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(54) Title: APPARATUS AND METHOD FOR SEALING AND MONITORING A BOLTED FLANGE JOINT

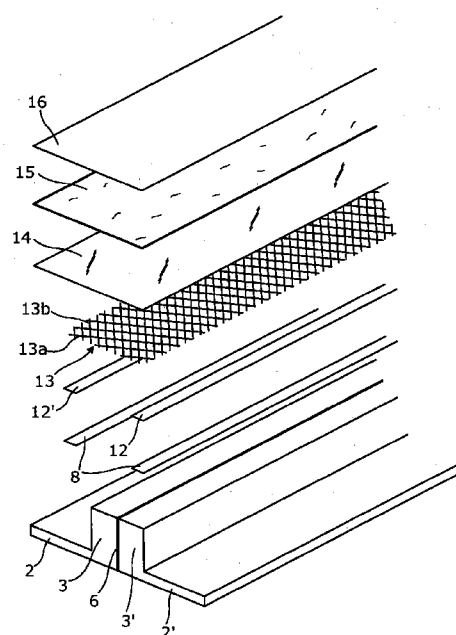


Figure 7

(57) Abstract: Bolted flange joint sealing and monitoring apparatus, the bolted flange joint comprising two flanges abutting one another at an interface and the abutting flanges providing an inner surface and an outer surface, the apparatus including: a layer of sealant (10) applied to the interface (6) and an area of the abutting flanges surrounding the interface on at least one of the inner and outer surfaces; on at least one of the inner and outer surfaces a first layer of sheet material (13) adapted to provide an air space; a second layer of sheet material (15) overlying the first layer (13); a fluid impermeable sealant (16) overlying the second layer (15); wherein an air tight space is formed around the first layer (13), a vacuum source in fluid communication with said air tight space, vacuum monitoring means configured to monitor the status of a vacuum created in the air tight space.

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Apparatus and Method for Sealing and Monitoring a Bolted Flange Joint

Field of the Invention

The present invention relates to bolted flange joints and in particular to an apparatus and method for sealing such a joint and which provides for monitoring of the integrity of the seal and the joint.

Background of the Invention

Bolted flange joints are used widely, usually for joining together hollow structures such as sections of pipes or tube. Often hollow structures have a circular cross-section although this is not always the case.

Wind turbine towers are often made from a plurality of hollow structural sections that are mounted one on top of another and fastened together. Whilst fastening of one hollow structural section to another may be by welding, a bolted flange joint is often preferred.

In a wind turbine tower the bolted flange joints must be capable of withstanding very large forces. As a result flanges are typically between 50 and 170mm thick and bolts be fastened with great torque.

In a bolted flange joint of a wind turbine towers a series of holes is provided in each flange, the holes in each flange are aligned and bolts passed through aligned holes in adjacent flanges.

For the continues safe operation of the wind turbine it is essential that if there is a fault at one of the bolted flange joints it is detected early so that the fault may be repaired. A typical fault would involve a bolt failing. If one bolt fails, the bolts immediately adjacent the failed bolt are placed under an increased load, and if one of those bolts fails the bolts immediately adjacent those failed bolts are placed under a still greater load.

The bolted flange is often covered externally with a steel cover. Such a cover can protect the joint from water penetration. Wind turbines are often located in harsh environments, such as at sea or in mountainous areas, and may be exposed to driving rain, and when offshore, sea water in the form of waves and sea spray. If the joint is penetrated the bolts could be caused to corrode.

In order to detect faults in bolted flanges of wind turbine towers a rigorous visual inspection regime is followed, with technicians entering the wind turbine towers and inspecting

the joints at regular intervals. If a failed or failing bolt or water ingress is detected, remedial action is taken. This may comprise replacing suspect bolts and/or fixing the outer cover.

It is possible to monitor bolts remotely. However, to date this has involved monitoring each bolt of the flange independently. The cost of such monitoring equipment has to date been considered prohibitive and hence a manual inspection regime is preferred in the industry.

It would be desirable to provide an improved apparatus and method for sealing a bolted flange. It would also be desirable to provide an improved apparatus and method for monitoring the integrity of a bolted flange, and in particular the seal of a sealed bolted flange.

