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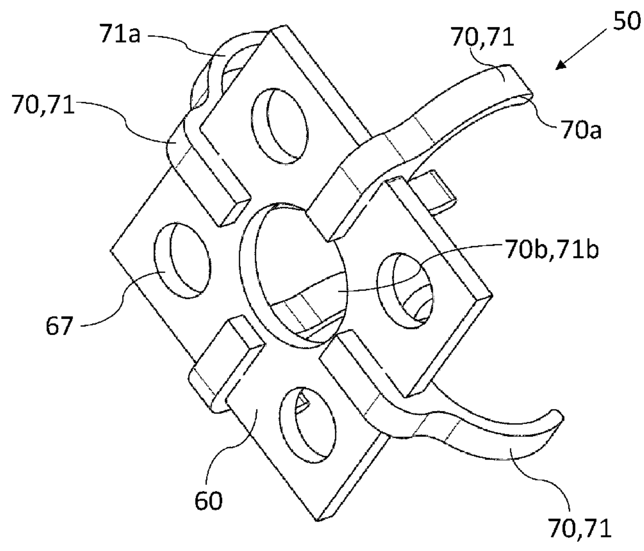

FIG. 10

(57) Abstract: A pipe spacer 50 for separating inner and outer pipes of a double-walled pipe assembly, the pipe spacer 50 comprising: an annular body 60 for positioning in an interspace between inner and outer pipes of a double-walled pipe assembly, the annular body 60 formed of a composite material; a plurality of outer arms 70a extending radially outwardly from the annular body 60 for contacting the outer pipe and/or a plurality of inner arms 70b extending radially inwardly from the annular body 60 for contacting the inner pipe; and wherein each of the inner and/or outer arms are springs 71 that extend radially from the annular body 60 and are configured to deform inwardly towards the annular body 70 on contact with the respective outer or inner pipe, the arms formed of a composite material.

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[Continued on next page]

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PIPE SPACER

FIELD OF THE INVENTION

[0001] The present invention relates to a pipe spacer, a double-walled pipe assembly, an aircraft assembly, and a method of manufacturing the pipe spacer.

BACKGROUND OF THE INVENTION

[0002] The cryogenic temperatures required to maintain hydrogen fuel lines typically necessitate double-walled pipe assemblies, with the interspace between the inner and outer pipes maintained at vacuum pressure in order to reduce thermal transfer between the fuel and atmosphere, and thereby maintain the cryogenic temperature of the fuel. Integrating such an assembly into an aircraft wing or similar structure presents various challenges, such as ensuring the pipes remain concentric whilst the structure bends or flexes.

[0003] Existing pipe spacers are sized with a clearance to the outer and inner pipes to account for manufacturing tolerances. Consequently, these pipe spacers have limited contact with each pipe that can allow undesirable relative movement between the inner and outer pipes.

SUMMARY OF THE INVENTION

[0004] A first aspect of the invention provides a pipe spacer for separating inner and outer pipes of a double-walled pipe assembly, the pipe spacer comprising: an annular body for positioning in an interspace between inner and outer pipes of a double-walled pipe assembly, the annular body formed of a composite material; a plurality of outer arms extending radially outwardly from the annular body for contacting the outer pipe and/or a plurality of inner arms extending radially inwardly from the annular body for contacting the inner pipe; and wherein each of the inner and/or outer arms are springs that extend radially from the annular body and are configured to deform inwardly towards the annular body on contact with the respective outer or inner pipe, the arms formed of a composite material.

[0005] With this arrangement, the pipe spacer can be oversized to tightly fit within the interspace between the pipes without over constraining the assembly whilst allowing some limited movement between the inner and outer pipes. The inner pipe will also be naturally biased towards a concentric configuration with the outer pipe. The formation of the arms from composite material can decrease thermal conductivity for hydrogen fuel applications and the like.

[0006] The springs can also allow manufacturing tolerances to be accounted for without the need to leave a gap, as well as provide damping of any vibrations of the inner and outer pipes.

[0007] The plurality of outer arms and/or plurality of inner arms may be attached to the annular body.

[0008] In other words, the arms may be formed separately to the annular body and subsequently attached to the annular body. This can provide improved manufacturability of the pipe spacer by increasing the number of manufacturing processes, and corresponding materials, to which the pipe spacer can be produced.

[0009] The annular body may have a constant cross-section extending between opposing planar sides.

[0010] Each of the inner and/or outer arms may have a constant cross-section extending between opposed planar sides.

[0011] The annular body may be plate-like. In other words, the annular body may have a thin body relative to its width and length.

[0012] The opposing planar faces of the annular body may be perpendicular to the opposing planar faces of the inner and/or outer arms.

[0013] The inner arms may be integrally formed with the annular body or the outer arms may be integrally formed with the annular body.

[0014] The inner arms may each be integrally formed with a respective outer arm.

[0015] The annular body may comprise a plurality of formations and/or each arm may comprise a formation. The formations are configured to facilitate mechanical interlocking between the annular body and a respective arm. The formations may be slots.

[0016] The pipe spacer may be configured to operate in cryogenic temperatures. In this way, the pipe spacer is suitable for withstanding cryogenic temperatures without significant thermal degradation and reduction in operational performance.

[0017] Optionally the annular body is formed of a fibre-reinforced composite material and/or each of the arms is formed of a fibre-reinforced composite material. The annular body and the arms may be formed of the same fibre-reinforced composite material, or different fibre-reinforced composite materials.

[0018] Optionally the annular body is formed of a glass-fibre-reinforced composite material and/or each of the arms is formed of a glass-fibre-reinforced composite material. The annular body and the arms may be formed of the same glass-fibre-reinforced composite material, or different glass-fibre-reinforced composite materials.

[0019] Optionally the annular body is formed of a fibre-reinforced polymer composite material, comprising a polymer matrix and reinforcement fibres and/or each of the arms is formed of a fibre-reinforced polymer composite material, comprising a polymer matrix and reinforcement fibres. The annular body and the arms may be formed of the same fibre-reinforced polymer composite material, or different fibre-reinforced polymer composite materials.

[0020] The annular body and/or each of the arms may be formed from a continuous fibre-reinforced composite material.

[0021] The annular body and/or each of the arms may be formed from a short fibre-reinforced composite material.

[0022] Optionally each of the springs comprises a flexible part which is formed of a composite material and configured to deform.

[0023] Optionally the flexible part is non-helical.

[0024] Optionally the composite material of the flexible part comprises reinforcement fibres which are configured to deform as the flexible part deforms.

[0025] A second aspect of the invention provides a double-walled pipe assembly, comprising: an inner pipe, an outer pipe, and the pipe spacer of the first aspect separating the inner pipe from the outer pipe.

[0026] The inner pipe may be configured to convey a cryogenic liquid. In this way, the inner pipe is constructed structurally and materially to function when conveying cryogenic liquids at cryogenic temperatures.

[0027] The interspace between the inner and outer pipes may be configured to be held at a vacuum pressure. The inner and outer pipe are therefore able to withstand the associated stresses that derive from withstanding vacuum pressures.

[0028] The inner pipe may comprise a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections.

[0029] The outer pipe may comprise a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections.

[0030] The pipe spacer may be located between the rigid pipe sections of the inner and outer pipes.

[0031] The double-walled pipe assembly may comprise a plurality of pipe spacers according to the first aspect, wherein each pipe spacer is located between the rigid pipe sections of the inner and outer pipes.

[0032] The double-walled pipe assembly may comprise a pair of flanges fixed to the inner pipe on either side of the pipe spacer to limit axial movement of the pipe spacer along the inner pipe. This assists in fixing the pipe spacer into position longitudinally.

[0033] A third aspect of the invention provides an aircraft assembly comprising a cryogenic fuel tank and the double-walled pipe assembly of the second aspect extending from the cryogenic fuel tank, wherein the inner pipe is configured to convey cryogenic fuel and the interspace is configured to be held at a vacuum pressure.

[0034] A temperature gradient across the interspace between the inner pipe and the outer pipe is configured to be at least 50 degrees, and optionally 100 degrees.

[0035] A fourth aspect of the invention provides a method of manufacturing the pipe spacer of the first aspect, comprising: forming the annular body; forming a set of the inner and/or outer arms; and attaching the set of arms to the annular body. With this method, the pipe spacer components are formed separately for subsequent attachment/coupling.

[0036] The annular body may be formed by cutting a composite fibre-reinforced panel and/or the set of arms may each be formed by cutting a composite fibre-reinforced panel. This can facilitate the use of additional materials, such as continuous fibre-reinforced composite materials, and additional manufacturing processes, such as composite layup, that may otherwise be difficult to use.

[0037] A fifth aspect provides a double-walled pipe assembly, comprising: an inner pipe having a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections; an outer pipe having a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections, wherein the inner pipe is enveloped by the outer pipe; and a pipe spacer located in the interspace between the rigid pipe sections of the inner and outer pipes, the pipe spacer comprising a plurality of flexible arms engaging at least one of the inner and outer pipes so as to bias the rigid pipe section of the inner pipe towards a centre of the rigid pipe of the outer pipe.

[0038] With this arrangement, the pipe spacer prevents over constraint of the double-walled pipe assembly and thereby allows the flexible pipe section to function appropriately, whilst also biasing the pipes into concentric alignment to avoid excessive or prolonged ‘snaking’ of the pipe sections at the flexible pipe sections.

[0039] The pipe spacer may comprise a plurality of projecting stops extending from the annular body which are configured to limit the inward deformation of the springs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0040] Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

[0041] Figure 1 shows an aircraft;

[0042] Figure 2 shows an aircraft wing box of the aircraft;

[0043] Figure 3 shows a starboard wing of the aircraft;

[0044] Figure 4 shows a wing rib;

[0045] Figure 5 shows a double-walled pipe assembly;

[0046] Figure 6 shows a perspective view of a first example of a pipe spacer;

[0047] Figure 7 shows an end view of the pipe spacer;

[0048] Figure 8 shows a side view of the pipe spacer;

[0049] Figure 9 shows a second example of a pipe spacer;

[0050] Figure 10 shows a perspective view of a third example of a pipe spacer;

[0051] Figure 11 shows a side view of the pipe spacer;

[0052] Figure 12 shows the annular body of the pipe spacer;

[0053] Figure 13 shows an arm of the pipe spacer;

[0054] Figure 14 shows a perspective view of a fourth example of a pipe spacer;

[0055] Figure 15 shows a fifth example of a pipe spacer;

[0056] Figure 16 shows a sixth example of a pipe spacer.

DETAILED DESCRIPTION OF EMBODIMENT(S)

[0057] Figure 1 shows an aircraft 1 with port and starboard wings 2, 3. Each wing has a cantilevered structure with a length extending in a generally spanwise direction 42 from a root to a tip, the root being joined to an aircraft fuselage 4.

