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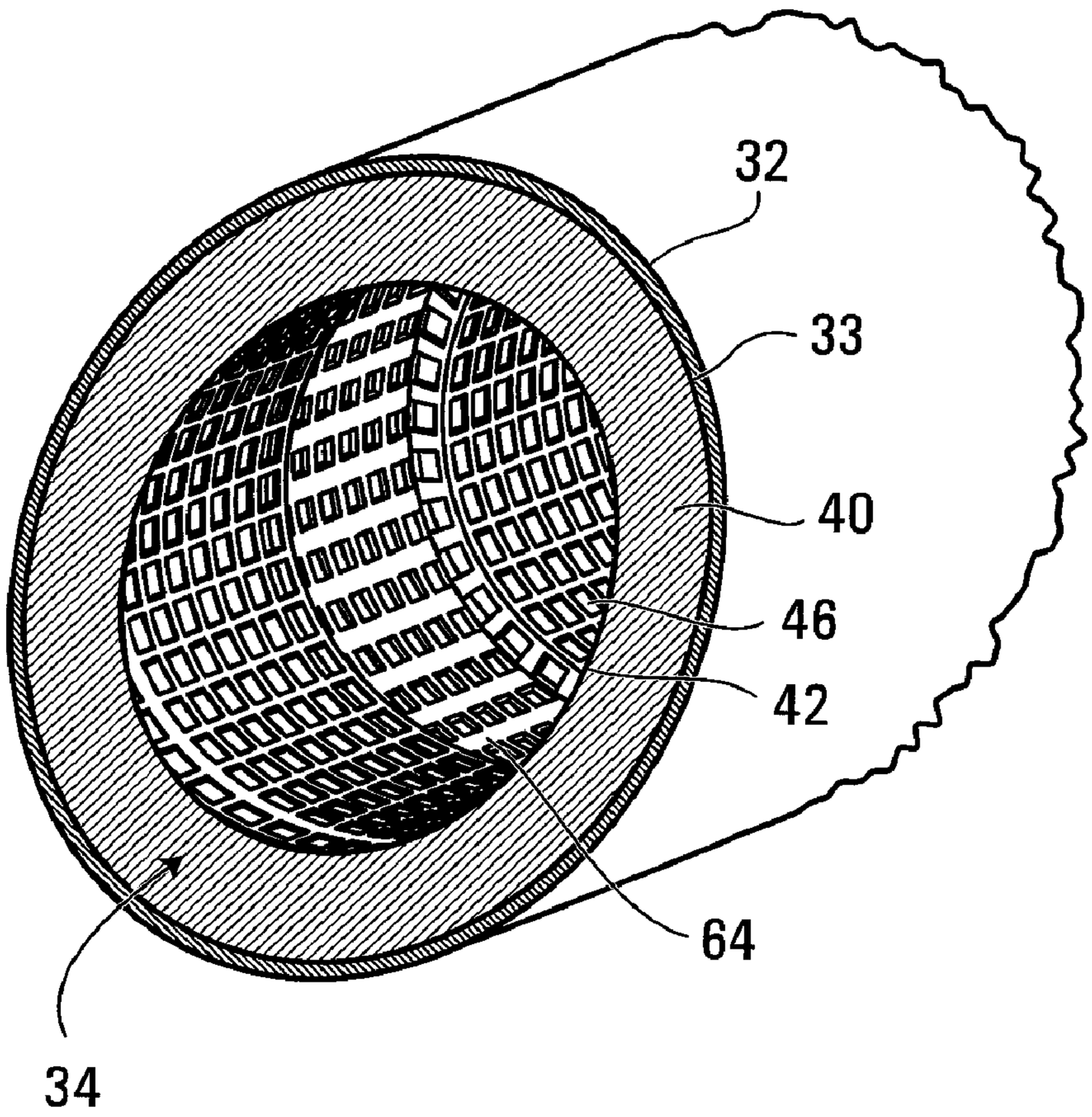
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(72) **Inventeur/Inventor:**
SIERRA, BALJIT, CA

(73) **Propriétaires/Owners:**
NOVO PLASTICS INC., CA;
SIERRA, BALJIT, CA

(74) **Agent:** SMART & BIGGAR

(54) **Titre : SOUS-SYSTEME D'ECHAPPEMENT A ENVELOPPE POLYMERE**
(54) **Title: EXHAUST SUBSYSTEM WITH POLYMER HOUSING**



(57) **Abrégé/Abstract:**
A vehicle exhaust system includes a subsystem having an exterior pipe formed of a polymer. A rigid liner extends along the length of the exterior pipe and defines a passageway. A fiber insulating layer is formed between the rigid liner and the exterior pipe. The

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(57) **Abrégé(suite)/Abstract(continued):**
liner is formed to define at least one groove circumscribing the periphery of the passageway. The groove defines a region of increased volume of the exhaust passage along the length. The liner is further formed to define at least one void extending between the wall of the liner and the insulating layer, around the periphery of the passageway. A plurality of apertures in the liner, allow sound waves to pass from the passageway into the fiber insulating layer, and into the void.

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(71) Applicant *(for all designated States except US)*: **NOVO PLASTICS INC.** [CA/CA]; 388 Markland Street, Markham, Ontario L6C 1Z6 (CA).

(72) Inventor; and
(71) Applicant : **SIERRA, Baljit** [CA/CA]; 10 Yonge Street, Apt 2404, Toronto, Ontario M5E 1R4 (CA).

(74) Agent: **SMART & BIGGAR**; ATTN: ZISCHKA, Matthew, 438 University Avenue, Suite 1500, Box 111, Toronto, Ontario M5G 2K8 (CA).

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(54) **Title**: EXHAUST SUBSYSTEM WITH POLYMER HOUSING

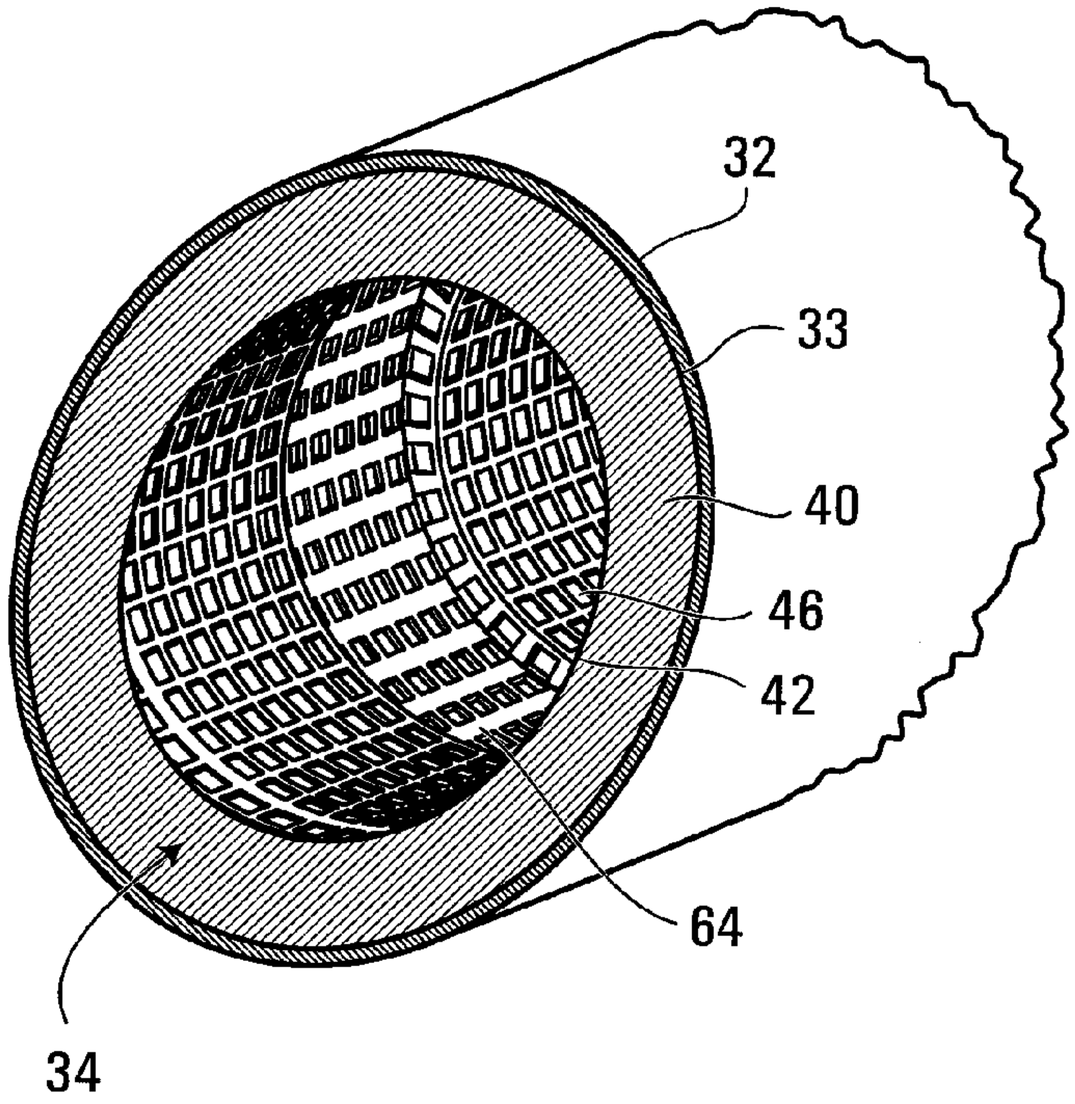


FIG. 2

(57) **Abstract**: A vehicle exhaust system includes a subsystem having an exterior pipe formed of a polymer. A rigid liner extends along the length of the exterior pipe and defines a passageway. A fiber insulating layer is formed between the rigid liner and the exterior pipe. The liner is formed to define at least one groove circumscribing the periphery of the passageway. The groove defines a region of increased volume of the exhaust passage along the length. The liner is further formed to define at least one void extending between the wall of the liner and the insulating layer, around the periphery of the passageway. A plurality of apertures in the liner, allow sound waves to pass from the passageway into the fiber insulating layer, and into the void.

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EXHAUST SUBSYSTEM WITH POLYMER HOUSING

FIELD OF THE INVENTION

[0001] The present invention relates generally to exhaust assemblies and methods, and more particularly to exhaust subsystems formed, at least in part, of polymeric materials.

BACKGROUND OF THE INVENTION

[0002] Vehicle exhaust assemblies are typically formed of sheet metal or stainless steel to allow the transport of hot exhaust gases from a combustion engine away from the vehicle. Such exhaust assemblies typically include one or more volume mufflers, designed to absorb and dissipate acoustic and thermal energy. Metal is typically primarily used to allow the exhaust system to withstand high temperatures, and transfer heat away in the gases away from the vehicle.

[0003] Metal, of course, has its limitations: it is somewhat cumbersome to form; it is heavy; and bulky. Also the shapes that can be formed are somewhat limited. Further, it is prone to corrosion.

[0004] More recently, synthetic materials, such as polymers, have been introduced into vehicle exhaust assemblies. The polymer material is less costly, lighter, and less susceptible to corrosion. At the same time, such materials are typically less able to dissipate heat.

[0005] Nevertheless exhaust systems that incorporate synthetic materials are in early stages of development. Accordingly, there remains a need for exhaust systems and subsystems that take advantage of synthetic materials.

SUMMARY OF THE INVENTION

[0006] In an embodiment, an exhaust subsystem includes an exterior pipe comprising polymer for carrying gases from an engine. A rigid liner within the exterior pipe extends along a length of the exhaust subsystem and defines a passageway having a periphery. A fiber insulating layer is formed between the rigid liner and the exterior pipe. The liner is formed to define at least one groove circumscribing the periphery of the passageway. The groove defines a region of increased cross-sectional area of the passageway along a length of the passageway. The liner is further formed to define at least one void extending between the liner and the insulating layer, around the periphery of the passageway. The liner comprises a plurality of apertures in communication with the void, allowing sound waves to pass from the passageway into the fiber insulating layer, and into the at least one void extending around the periphery of the passageway.

[0006a] In another embodiment, there is provided an exhaust subsystem comprising an exterior pipe comprising polymer, defining an exhaust passage along a length of the exterior pipe, for carrying gases from an engine; a rigid liner within the exterior pipe, extending along the length, defining a passageway having a periphery; a fiber insulating layer formed between the rigid liner and the exterior pipe; wherein the liner is formed to define at least one void extending between the liner and the insulating layer, around the periphery of the passageway and extending along the length, the at least one void defining a resonance chamber to attenuate at least one specific frequency emitted by a specific engine; wherein the liner comprises a plurality of apertures, allowing sound waves to pass from the exhaust passage into the fiber insulating layer, and into the at least one void.