Summary of the Invention

According to the invention there is provided a bolted flange joint sealing and monitoring apparatus, the bolted flange joint comprising two flanges abutting one another at an interface, each flange having a series of holes therein, the holes of the two flanges of the joint aligned and receiving bolts therein, and the abutting flanges providing an inner surface and an outer surface, the sealing and monitoring apparatus including:

- a. a layer of sealant applied to the interface and an area of the abutting flanges surrounding the interface on at least one of the inner and outer surfaces;
- b. and on at least one of the inner and outer surfaces a first layer of sheet material adapted to provide an air space and overlying the following step a;
- c. a second layer of sheet material overlying the first layer of sheet material;
- d. a fluid impermeable sealant overlying the second layer of sheet material;

wherein an air tight space is formed around the first layer of sheet material, the apparatus further including a vacuum source, and wherein the said air tight space is in fluid communication with the vacuum source, the apparatus further including vacuum monitoring means configured to monitor the status of a vacuum created in the air tight space.

The bolted flange joint sealing and monitoring apparatus may further include a third layer of sheet material situated between the first and second layers of sheet material.

The third layer of sheet material may be a fluid impervious foil. The foil may be an aluminium foil, or a plastics foil.

The bolted flange joint sealing and monitoring apparatus may further comprise a fourth layer of sheet material situated between the first layer of sheet material and the flange surface or a layer of sealant on the flange surface, wherein the fourth layer of sheet material is attached to the flange surface or sealant by adhesive.

The fourth layer of sheet material may be either covered on opposing faces thereof with adhesive, or is impregnated with adhesive such that the opposing faces thereof have adhesive thereon.

At least one face of the third layer of sheet material may be covered with adhesive.

Advantageously, the second layer of sheet material is a cloth, and the cloth may be a glass fibre cloth.

Preferably, one side of the second layer of sheet material is covered with adhesive.

It is preferred that the peripheral edge of the first layer lies inside the peripheral edge of the fluid impermeable sealant overlying the second layer of sheet material.

Advantageously, the peripheral edge of the second layer of sheet material extends beyond or is co-terminus with the peripheral edge of the first layer of sheet material.

The peripheral edge of the third layer of sheet material may extend beyond or may be co-terminus with the peripheral edge of the first layer of sheet material.

It is preferred that the peripheral edge of the fourth layer of sheet material extends beyond or is co-terminus with the peripheral edge of the first layer of sheet material.

According to a second aspect of the invention there is provided a structure comprising a bolted flange joint, the bolted flange joint being provided with bolted flange joint sealing and monitoring apparatus according to the first embodiment of the invention.

The structure may comprise a plurality of bolted flange joints, each bolted flange joint being provided with at least one bolted flange joint sealing and monitoring

apparatus according to any the first aspect of the invention, wherein each apparatus provides an isolated air tight pocket.

According to a third aspect of the invention there is provided a method of fabricating a bolted flange joint sealing and monitoring apparatus on a bolted flange joint, the bolted flange joint comprising two flanges abutting one another at an interface, each flange having a series of holes therein, the holes of the two flanges of the joint aligned and receiving bolts therein, and the abutting flanges providing an inner surface and an outer surface comprising the steps of:

- e. Preparing inner and outer surfaces of abutting flanges of a bolted flange joint in and area around the interface the bolted flange joint;
- f. Applying a layer of sealant to the interface and an area of the abutting flanges surrounding the interface on at least one of the inner and outer surfaces; and on at least another of the inner and outer surfaces,
- g. Attaching a first layer of sheet material adapted to provide an air space overlying the interface to the prepared flange surface to each side of the interface or to the layer of sealant applied in step b ;
- h. Attaching the second layer of sheet material such that it overlies the first layer of sheet material;
- i. Applying a layer sealant over the second layer of sheet material, the layer of sealant extending over the prepared flange surface to each side of the interface or the sealant applied in step b;
- j. Connecting a vacuum source to a space formed about the first layer of sheet material.

Advantageously, the method includes the step of preparing the surface of the bolted flange joint includes the step of repairing the bolted flange joint.

The method may comprise the further step of applying a third layer of sheet material between the first and third layers of sheet material.

The method may comprise the further step of applying a fourth layer of sheet material between the surface of the sealant applied to the prepared surface around the bolted flange joint and the first layer of sheet material.

According to a fourth aspect of the invention there is provided a method of sealing and monitoring a bolted flange joint comprising the steps of applying a bolted flange joint sealing and monitoring apparatus of the first aspect of the invention to a bolted flange joint, and monitoring the status of a vacuum in the bolted flange joint monitoring apparatus.

The method of sealing and monitoring a bolted flange joint may comprise the further step of relaying the detected status of the vacuum to a remote monitoring station.