[0058] The main structural element of the wing 3 is a wing box 20 that may be formed by upper and lower covers 21, 22 and front and rear spars 6, 7 shown in cross-section in figure 2. The covers 21, 22 and spars 6, 7 may each be formed of Carbon Fibre Reinforced Polymer (CFRP) laminate components. Each cover 21, 22 comprises a panel assembly and may have a curved aerodynamic outer surface (e.g. the upper surface of the upper cover 21 and the lower surface of the lower cover 22) over which air flows during flight of the aircraft 1. Each cover 21, 22 has an inner surface carrying a series of stiffeners 8 extending in the spanwise direction 42 (only some of the stiffeners 8 are labelled). Each stiffener 8 is joined to one cover 21, 22 but not the other.

[0059] The wing box 20 may have a plurality of transverse ribs 10, each rib 10 being joined to the covers 21, 22 and the spars 6, 7, such as shown in figure 3. The ribs 10 may include an inner-most inboard rib 10 which forms the root of the wing box 20 and is joined to a centre wing box 18 within the body of the fuselage 4 and an outer-most rib 10 at the tip of the wing box 20.

[0060] An aperture 11 is formed in one or more of the ribs 10, such as shown in figure 4. A double-walled pipe assembly 30 extends through the aperture 11 so that a longitudinal axis of the pipe assembly 30 extends through the aperture 11. The double-walled pipe assembly 30 comprises an outer pipe 30a and an inner pipe 30b enveloped by the outer pipe 30a.

[0061] The double-walled pipe assembly may be coupled to the rib by a fixture arrangement. The fixture arrangement may include a sleeve 26 fixedly attached to an outer surface of the outer pipe 30a, for instance by a weld or a layer of adhesive (not shown). The sleeve 26 extends across at least a portion of the outer pipe 30a. The fixture arrangement may further comprise a flange 28 that extends between a part of the sleeve 26 and the rib 10 to form the connection therebetween.

[0062] The outer pipe 30a comprises a series of rigid outer pipe sections 31a and flexible outer pipe sections 32a that alternative along the length of the outer pipe 30a, such that a rigid outer pipe section 31a is located between a pair of flexible outer pipe sections 32a (See figure 5). Similarly, the inner pipe 30b comprises a series of rigid inner pipe sections 31 and flexible inner pipe sections 32b that alternate along the length of the inner pipe 30b, such that a rigid inner pipe section 31a is located between a pair of flexible inner pipe sections 32b. The flexible outer pipe sections 32a and flexible inner pipe sections 32b may be substantially axially aligned along the length of the pipe assembly 30 such that each flexible outer pipe section 32a is located adjacent a corresponding flexible inner pipe section 32b.

[0063] Each flexible pipe section 32a, 32b facilitates relative moment between the respective rigid pipe sections 31a, 31b. The movement may be axial and/or rotational. In this manner, load transfer between the pipe assembly 30 and the rib 10 is reduced. With the present arrangement, the load transfer is reduced or mitigated by the flexible pipe sections 32a, 32b providing for relative movement between the rigid pipe sections 31a, 31b.

[0064] Each flexible pipe section 32a, 32b may be a bellows pipe comprising a series of undulations or other suitable arrangement for absorbing movements in the pipe assembly 30.

[0065] The double-walled pipe assembly 30 may be configured to convey a cryogenic fuel, for example liquid or gaseous hydrogen fuel. The cryogenic fuel may be conveyed between a cryogenic fuel tank 25 (see the simplified representation on figure 5) and a power plant or refuelling coupling (not shown).

[0066] The cryogenic temperatures required for the storage of hydrogen fuels, in contrast to the temperature of the surrounding wing box 20, may give rise to additional loads acting on the pipe assembly 30 due to the significant temperature gradients across the interspace between the inner and outer pipes 30a, 30b.

[0067] The inner pipe 30b may be configured to convey hydrogen fuel, with the interspace between the inner and outer pipes 30a, 30b forming a thermal barrier between the hydrogen fuel and the temperature in the wing box 20, thereby reducing heat transfer to maintain the low temperature of the hydrogen fuel.

[0068] The hydrogen fuel may be a gaseous hydrogen fuel or a liquid hydrogen fuel. In examples in which the hydrogen fuel is a gaseous hydrogen fuel, the space between the outer pipe 30a and the inner pipe 30b may comprise nitrogen gas or another inert gas. The inert gas may have a high concentration (e.g. 98% or 99%) so as to prevent any reaction of the gaseous hydrogen with oxygen. In examples in which the hydrogen fuel is a liquid hydrogen fuel, the space between the outer pipe 30a and the inner pipe 30b may comprise a vacuum. The vacuum reduces heat transfer between the inner and outer pipes 30a, 30b.

[0069] The temperature gradient across the interspace may be at least 50 degrees or at least 100 degrees. The inner and outer pipes 30a, 30b may be formed of any suitable material for withstanding these temperatures and temperature gradients, for example a metal, such as stainless steel.

[0070] To accommodate the relative movement between the rigid outer pipe sections 31a, the sleeve 26 may be formed of a first sleeve portion 26a and a second sleeve portion 26b that are slidable relative to each other along a bearing surface. The sleeve portions 26a, 26b define a spacing arrangement intended to fix the radial distance between the inner and outer pipes 30a, 30b during relative movement at the location of the sleeve 26.

[0071] The double-walled pipe assembly 30 includes a series of pipe spacers 50 separating the inner and outer pipes 30a, 30b. In the example shown in figure 5, a pair of spacers 50 are evenly distributed along the length of the outer and inner rigid pipe sections 31a, 31b to separate the outer and inner rigid pipe sections 31a, 31b. The pipe spacers 50 are restrained longitudinally between the pipes 30a, 30b by a pair of flanges 90 positioned either side of each respective pipe spacer 50. In the example shown in figure 5, the flanges 90 are fixed to the inner pipe 30b.

[0072] Conventional pipe spacers are manufactured to account for variably in the dimensions of the pipes 30a, 30b and the spacers themselves due to manufacturing tolerances assigned to the parts. Consequently, when installed, these pipe spacers typically include a gap between the pipe spacer and one or both of the pipes 30a, 30b. Pipes 30a, 30b are typically manufactured based on

[0073] Typically, the pipes 30a, 30b are measured based on a tolerance for the outer diameter and a thickness of the pipes, such that the inner diameter includes the compound tolerance of both. Hence, the variability in the gap may be greater between the pipe spacer and the inner surface of the outer pipe 30a.

[0074] This gap between the spacer and the pipes 30a, 30b can become an issue in vibration cases, especially in examples in which the pipes 30a, 30b include flexible pipe sections 32a, 32b. Yet spacers ensure that the outer and inner pipes 30a, 30b remain concentric, and this can reduce respective radial movement between the pipes 30a, 30b that could otherwise hasten the deterioration of the flexible pipe sections 32a, 32b. This respective radial movement may be referred to as ‘snaking’, in which the rigid pipe sections 31b of the inner pipe 30b that lie either side of the flexible pipe section 32b of the inner pipe 30b are radially displaces so as to form a generally ‘S’ shape across the flexible pipe section 32b.

[0075] Excessive longitudinal movement of the inner pipe 30b may also result from the inclusion of the flexible pipe sections 32a, 32b due to the inner pipe 30b being generally unconstrained. Excessive axial movement could induce large inertia loads.

[0076] The pipe spacer 50 of the present invention is intended to address one or more of these challenges.

[0077] The pipe spacer 50 includes a plurality of arms 70 that extend from a rigid annular body 60 of the pipe spacer 50. The present example includes eight arms 70 (only some of which are labelled) although it will be appreciated pipe spacer 50 may have any suitable number of arms. The arms 70 are springs 71 (alternatively referred to as flexible arms) that are configured to engage one of the inner and outer pipes 30a, 30b so as to bias the rigid pipe section 31b of the inner pipe 30b towards a centre of the rigid pipe 31a of the outer pipe 30a. In this manner, the axis 51 of the pipe spacer 50 is generally concentric with the axis of the outer pipe 30a and the inner pipe 30b. An example of the pipe spacer 50 is shown in figures 6-9.

[0078] In this example, the pipe spacer 50 includes outer arms 70a and inner arms 70b, although it will be appreciated the pipe spacer 50 may include only one or the other.

[0079] The outer arms 70a are outer springs 71a (also referred to as flexible outer arms) that extend radially outwardly from the annular body 60 and are configured to deform inwardly towards the annular body 60 on contact with the outer pipe 30a. Similarly, the inner arms 70b are inner springs 71b (also referred to as flexible inner arms) that extend radially inwardly from the annular body 60 and are configured to deform inwardly towards the annular body 60 on contact with the inner pipe 30b.

[0080] In particular, each spring 71 has a fixed part 75 which is fixed relative to the annular body 60 and positioned at a first radial distance r1 from the axis 51 of the pipe spacer 50, and a contact part 76 which is positioned at a second radial distance r2 from the axis 51 of the pipe spacer 50. This is shown in figure 8 in respect to the outer springs 71a although it will be appreciated this similarly applies to the inner springs 71b. In this manner, the contact part 76 is configured to contact the respective pipe 30a, 30b and move relative to the annular body 60 as the respective spring 71 deforms inwardly. Each of the arms 70 is formed of a fibre-reinforced composite material, and the reinforcement fibres in the flexible contact part 76 are configured to deform as the arm 70 deforms.

[0081] With this arrangement, it will be understood that in the uncompressed state of the pipe spacer 50 in which each spring 71 is substantially undeformed, the outer diameter of the pipe spacer 50 will be greater than the inner diameter of the outer pipe

30a and/or the inner diameter of the pipe spacer 50 is greater than the outer diameter of the inner pipe 30b. It will be appreciated that reference to a ‘diameter’ of the respective pipe 30a, 30b refers to the diameter of the pipe 30a, 30b at the position of the pipe spacer 50 unless stated otherwise.

[0082] In this manner, the pipe spacer 50 can damp concentric movement and vibration of the inner pipe 30b in relation to the outer pipe 30a. The springs 71 will press on the inner/outer pipes 30a, 30b creating friction to resist axial movement. The springs 71 will accommodate tolerances of the outer pipe 30a, inner pipe 30b and the pipe spacer 50 itself, such that pipe spacer 50 will fill the gap between the inner and outer pipe 30a, 30b to press on both walls of the pipes 30a, 30b unlike existing rigid spacers.

[0083] To limit the inward deflection of the springs 71, the pipe spacer 50 includes a corresponding plurality of projecting stops 80 extending outwards radially from the annular body 60 which are configured to limit the inward deformation of the springs 71. Each of the projecting stops 80 may be associated with a respective spring 71 such that there are equal numbers of springs 71 and projecting stops 80. The projecting stops 80 align circumferentially with the springs 71 although it will be appreciated other examples may have the projecting stops 80 offset from the springs 71.

