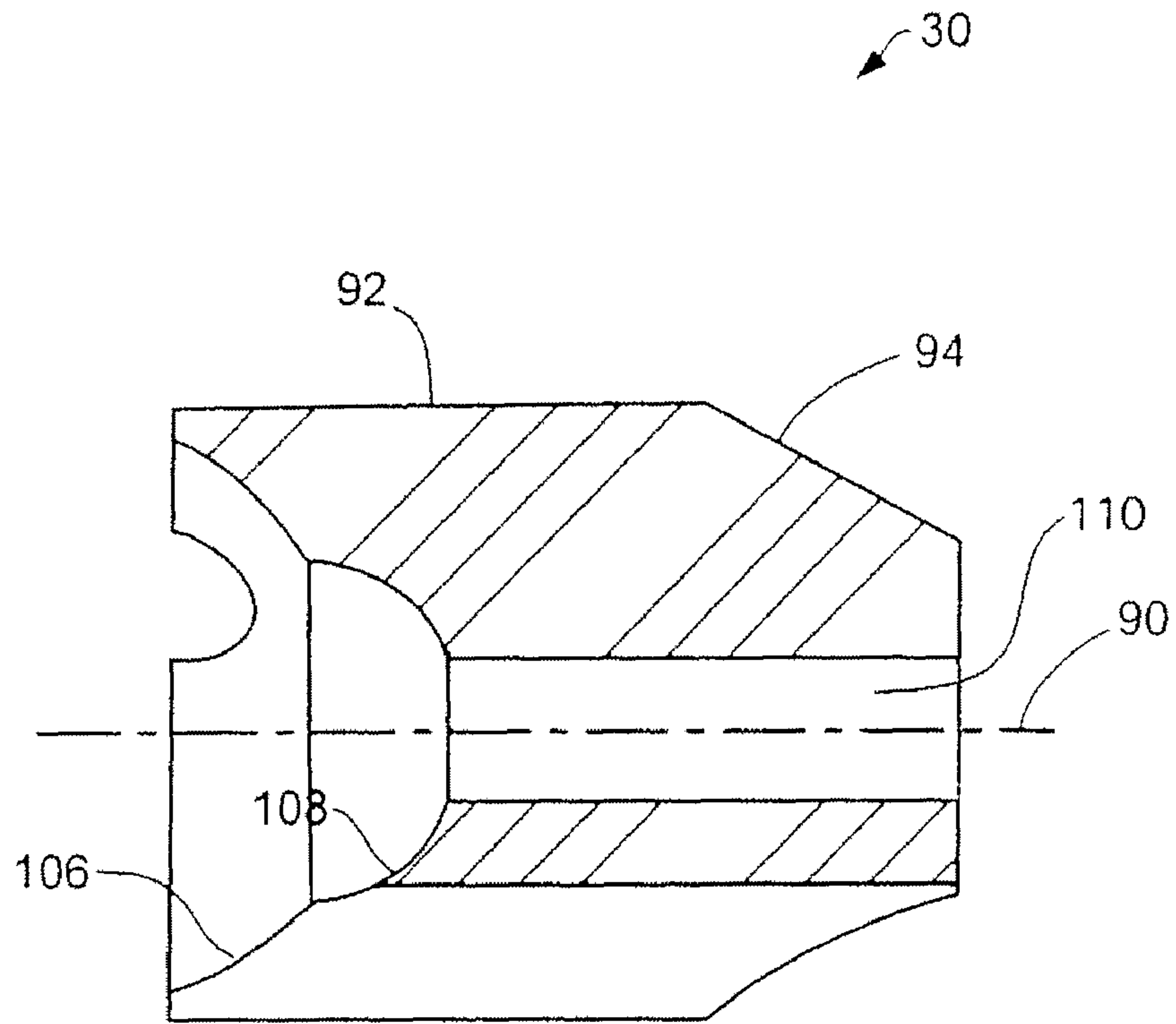


FIG. 5B

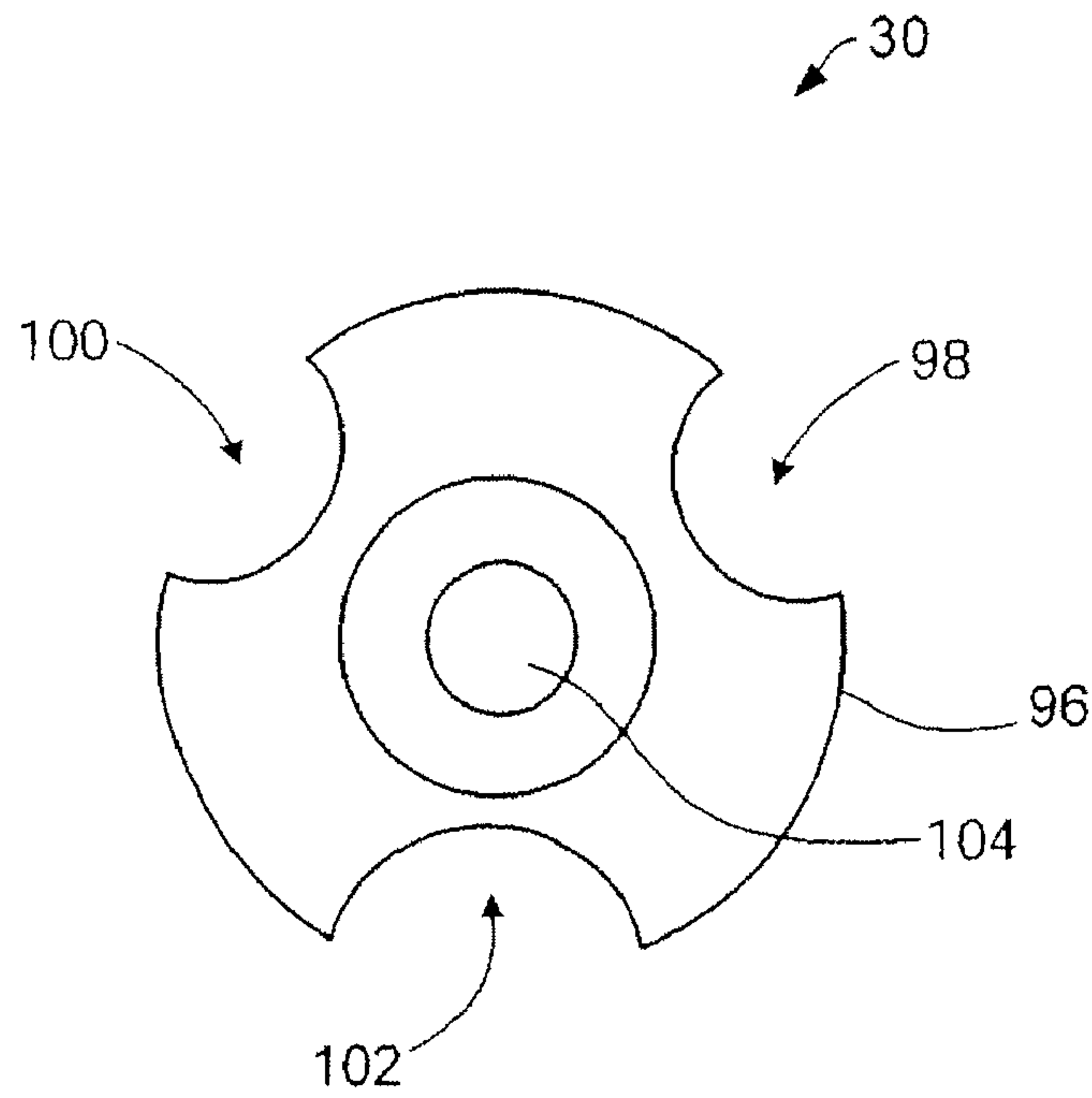


FIG. 5C

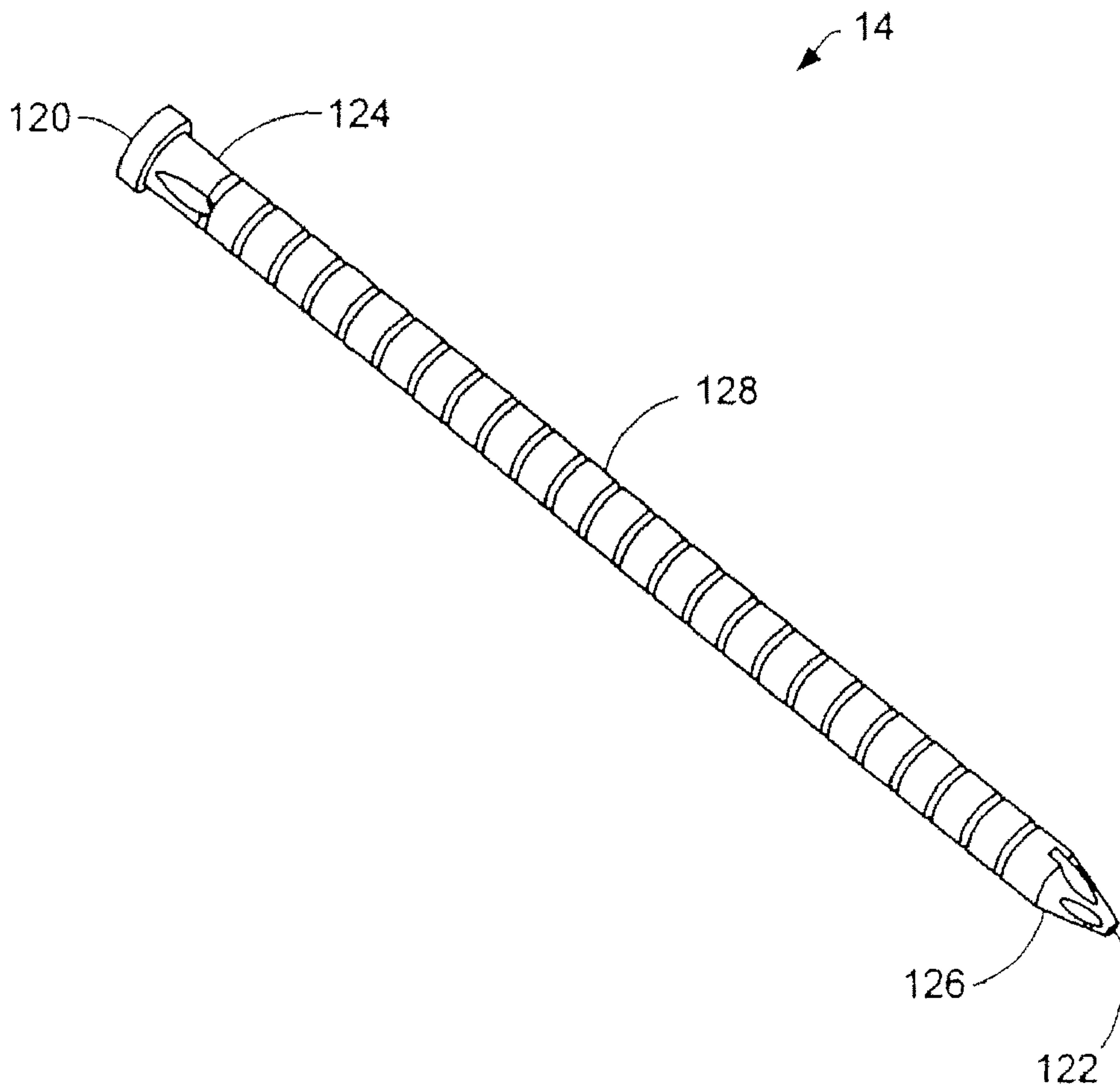