[0007] Other aspects and features of the present invention will become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] In the figures which illustrate by way of example only, embodiments of the present invention,

[0009] **FIG. 1** is a schematic view of a vehicle including an exhaust assembly and exhaust subsystem, exemplary of an embodiment of the present invention;

[0010] **FIG. 2** is an end perspective view of an exhaust subsystem of **FIG. 1**;

[0011] **FIG. 3** is a cross-sectional view of the exhaust subsystem of **FIG. 1** at III-III

[0012] **FIGS. 4** and **5** are axial cross-sectional views of a portion of the exhaust subsystem of **FIG. 2**;

[0013] **FIG. 6** is a plan of a liner forming part of the exhaust subsystem of **FIG. 2**;

[0014] **FIGS. 7** to **9** are cross-sectional views of the exterior shell of the exhaust subsystem of **FIG. 2**;

[0015] **FIG. 10** an end view of an alternative exhaust subsystem, exemplary of an embodiment of the present invention;

[0016] **FIG. 11** is an axial cross-sectional views of a portion of the exhaust subsystem of **FIG. 10**;

[0017] **FIGS. 12** is an axial cross-section of a volume muffler that may form part of the exhaust subsystem of **FIG. 2**;

[0018] **FIG. 13** is a radial cross-section of the volume muffler of **FIG. 12**;

[0019] **FIG. 14** is a partial cut-away perspective view of a further volume muffler that may form part of the exhaust subsystem of **FIG. 2**;

[0020] **FIG 15** is an axial cross-sectional view of the volume muffler of **FIG. 14**.

[0021] **FIG. 16** is a cross-sectional view of a portion of the exhaust subsystem of **FIG. 2**, illustrating a coupling assembly;

[0022] **FIG. 17** is a cross-sectional view of a portion of the exhaust subsystem of **FIG. 2**, illustrating a baffle; and

[0023] **FIG. 18** is a radial cross-sectional view of a portion of the exhaust subsystem of **FIG. 2**, illustrating a baffle.

DETAILED DESCRIPTION

[0024] **FIG. 1** illustrates a vehicle **10** which includes an exhaust assembly **12**, formed of two separate exhaust subsystems: a forward exhaust subsystem **14** formed predominantly of metal exhaust components, in the form of stainless steel, steel, iron, nickel and the like; and an aft exhaust subsystem **16**, having a polymeric exterior housing, exemplary of an embodiment of the present invention.

[0025] As illustrated in **FIG. 1**, vehicle **10** includes an internal combustion engine **18**, located forward of a passenger compartment **20**. Exhaust assembly **12** interconnects to internal combustion engine **18** and guides exhaust gases from internal combustion engine **18** to the rear of vehicle **10**, allowing those gases to exhaust away from vehicle **10**. Forward exhaust subsystem **14** is in fluid communication with internal combustion engine **18**, and may include one or more exhaust components, such as exhaust manifolds **22**, catalytic convertors/particle filters **24**, and one or more metal pipes **26** emanating from internal combustion engine **18** and connected in flow series. Forward exhaust subsystem **14** is further in flow communication with aft exhaust subsystem **16**. Aft exhaust subsystem **16** is located downstream of forward exhaust subsystem **14**, in the direction of exhaust flow.

[0026] Exhaust subsystems **14**, **16** are physically mounted to the vehicle in a conventional manner, for example, by being suspended from the chassis of vehicle **10**.

[0027] Forward exhaust subsystem **14** may define one or more flow paths **28** between internal combustion engine **18** and aft exhaust subsystem **16**. As illustrated, forward exhaust subsystem **14** may provide a discrete flow path **28** on each side of internal combustion engine **18** to aft exhaust subsystem **16**. Multiple flow paths **28** may converge to a single path to feed aft exhaust subsystem **16**.

[0028] Aft exhaust subsystem **16** includes one or more coupling assembly(ies) **30** which connect forward exhaust subsystem **14** with aft exhaust subsystem **16**. Coupling assemblies **30** are typically also formed of metal, and provide an interface between the substantially polymeric components of aft exhaust subsystem **16** and forward exhaust subsystem **14**. As illustrated, coupling assembly **30** is located downstream of the catalytic convertor/particle filter **24** of vehicle **10**. However, coupling assembly **30** may be located anywhere downstream of exhaust manifold **22** of vehicle **10**.

[0029] Aft exhaust subsystem **16** is housed in a non-metal exterior pipe **32**. As illustrated in **FIG. 1**, exterior pipe **32** is cylindrical in cross-section, and may be of a constant diameter. However, exterior pipe **32** may be of any arbitrary cross-section. Exterior pipe **32** defines an interior passage **34** for the transport of exhaust gases to outlet **36** of vehicle **10**. Aft exhaust subsystem **16** may include one or more sound attenuation regions **38** downstream of coupling assembly **30**. Sound attenuation regions **38** may extend from coupling assembly **30** to the exhaust outlet **36**, or may extend along the length of exterior pipe **32** at discrete intervals along the length of aft exhaust subsystem **16**.

[0030] Throughout at least a portion of the length of exterior pipe **32**, aft exhaust subsystem **16** is formed of four or more distinct layers, as best illustrated in **FIGS. 2** and **3**: an exterior pipe **32**; a thermal reflective coating **33** applied to the inner wall of exterior pipe **32**, an acoustic insulation layer **40** formed interior to exterior pipe **32**; and a liner **42**, located between interior passage **34** and liner **42**. Acoustic insulation layer **40** and liner **42** extend along the length of interior passage **34**, and may extend substantially along the length of aft exhaust subsystem **16**.

[0031] Exterior pipe **32** may be formed in whole or in part of a polymer material, such as a polyester, ethylene terepthelate, or the like, or composites thereof.

[0032] Thermal reflective coating **33** may be a thin double-layer foil of melamine and heat-reflective paint, and may be applied to exterior pipe **32** during the plastic forming process. However, thermal reflective coating **33** may be any thin coating with suitable thermal properties, known to those of ordinary skill, and may be applied to the interior of exterior pipe **32**, after formation of exterior pipe **32**.

[0033] In the depicted embodiment, representative of a passenger vehicle having a small-displacement engine, the diameter of exterior pipe **32** is between approximately 70 mm and 100 mm; the thickness of thermal reflective coating **33** is between approximately 0.2 mm and 0.5 mm; the diameter of liner **42** is between approximately 40 mm and 60 mm; the thickness of liner **42** is between approximately 0.5 mm and 2.5 mm and the thickness of acoustic insulation layer **40** is between about 10 mm and 30 mm. These dimensions may be chosen based on the size and type of internal combustion engine **18**, the flow rate and temperature of gas to be exhausted, and the frequencies of sound that are being attenuated. The arrangement of insulation layer **40**; and liner **42** allow the formation of sound attenuation regions **38**, along the length of exterior pipe **32**.

[0034] As illustrated, liner **42** is located radially outward of interior passage **34**, and retains or supports acoustic insulation layer **40** against the inner wall of exterior pipe **32**. Liner **42** further provides fluid communication between interior passage **34** and acoustic insulation layer **40**, allowing sound waves to pass into acoustic insulation layer **40**.

[0035] Acoustic insulation layer **40** is preferably formed of mineral fiber insulation to provide for acoustic and thermal insulation, but may be any type of insulation material or combination of materials with sufficient thermal and acoustic insulation properties, such as glass fiber.

[0036] The depicted liner **42** has the same cross-sectional shape as exterior pipe **32**. However, liner **42** and exterior pipe **32** may have different cross-

sectional shapes, provided liner **42** fits inside exterior pipe **32**, around interior passage **34**. Moreover, as will become apparent, liner **42** may have differing cross-sectional sizes, at various axial positions along passage **34**. In the depicted embodiment, liner **42** is made from stainless steel so that its shape is self-supporting. However, other suitable materials – including plastics, composites or the like, will be appreciated by those of ordinary skill. Likewise, it may be made from other metal materials, provided they are of sufficient strength for the shape to be self-supporting. To allow fluid communication between interior passage **34** and acoustic insulation layer **40**, liner **42** includes a plurality of perforations **46**. Liner **42** may be formed from a generally flat sheet as depicted in **FIG. 6**, and rolled into a lengthwise extending cylindrical tube, as further described.

[0037] As best shown in **FIG. 6**, perforations **46** are formed throughout the surface **62** of liner **42**. Perforations **46** may be of a consistent size and shape, or may be of a number of different sizes and shapes. Perforations **46** may be evenly spaced, or the spacing may be varied. In particular, as will be discussed below, the relationship between the size and spacing of perforations **46** and the dimensions of grooves **48** or voids **50** may affect the acoustic performance of exhaust subsystem. Thus, the size and spacing of perforations **46** may be selected to maximize attenuation of sounds in certain frequency ranges.

[0038] Perforations **46** in liner **42** create absorption regions along the length of interior passage **34**. More specifically, energy in the form of acoustic and thermal energy within the exhaust gases passes through perforations **46** into acoustic/thermal insulation layer **40**, where it may be substantially absorbed by the material forming acoustic/thermal insulation layer **40**. Conveniently, such absorption regions may be located at curves in the exhaust for improved acoustic performance; however absorption regions may be located anywhere along the length of interior passage **34**.

[0039] Liner **42** may further define a series of grooves **48** and voids **50**

extending around periphery of interior passage **34** in each sound attenuation region **38**, to further assist in attenuating engine and exhaust noise.

[0040] As illustrated in **FIG. 4**, each of voids **50** take the form of an annular cavity between liner **42** and insulation layer **40**. Each of voids **50** is formed by two opposing annular ribs **52** which extend radially outward from passageway **34** and hold insulation **40** away from liner **42**. As illustrated, ribs **52** are formed from liner **42**. Ribs **52** may, for example be formed by folding or pinching liner twice into overlapping relationship (example fold lines are shown in **FIG. 6**). However, ribs **52** could be formed in other ways.

[0041] Insulation layer **40** is pre-formed into the required shape and wrapped around liner **42**. The pre-forming, along with ribs **52**, ensures that the material of insulation layer **40** is held taut between ribs **52**.

[0042] The resulting voids **50** define resonance chambers **54** bounded on the radially inward surface by liner **42**, on the radially outward surface by acoustic insulation layer **40**, and at the ends by ribs **52**. Each resonance chamber **54** has a width, measured along the length of passageway **34** and a depth, measured in the radial direction of aft exhaust subsystem **16**.

[0043] Resonance chambers **54** may be annular in shape, or may be formed in alternative shapes and orientations. Resonance chambers **54** may be of a consistent length, depth and shape, or there may be resonance chambers **54** of multiple shapes and dimensions.

[0044] Resonance chambers **54** are in fluid communication with interior passage **34** through one or more perforations **46**. Sound waves in interior passage **34** excite the air in perforations **46**. This causes the air inside each resonance chamber **54** to resonate at a particular frequency, determined, in the simple case, by the following relationship:

$$V = \frac{s^2 A_t}{f^2 (t_o + 1.6r)}$$

Where *f* is the frequency, A_t is the total surface area of all perforations **46** through which resonance chamber **54** is in communication with interior passage **34**, *r* is the radius of one perforation **46,** s is the speed of sound at operating temperature, t_o is the thickness of liner **42**, and *V* is the volume of resonance chamber **54**.

[0045] For a perforation **46** which is non-circular, the effective radius *r* may be used. For example, the effective radius *r* may be approximated as one-half of the hydraulic diameter of the perforation **46**, where hydraulic diameter is determined by the following equation, in which A_p and *P* are the area and perimeter of the perforation, respectively:

$$D_{hydraulic} = \frac{4A_p}{P}$$

[0046] Conveniently, aft exhaust subsystem **16** may be designed by selecting parameters A, r and t_o to attenuate specific frequencies, as required or desired as a result of frequencies by engine **18**. That is for any particular engine **18**, and desired acoustic properties, A, r and t_o, may be chosen and one or more resonance chambers **54** may be placed along the passage **34**.

[0047] A person of skill will readily recognize that the above mathematical relation is intended to be illustrative for a simple case, where the size of perforations **46** and thickness of liner **42** is uniform. Of course, where the thickness and size is not uniform, the resonance frequency will vary. Likewise, if multiple resonance chambers **54** are coupled, by common air volume, for example, their resonance frequency may vary. Such variation may be determined by computer simulation, or trial and error.

[0048] Resonance chambers **54** may be located at any point, or at multiple points along the axis of aft exhaust subsystem **16**. Preferably, a resonance chamber **54** which is tuned to attenuate sounds at a particular frequency should be located at a distance from the inlet of aft exhaust subsystem **16** equivalent to

at least one quarter of the wavelength corresponding to a sound wave at the particular frequency. This placement may ensure that resonance chamber **54** is exposed to the peak pressure created by the sound wave, maximizing the amplitude of the resonant vibration. Resonance chambers placed less than one quarter wavelength away from exhaust manifold **22** will typically not be exposed to such peak pressures, as will be appreciated, this will result in decreased effectiveness.

[0049] Sound attenuation region **38** also includes one or more grooves **48** on the radially inward side of liner **42**, around the periphery of passage **34** defining expansion regions **64**. As illustrated in **FIG. 5**, grooves **48** may be formed as generally annular deformations in liner **42**. As a consequence, the cross sectional area of interior passage **34** increases beyond the cross sectional area in the absence of such grooves. Each groove **48** may be defined by two opposing annular walls **56**, each defined by two sharp bends **58** and **60** in liner **42**. The resulting expansion regions **64** have a width, measured along the length of interior passage **34** of aft exhaust subsystem **16** and a depth, measured in the radial direction of aft exhaust subsystem **16**.

[0050] Again, grooves **48** may be annular in shape, or may be formed in alternative shapes. Similarly, grooves **48** may be of a consistent length, depth and shape, or there may be grooves **48** of multiple shapes and dimensions.

[0051] Expansion regions **64** are effective at attenuating lower frequency sounds than those attenuated in resonance chambers **54**. Further, expansion regions **64** of large volume attenuate lower frequencies than expansion regions **64** which are smaller in volume. The optimal dimensions of an expansion region **64** can again be determined heuristically or by computer simulation, given a particular frequency of interest and a particular diameter of passage **34**.