Brief Description of the Drawings

In the Drawings, which illustrate bolted flange joints and structures including such joints, and are by way of example:

Figure 1 is a schematic illustration of a part of a bolted flange joint;

Figure 2 is a schematic illustration of two types of flange joint;

Figure 3 is a schematic illustration of a wind turbine tower having bolted flange joints and provided with a sealing and monitoring apparatus according to an embodiment of the invention;

Figure 4 is a schematic illustration of a part of a bolted flange joint according to an embodiment of the invention;

Figure 5 is a schematic illustration of a part of bolted flange joint according to another embodiment of the invention;

Figures 6a to 6e are a schematic illustrations showing different configurations of sealing and monitoring apparatus according to the invention;

Figure 7 is an exploded view of the components of the bolted flange sealing and monitoring apparatus shown in Figure 3;

Figure 8 is a plan view of a weld seam with some of the components of the bolted flange sealing and monitoring apparatus attached thereto;

Figure 9 is a cross-section through a part of the bolted flange sealing and monitoring apparatus;

Figure 10 is a schematic representation of an alternative embodiment of the invention;

Figure 11 is a schematic representation of a further alternative embodiment of the invention; and

Figure 12 is a schematic representation of a further alternative embodiment of the invention.

Detailed Description of the Preferred Embodiments

Referring now to Figure 1, a structure 1 comprises two structural elements 2, 2' each including a flange 3, 3'. The flanges 3, 3' include holes (not shown) which are aligned and which receive bolts 4.

Figure 2 illustrates two views of an L-shaped flanged joint and two views of a T-shaped flanged joint. Each view illustrates an exaggerated form of bowing of the flanges 3, 3' representing how the flatness of a flange may deviate from being completely flat. In the case of wind turbine towers, the extent of deviation in flatness may be 2.00mm over the total circumference and 1.00mm over a segment of 30 degrees where a particular area of the tower wall is critical.

Figure 3 illustrates part of an assembled tower 5, which comprises structural elements 2, 2', 2". Each structural element 2, 2', 2" has flanges 3, 3' (not shown in this Figure but as shown in Figures 1 and 2) which form an interface 6 where they abut. The structural elements 2, 2', 2" are joined together by bolts 4 as shown in Figures 1 and 2. The interfaces 6 between structural elements 2, 2' is shown enclosed by a collar 7. The function of the collar 7 is to protect the interface 6 from weather. The collar 7 can prevent rain, snow, sea spray, dust and other debris from entering the interface 6. It is desirable to protect the interface 6 from ingress of such matter in order to prevent corrosion of the bolts 4, flanges 3, 3' and the structural elements 2, 2', 2". The collars 7 may be configured such that are removable. For example, the collars 7 may be fastened to the structural elements 2, 2', 2" with screws.

Figure 3 also illustrates the interface 6 between the structural elements 2', 2" provided with a structure 11, described in greater detail below. The structure 11 may be protected by a collar similar to collar 7. The structure 11 is connected to a vacuum monitoring apparatus 30 by a pipe 31. The vacuum monitoring apparatus 30 subjects the inside of the structure to a negative pressure and monitors that negative pressure constantly. The vacuum monitoring apparatus 30

also includes a transmitter 32 for transmitting data indicative of the status of the negative pressure at a preset sampling rate, for example once a second. The apparatus 30 may also include a data recording means.

As mentioned above, there is a need for an apparatus and method of monitoring the state of the bolts 4 of a bolted flange joint 1, and it would be desirable to monitor the bolts 4 without the requirement to instrument each bolt.

The apparatus of the invention monitors the condition of the bolts 4 by monitoring the status of a vacuum in the region of the bolts 4. If a bolt has failed or stretched by a certain amount a gap will develop between the flanges 3, 3'.

In order to provide a space which can be subjected to a vacuum it is necessary to provide a seal around the bolts 4. This is achieved by sealing the interface 6 on around both the outside and inside of the interface 6.

Figures 6a to 6e illustrate different configurations of the invention. Common to each configuration is that the interface 6 is sealed on both the inner and outer surfaces and that one or both of those surfaces is provided with a means of subjecting the joint to a vacuum.

The configuration in Figure 6a includes a seal 10 on the outer surface of the interface 6. In this embodiment the seal 10 comprises a layer of epoxy resin, such as SikaCor SW-1000 RepaCor, a solvent free, two component coating available from Sika Deutschland GmbH or AB-COR 950 SW-H, a 2 component solvent free epoxy repair and corrosion protection paint available from AB-Polymerchemie GmbH. The inner surface of the interface 6 is provided with a structure 11. The structure 11 extends over the bolts 4 to the inner surfaces of the structural elements 2, 2' to which it is attached. The structure is also attached to the vertical surfaces of the flanges 3, 3'. By sealing the outer surface of interface 6 and encapsulating the inner surface of interface 6 and the bolts to both the upper and lower horizontal surfaces of the flanges 3, 3' the whole bolted flange interface 6 may be subjected to a vacuum. The vacuum will only fail if the 10 or structure 11 fails. If a bolt 4 fractures or is stretched, the structural elements 2, 2' may move relative to one another. If the movement is sufficient to break either the seal 10 or the structure 11, the vacuum will fail and an alarm will be triggered. Given the nature of the structures and the environments in which they are placed, it is inevitable that there will be some small movement at the interface 6.