FIG. 6

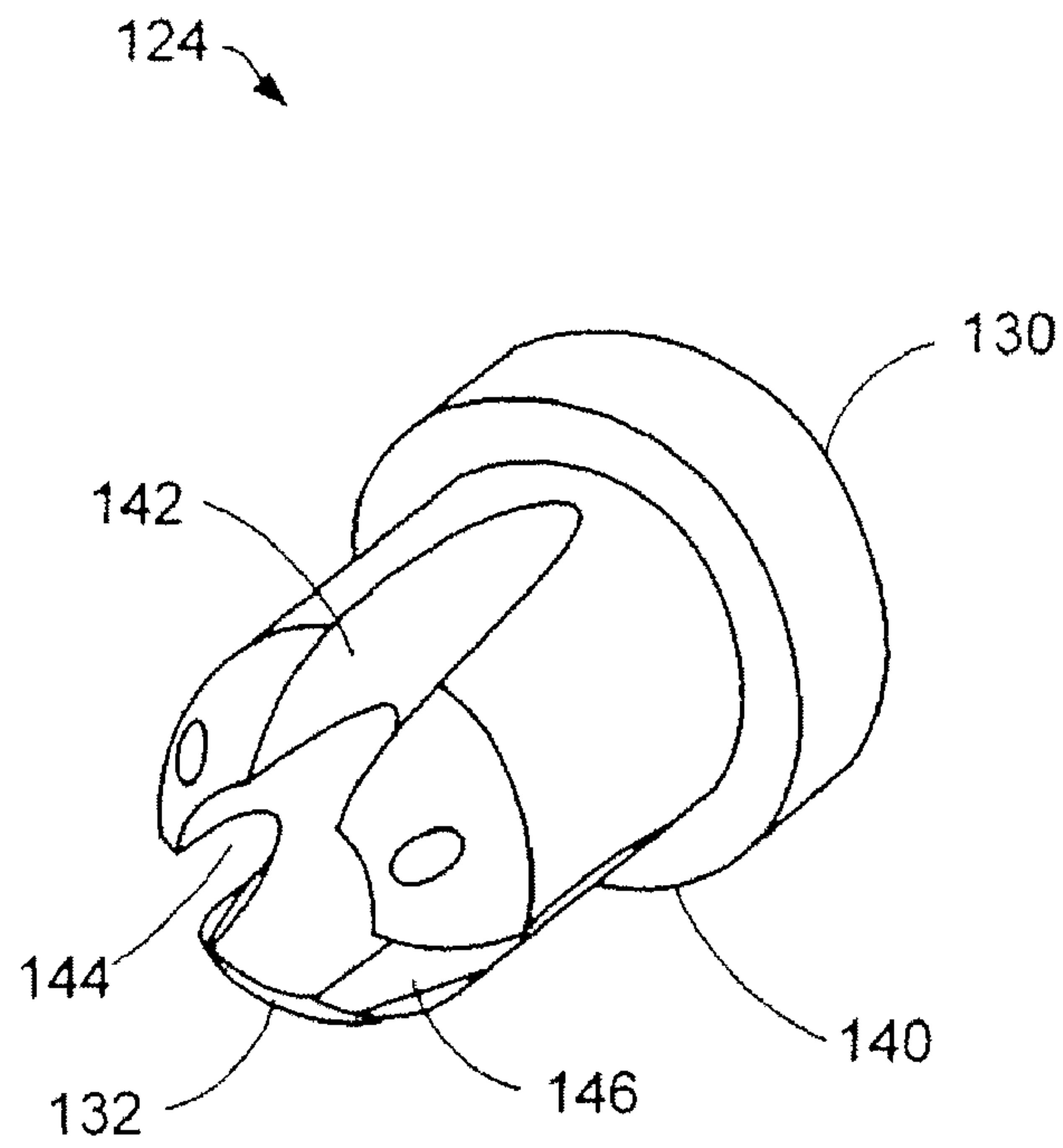


FIG. 7A

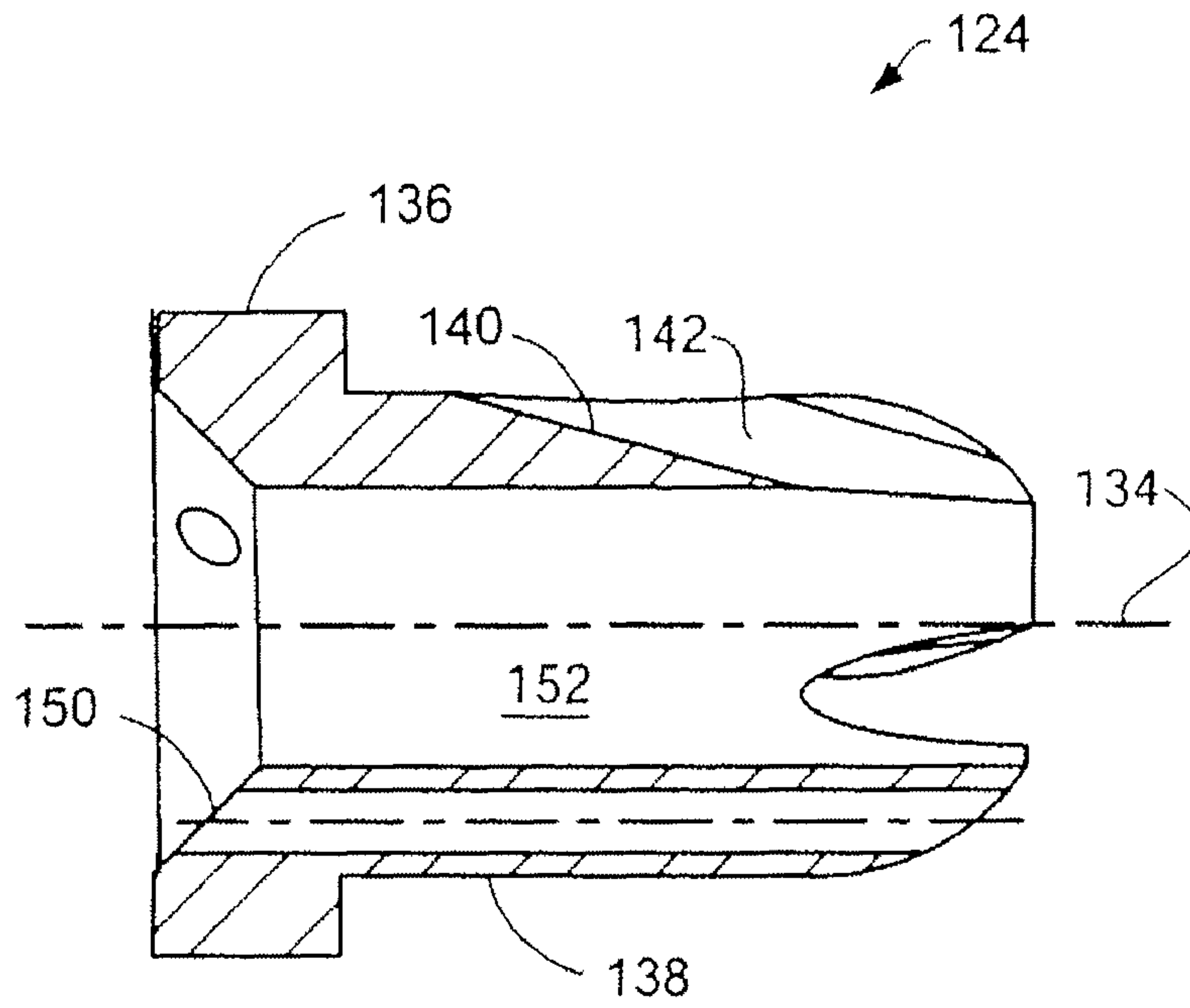