[0084] Each projecting stop 80 extends to a tip 81 which is positioned at a third radial distance r3 from the axis 51 of the pipe spacer 50, wherein $r1<r3<r2$ for the outer springs 71a and $r2<r3<r1$ for the inner springs 71b. More generally speaking: r3 has a dimensional value between that of r1 and r2. The required deflection of the springs 71, to ensure contact with the respective pipe 30a, 30b, is generally quite small in comparison to the diameter of the pipes 30a, 30b, for example less than 2mm. For comparative purposes, the outer pipe 30a may have a diameter between 65mm (~2.5 inches) and 100mm (~4 inches) whilst the inner pipe 30b may have a diameter of between 12.5mm (~0.5 inches) and 50mm (~2 inches). As such, the radial distance between the contact part 76 and the tip 81 may be less than 20% of the radius of the pipe spacer 50, or less than 10%, or less than 5%.

[0085] With this arrangement, the pipe spacer 50 permits limited movement between the inner and outer pipes 30a, 30b with the maximum extent of that movement dictated by the size of the projecting stops 80.

[0086] The springs 71 extend out from the annular body 60 at an oblique angle to the axis 51 of the pipe spacer 50 such that the springs 71 extend radially and longitudinally relative to the axis 51. In particular, the springs 71 are shown to have a curved profile relative to the axis 51 of the pipe spacer 50. Each spring 71 may extend from the annular body 60 in the same longitudinal direction (See e.g. figure 8). This can ease installation of the pipe spacer 50 onto the respective pipe 30a, 30b as it is slid past the end of the pipe 30a, 30b.

[0087] The annular body 60 may be disc-shaped such as shown in the examples of figures 6-8. This provides structural rigidity in the radial direction of the annular body 60, i.e. in the direction in which the majority of the forces from the pipes 30a, 30b are directed. As shown in figure 8, the annular body 60 may have at least one planar face 62 in a plane normal to the axis 51 of the pipe spacer 50.

[0088] The projecting stops 80 extend from the annular body 60, with the projecting stops shown in the example of figures 6-8 integrally formed with the annular body 60 and lying in the plane of the annular body 60.

[0089] The projecting stops 80 may include a planar face that is parallel to and/or forms part of the planar face 62 of the annular body 60, such as shown in figures 6 to 8.

[0090] Each projecting stop 80 is configured to contact the respective inner or outer pipe 30a, 30b when one of the springs 71 deforms inwardly, thereby limiting the inward deformation of the springs 71. For instance, outer projecting arms 80a extend radially outwardly towards the outer pipe 30a and are configured to contact the outer pipe 30a, whilst inner projecting arms 80b extend radially inwardly towards the inner pipe 30b and are configured to contact the inner pipe 30b.

[0091] The cryogenic temperatures that the pipe spacer 50 may encounter, and the need to ensure a thermal barrier between the inner pipe 30b and the outer atmosphere put certain requirements on the materials that can be used. For instance, a temperature gradient across the interspace between the inner pipe 30b and the outer pipe 30a may be more than 50 degrees, or more than 100 degrees.

[0092] A low conductivity material is therefore required that is able to withstand very low temperatures (e.g. below -150 degrees C). One such material is fibre-reinforced composite, such as glass or carbon fibre-reinforced composite material.

[0093] The complex shape of the pipe spacer 50 may be suitably formed by additive manufacturing processes (e.g. 3D printing). The pipe spacer 50 may be formed of chopped fibre-reinforced composite material that allows manageable processing of 3D printing.

[0094] It will be appreciated that other configurations of the pipe spacer 50 may be envisaged. Figure 9 shows an example in which the annular body 60 is cylindrical.

[0095] Four springs 71 extend continuously between ends 64 of the annular body 60 so as to have a generally U-shaped profile and having opposing ends of the springs 71 attached at either end to the ends 64 of the annular body 60. Each projecting stop 80 is located beneath a respective spring 71, generally centrally so as to be directly underneath the radially outermost part of the spring 71 and offset from the ends 64 of the annular body 60. As such, each projecting stop 80 is configured to contact the respective spring 71 when the spring 71 deforms inwardly, in contrast to the example of figures 6-9 in which the projecting stop 80 is configured to contact the respective inner or outer pipe 30a, 30b.

[0096] Figures 10-14 show alternative examples in which the pipe spacer 50 has a multi-part construction in which the annular body 60 and the springs 71 are formed separately. In other words, the outer arms 70a and inner arms 70b are attached to the annular body 60 so as to be non-integral (e.g. mechanically interlocked) with the annular body 60. This construction can improve manufacturability. For instance, the pipe spacer 50 may be formed from a panel/plate having a constant cross-section that is subsequently cut to form the arms 70 and annular body 60, which in turn can facilitate easier construction from certain materials such as continuous fibre-reinforced composite materials.

[0097] Reference to a panel/plate is intended to refer to a structure that is flat, and relatively thin sheet of material compared to its width.

[0098] In an example, a continuous fibre-reinforced composite panel may be cut to separately form the annular body 60 and arms 70, with the springs 71 subsequently attached to the annular body 60, such as shown in figures 10 and 11. It will be appreciated that the annular body 60 and arms 70 may be formed of the different materials, from the same material from the same or a different panel.

[0099] To improve the connection between the annular body 60 and each of the arms 70, the annular body 60 and/or arms 70 may each be formed with a slot 66, 77 or other formation that facilities mechanical interlocking therebetween, such as shown in figures 12 & 13, with their interconnection shown in figures 10 & 11.

[0100] In the present example, the projecting stops 80 are each integrally formed with the annular body 60. Outer projecting stops 80a are formed at the apex of corners 61 of the annular body 60, whilst an inner projecting stop 80b is formed as a central aperture 85 (although it will be appreciated that the annular body 60 may include inner protrusions/lobes that function as discrete inner projecting stops 80b). The outer projecting stops 80a thereby result in the annular body 60 having a generally square outer profile, although the corners of the square profile may have rounded corners. It will be appreciated that the shape of the annular body 60 may be determined by the number of outer projecting stops 80a integrally formed with it. For example, a triangle-shaped annular body 60 may define three outer projecting stops 80a, and a pentagon-shaped annular body 60 may define five outer projecting stops 80a, and so on. Alternatively, the profile of the annular body 60 may be circular such that a single outer projecting stop 80a functions to prevent deformation of each arm 70.

[0101] It will be apparent that the configuration of the annular body 60, shown most clearly in figure 12, may be suitably formed by cutting the outline of the annular body 60 from a panel/plate. In this sense, the annular body 60 includes opposing planar faces 62 that are normal to the axis 51 of the pipe spacer 50 and normal to the axis of the inner and outer pipes 30a, 30b. Similarly, the arms 70 may be formed by cutting a panel/plate, such that the arms 70 include opposing planar faces 78 (See Figure 13). The opposing planar faces 62 of the annular body 60 may be perpendicular to the opposing planar faces 78 of the arms 70. The annular body 60 may further comprise one or more apertures 67 spaced from the central axis for providing fluid flow holes through which a fluid can flow.

[0102] In this example, the outer arms 70a and inner arms 70b are integrally formed. Each outer spring 71a is integrally formed with a respective inner spring 71b to form a set of integral arm configurations that each include a tab 74 forming the connector for connecting to the annular body 60.

[0103] It will be appreciated that the form and function of the example shown in figures 10 to 13 is otherwise substantially the same as described for the other examples. It will be appreciated that the outer and inner projecting stops 80a, 80b may be integrally formed with the annular body 60 or arms 70, any combination of both, or may be formed as a separate component to each.

[0104] In alternative examples, the outer arms 70a and inner arms 70b may be separately formed. For instance, each outer arm 70a or inner arm 70b may be separately connected to the annular body 60, or one or the other of the arms 70a, 70b may be integrally formed with the annular body 60.

[0105] In the example shown in figure 14, the outer arms 70a are outer springs 71a separately formed to the annular body 60 and subsequently attached to the annular body 60, whereas the pipe spacer 50 does not include inner arms but instead sits directly on the inner pipe 30b. It will be apparent that in this example, the inner profile of the annular body 60 is similar to the inner profile of the annular body 60 in the example of figures 10 to 13 but that the use of the inner profile has been adapted for direct use analogous to inner arms that substantially maintain contact with the inner pipe 30b (notwithstanding gaps provided to accommodate tolerances) rather than inner projecting stops 80b that contact the inner pipe 30b upon the threshold deformation of the respective arm 70.

[0106] In alternative examples, the pipe spacer 50 may include inner arms 70b that act as inner springs 71b and the outer arms 70a may be outer rigid arms. Due to dimensions of the pipes 30a, 30b typically manufactured accordingly to tolerances assigned to the outer diameter and the thickness of the pipes 30a, 30b, it is generally preferable to have outer springs 71a.

[0107] It will be appreciated that each of the examples disclosed herein may have rigid inner or outer arms 72a, 72b, although the other of the inner and outer arms 70a, 70b will be springs 71a, 71b. Each set of outer or inner arms 70a, 70b will typically be similarly formed, such that all outer arms 70a will be outer springs 71a or all outer arms 70a will be outer rigid arms 72a. Similarly, all inner arms 70b will be inner springs 71b or all inner arms 70b will be inner rigid arms 72b.

[0108] It will be appreciated that some examples may not include the projecting stops 80. Figure 15 shows an example of a pipe spacer 50 similar to the pipe spacer 50 shown in figure 9 except without projecting stops 80. In addition, the inner extent of the cylindrical shape of the annular body 60 shown in the example of figure 9 may be removed such that the annular body 60 is formed of two spaced apart annular body member 60a, 60b (such as shown here).

[0109] Figure 16 shows a yet further example of a pipe spacer 50. In this example, the faces of the annular body 60 are curved to correspond generally to the curvature of the inner and outer arms 70a, 70b, such that the opposing faces of the annular body 60 smoothly transition into the respective opposing faces of the arms 70a, 70b. In this case, the pipe spacer 50 is integrally formed.

[0110] Preferably each of the springs comprises a flexible part (for example the contact part 76) which is configured to deform, and the flexible part is non-helical (in other words, it is not a coil spring). This non-helical geometry makes the flexible part easy to manufacture from composite material.

[0111] In any of the embodiments disclosed above, the annular body 60 is optionally formed of a fibre-reinforced composite material and/or each of the arms 70a, 70b is optionally formed of a fibre-reinforced composite material. The annular body 60 and the arms 70a, 70b may be formed of the same fibre-reinforced composite material, or different fibre-reinforced composite materials. The use of a fibre-reinforced composite material is advantageous due to its low weight and the reinforcing effect of the fibres. Optionally the reinforcement fibres in the arms are configured to deform as the arm deforms.