Figure 6b differs from Figure 6a in that the structure 11 is attached to and covers the vertical surfaces of the flanges 3, 3' and the bowls 4 are not encapsulated. In this embodiment washers 4a, 4b which are secured between the upper surface of the flange 3 and the head of bolt 4 and the underside of flange 3' and nut 4c respectively, are compressible sufficiently to form an effective seal around the bolt holes.

Figure 6c differs from Figure 6a in that seal 10 is replaced by a structure 11', so that both sides of the interface 6 are subjected to a vacuum that may be monitored.

Figure 6d differs from Figure 6a in that the structure 11 is attached to the outer surface of the interface 6, with the inner surface having a seal 10 applied thereto.

The embodiment of Figure 6e is most similar to the embodiments of Figure 6b. However the embodiment of Figure 6e, the structure 11 is attached to the outer surface of the interface 6, with the inner surface having a seal 10 applied thereto.

The embodiments illustrated in Figures 6b and 6d may be provided with caps to cover and seal the bolts 4 around the bolt heads and the nuts 4c. Two possible forms of cap are illustrated in Figures 4 and 5. In Figure 4 each bolt is provided with its own cap, whereas in Figure 5 one cap is provided for a plurality of bolts 4. Where such caps are used they would be placed over both the bolt heads and nuts 4c.

Referring to Figure 4, the individual cap comprises a piece of plastic that is attached to the flange 3' and the inner surface of the structural element 2' by means of adhesive extending around the edge of the plastic 20. The plastic 20 is then heat sealed, removing air between the plastic, flange 3' and inner surface of the structural element 2' in the process. The seal created by the adhesive 21 is capable of holding the vacuum applied at the interface 6 of the bolted flange joint 1.

Referring to Figure 5, the cap 25 is a one piece plastic moulding that is shared and dimensioned to surround each bolt head and attach to the inner surface of the structural element 2' and the flange 3' by means of adhesive 26. The adhesive 26 seals any remaining spaced between the underside of the cap 25 and the inner surface of the structural element 2' and the flange 3' against ingress or egress of fluid, that is the seal created by the adhesive 26 is capable of holding the vacuum applied at the interface 6 of the bolted flange joint 1.

Figures 10 to 12 illustrate alternatives to the embodiments shown in Figures 4 and 5. The embodiment illustrated in Figure 10 includes plates 30, 30' whose shape corresponds to the internal shape of the structural elements 2, 2' (typically circular). The plates 30, 30' are attached to the inner wall of the structural elements 2, 2' by brackets 31, 31'. The interface of the edge of the plate 30, 30' with the inner surface of the structural element 2, 2' is sealed with a suitable sealant, for example a mastic or a silicone sealant 32, 32' which may be applied in a bead using a commonly available sealant applicator.

The function of the embodiment of Figure 10 (and 11) is to prevent the vacuum created in the structure 11 failing due to ingress of air through the bolt holes in the flanges 3, 3'. The plates 30, 30' provide a sealed space so that if there is an air pathway through the bolt holes, there cannot be ingress of air into the space between plates 30, 30'.

The embodiment illustrated in Figure 11 addresses the same issue as the embodiment of Figure 10 in a slightly different way. In this embodiment rings 40, 40' which each comprise two flanges 40a, 40b extending in the longitudinal direction of the structural elements 2, 2' joined together by a flange 40c perpendicular to the flanges 40a, 40b. The shape of the rings 40, 40' corresponds to the internal shape of the structural elements 2, 2' and are attached to the said inner surfaces of the structural elements 2, 2'. In the illustrated example they are held in place with an adhesive sealant, but brackets similar to brackets 31 in Figure 10 may be provided. The edges of the flanges 40a, 40b, are sealed with a sealant 41, 42 in the manner described above in relation to Figure 10. In Figure 11, for the sake of clarity, the structure 11 is not shown. However, the structure would be attached to the inner faces of the flanges 3, 3' as shown in Figure 10.

The embodiment illustrated in Figure 12 differs from the embodiments illustrated in Figures 10 and 11 in that the bolt holes in the flanges 3, 3' are sealed by a gasket 50. In use, the bolts 4 are tightened against the gasket and the gasket seals any possible air pathway through the bolt holes.