FIG. 7B

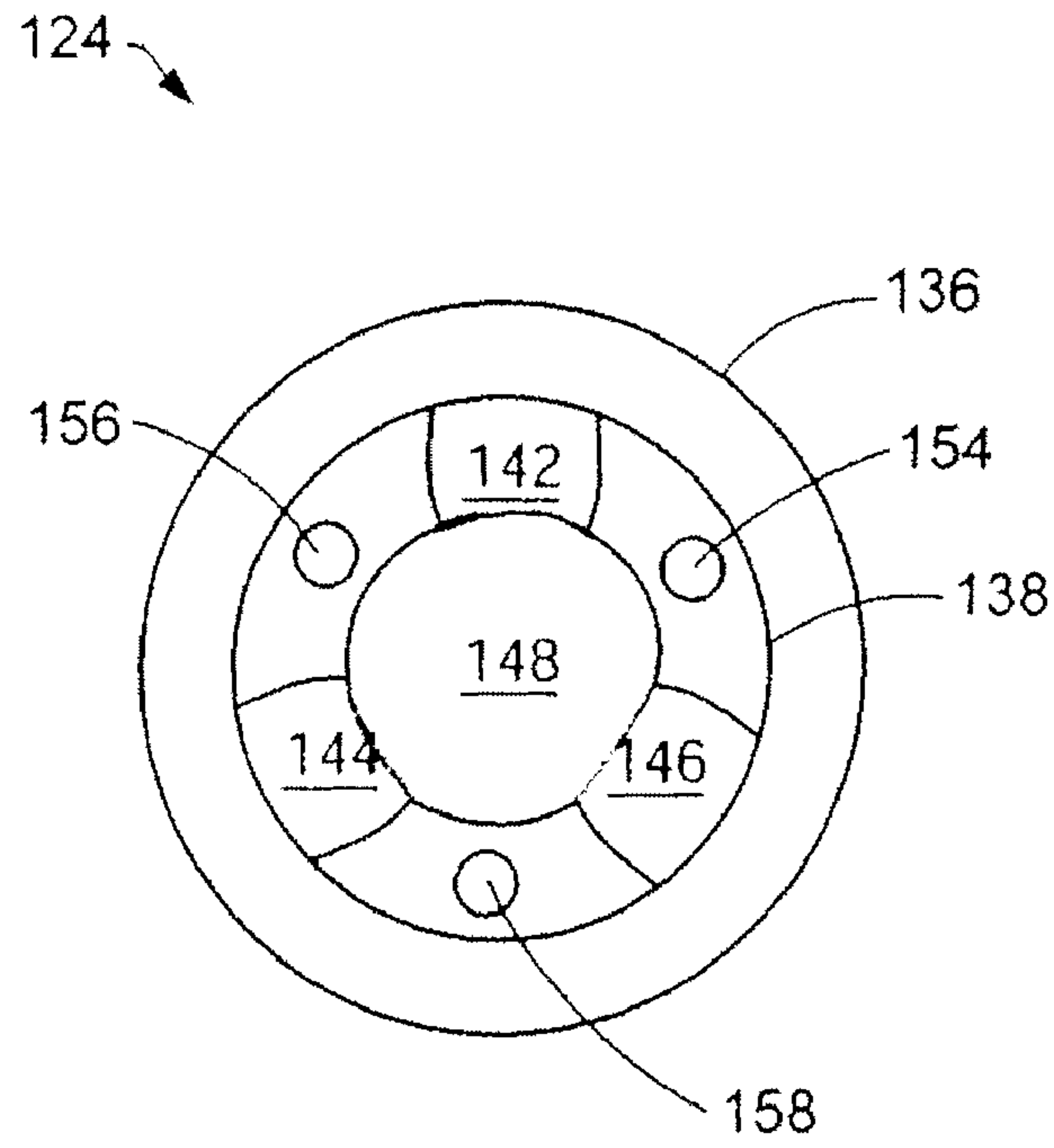


FIG. 7C

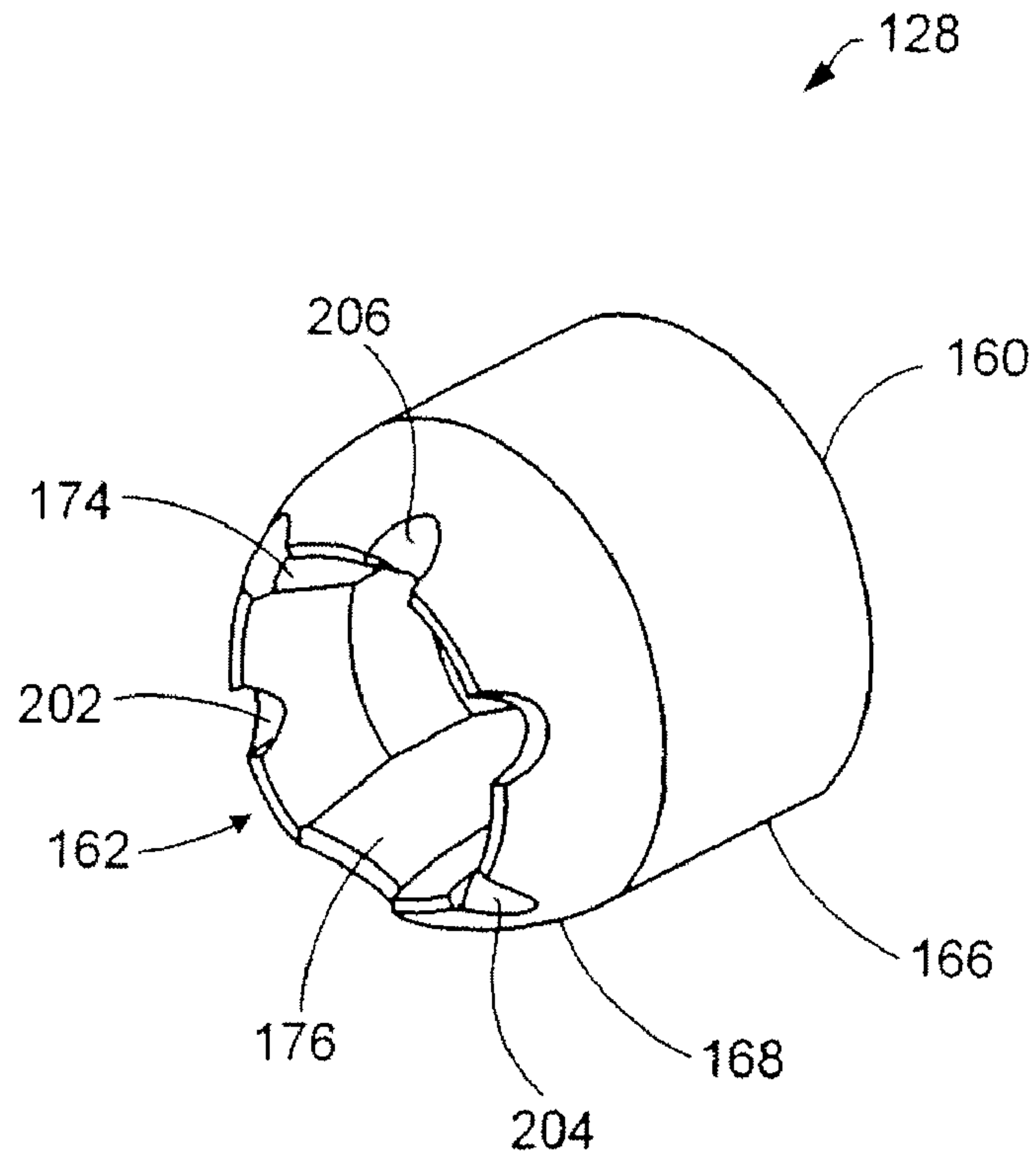


FIG. 8A