[0052] Expansion regions **64** may be located at any point along passage **34** of aft exhaust subsystem **16**. Preferably, expansion regions **64** are located anywhere in aft exhaust subsystem **16** where there are no resonance chambers

54. Expansion regions **64** which are intended to attenuate sounds at a particular frequency are preferably located at a distance from the inlet of aft exhaust subsystem **16** of at least one-quarter of the wavelength corresponding to that frequency.

[0053] Conveniently exterior pipe **32** may be injection or extrusion molded. As illustrated in **FIG. 7**, exterior pipe **32** may be fabricated by forming a clam shell **80.** Shell **80** may be formed by injection-molding, extrusion, blow molding, or any other polymer manufacturing process. Clam shell **80** includes two half-shells that may that may be joined together. In the depicted embodiment, the half-shells may be injection-molded as a single shell **80**, joined at their inner edge by hinge **82**. Hinge **82** may be formed by molding the connection between the two halves of clam shell **80** as a thin wall portion, as more particularly illustrated in **FIG. 8**.

[0054] Outer edges **84** and **86** of shell **80** may include elements that engage to lock shell **80** into a cylinder to form exterior pipe **32**. As illustrated more particularly in **FIG. 9**, each end of shell **80** includes a complementary lock portion. In particular, one end may be formed to include a lock socket **88** that may receive a complementary lock edge **86** having a retaining nib **90**. Nib **90** may be received in a groove of lock socket **88**, to retain lock edge **86** in lock socket **88**. Optionally, the lock may be glued or welded shut.

[0055] Conveniently, exhaust subsystem **16** may be formed by injection molding exterior pipe **32**, as clamshell **80**; filling clamshell **80** with a layer of fibrous insulation to form insulation layer **40**; and inserting liner **42** and optionally pipe **44**. Once the insulation, liner **42** and pipe **44** are contained within clamshell **80**, it may be closed and locked.

[0056] In an alternative embodiment, illustrated in **FIG. 10** and **11**, exhaust subsystem **16** may further include an interior pipe **44.** Interior pipe **44** may be a conventional metal pipe, defining passage **34'** parallel to exterior pipe **32**. Pipe **44** may be spaced from liner **42** by radially-extending discs (not shown) which

support pipe **44** on liner **42** and which are attached to liner **42** by conventional means, for example, welding or crimping. The spacing of pipe **44** from liner **42** defines a void **45** between liner **42** and pipe **44**. Pipe **44** may include multiple apertures **47** through which void **45** is in fluid communication with passage **34'**. Apertures **47** may optionally be provided with extensions **49**, having a height in the radial direction. Void **45** forms a resonance chamber analogous to resonance chambers **54**. Sound waves travelling in pipe **44** cause excitation of the air in apertures **47**, which cause the air in void **45** to resonate. Similar to resonance chambers **54**, this resonance frequency is dependent on the volume of void **45** and the number and size of apertures **47**, as well as the wall thickness of pipe **44**. Thus, likewise to resonance chambers **54**, the sound attenuation performance of resonance chambers **54** can be tuned for a particular frequency. Again the resonance frequency achieved by apertures **47** may be calculated as

$$V = \frac{s^2 A}{f^2 \left(t_o + 1.6r\right)}$$

where V is the volume of void **45**, s is the speed of sound at operating temperature, t_o is thickness of pipe **44**, A is the surface area of apertures 47, and r is the radius of one aperture **47**.

[0057] Optionally, some or all of apertures **47** may be surrounded by cylindrical extensions **49**. Extensions **49** increase the effective volume of air which interacts with the air in void **45**, causing it to resonate. For a fixed number of apertures **47** having a fixed size and interacting with a void **45** of fixed volume, the frequency at which the system resonates will be reduced as a result the addition of extensions **49**. If all apertures **47** are surrounded by extensions **49** of a particular height measured in the radial direction, that height will replace the term t_o in the above relationship. If only some of apertures **47** are surrounded by extensions **49**, the frequency at which the air in void **45** resonates may be determined heuristically.

[0058] In an alternate embodiment, aft exhaust subsystem **16** may further

include a volume muffler **66**, depicted in **FIGS. 12** and **13**. Volume muffler **66** additionally includes a non-metal (e.g. polymeric) muffler housing **70**. Muffler housing **70** may retain an interior metal pipe **71** (best viewed in **FIG. 12**). The pipe may be an extension of pipe **44** (**FIG. 10**) having apertures **47'** and/or extensions **49'** along its length, or may be another pipe segment that may be interconnected with/in flow communication with pipe **44** or passage **34**. A catalytic convertor or particulate filter **74** may be contained in housing **70** proximate the inlet to volume muffler **66**. Pipe **71** in muffler housing **70** may be surrounded by a mesh **68**, spaced radially outward from pipe **71**. The gap between pipe **71** and mesh **68**, and the apertures in pipe **71** interact to form a resonance chamber akin to that of the embodiment depicted in **FIG. 10**. Fibrous insulation may fill the region between mesh **68** and housing **70**. Conveniently, housing **70** may include lengthwise extending ribs **72**, providing structural rigidity to muffler housing **70**. Each rib **72** may be generally rectangular, defined by an arced wall portion and opposing, radially extending walls. Housing **70** may be extrusion or injection molded. As illustrated, volume muffler **66** has a generally circular cross-section with protruding ribs. However, volume muffler **66** may be formed in any arbitrary shape.

[0059] In a further alternate embodiment, depicted in **FIGS. 14** and **15**, aft exhaust subsystem **16** may include a volume muffler **76** which includes a housing **78**, insulation **80** (like insulation layer **40**), and a liner **82** (like liner **42**). Liner **82** may define a passage **84** through the lengthwise extent of volume muffler **76**. Resonance chambers **86** (like resonance chambers **54**) and expansion regions **88** (like expansion regions **64**) may be formed in liner **82**. Insulation **80** (like insulation layer **40**) may fill the region between housing **78** and liner **82**.

[0060] Coupling assembly **30** used to connect aft subsystem **16** to forward subsystem **14** is more particularly illustrated in **FIG. 16**. Coupling assembly **30** may attach to forward subsystem **14** at any suitable location downstream of exhaust manifold **22** of vehicle **10**. As illustrated, coupling assembly **30** includes

a metal pipe stub **120** that is attached, for example, by welding, at its upstream end to a metallic upstream flange **122**. Upstream flange **122** allows for metal-to-metal flange connection by abutting a complementary flange on forward subsystem **14** thereby sealingly attaching aft exhaust subsystem **16** in fluid communication to forward subsystem **14**. Upstream flange **122** is mechanically affixed using a conventional fastener, locking the position of coupling assembly **30**, and thus aft exhaust subsystem **16**, to upstream forward exhaust subsystem **14**.

[0061] Metal pipe stub **120** is attached at its other end, for example, by welding, to a thin metal flange **124**, proximate the downstream end of metal pipe stub **126**. Thin metal flange **124** should be thin – possibly as thin as possible, while remaining rigid. Typically, thin metal flange **124** is approximately 1.5 mm thick. Metal flange **124** connects coupling assembly **30** in fluid communication with exterior pipe **32**. Thin metal flange **124** has a small flange-pipe surface area **126** in direct contact with metal pipe **120** and a large convective surface area **128** in contact with ambient air. The large size of convective surface area **128** relative flange-pipe surface area **126**, promotes heat dissipation to ambient air. Thin metal flange **124** further includes an annular collar **130** extending axially in the downstream direction, which engages a retaining ring **132**. Retaining ring **132** engages a set of tabs **134** on the outer surface of exterior pipe **32**. Tabs **134** lock the axial and rotational position of exterior pipe **32** relative to coupling assembly **30**. Alternatively, two separate sets of tabs may be used, with one set to lock the axial position of exterior pipe **32**, and one set to lock the rotational position of exterior pipe **32**.

[0062] Metal pipe stub **120** may extend downstream of thin metal flange **124** in the axial direction. The downstream end of metal pipe stub **120** may be shaped to enhance the fluid mechanic properties of exhaust gases entering exhaust subsystem. For example, metal pipe stub **120** may terminate in a converging or diverging nozzle.

[0063] As will be appreciated, gases in metal pipe stub **120** may be extremely hot. In certain operating conditions, metal pipe stub **120** may reach temperatures in excess of 600 °C. Exposure to such high temperatures could damage exterior pipe **32**. For example, if placed in direct thermal contact with metal pipe stub **120**, exterior pipe **32** could melt.

[0064] As such, metal flange **120** provides thermal protection of exterior pipe **32**. The quantity of conduction from metal pipe stub **120** to thin metal flange **120** is limited by small size of flange-pipe surface area **126**. Moreover, the area of convective surface **128** is large relative to flange-pipe surface area **126**. As a result, a significant quantity of the heat transferred into thin metal flange **124** by conduction from metal pipe **120** is transferred to ambient air, rather than being conducted to exterior pipe **32**.

[0065] Metal pipe stub **120** may further include an accordion-like bellows section **138** located upstream of thin metal flange **124**. Bellows section **138** may be capable of deforming in an axial direction, to absorb mechanical and thermal stresses. Conveniently, bellows section **138** prevents axial vibrations from being transmitted to exhaust subsystem **16** from engine **18** and forward exhaust subsystem **14**.

[0066] Additionally and optionally, exhaust subsystem **16** may also include one or more baffles **150** within passage **34** along its length, depicted in **FIGS. 17 and 18**. Baffles **150** may be located proximate the upstream end of exhaust subsystem **16**, or may be located at any point. Baffles **150** include a face **152** positioned generally normal to the flow of gases through passage **34** and a baffle flange **154** attached to liner **42** by conventional means, for example, by spot welding. Face **152** has an aperture **156** which allows exhaust gases to pass through baffle **150** and which defines one or more lobes **158** in face **152**. Baffles **150** may be constructed of a metal material, for example, stainless steel or spring steel. The material, thickness and shape of lobes **158** is chosen so that lobes **158** resonate at a particular frequency. Sound waves of this frequency in

passage **34** cause the lobes to vibrate. This resonant vibration causes an out of phase pressure wave to propagate in the upstream direction of the pipe, destructively interfering with waves of the particular frequency. The material, thickness and shape of the lobes is also chosen so that pressure from exhaust gases can cause lobes **158** to deflect in the downstream direction as illustrated in **FIG. 14**. When lobes **158** deflect, the size of aperture **156** increases, allowing exhaust gases to pass through baffle **150** more easily.

[0067] As will be appreciated, engine **18** produces high-temperature and pressure and expels exhaust gases. Exhaust gases travel through sealed exhaust subsystem **14**. Partially cooled exhaust gases exit from subsystem **14** into aft exhaust subsystem **16** by way of coupling assembly **30**.

[0068] As exhaust gases propagate along passage **34**, exhaust gases gradually cool by transferring heat to exhaust subsystem **16**, and more particularly to insulation layer **40**, which resists heat transfer toward exterior pipe **32**.

[0069] Although insulation layer **40** may provide sufficient thermal protection, to ensure that heat absorbed from the exhaust gases does not cause exterior pipe **32** to melt or materially deform, insulation **40** limits the amount of heat that may be transferred from the exhaust gases to exhaust subsystem **16**. As a consequence, exhaust gases exiting exhaust subsystem 16 exit at higher temperatures than they would in the absence of insulation layer **40**. With modern combustion engines, this remains acceptable as such engines produce lower temperature exhaust gases.

[0070] In any event, engine **18,** in operation, also causes sound waves to propagate down exhaust passage **34**. The sounds created by engine **18** may be particularly loud within a certain characteristic frequency range, which is determined by factors including the operating speed (revolutions per minute), number of cylinders and configuration of cylinders of engine **18**. Sound waves are created by pulses of high pressure emitted from engine **18**, which pass

through upstream subsystem **14** to and through exhaust subsystem **16**.

[0071] As the sound waves travel along passage **34**, they may be attenuated in several ways. Specifically, the sound waves may be attenuated by absorption regions along passage **34**; resonance chambers **54**; expansion regions **64**; or by baffles **150**.

[0072] In the absorption regions, sound waves propagating along passage **34** may pass through perforations **46** in liner **42** and into insulation layer **40**. Sound waves entering insulation layer **40** in this manner are absorbed and the energy associated with such waves is dissipated by insulation layer **40**. The performance of absorption regions is dependent on their location in exhaust subsystem **16**. Absorption regions located in curved sections of exhaust subsystem **16** may be more effective at attenuating sound as sound waves in such curved sections may travel directly into insulation layer **40**. Conversely, where passage **34** is aligned with the average direction of propagation of sound waves, waves can enter insulation layer **40** in a direction normal to the direction of the wave's propagation.

[0073] In expansion regions **64**, the cross-sectional area of interior passage **34** is increased, slowing down the flow of exhaust gases. This improves the effectiveness of sound attenuation insulation layer **40** adjacent to expansion regions **64**.

[0074] Attenuation of sound by absorption in this manner is particularly effective for high-frequency sounds.

[0075] As sound waves pass resonance chambers **54**, the waves excite the air in perforations **46**, which causes the air inside resonance chambers **54** to resonate. More specifically, sound waves induce Helmholtz resonance at a particular frequency in resonance chambers **54**. As set out above, the frequency of this resonance is dependent on the volume of resonance chamber **54**, the number and area of perforations **46** through which resonance chamber **54** is in

fluid communication with interior passage **34**, and the thickness of liner **42**. Resonance of the air in resonance chambers **54** causes destructive interference with, and thus attenuates sound waves of the same frequency in interior passage **34**.