Referring now to Figure 7, the area to each side of the interface 6 is prepared back to bare metal and repaired if necessary. This may be done using any known technique. The area prepared back to bare metal extends, for example by 50mm or the over whole of the vertical surface of each flange 3, 3', to each side of the interface 6. A layer of sealant 8 may then be applied to the prepared area around the interface 6. The sealant may be urethane for example, or an epoxy sealant. Advantageously, the sealant is solvent free. The sealant may be a two component

sealant that is mixed prior to application, and may be a sealant that requires heating prior to application in order to reduce its viscosity. The sealant 8 provides for better adhesion of an adhesive thereto than bare metal.

The sealant is allowed to cure. A layer of adhesive is attached to the cured sealant 8, or directly to the bare metal where the sealant 8 is not used. In the illustrated example, this is achieved by mounting sheet material 12, such as paper, that is either coated on both sides with adhesive or impregnated with adhesive such that both sides of the sheet material have adhesive properties. The sheet material 12 is attached to the structure both above and below the interface 6, leaving a space in the region of the interface 6.

For ease of use, the sheet material 12 is preferably supplied with peel off layers of material on each side of the material 12. In this way the material 12 may be supplied on a roll without the material adhering to itself. In the illustrated embodiment, the sheet material 12 is in the form of a tape. To apply the sheet material 12 to the cured layer of sealant 8, sheet material 12 in the form of a roll of tape is attached to the structural elements above and below the interface 6.

Instead of using sheet material 12 in the form of a tape, a single piece of sheet material having an opening 12a therein may be used. The opening 12a may be formed by removing a piece of material from the sheet 12 after its attachment to the structural elements 2, 2', 2'', or by using a sheet material 12a which has a pre-formed opening therein. This is particularly useful where it is desirable to monitor sections of the joint. Such a configuration allows the section of the joint where a bolt is defective to be identified.

To attach the sheet material to the structural element 2, 2', 2'', the peel off layer (if provided) is removed from one side thereof, and the material is placed onto the surface of the sealant 8. Where the sheet material is in the form of a tape, the tape is attached to the structural element 2, 2', 2'' so as to leave a small area of sealant covered surface to the outside of the tape, that is the other side of the tape to the interface 6. Where a single piece of sheet material 12 is used, it is selected or prepared such that it is slightly smaller than the area covered with sealant 8. Such a pre-formed sheet material 12 is illustrated in Figure 8, which shows the prepared interface 6, the prepared area around the joint to which sealant 8 has been applied, and the sheet material 12 attached around the interface 6 and on the sealant 8.

If both sides of the sheet 12 were covered with a peel off layer, the remaining peel off layer is removed.

Next a layer of mesh 13 is applied to the adhesive surface of the sheet material 12. The peripheral shape and dimension of the mesh 13 is prepared such that the layer of mesh sits on top of the tape 12 or sheet 12. The peripheral shape and dimension of the mesh 13 may match substantially the peripheral shape and dimension formed by the spaced apart pieces of tape 12 or the sheet 12. It is this mesh 13 that provides the space which may be subject to a vacuum. The mesh is described in greater detail with reference to Figure 7.

The mesh 13 is next covered with a layer of fluid impervious sheet material, which in the example is a layer of aluminium foil 14. The aluminium foil 14 is prepared such that its peripheral shape and dimension is substantially the same as the shape and dimension of the mesh 13. The aluminium foil is adhered to the mesh 13 with the each edge of the aluminium foil substantially co-terminus with the edge of the mesh 13.

In this example, the aluminium foil has adhesive on one side thereof and is this is covered with a peel off layer. Hence, the peel off layer is removed and the aluminium foil is applied and attached to the free surface of the mesh 13.

The foil 14 is then covered with a layer of cloth 15, which is glass fibre cloth in this example. The cloth 15 is attached to the foil 14 by adhesive, which in the example is provided as a covering to the glass fibre cloth 15. The glass fibre cloth may have a peel off layer covering the adhesive. If so, the peel off layer is removed and the adhesive face of the glass fibre cloth 15 is presented up to and pressed on to the foil 14. The glass fibre cloth is prepared such that its shape and dimension matches the shape and dimension of the foil 14.

The final step in creating the structure 11 involves applying a sealant 16 to the glass fibre cloth 15 and around the cloth 15 over the sealant 8 or bare metal surface around the interface 6. Where the mesh 13 sits on top of the layer of sheet material 12, the sealant 16 seals the edges of the mesh and other layers of sheet material, such that all the components of the structure 10, 10' are encapsulated in the sealant 16. The sealant 16 is preferably the same as or of the same family as the sealant 8. For example, if the sealant 8 is urethane based, it is

preferred that the sealant 16 is also a urethane based, whereas if the sealant 8 is epoxy based, it is preferred that the sealant 16 is epoxy based.