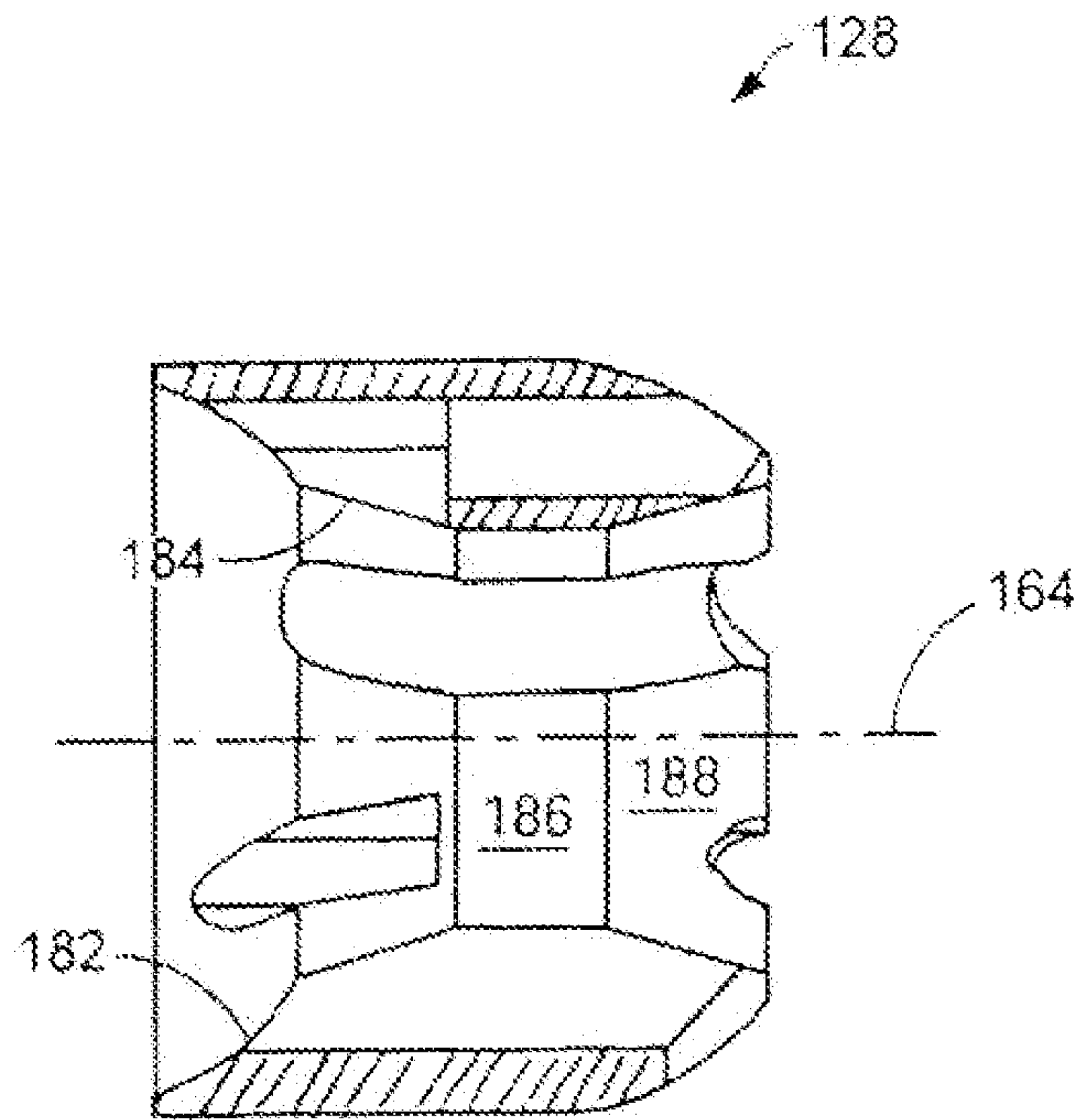


FIG. 8B

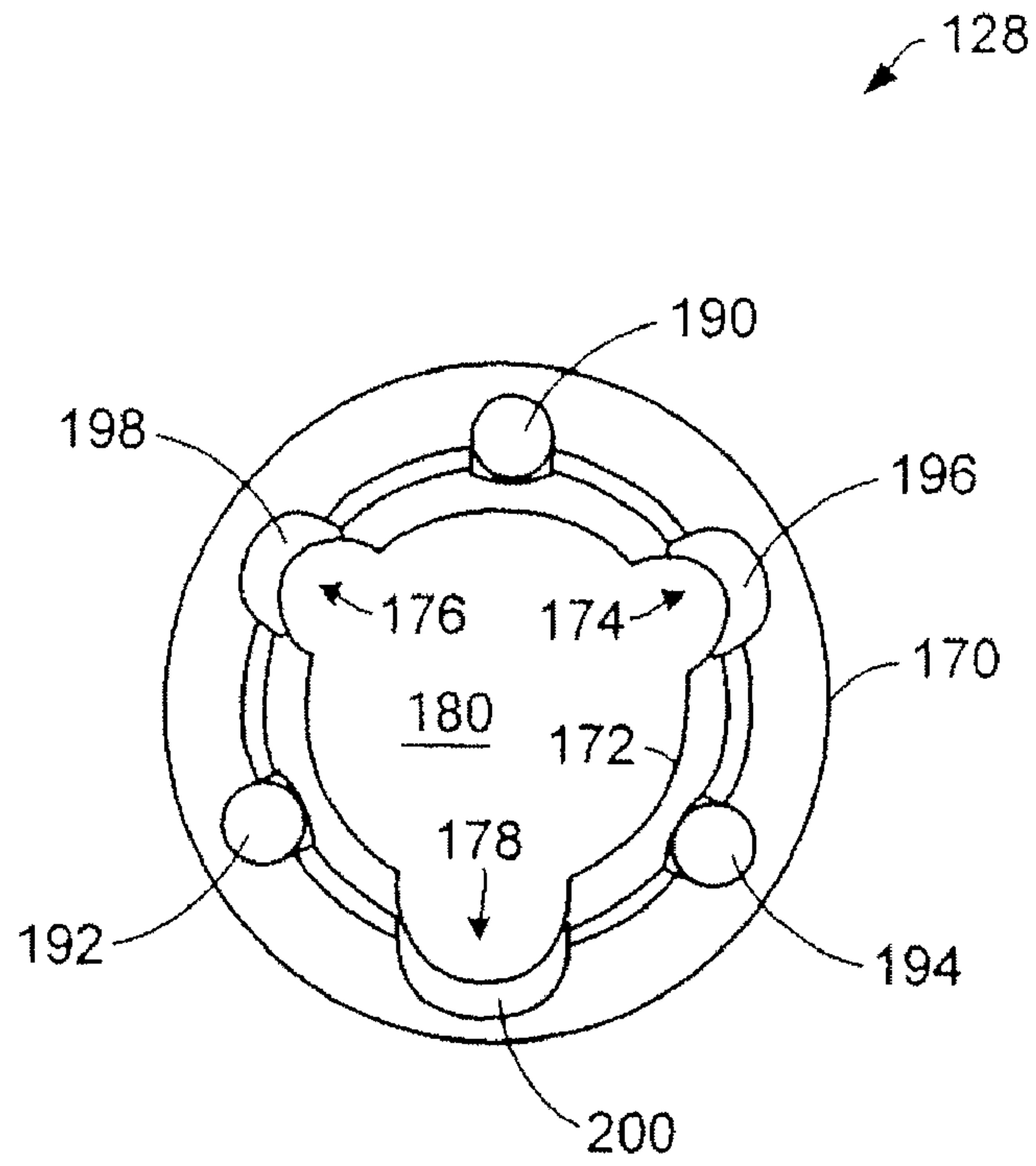


FIG. 8C

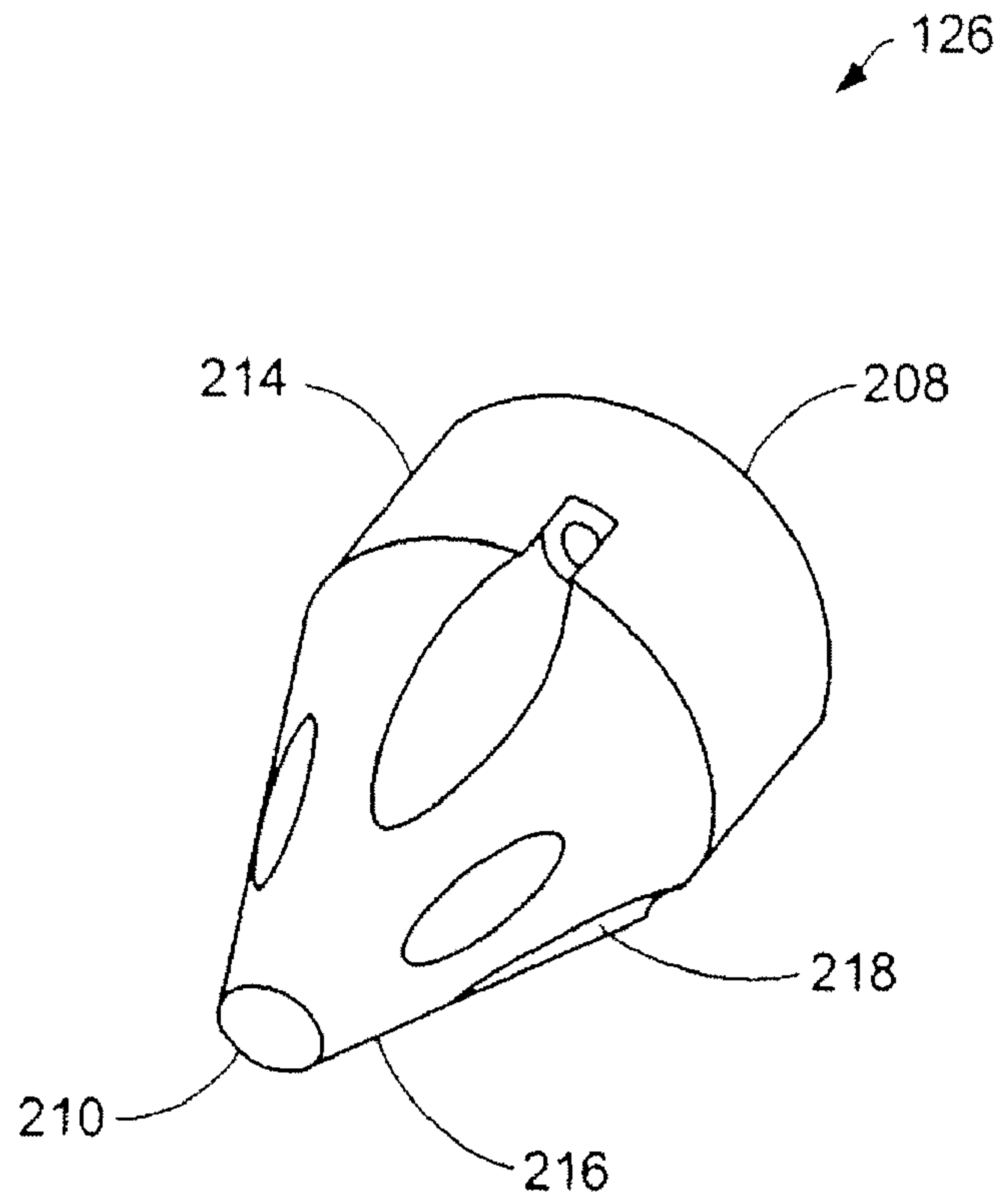