[0076] Sound waves in interior passage **34** also cause air in expansion regions **64** to reflect and /or resonate. Reflection/resonance in expansion regions **64** occurs at low frequencies, for example, less than 500 Hz, less than 300 Hz or less than 200 Hz.

[0077] Likewise, propagating sound waves may encounter baffles **150**. Upon striking baffles **150**, sound waves excite lobes **158**. As set out above, lobes **158** are designed such that they resonate at a particular frequency. Resonance of lobes **158** causes waves of the same frequency to propagate along the interior passage **34**, in the upstream direction. These waves destructively interfere with waves of the same frequency originating from engine **18**, and thus, attenuate sound at that frequency.

[0078] As noted, each baffle **150** has lobes **158** and at least one aperture **156**. Aperture **156** permits exhaust gases to flow through baffle **150**. At higher operating speeds of engine **18**, the flow rate of exhaust gases increases. At high flow rates, baffle **150** may restrict flow. When this occurs, pressure will increase upstream of baffle **150**, causing lobes **158** to deflect in the downstream direction, increasing the size of aperture **168** and reducing the restriction on gas flow. However, the sound attenuation resulting from the resonance of lobes **158** may be reduced when lobes **158** are deflected in this manner. Thus, lobes **158** may be tuned for attenuation of low frequency sounds, which are prevalent at low engine speeds, when the flow rate of exhaust gas is comparatively low. At higher engine speeds, when higher frequency sounds are predominant, increased exhaust gas flow will cause lobes **158** to deflect, reducing the backpressure created by baffles **150**. As should now be apparent, the overall acoustic properties of exhaust subsystem **16** can be customized for application to

a specific engine **16**. Each of the baffles **150**, resonance chambers **54** and expansion regions **64** can be specifically tuned as described above to attenuate sounds in a particular range of frequencies.

[0079] Conveniently, subsystem **16** may extend all the way to the exhaust system exit, and may obviate the need for a volume muffler. Conveniently, sound attenuation may occur all the way along the length.

[0080] Of course, the above described embodiments are intended to be illustrative only and in no way limiting. The described embodiments of carrying out the invention are susceptible to many modifications of form, arrangement of parts, details and order of operation. The invention, rather, is intended to encompass all such modification within its scope, as defined by the claims.

WHAT IS CLAIMED IS:

1. An exhaust subsystem comprising:

an exterior pipe comprising polymer, for carrying gases from an engine;

a rigid liner within said exterior pipe, extending along a length of said exhaust subsystem, defining a passageway having a periphery;

a fiber insulating layer formed between said rigid liner and said exterior pipe;

wherein said liner is formed to define at least one groove circumscribing the periphery of said passageway, said at least one groove defining a region of increased cross-sectional area of said passageway along a length of said passageway;

wherein said liner is further formed to define at least one void extending between said liner and said insulating layer, around the periphery of said passageway; and

wherein said liner comprises a plurality of apertures in communication with said void, allowing sound waves to pass from said passageway into said fiber insulating layer, and into said at least one void extending around the periphery of said passageway.

2. The exhaust subsystem of claim 1, wherein at least some of said at least one groove and said at least one void are independently sized to respectively attenuate a specific selected frequency emitted by a specific engine

3. The exhaust subsystem of claim 1 or claim 2, wherein at least some of said at least one groove and said at least one void are sized to attenuate specific frequencies emitted by a specific engine.

4. The exhaust subsystem of claim 1 or claim 2, wherein said exterior pipe has a generally circular cross-section.

5. The exhaust subsystem of claim 3, wherein said at least one void is designed to attenuate a frequency f, and wherein the volume of said at least one void, V, is chosen such that $V \approx \frac{s^2 A}{f^2 (t_o + 1.6r)}$, where t_0 is the thickness of said liner, s is the speed of sound, A is the total area of said apertures in communication with said void, and r is the effective radius of one of said apertures extending into said void.

6. The exhaust subsystem of claim 5, wherein said at least one void is formed at least one quarter wavelength of sound at said frequency f from an inlet of said exhaust subsystem.

7. The exhaust subsystem of claim 3, wherein said at least one groove is formed at least one quarter wavelength of sound at said specific frequency from an inlet of said exhaust subsystem.

8. The exhaust subsystem of claim 1 or claim 2, further comprising a thermal coating located between said fiber insulating layer and said exterior pipe.

9. The exhaust subsystem of claim 1 or claim 2, further comprising an interior pipe formed interior to said exterior pipe in said passageway, said interior pipe comprising a plurality of openings.

10. The exhaust subsystem of claim 9, wherein at least one of said plurality of openings is surrounded by a cylindrical, radially extending collar.

11. The exhaust subsystem of claim 1 or claim 2, further comprising a metal coupling to provide fluid communication into said passageway, and to allow

interconnection of said subsystem to upstream components of an exhaust assembly.

12. The exhaust subsystem of claim 1 or claim 2, wherein said apertures are substantially rectangular and are formed at regular intervals along said liner.

13. The exhaust subsystem of claim 1 or claim 2, wherein said fiber insulating layer comprises at least one of glass fiber and mineral fiber.

14. The exhaust subsystem of claim 1 or claim 2, wherein said fiber insulating layer is sufficiently thick to prevent the said polymer material from degrading due to heat of said gases.

15. The exhaust subsystem of claim 1 or claim 2, wherein each of said voids is defined by outwardly extending ribs, extending outwardly from said liner toward said exterior pipe and formed from said liner.

16. The exhaust subsystem of claim 15, wherein each of said ribs is defined by two layers of said liner, folded to project outwardly.

17. The exhaust subsystem of claim 1 or claim 2, wherein said liner is deformed to define each of said grooves as two outwardly extending annular walls.

18. The exhaust subsystem of claim 17, wherein each of said annular walls is defined by two generally sharp folds in said liner.

19. The exhaust subsystem of claim 1 or claim 2, wherein said liner is formed of at least one of stainless steel, and aluminium.

20. The exhaust subsystem of claim 1 or claim 2, wherein said exterior pipe comprises injection molded polymer.

21. The exhaust subsystem of claim 20, wherein said exterior pipe is injection molded as a hinged clam shell.

22. The exhaust subsystem of claim 1 or claim 2, wherein said liner extends substantially along the entire length of said exterior pipe.

23. An exhaust system comprising a volume muffler in flow communication with said exhaust subsystem of claim 1 or claim 2.

24. The exhaust system of claim 23, wherein said volume muffler comprises an outer shell formed of polymer.

25. The exhaust system of claim 23, wherein said volume muffler comprises a catalytic converter.

26. An exhaust subsystem comprising:

an exterior pipe comprising polymer, defining an exhaust passage along a length of said exterior pipe, for carrying gases from an engine;

a rigid liner within said exterior pipe, extending along said length, defining a passageway having a periphery;

a fiber insulating layer formed between said rigid liner and said exterior pipe;

wherein said liner is formed to define at least one void extending between said liner and said insulating layer, around the periphery of said passageway and extending along said length, said at least one void defining a resonance chamber to attenuate at least one specific frequency emitted by a specific engine;

wherein said liner comprises a plurality of apertures, allowing sound waves to pass from said exhaust passage into said fiber insulating layer, and into said at least one void.