As can be seen from Figure 9, the sealant 16 is taken over the edge of the sheet materials 12 to 15 so that the edges thereof are sealed.

Referring to Figure 7, it can be seen that the mesh 13 is made up of strands of material 13a extending in one direction and strands of material 13b extending substantially perpendicularly to the strands 13a. The strands 13a and 13b lie in two different planes. Hence, an air space is formed between the lower surface of strands 13a and the upper surface of strands 13b.

In an alternative embodiment, the mesh 13 is formed such that its peripheral shape and dimension corresponds to the internal shape and dimension between the pieces of tape 12 or of the opening 12a. The mesh 13 is then placed within the opening 12a. An adhesive may be applied to the sealant 8 or bare metal prior to placing of the mesh 13 thereon. The remaining layers are applied in the same manner as described above. Hence, peripheral shape and dimension of the layer 14 corresponds to the peripheral shape and dimension of the layer 12, and so on.

A vacuum system is connected to the interstitial space formed in the structure 11.

The condition of the bolted flange joint 1 is monitored by monitoring the status of the vacuum. If the position of one structural element 2 changes relative to another 2' by a sufficient amount, for example by 1mm, then a crack will develop in either one of the layers of the structure 11 or in the sealant 10 on the other side of the structural elements, causing the negative pressure in the vacuum to rise and triggering an alarm. The alarm is an indication of one or more defective bolts.

Claims

1. A bolted flange joint sealing and monitoring apparatus, the bolted flange joint comprising two flanges abutting one another at an interface, each flange having a series of holes therein, the holes of the two flanges of the joint aligned and receiving bolts therein, and the abutting flanges providing an inner surface and an outer surface, the sealing and monitoring apparatus including:

a layer of sealant applied to the interface and an area of the abutting flanges surrounding the interface on at least one of the inner and outer surfaces;

and on at least one of the inner and outer surfaces a first layer of sheet material adapted to provide an air space and overlying the following step a;

a second layer of sheet material overlying the first layer of sheet material;

a fluid impermeable sealant overlying the second layer of sheet material;

wherein an air tight space is formed around the first layer of sheet material, the apparatus further including a vacuum source, and wherein the said air tight space is in fluid communication with the vacuum source, the apparatus further including vacuum monitoring means configured to monitor the status of a vacuum created in the air tight space.

2. A bolted flange joint sealing and monitoring apparatus according to Claim 1, further including a third layer of sheet material situated between the first and second layers of sheet material.
3. A bolted flange joint sealing and monitoring apparatus according to Claim 2, wherein the third layer of sheet material is a fluid impervious foil.
4. A bolted flange joint sealing and monitoring apparatus according to Claim 3, wherein the foil is an aluminium foil, or a plastics foil.
5. A bolted flange joint sealing and monitoring apparatus according to any preceding claim, further comprising a fourth layer of sheet material situated between the first layer of sheet material and the flange surface or a layer of sealant on the flange surface, wherein

the fourth layer of sheet material is attached to the flange surface or sealant by adhesive.

6. A bolted flange joint sealing and monitoring apparatus according to Claim 5, wherein the fourth layer of sheet material is either covered on opposing faces thereof with adhesive, or is impregnated with adhesive such that the opposing faces thereof have adhesive thereon.
7. A bolted flange joint sealing and monitoring apparatus according to any of Claims 2 to 6, wherein at least one face of the third layer of sheet material is covered with adhesive.
8. A bolted flange joint sealing and monitoring apparatus according to any preceding claim, wherein the second layer of sheet material is a cloth.
9. A bolted flange joint monitoring apparatus according to Claim 8, wherein the cloth is a glass fibre cloth.
10. A bolted flange joint sealing and monitoring apparatus according to Claim 8 or 9, wherein one side of the second layer of sheet material is covered with adhesive.
11. A bolted flange joint sealing and monitoring apparatus according to any preceding claim, wherein the peripheral edge of the first layer lies inside the peripheral edge of the fluid impermeable sealant overlying the second layer of sheet material.
12. A bolted flange joint sealing and monitoring apparatus according to any preceding claim, wherein the peripheral edge of the second layer of sheet material extends beyond or is co-terminus with the peripheral edge of the first layer of sheet material.
13. A bolted flange joint sealing and monitoring apparatus according to any of Claims 2 to 12, wherein the peripheral edge of the third layer of sheet material extends beyond or is co-terminus with the peripheral edge of the first layer of sheet material.
14. A bolted flange joint sealing and monitoring apparatus according to any of Claims 5 to 13, wherein the peripheral edge of the fourth layer of sheet material extends beyond or is co-terminus with the peripheral edge of the first layer of sheet material.
15. A structure comprising a bolted flange joint, the bolted flange joint being provided with bolted flange joint sealing and monitoring apparatus according to any of Claims 1 to 14.