[0112] Optionally the annular body 60 is formed of a glass-fibre-reinforced composite material and/or each of the arms 70a, 70b is formed of a glass-fibre-reinforced composite material. The annular body 60 and the arms 70a, 70b may be formed of the same glass-fibre-reinforced composite material, or different glass-fibre-reinforced composite materials. The use of glass fibre is advantageous due to the low thermal conductivity of glass.

[0113] Optionally the annular body 60 is formed of a fibre-reinforced polymer composite material, comprising a polymer matrix (such as an epoxy resin or a bio-resin) and reinforcement fibres and/or each of the arms 70a, 70b is formed of a fibre-reinforced polymer composite material, comprising a polymer matrix (such as an epoxy resin or a bio-resin) and reinforcement fibres. The annular body 60 and the arms 70a, 70b may be formed of the same fibre-reinforced polymer composite material, or different fibre-reinforced polymer composite materials. The use of a polymer matrix is advantageous due to its low thermal conductivity.

[0114] In some embodiments the annular body 60 and/or each of the arms 70a, 70b is formed of a glass-fibre-reinforced polymer composite material, comprising a polymer matrix and glass reinforcement fibres.

[0115] In some embodiments the annular body 60 and/or each of the arms 70a, 70b is formed of a fibre-reinforced bio-resin, with natural reinforcement fibres.

[0116] In some embodiments the annular body 60 and/or each of the arms 70a, 70b is formed of a non-composite material (such as a thermoplastic polymer or a thermoset polymer).

[0117] Suitable manufacturing processes for the annular body 60 and/or each of the arms 70a, 70b include machining, injection moulding, and 3D printing.

[0118] Where the word 'or' appears this is to be construed to mean 'and/or' such that items referred to are not necessarily mutually exclusive and may be used in any appropriate combination.

[0119] Although the invention has been described above with reference to one or more preferred embodiments, it will be appreciated that various changes or modifications may be made without departing from the scope of the invention as defined in the appended claims.

CLAIMS

1. A pipe spacer for separating inner and outer pipes of a double-walled pipe assembly, the pipe spacer comprising:

   an annular body for positioning in an interspace between inner and outer pipes of a double-walled pipe assembly, the annular body formed of a composite material;

   a plurality of outer arms extending radially outwardly from the annular body for contacting the outer pipe and/or a plurality of inner arms extending radially inwardly from the annular body for contacting the inner pipe; and

   wherein each of the inner and/or outer arms are springs that extend radially from the annular body and are configured to deform inwardly towards the annular body on contact with the respective outer or inner pipe, the arms formed of a composite material.

2. The pipe spacer of claim 1, wherein the plurality of outer arms and/or plurality of inner arms are attached to the annular body.

3. The pipe spacer of claim 1 or 2, wherein the annular body has a constant cross-section extending between opposing planar faces.

4. The pipe spacer of any preceding claim, wherein each of the inner and/or outer arms has a constant cross-section extending between opposing planar faces.

5. The pipe spacer of claims 3 and 4, wherein the opposing planar faces of the annular body are perpendicular to the opposing planar faces of the inner and/or outer arms.

6. The pipe spacer of any preceding claim, wherein the annular body is plate-like.

7. The pipe spacer of any preceding claim, wherein the inner arms are integrally formed with the annular body or the outer arms are integrally formed with the annular body.

8. The pipe spacer of any preceding claim, wherein the inner arms are each integrally formed with a respective outer arm.

9. The pipe spacer of any preceding claim, wherein the annular body comprises a plurality of formations and/or each arm comprises a formation configured to facilitate mechanical interlocking between the annular body and the respective arm.

10. The pipe spacer of claim 9, wherein the formations are slots.

11. The pipe spacer of any preceding claim configured to operate in cryogenic temperatures.

12. The pipe spacer of any preceding claim wherein the annular body and/or each of the arms is formed from a continuous fibre-reinforced composite material.

13. The pipe spacer of any one of claims 1 to 11 wherein the annular body and/or arms is formed from a short fibre-reinforced composite material.

14. A double-walled pipe assembly, comprising:

an inner pipe, an outer pipe, and the pipe spacer of any preceding claim separating the inner pipe from the outer pipe.

15. The double-walled pipe assembly of claim 14, wherein the inner pipe is configured to convey a cryogenic liquid.

16. The double-walled pipe assembly of claim 14 or 15, wherein the interspace between the inner and outer pipes is configured to be held at a vacuum pressure.

17. The double-walled pipe assembly of any one of claims 14 to 16, wherein:

the inner pipe comprises a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections;

the outer pipe comprises a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections,

wherein the pipe spacer of any one of claims 1 to 13 is located between the rigid pipe sections of the inner and outer pipes.

18. The double-walled pipe assembly of claim 17, comprising a plurality of pipe spacers according to any one of claims 1 to 13, wherein each pipe spacer is located between the rigid pipe sections of the inner and outer pipes.

19. The double-walled pipe assembly of any one of claims 14 to 18, comprising a pair of flanges fixed to the inner pipe on either side of the pipe spacer to limit axial movement of the pipe spacer along the inner pipe.

20. An aircraft assembly comprising a cryogenic fuel tank and the double-walled pipe assembly of any one of claims 14 to 19 extending from the cryogenic fuel tank, wherein the inner pipe is configured to convey cryogenic fuel and the interspace is configured to be held at a vacuum pressure.

21. The aircraft assembly of claim 20, wherein a temperature gradient across the interspace between the inner pipe and the outer pipe is configured to be at least 50 degrees, and optionally 100 degrees.

22. A method of manufacturing the pipe spacer of any one of claims 1 to 13, comprising:

forming the annular body;

forming a set of the inner and/or outer arms; and

attaching the set of arms to the annular body.

23. The method of claim 22, wherein the annular body is formed by cutting a composite fibre-reinforced panel and/or wherein the set of arms are each formed by cutting a composite fibre-reinforced panel.

24. A double-walled pipe assembly, comprising:

an inner pipe having a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections;

an outer pipe having a first flexible pipe section, a second flexible pipe section and a rigid pipe section extending between the first and second flexible pipe sections, wherein the inner pipe is enveloped by the outer pipe; and

a pipe spacer located in the interspace between the rigid pipe sections of the inner and outer pipes, the pipe spacer comprising a plurality of flexible arms engaging at least one of the inner and outer pipes so as to bias the rigid pipe section of the inner pipe towards a centre of the rigid pipe of the outer pipe.