FIG. 9A

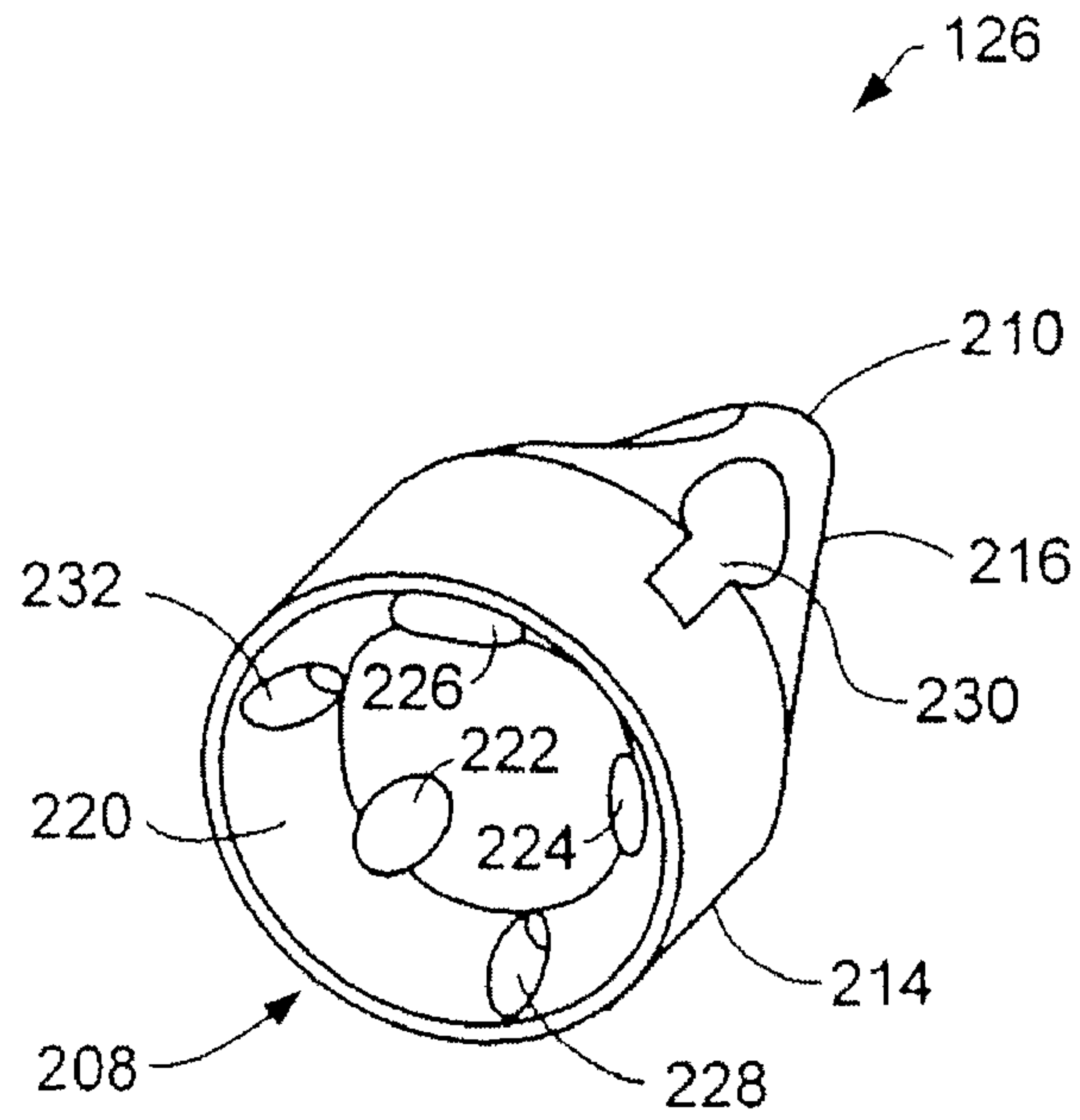


FIG. 9B

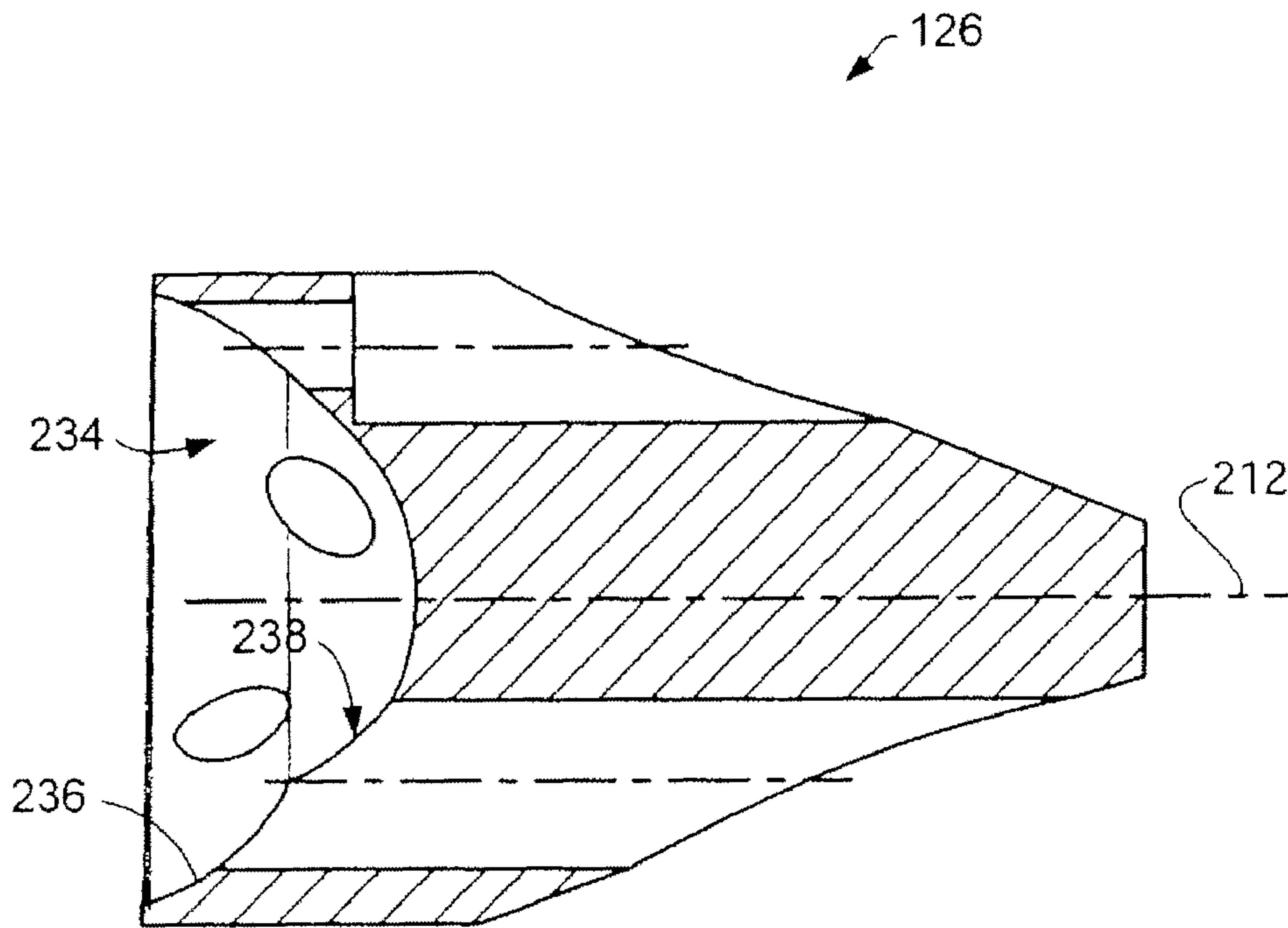


FIG. 9C