16. A structure according to Claim 15, comprising a plurality of bolted flange joints, each bolted flange joint being provided with at least one bolted flange joint sealing and monitoring apparatus according to any of Claims 1 to 14, wherein each apparatus provides an isolated air tight pocket.
17. A structure according to Claim 15 or 16, further comprising bolt hole seal means.
18. A structure according to Claim 17, wherein the bolt hole seal means comprises two spaced apart plates situated above and below respective flanges and sealed against the inner surface of the structure, or one or more rings sealed against the inner surface of the structure, or a gasket or a plurality of washers, or one or more sealed caps.
19. A method of fabricating a bolted flange joint sealing and monitoring apparatus on a bolted flange joint, the bolted flange joint comprising two flanges abutting one another at an interface, each flange having a series of holes therein, the holes of the two flanges of the joint aligned and receiving bolts therein, and the abutting flanges providing an inner surface and an outer surface comprising the steps of:
- a. Preparing inner and outer surfaces of abutting flanges of a bolted flange joint in and area around the interface the bolted flange joint;
 - b. Applying a layer of sealant to the interface and an area of the abutting flanges surrounding the interface on at least one of the inner and outer surfaces; and on at least another of the inner and outer surfaces,
 - c. Attaching a first layer of sheet material adapted to provide an air space overlying the interface to the prepared flange surface to each side of the interface or to the layer of sealant applied in step b ;
 - d. Attaching the second layer of sheet material such that it overlies the first layer of sheet material;
 - e. Applying a layer sealant over the second layer of sheet material, the layer of sealant extending over the prepared flange surface to each side of the interface or the sealant applied in step b;
 - f. Connecting a vacuum source to a space formed about the first layer of sheet material.

20. A method according to Claim 19, wherein the step of preparing the surface of the bolted flange joint includes the step of repairing the bolted flange joint.
21. A method according to Claim 19 or 20, comprising the further step of applying a third layer of sheet material between the first and third layers of sheet material.
22. A method according to any of Claims 19 to 21, comprising the further step of applying a fourth layer of sheet material between the surface of the sealant applied to the prepared surface around the bolted flange joint and the first layer of sheet material.
23. A method of sealing and monitoring a bolted flange joint comprising the steps of applying a bolted flange joint sealing and monitoring apparatus of any of Claims 1 to 14 to a bolted flange joint, and monitoring the status of a vacuum in the bolted flange joint monitoring apparatus.
24. A method of sealing and monitoring a bolted flange joint as claimed in Claim 23, comprising the further step of relaying the detected status of the vacuum to a remote monitoring station.