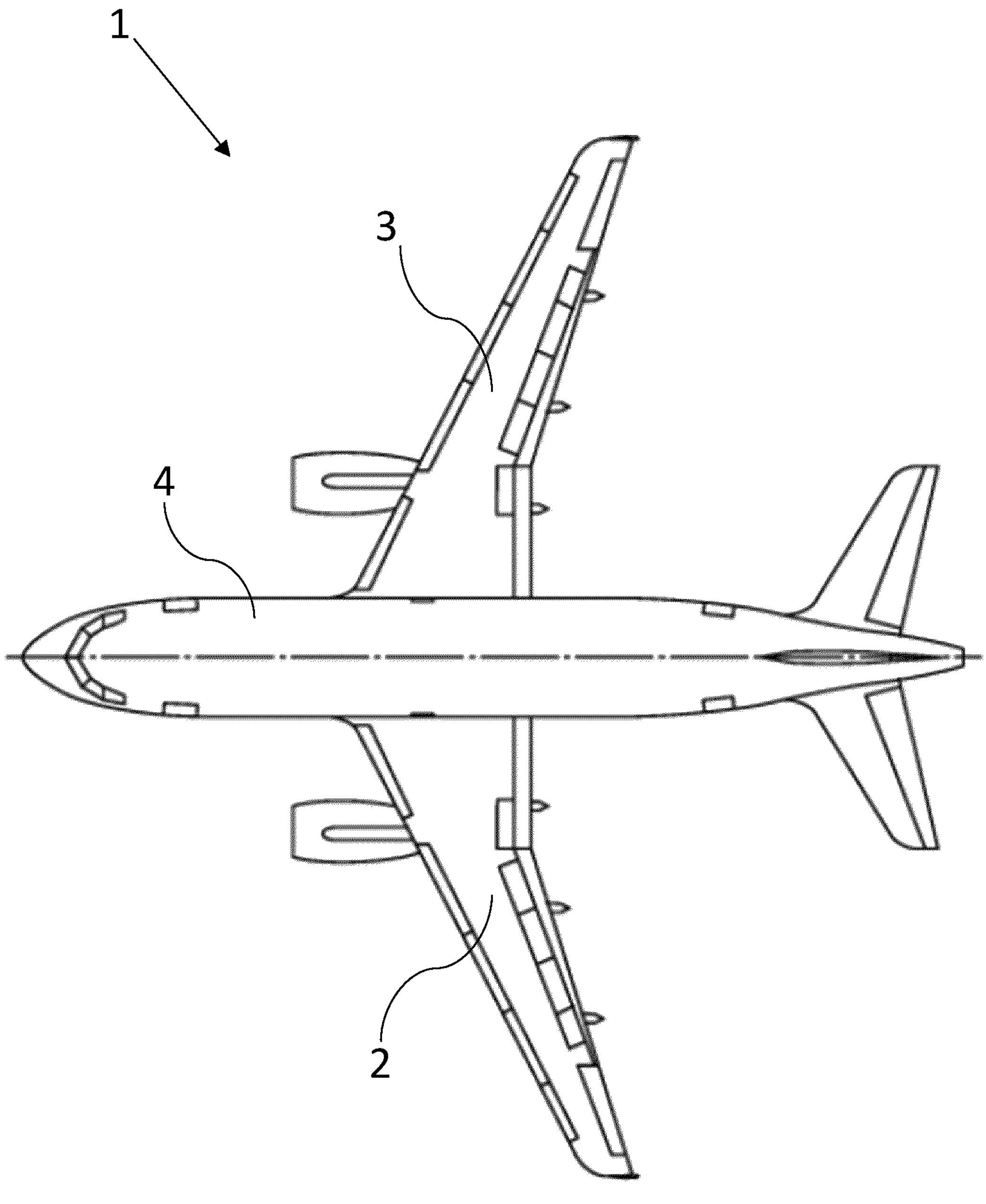


FIG. 1

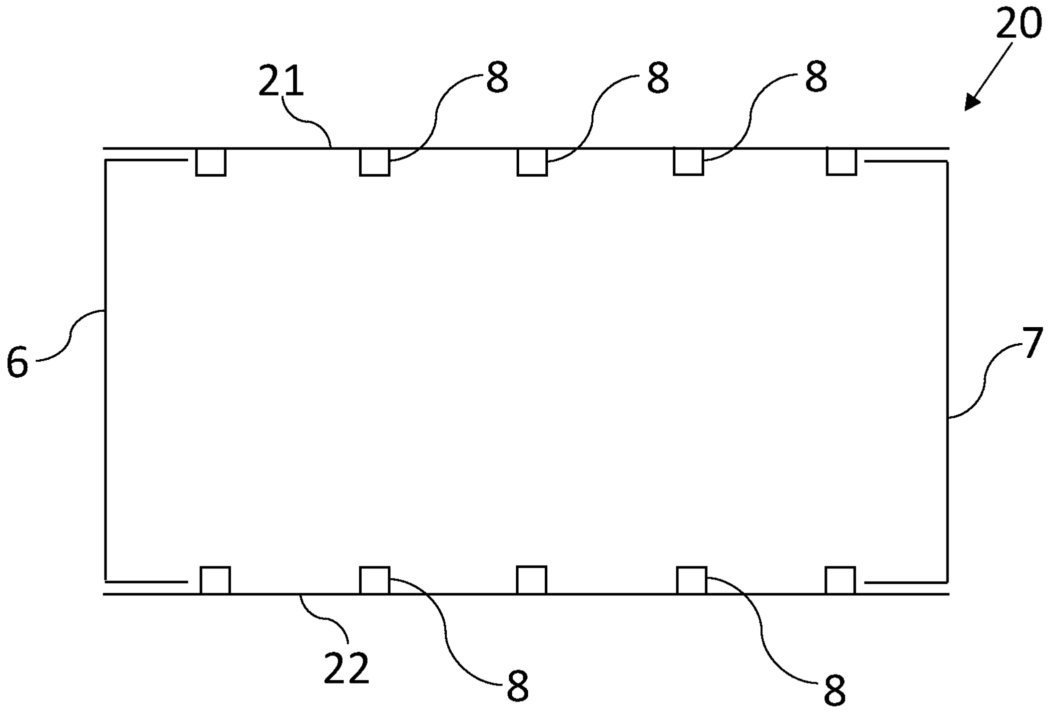


FIG. 2

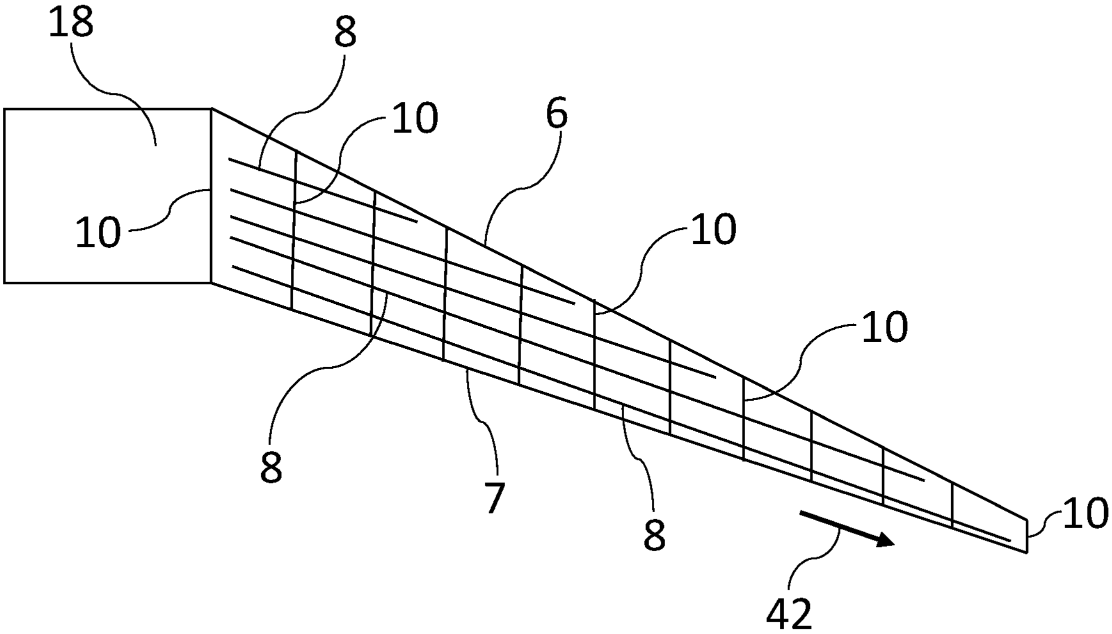


FIG. 3

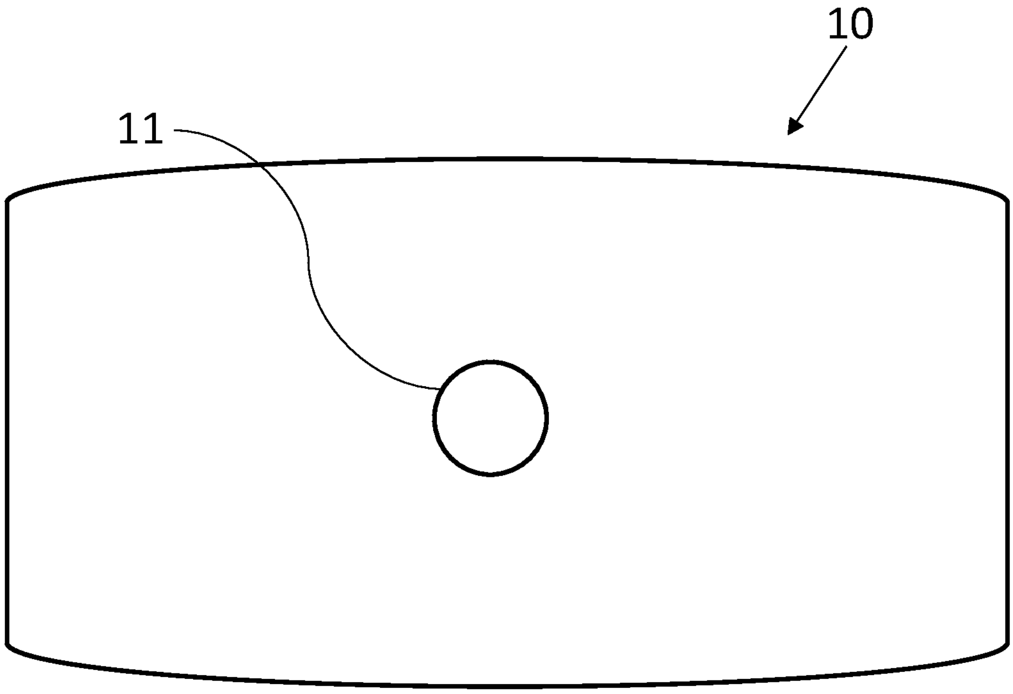
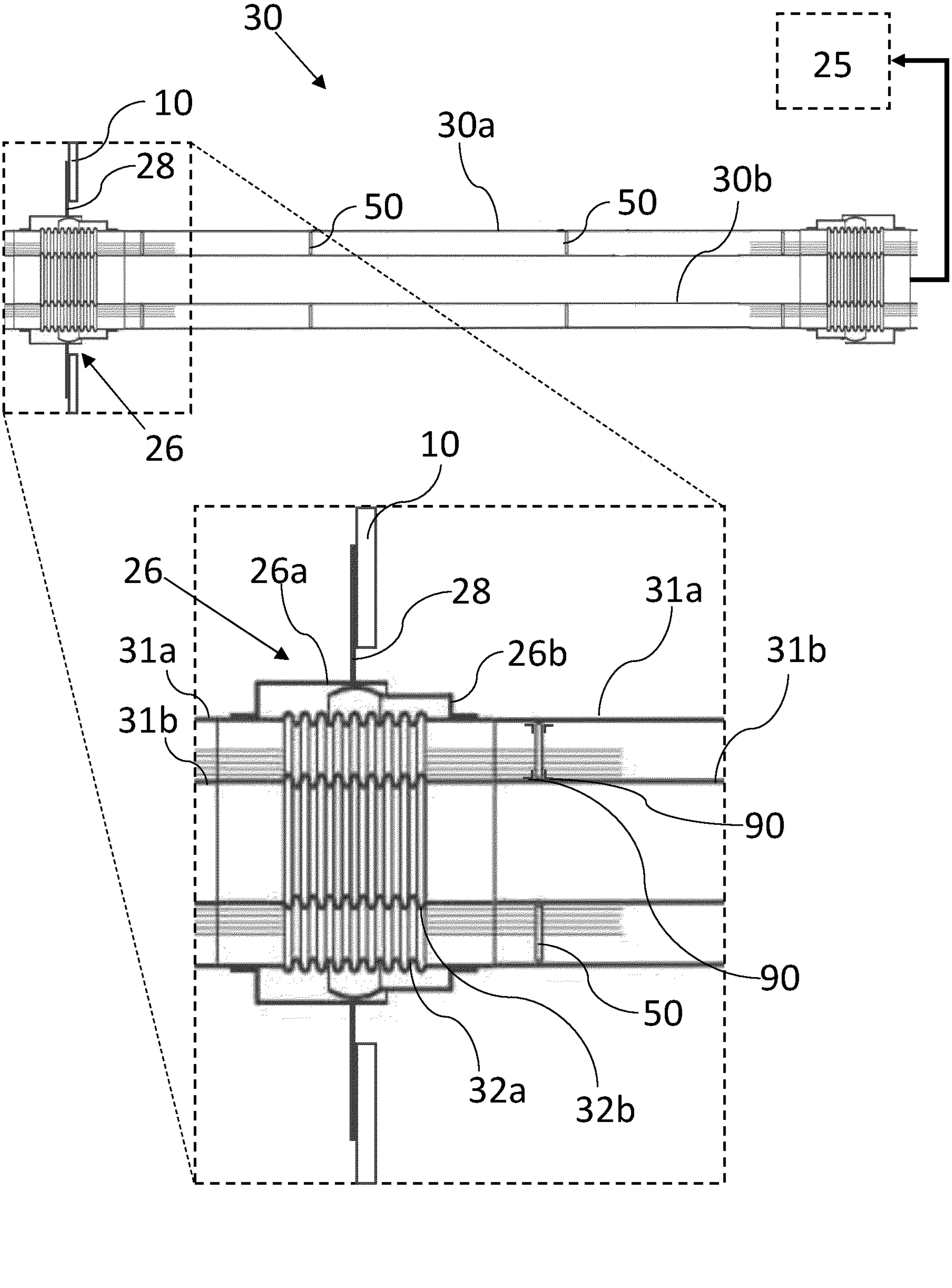


FIG. 4



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30b
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32a
32b