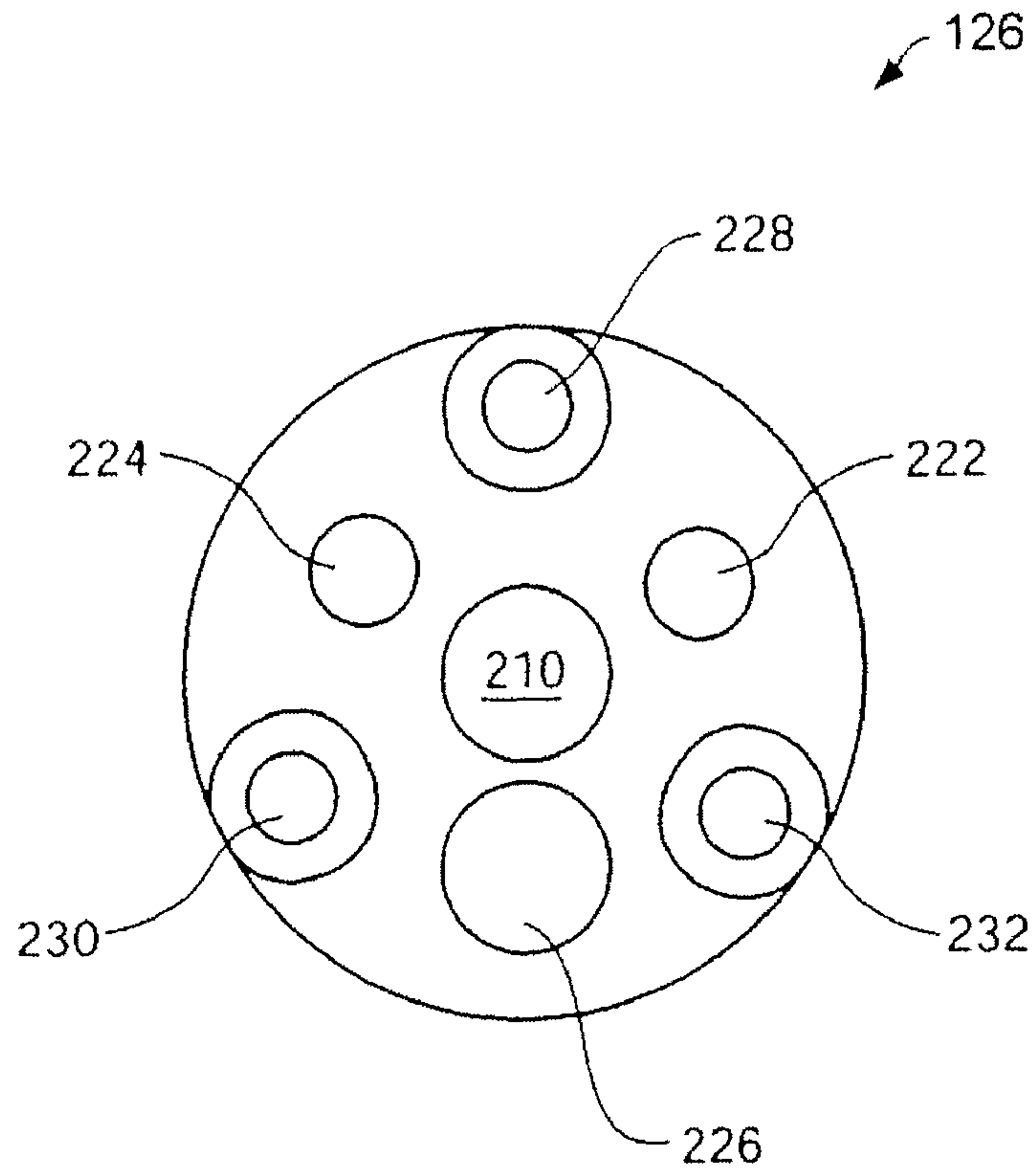


FIG. 9D

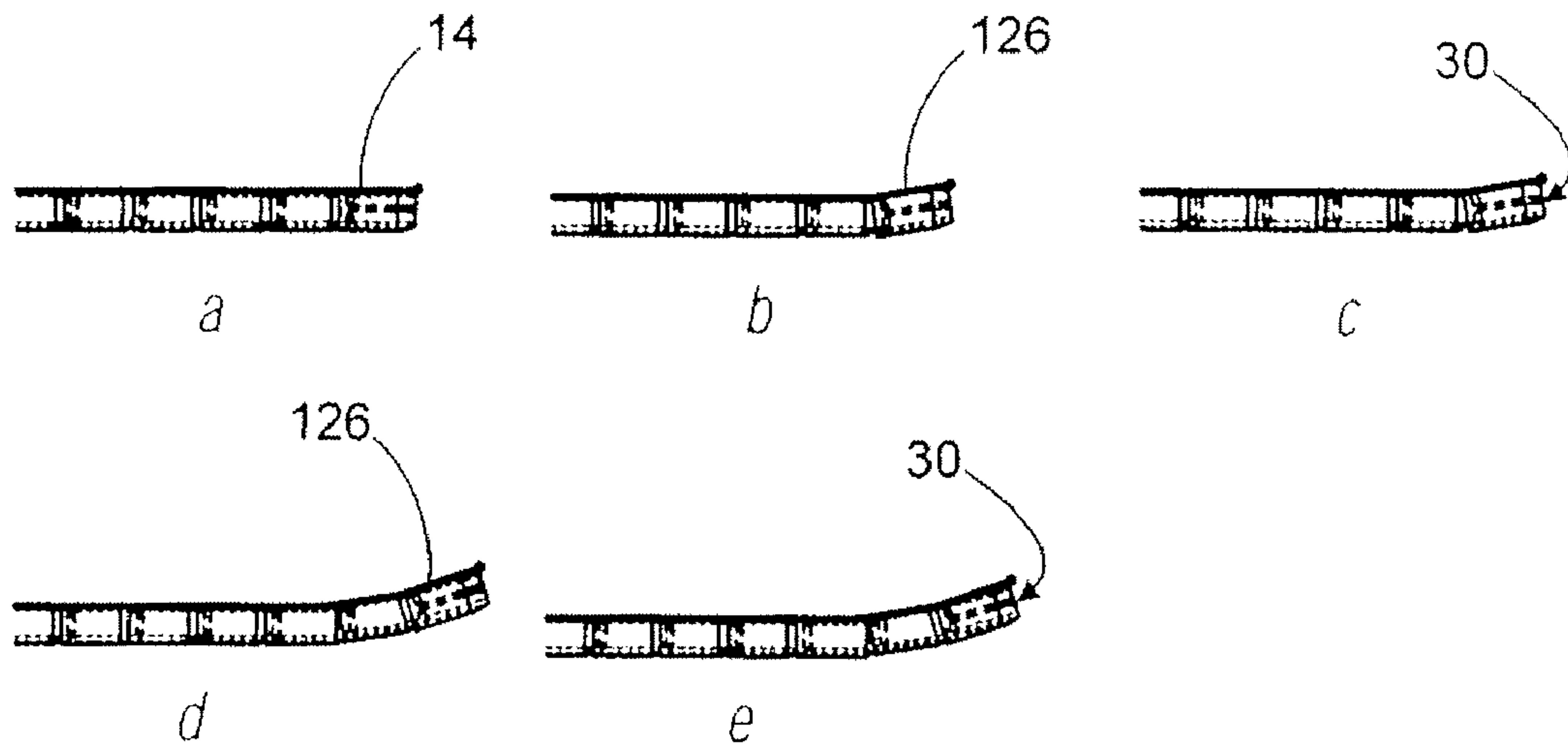


FIG. 10

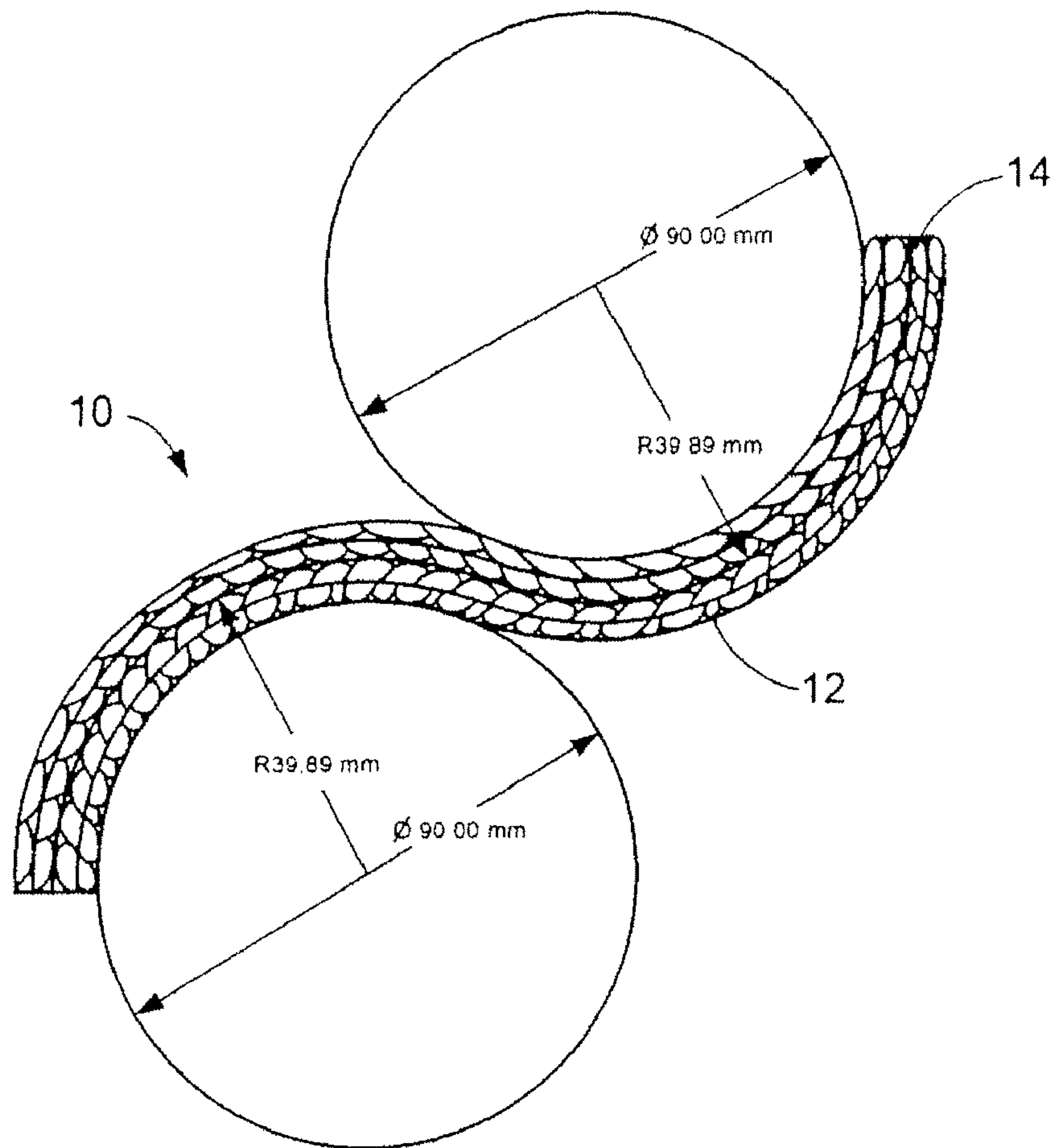