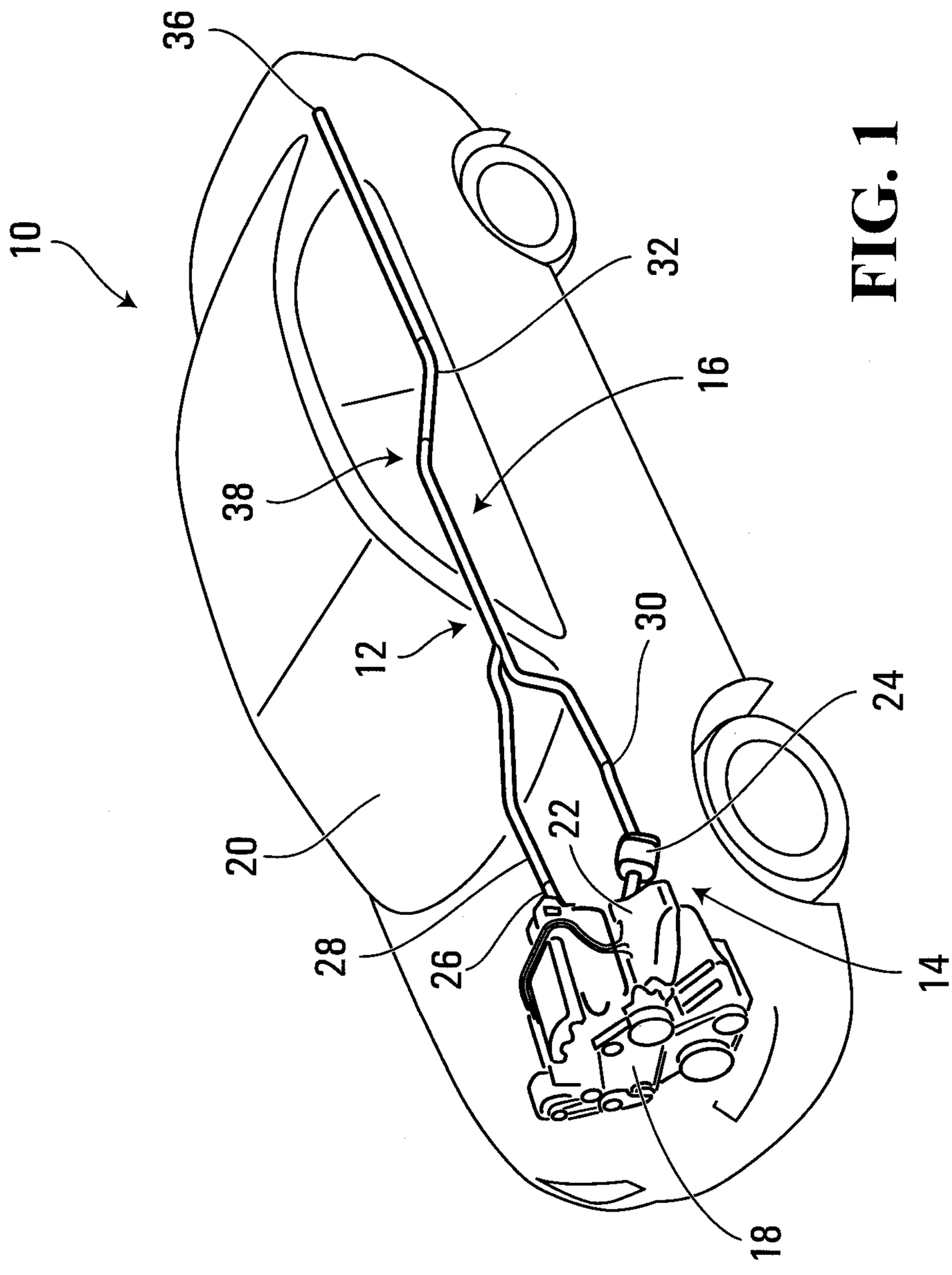


FIG. 1

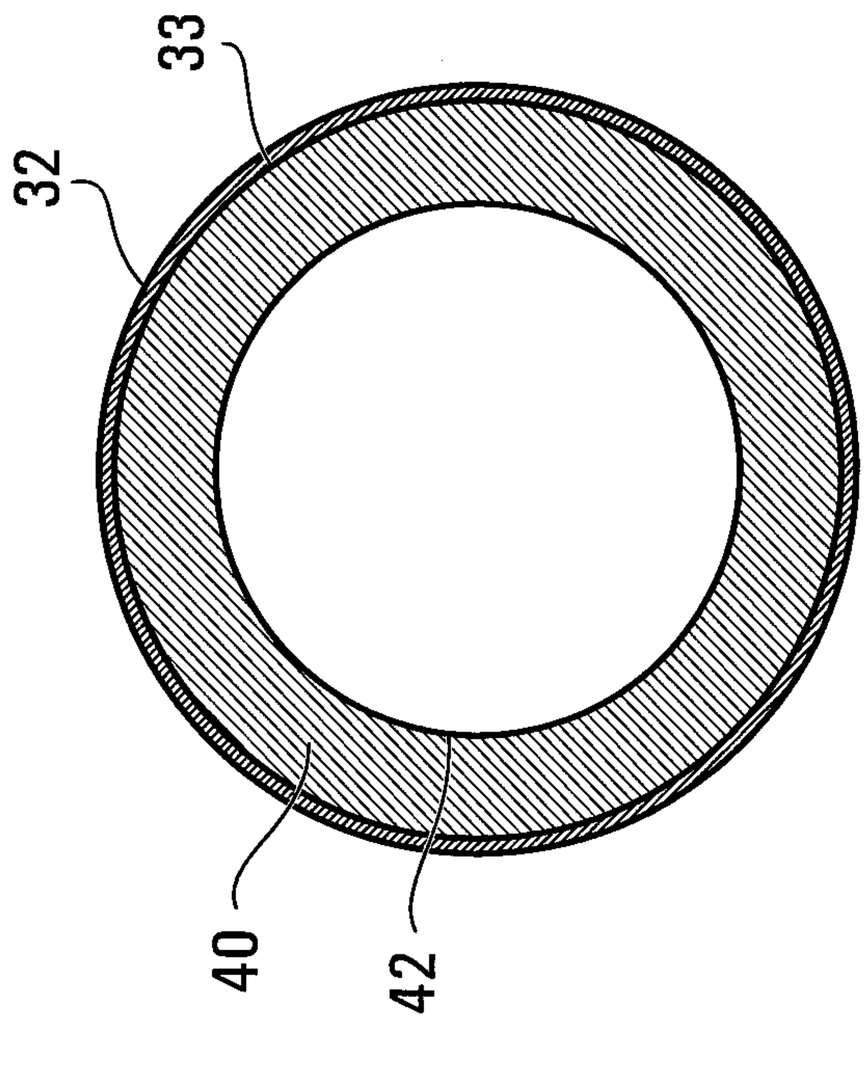


FIG. 3

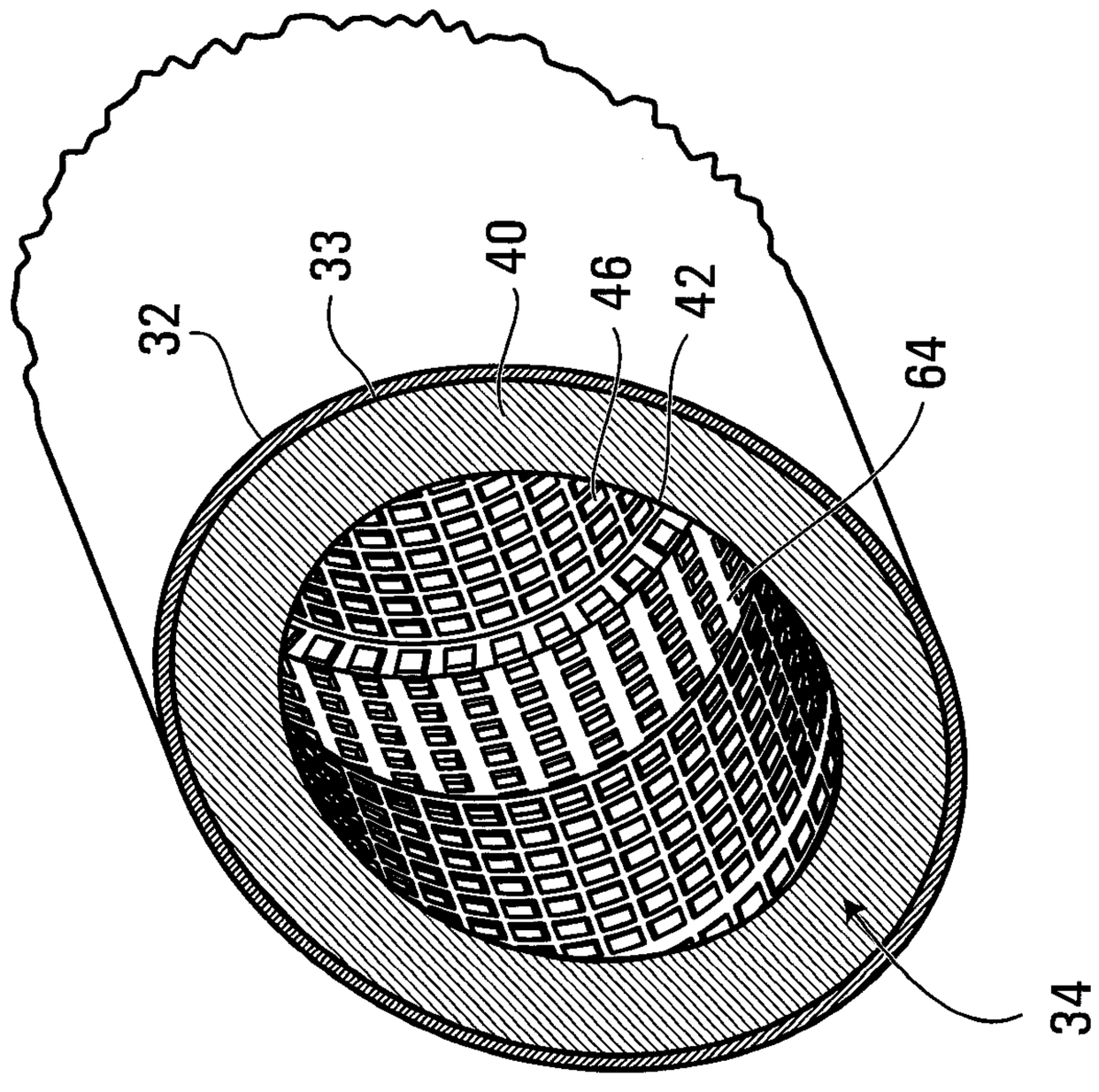


FIG. 2

FIG. 4

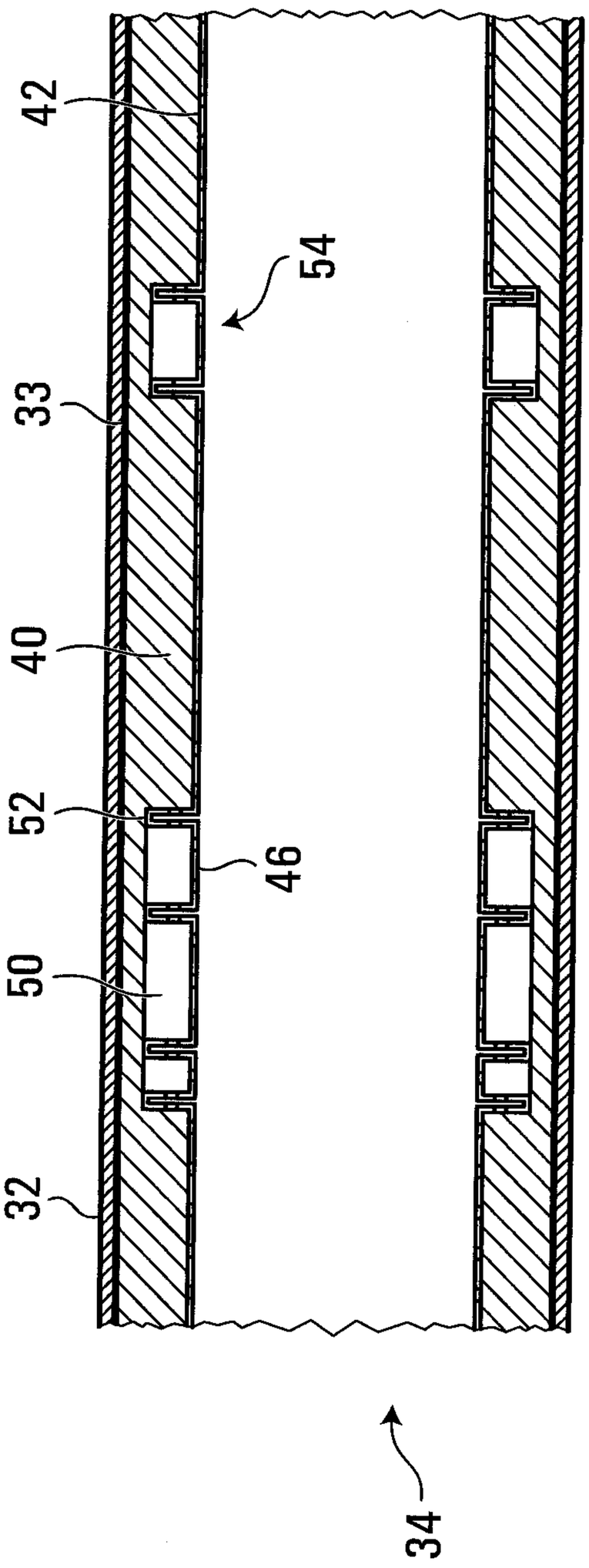
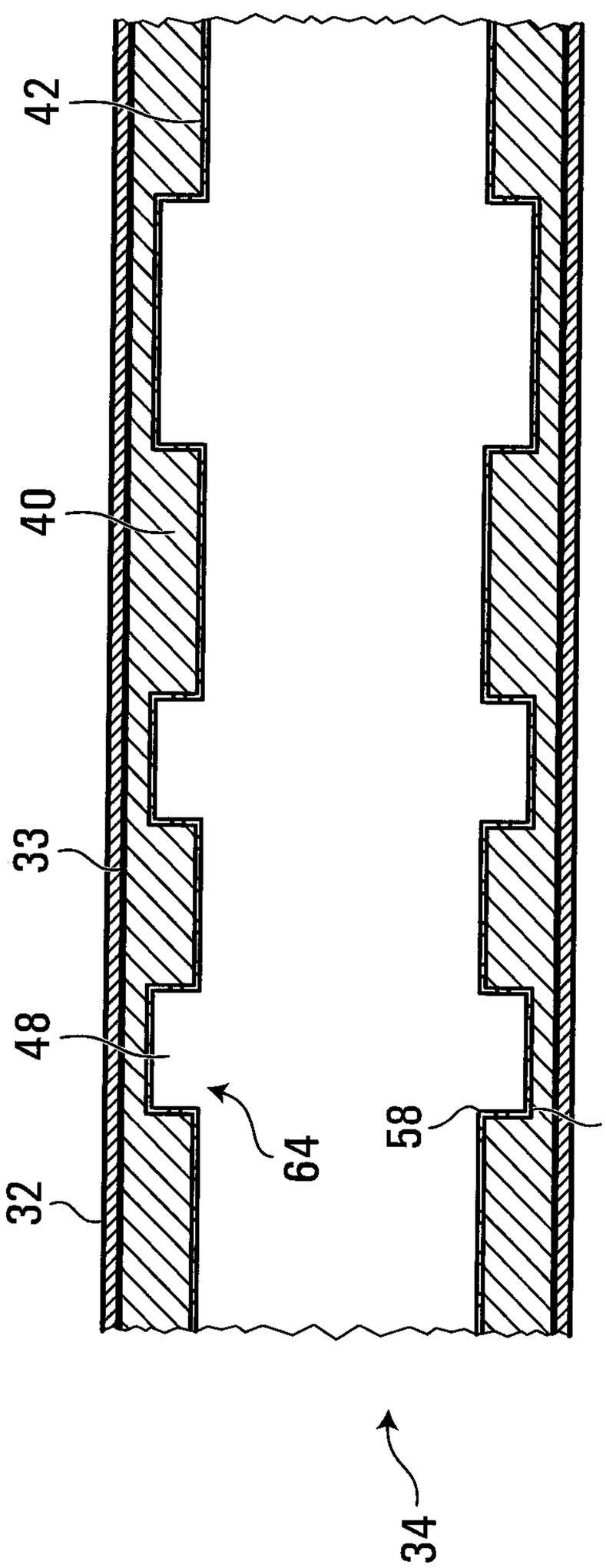