FIG. 5

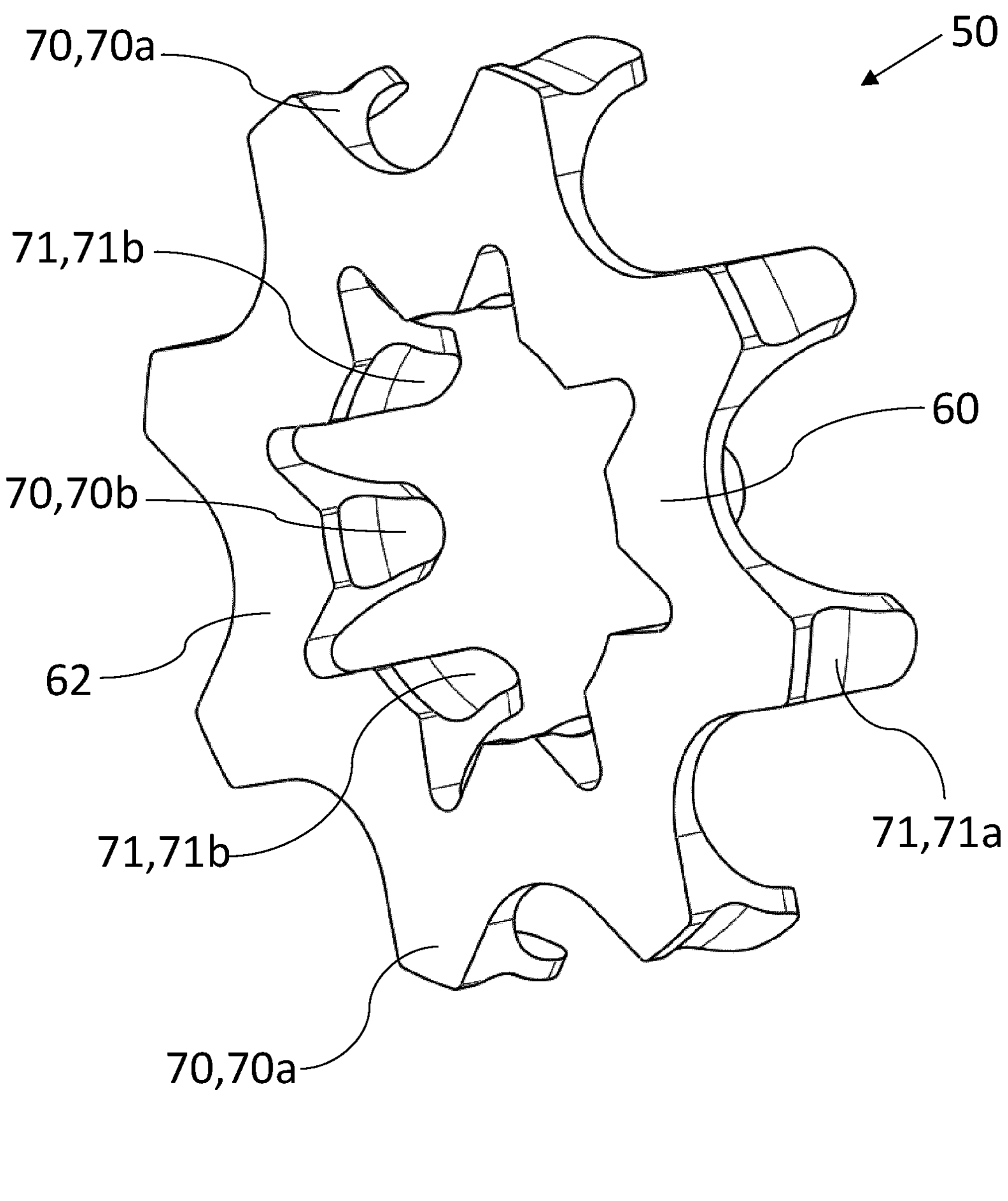

FIG. 6

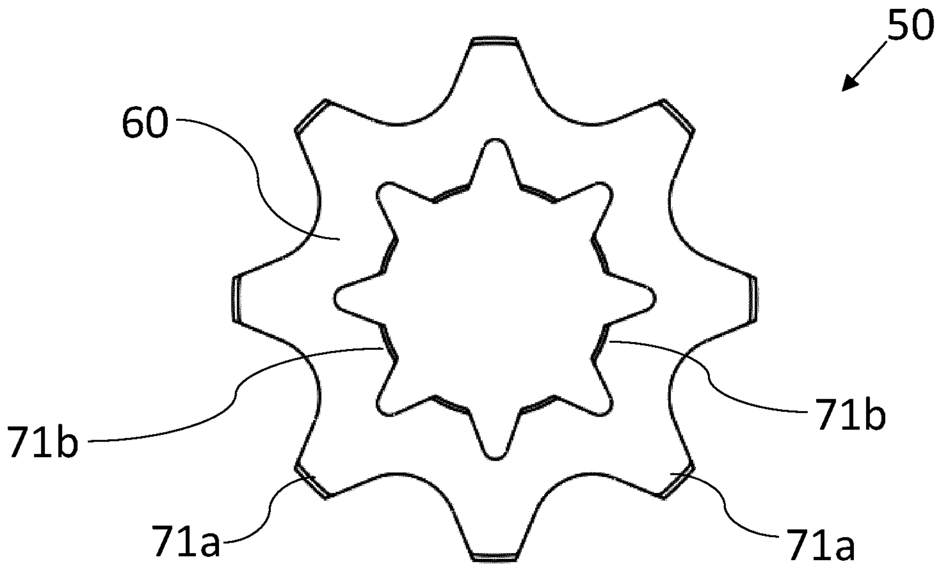

FIG. 7

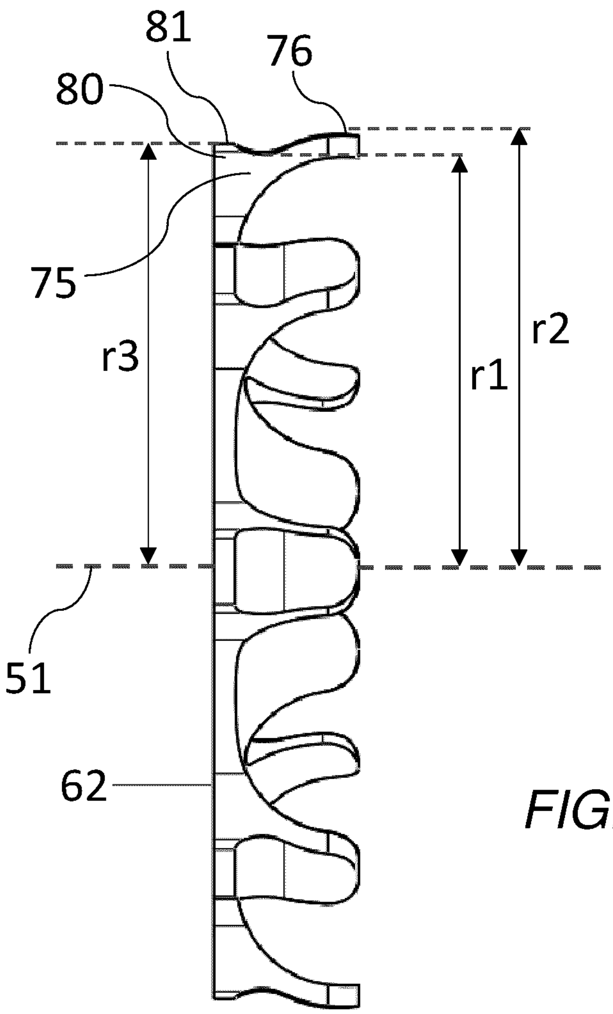

FIG. 8

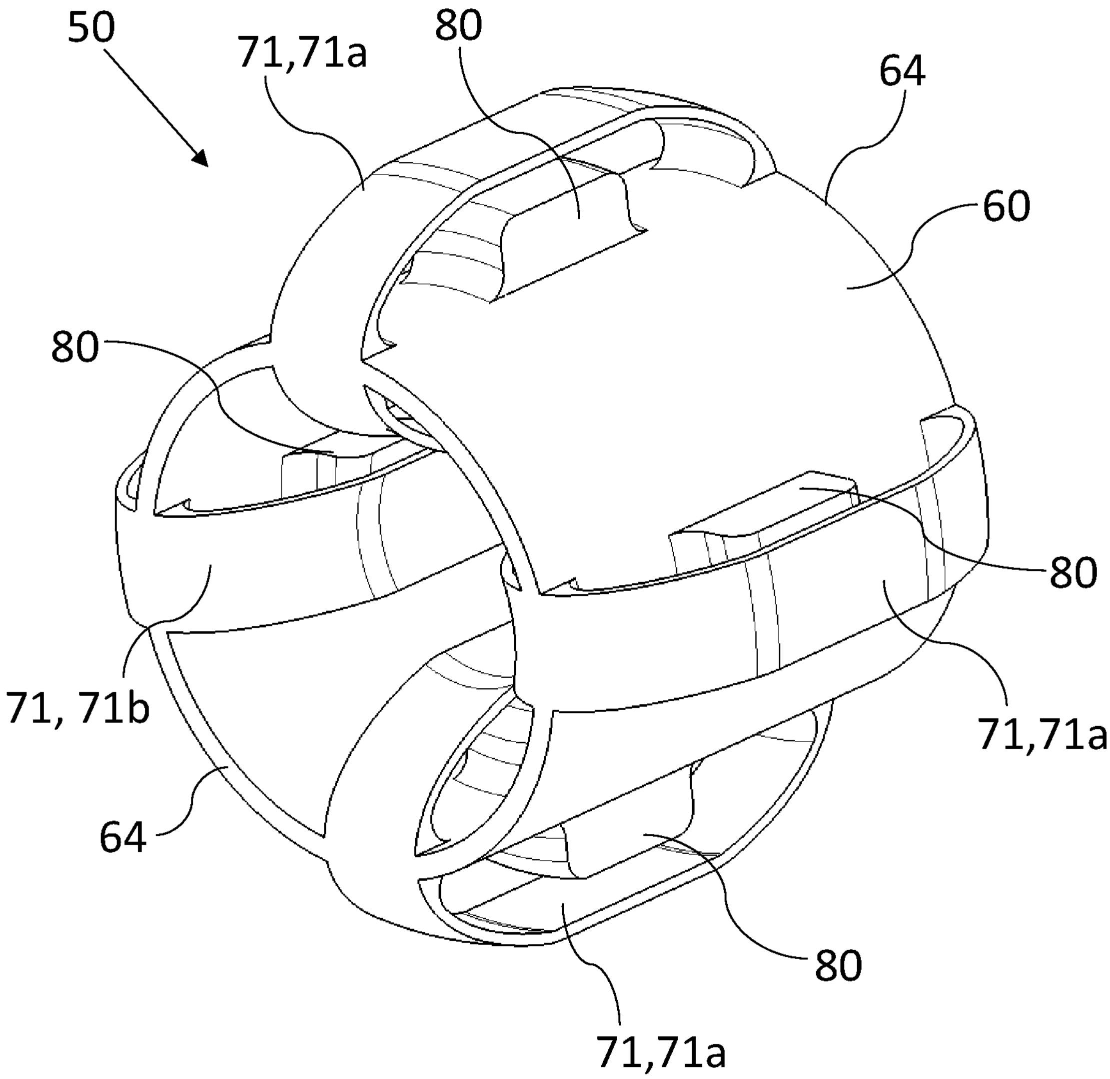

FIG. 9

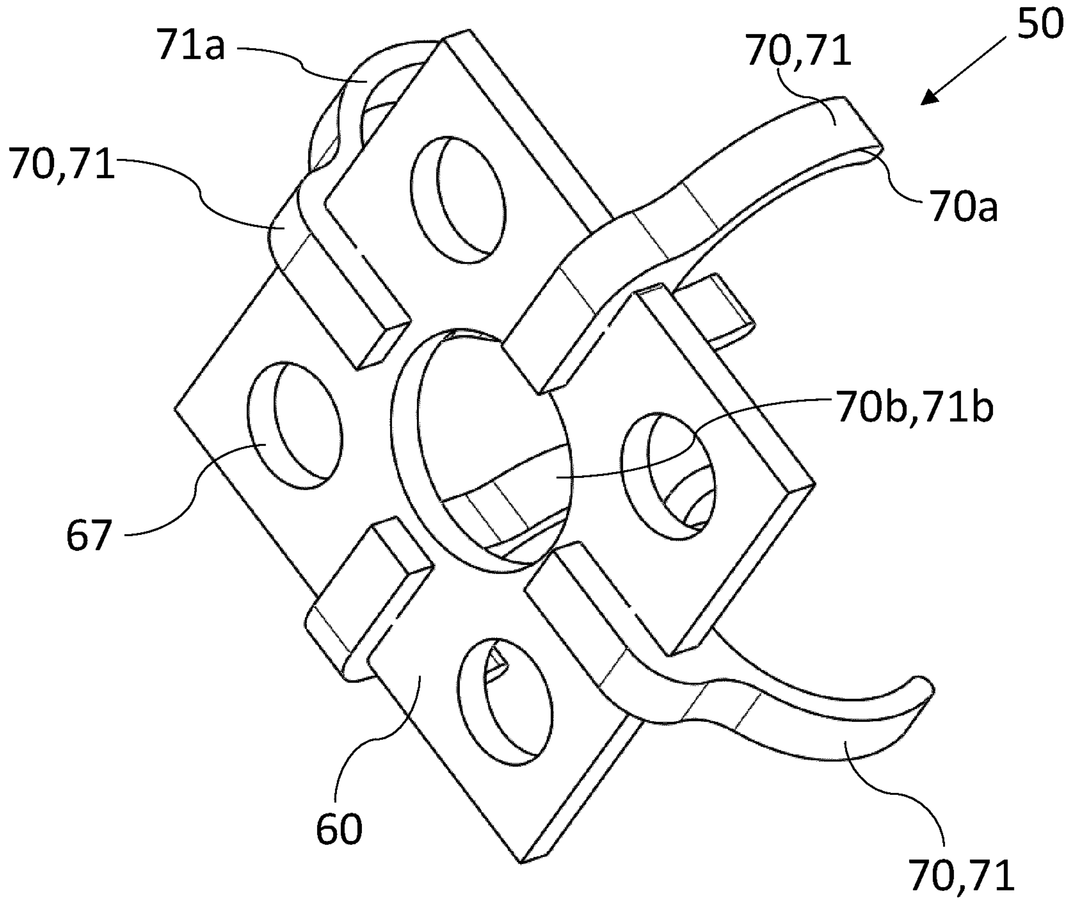

FIG. 10

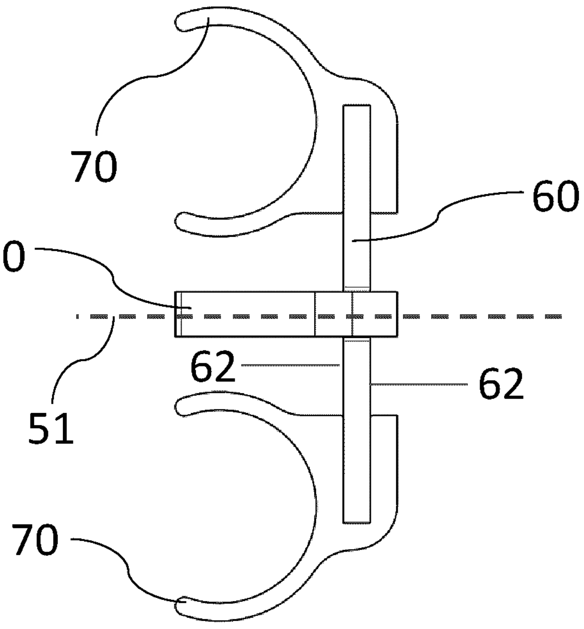

FIG. 11

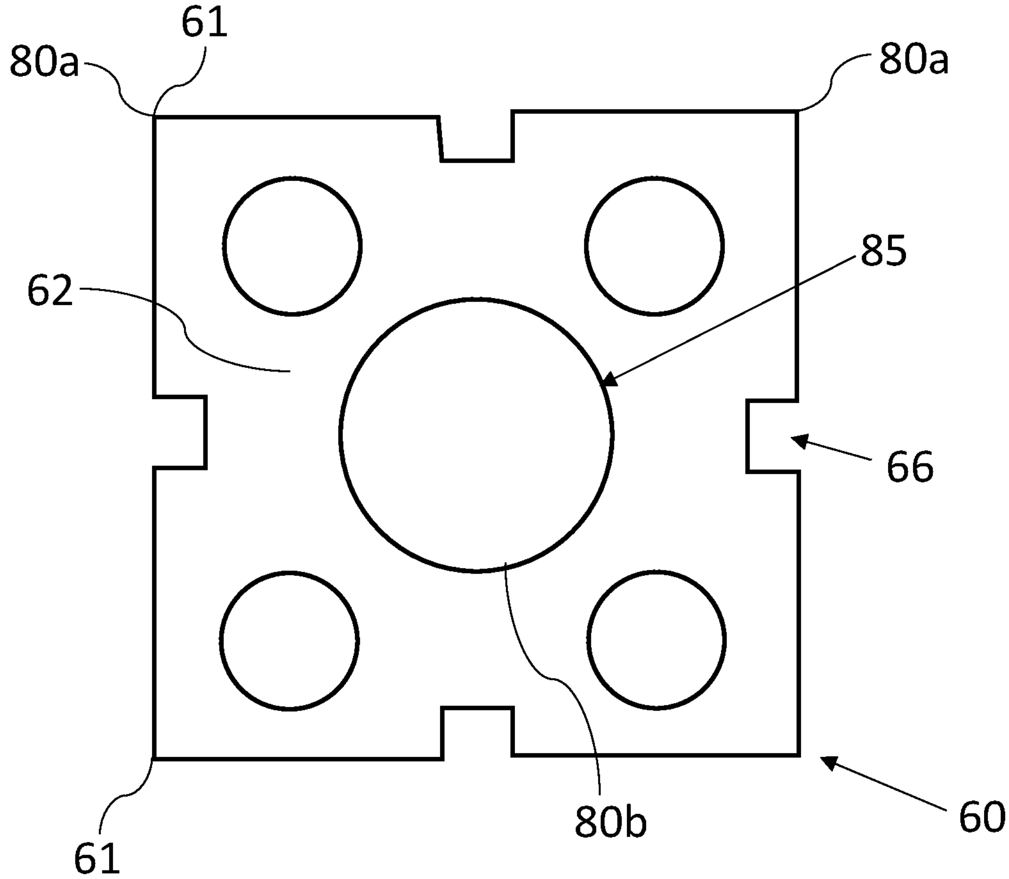

FIG. 12

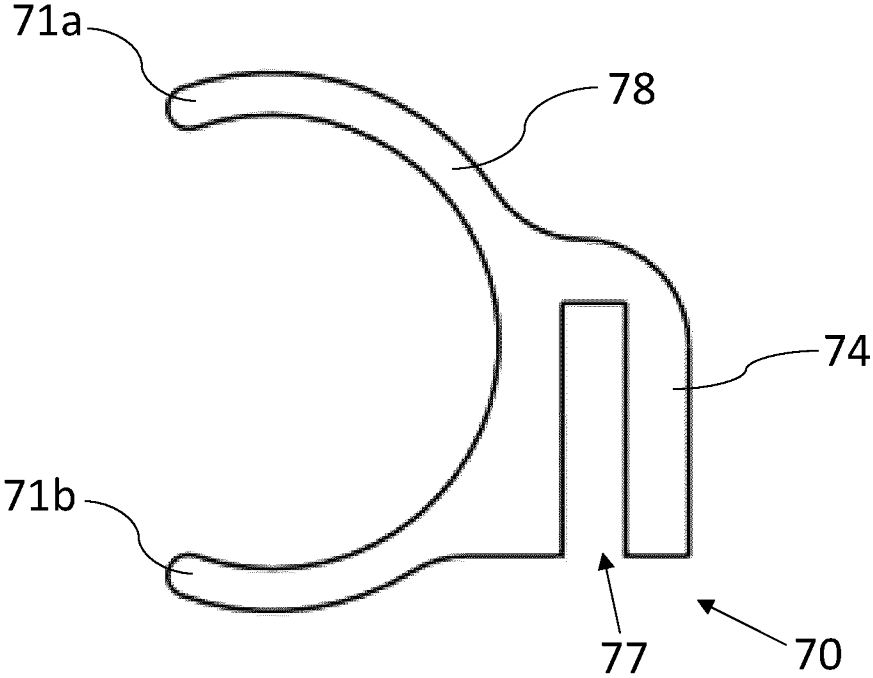

FIG. 13

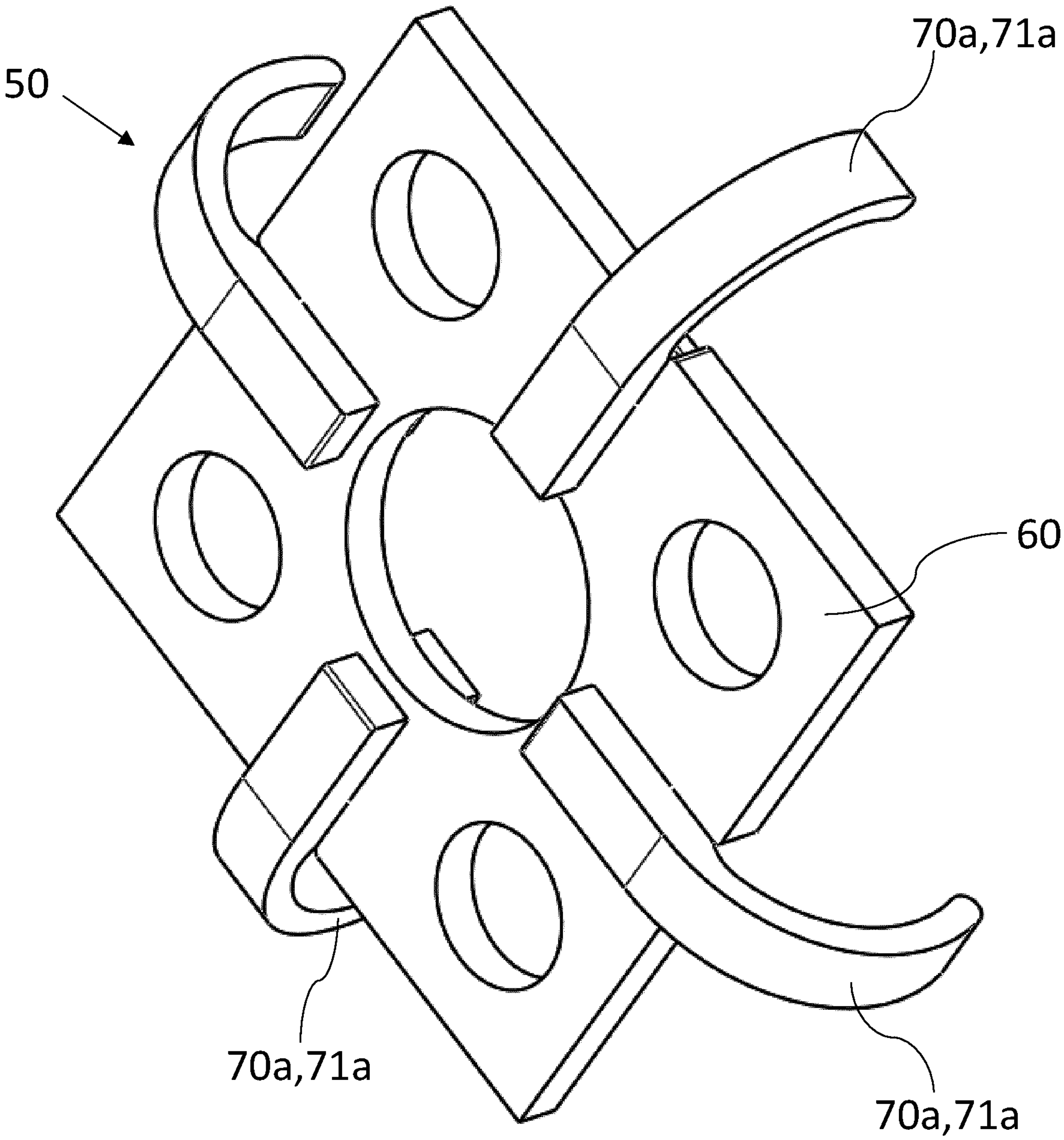

FIG. 14

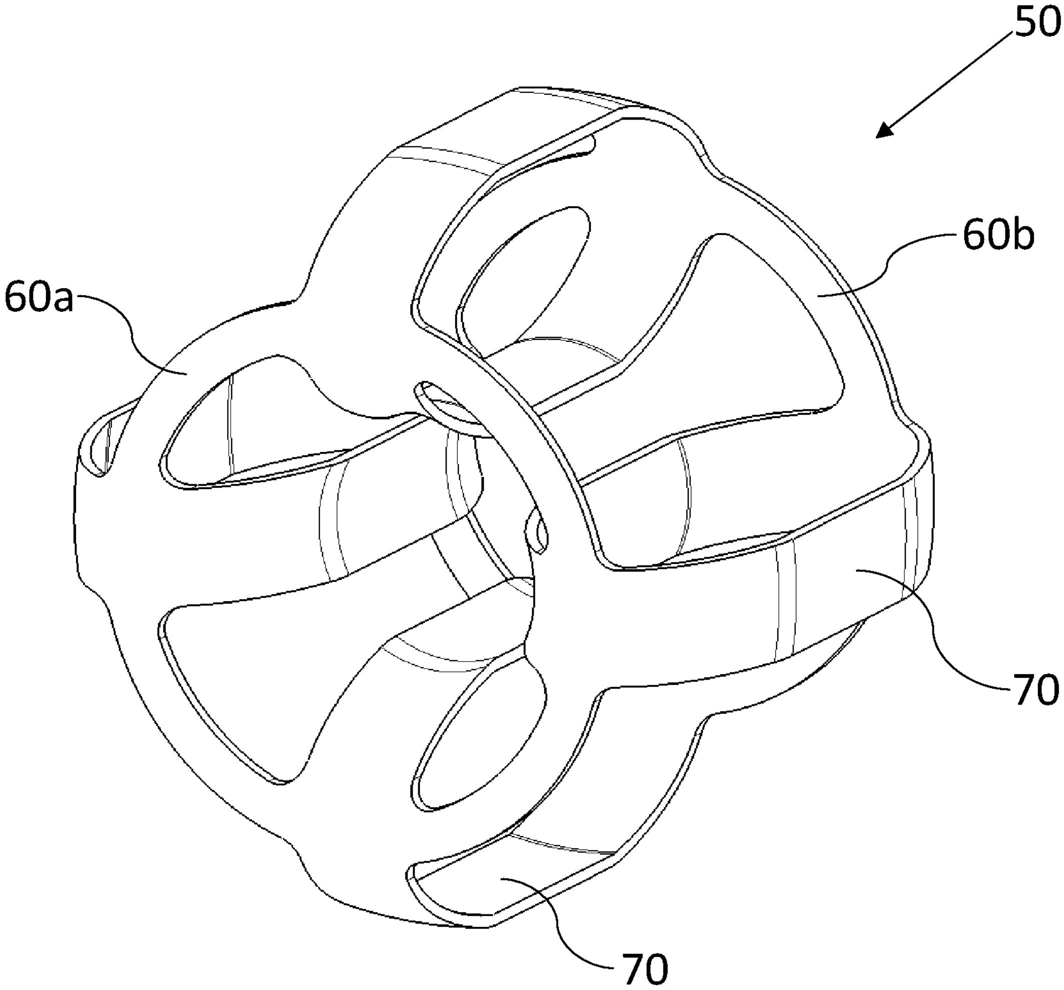

FIG. 15

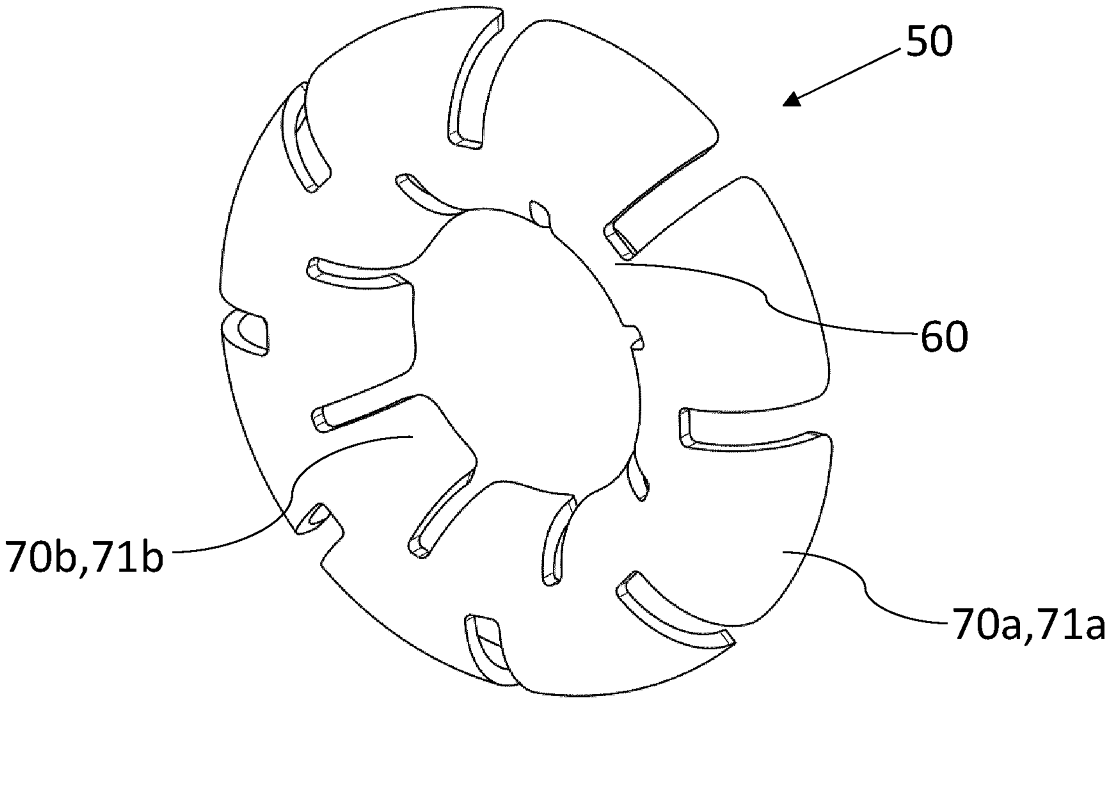

FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2024/066098

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:
   1-23

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/066098