FIG. 11

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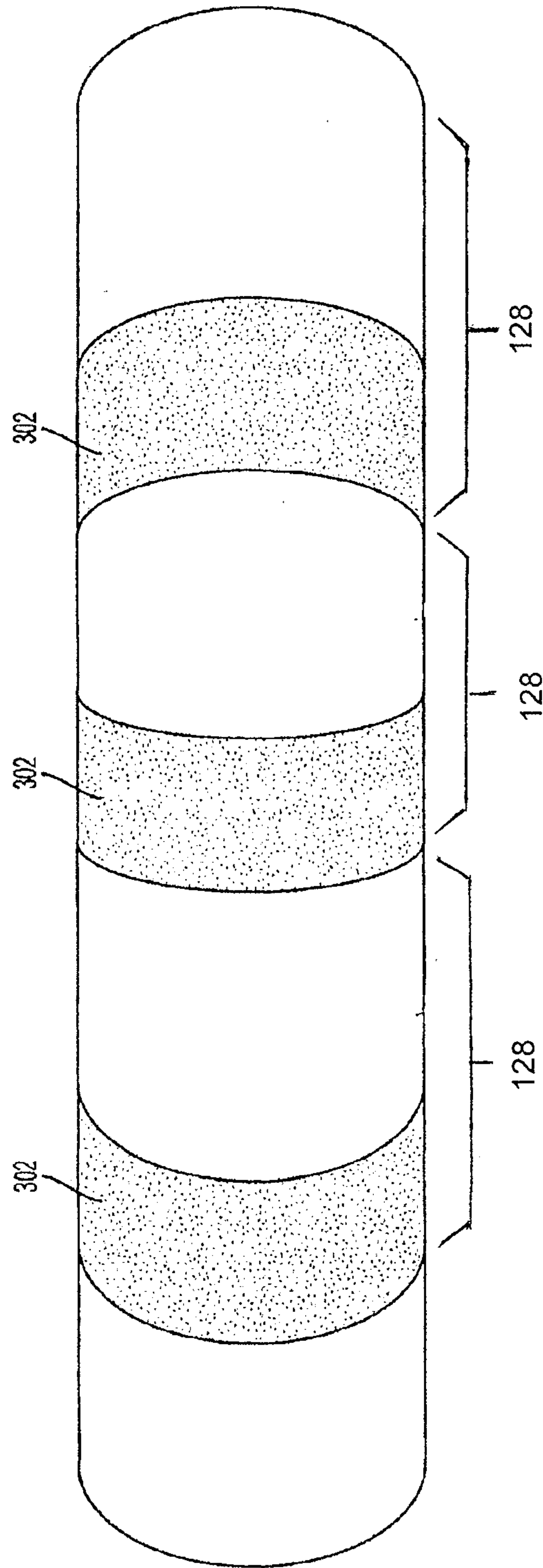