FIG. 5



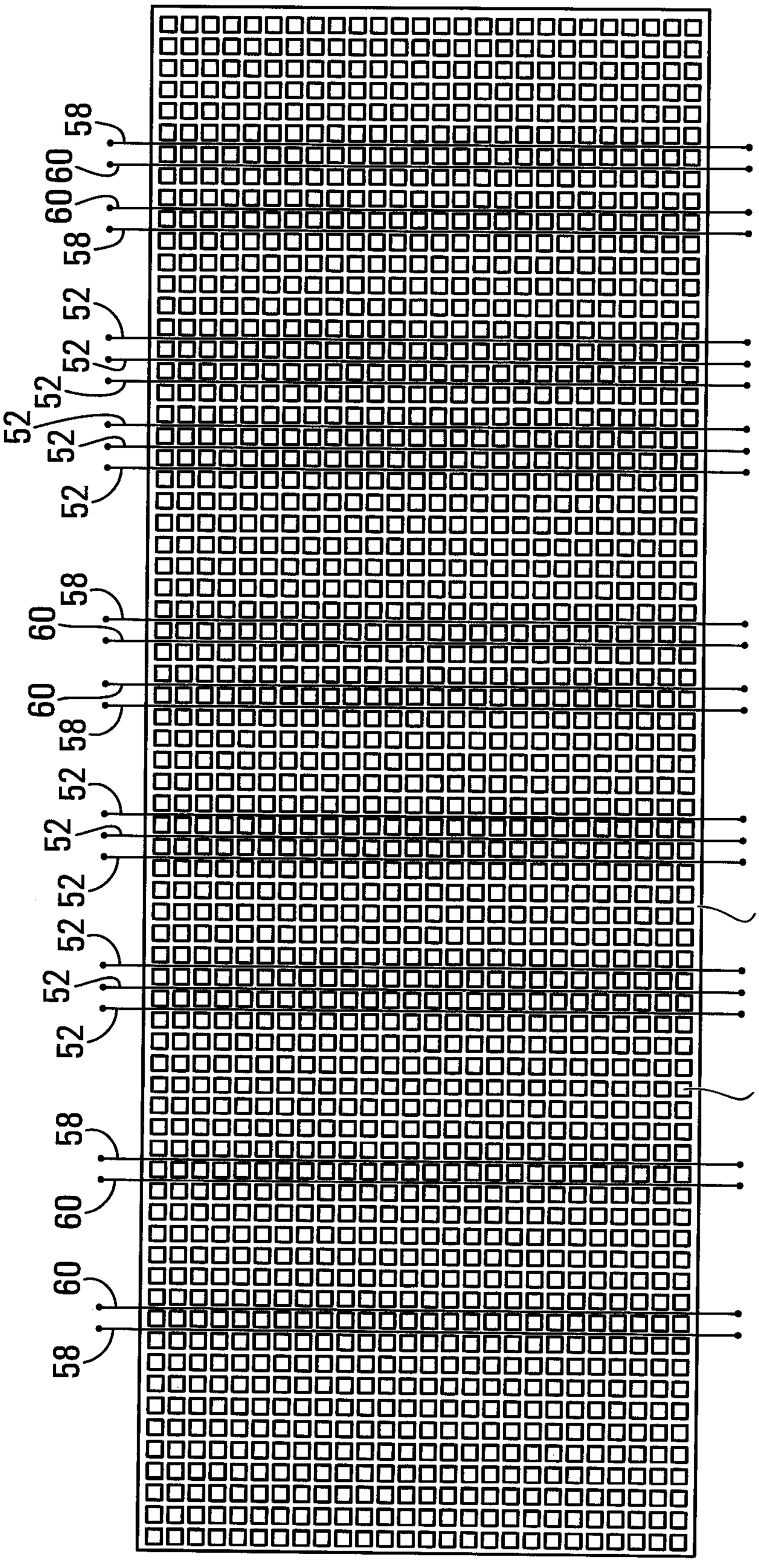

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FIG. 6

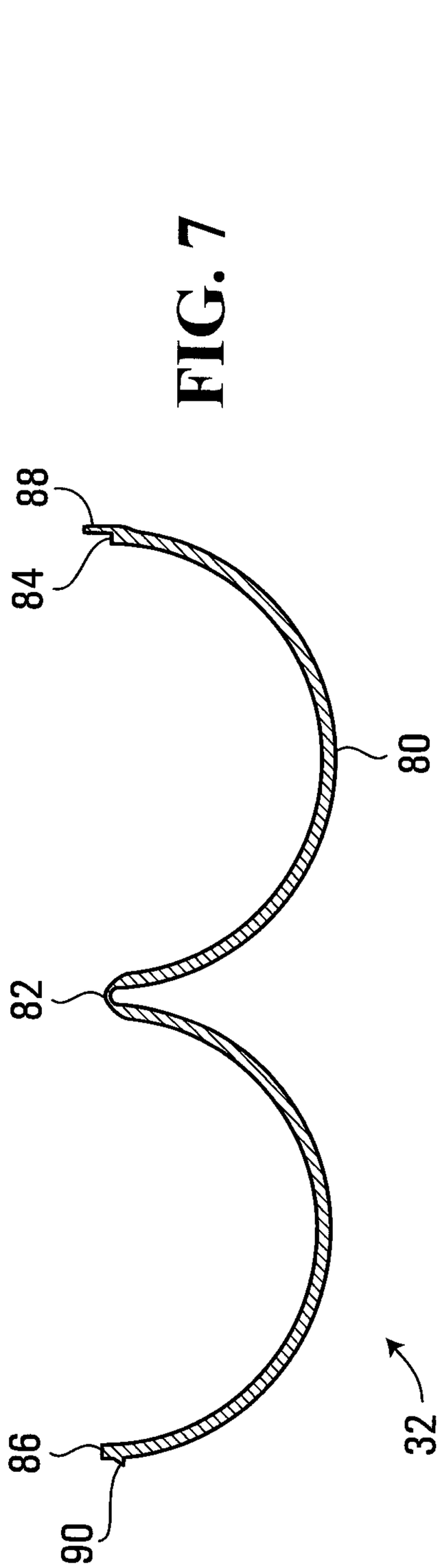


FIG. 7

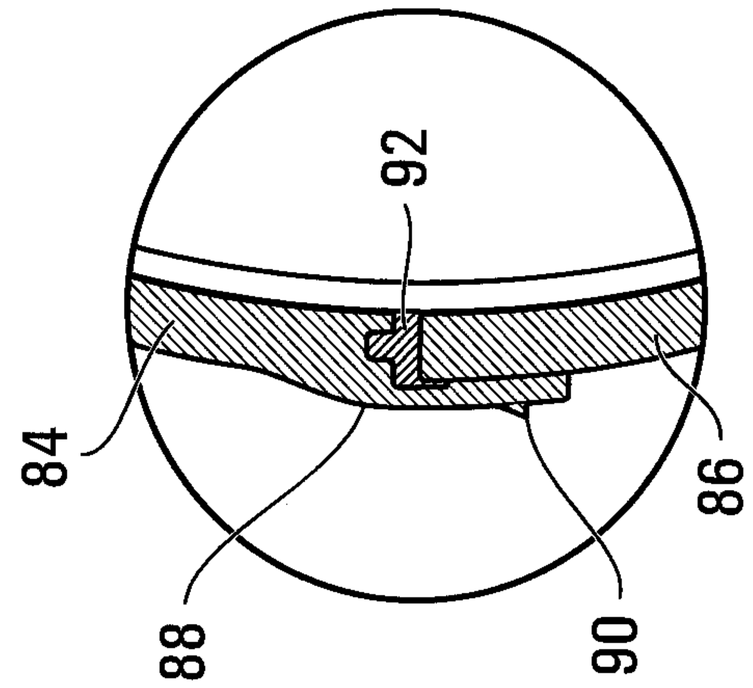


FIG. 9

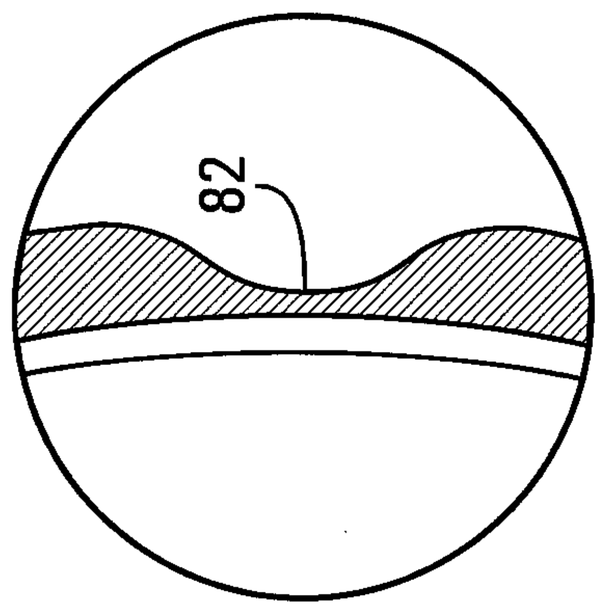


FIG. 8