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16L7/00 F16L39/00
ADD. F16B7/04 F16L3/01 F16L59/13

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F16L F16B H01B G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	DE 15 91 362 A1 (PHILIPS PATENTVERWALTUNG) 23 December 1970 (1970-12-23) page 2, line 16 - page 5, line 20; figures 1-4	1-4,6-8, 11-16,22 5,9,10, 17,18 19-21,23
Y	DE 20 2006 001546 U1 (BAECHLE DIETER [CH]) 20 July 2006 (2006-07-20) figure 15	5
Y	CN 116 146 795 A (SINOMA BEIJING GEOTHERMAL ENERGY TECH LTD) 23 May 2023 (2023-05-23) figures 3-5	9,10
Y	EP 4 174 357 A1 (AIRBUS SAS [FR]; AIRBUS OPERATIONS SAS [FR]) 3 May 2023 (2023-05-03) paragraphs [0004] - [0007]; figures 2-4	17,18

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 August 2024	30/10/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Schlossarek, M

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/066098

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
DE 1591362	A1	23-12-1970	NONE			
DE 202006001546	U1	20-07-2006	NONE			
CN 116146795	A	23-05-2023	NONE			
EP 4174357	A1	03-05-2023	CN	116045114	A	02-05-2023
			EP	4174357	A1	03-05-2023
			FR	3128760	A1	05-05-2023
			US	2023139421	A1	04-05-2023

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-23

   relates to a pipe spacer formed of a composite material

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2. claim: 24

   relates to a double walled pipe assembly having a pipe spacer and flexible pipe sections

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