FIG. 12

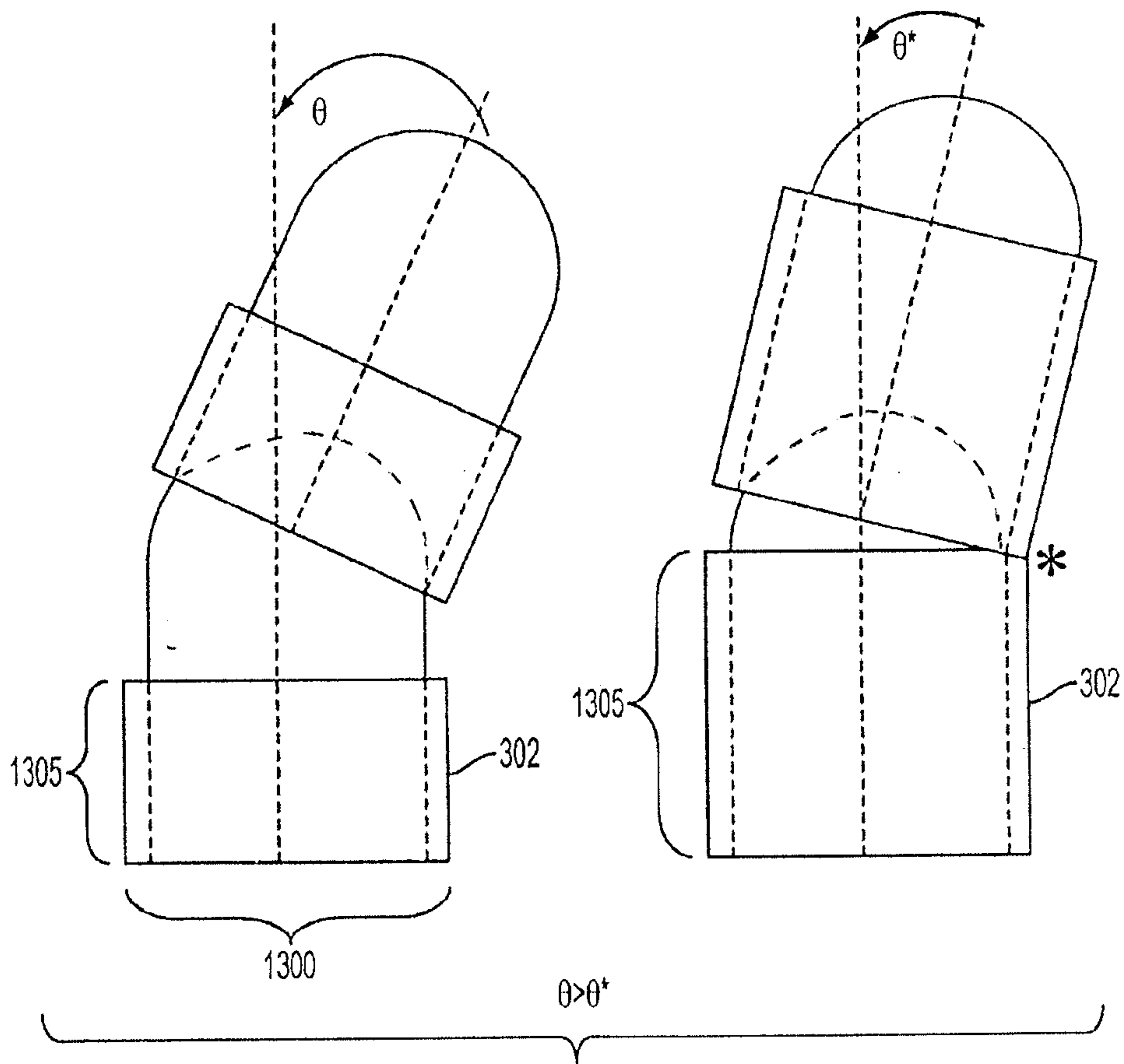


FIG. 13

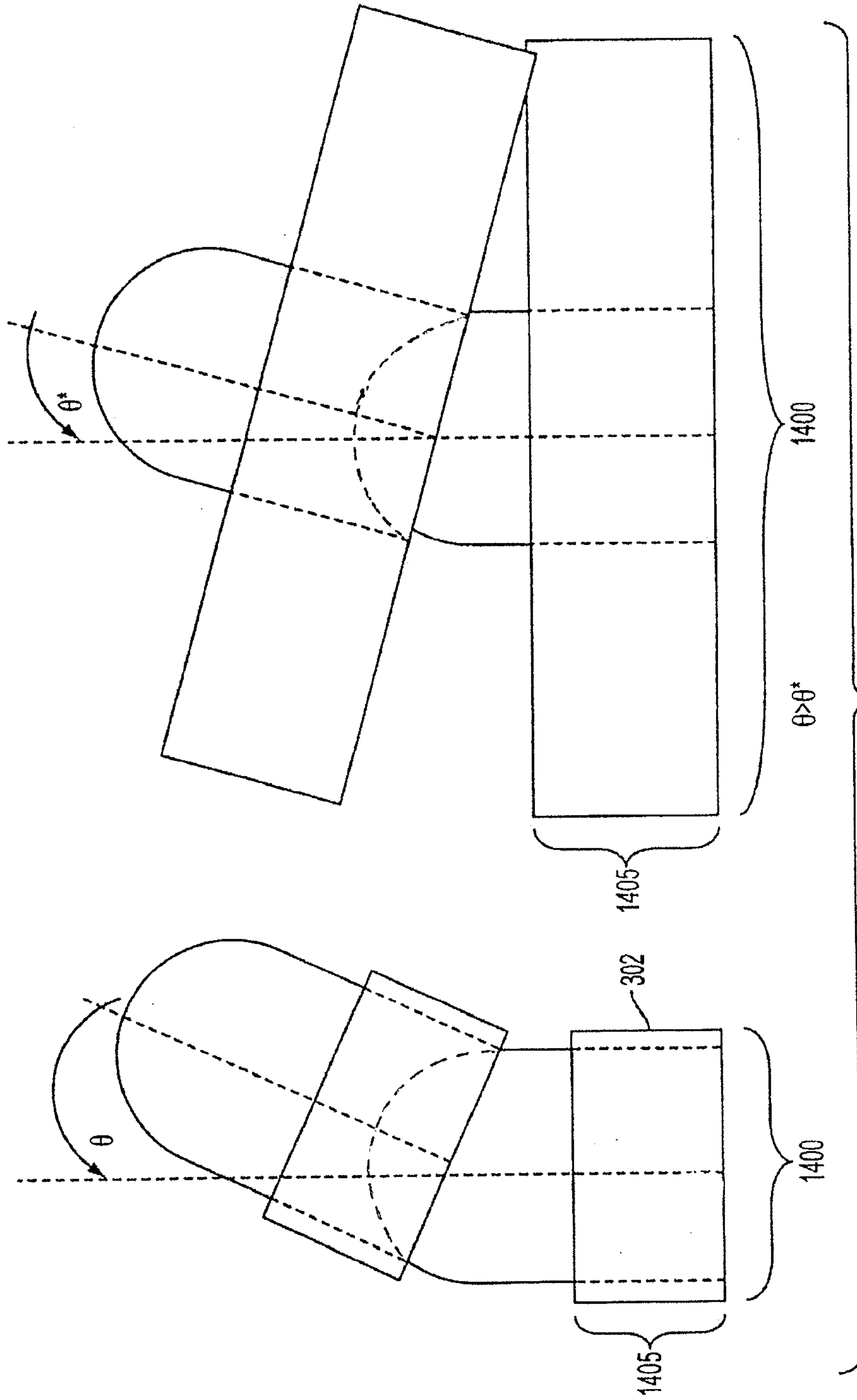


FIG. 14