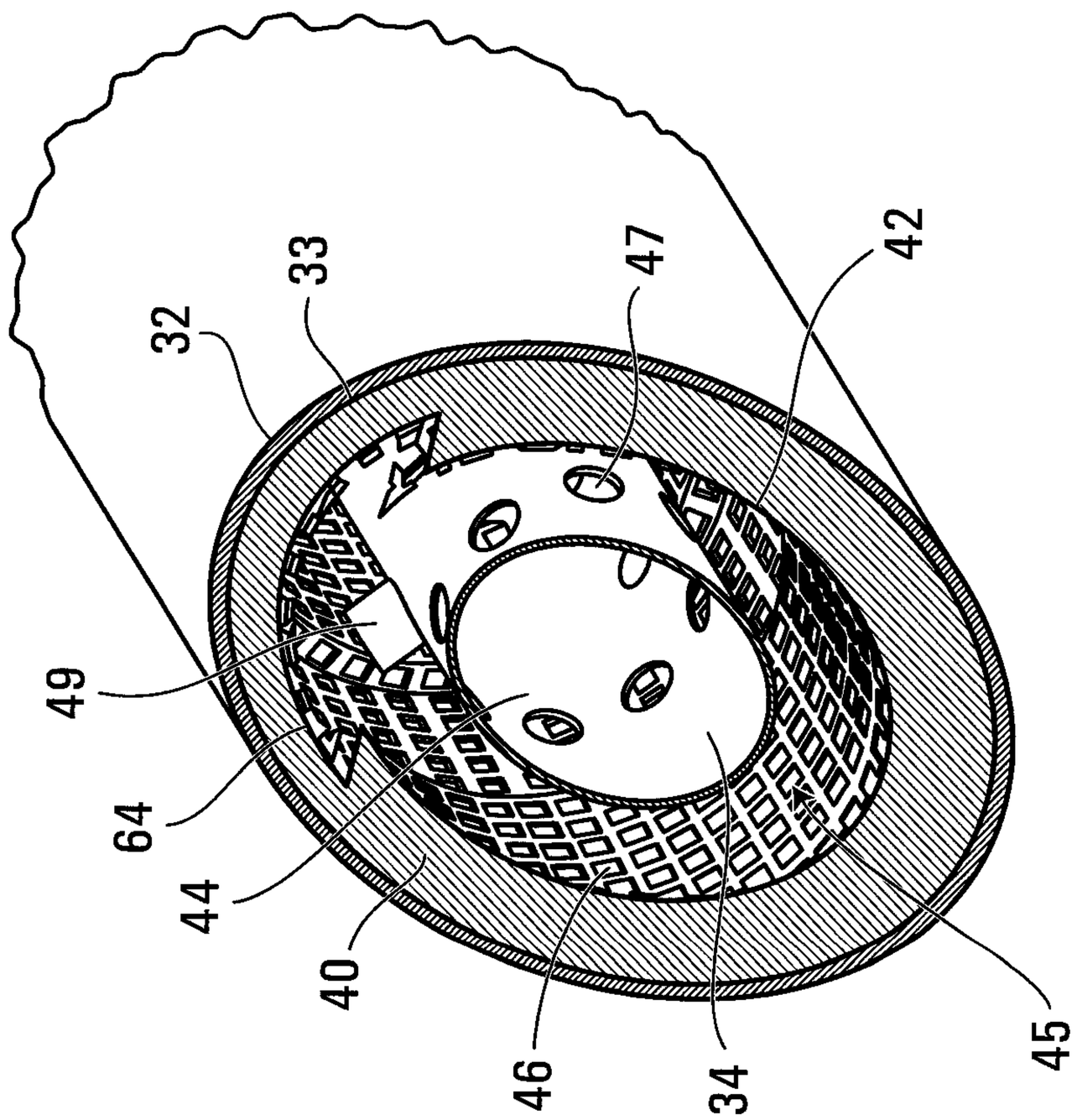


FIG. 10

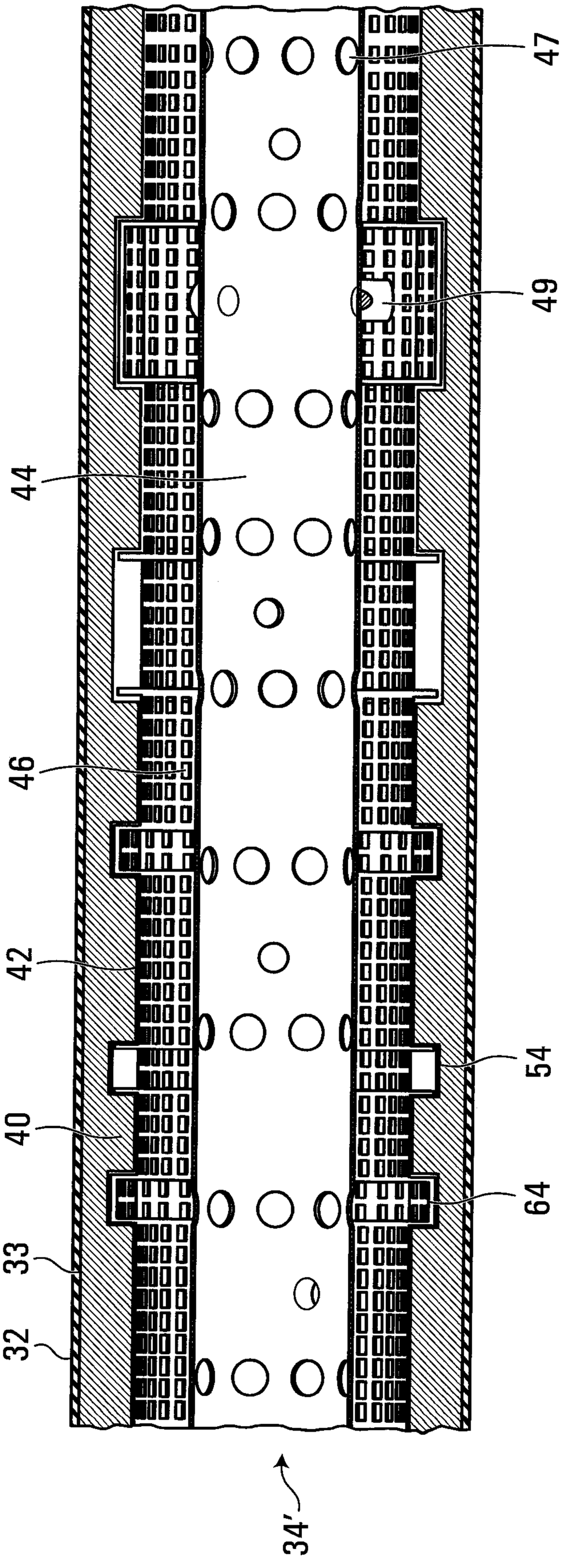


FIG. 11

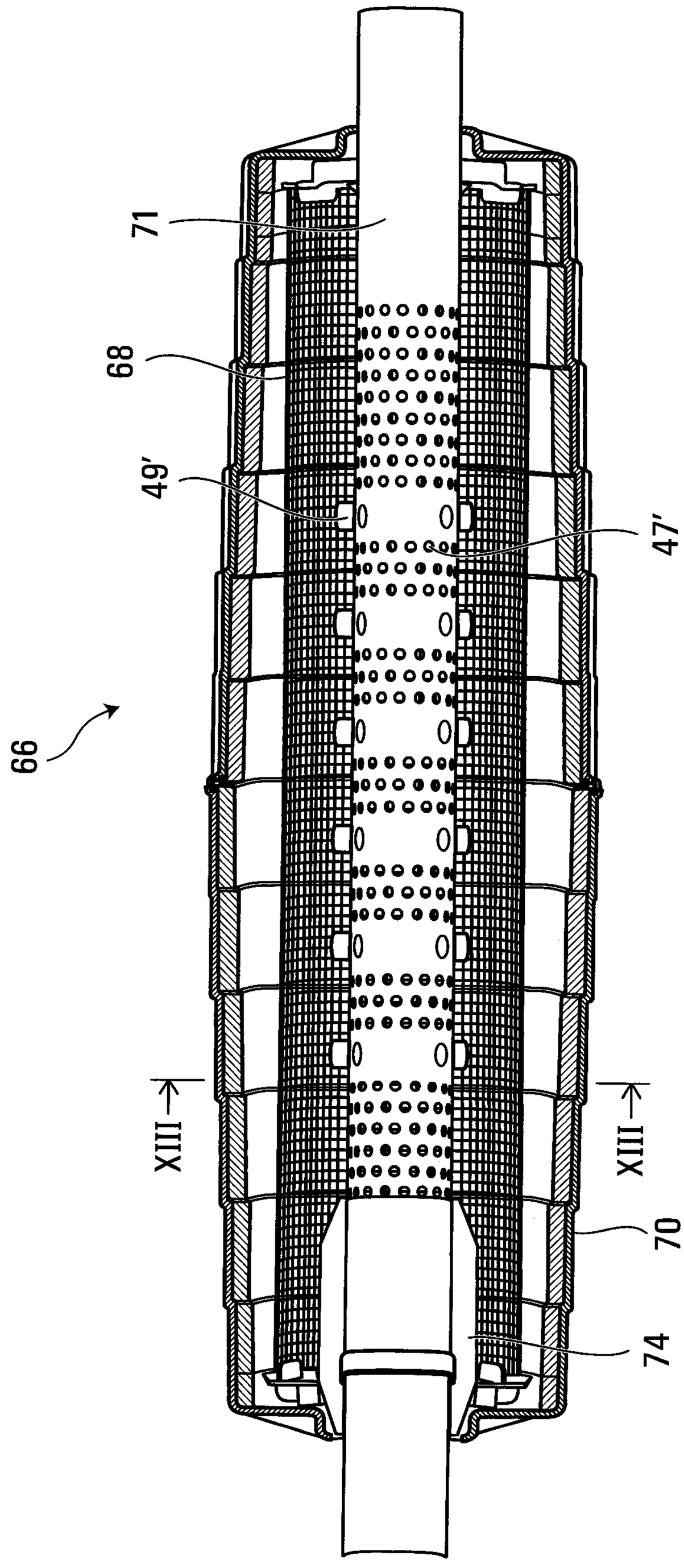


FIG. 12

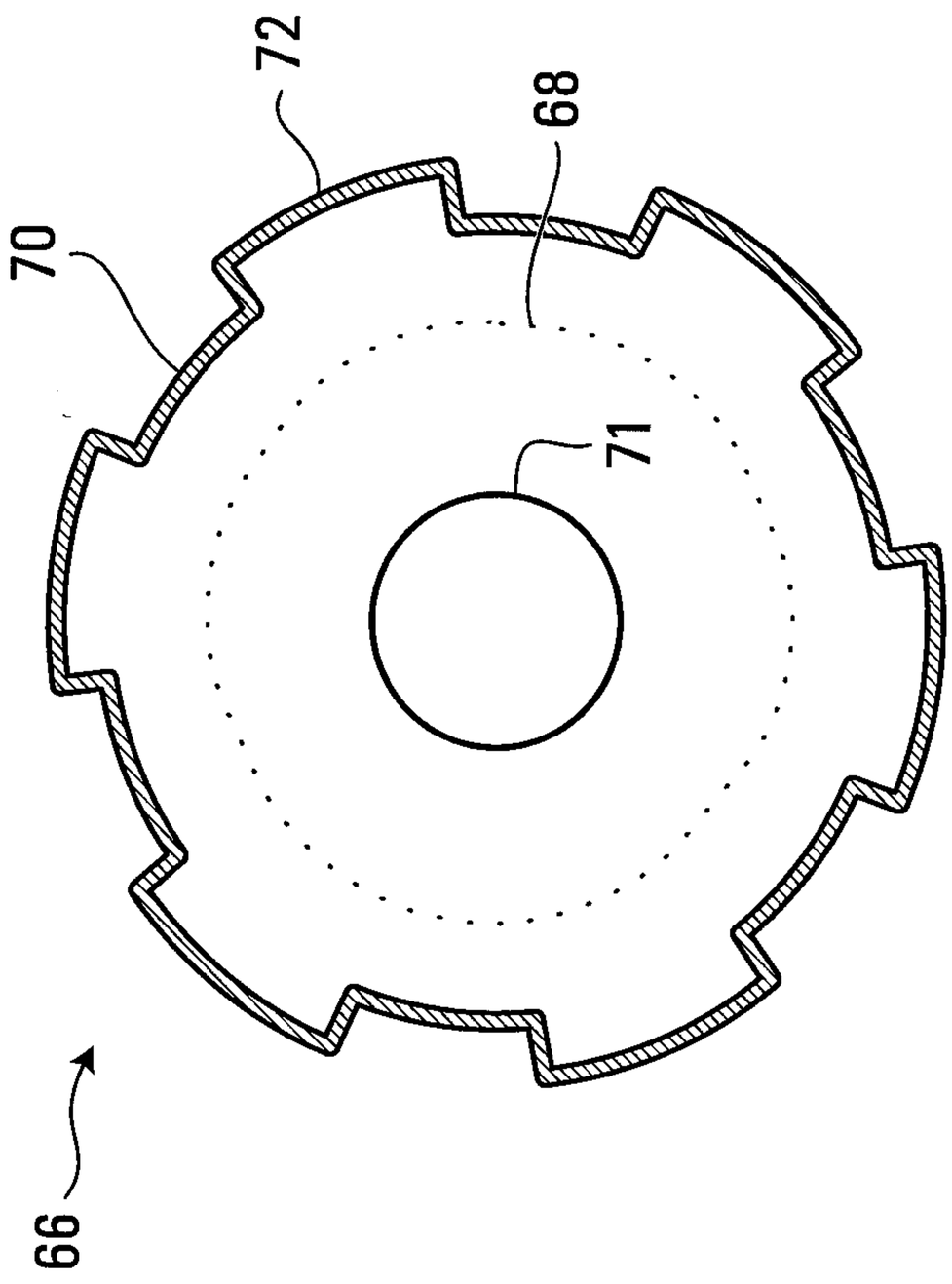


FIG. 13

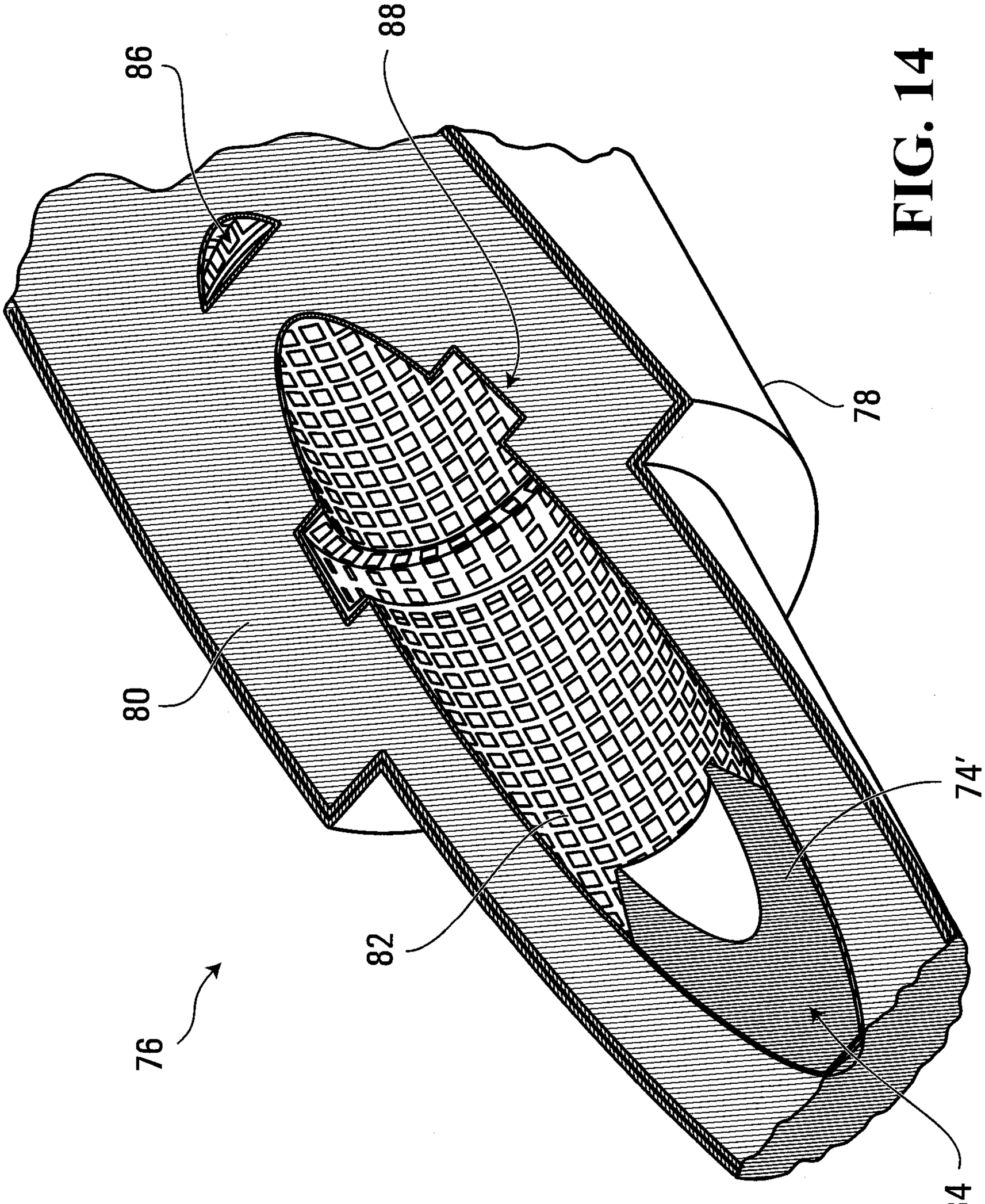


FIG. 14

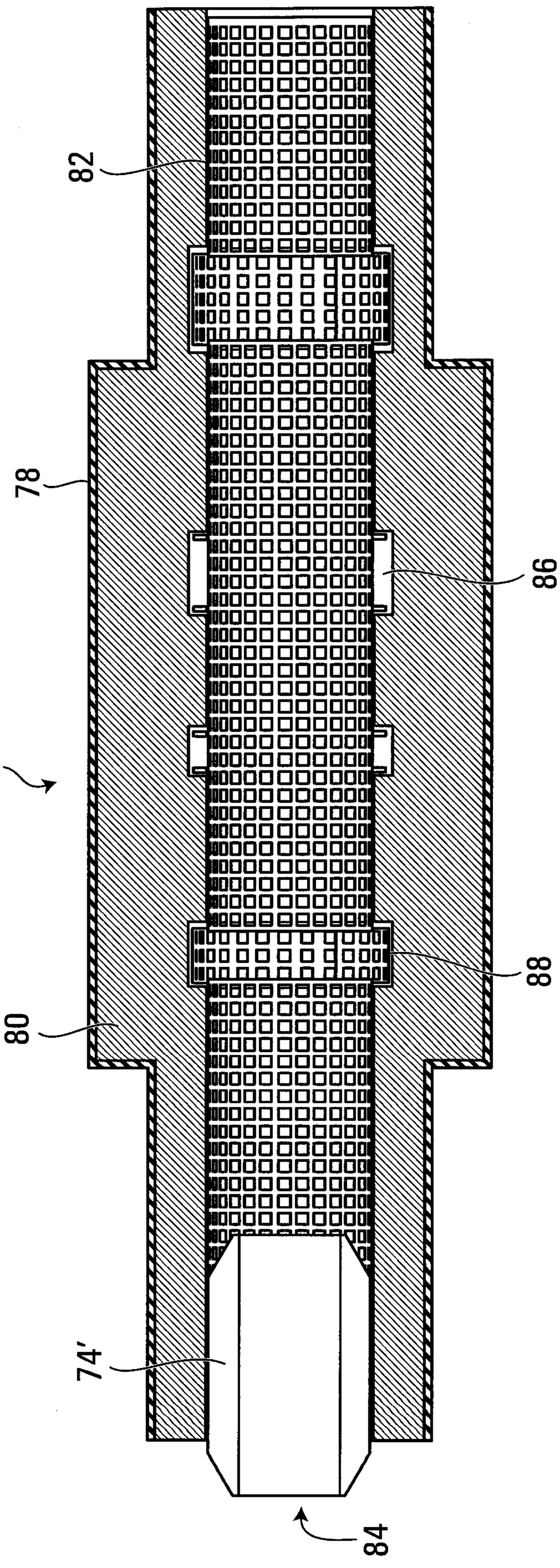


FIG. 15

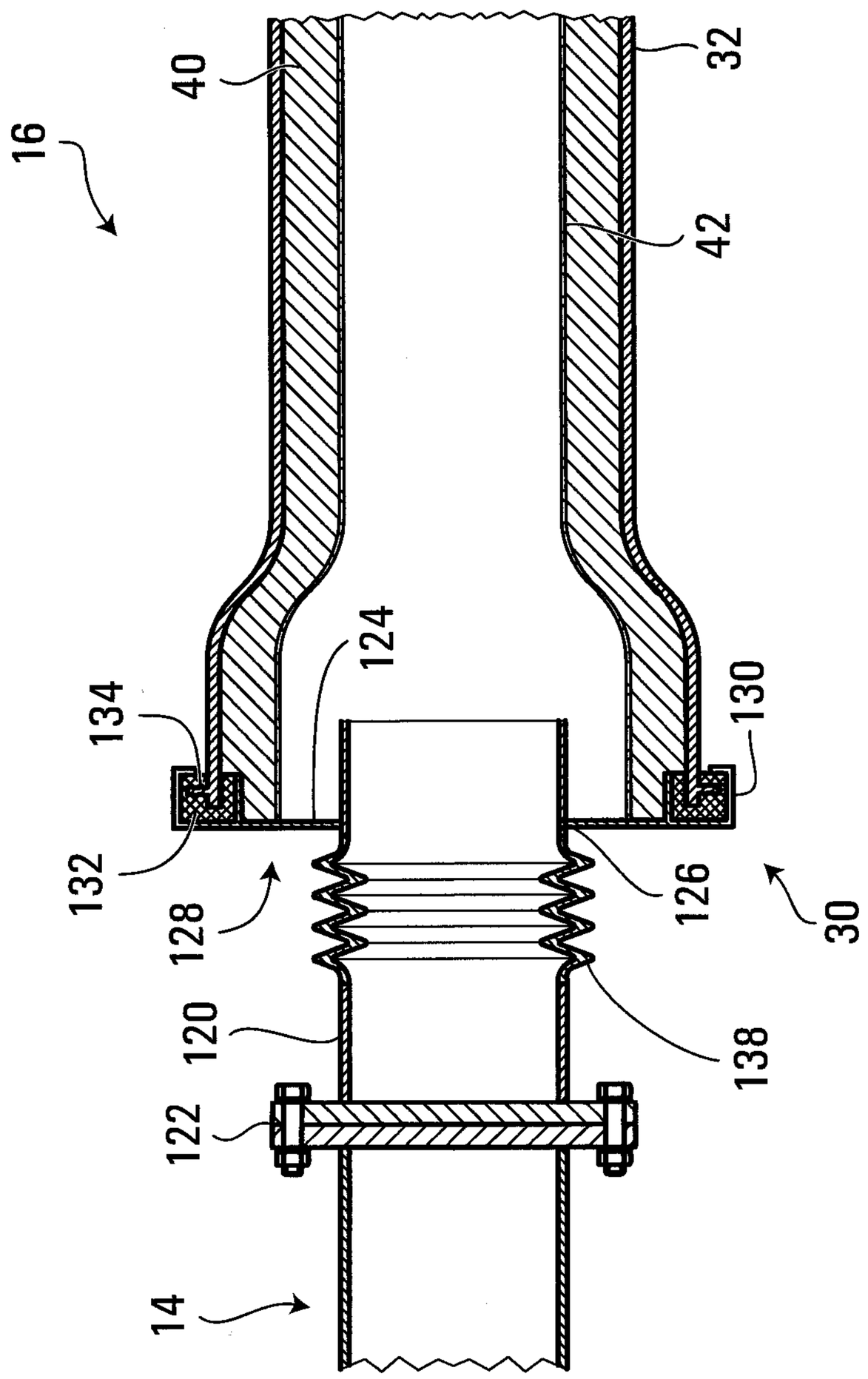


FIG. 16

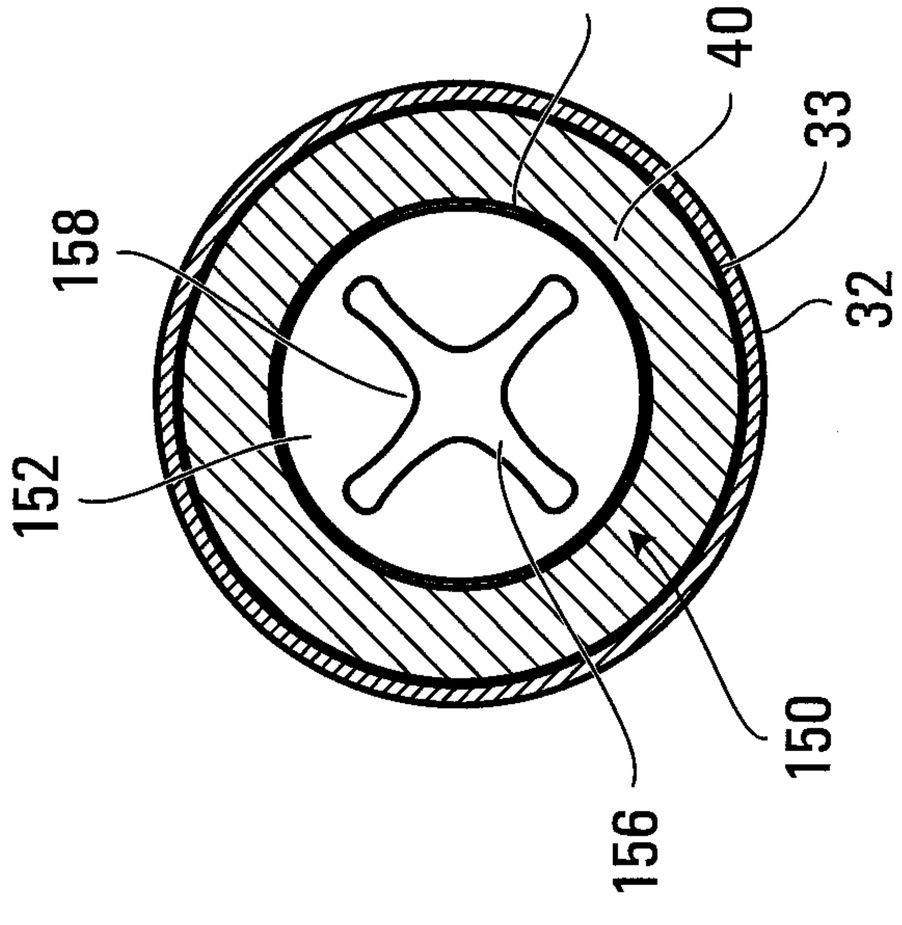


FIG. 18

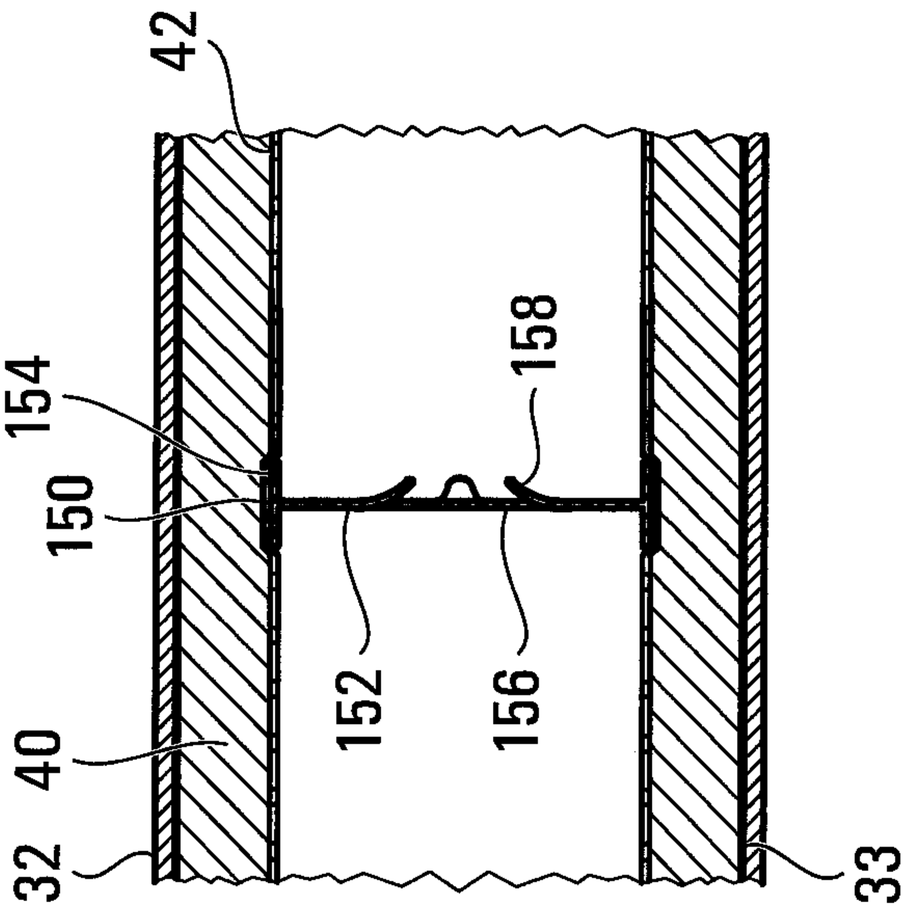
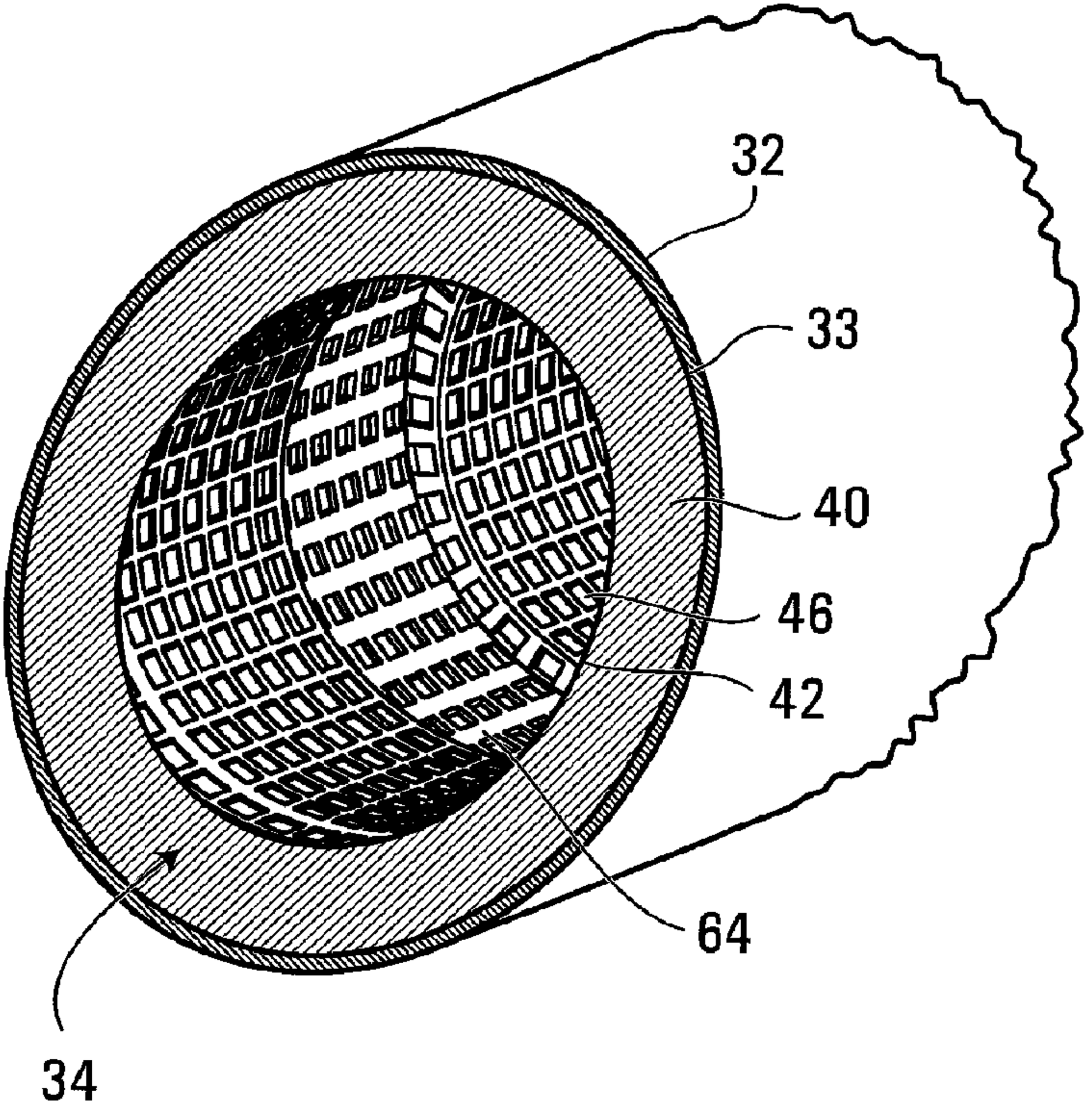


FIG. 17


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