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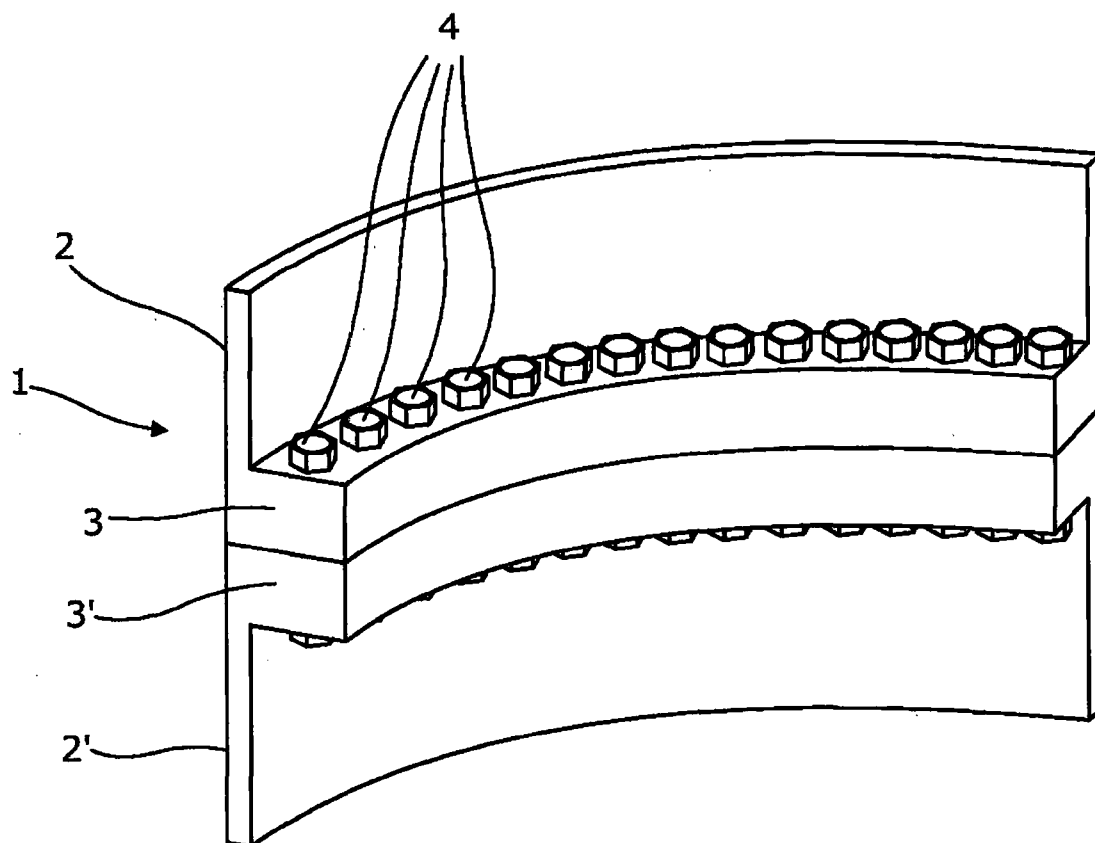


Figure 1

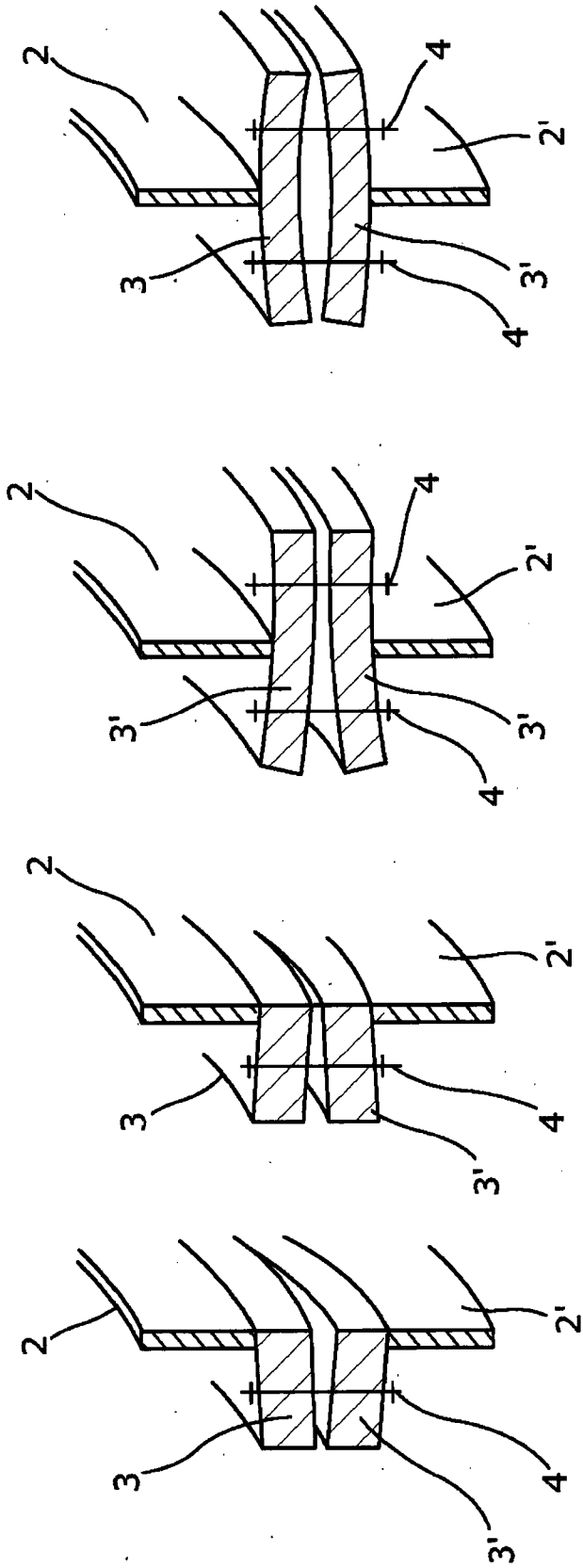


Figure 2

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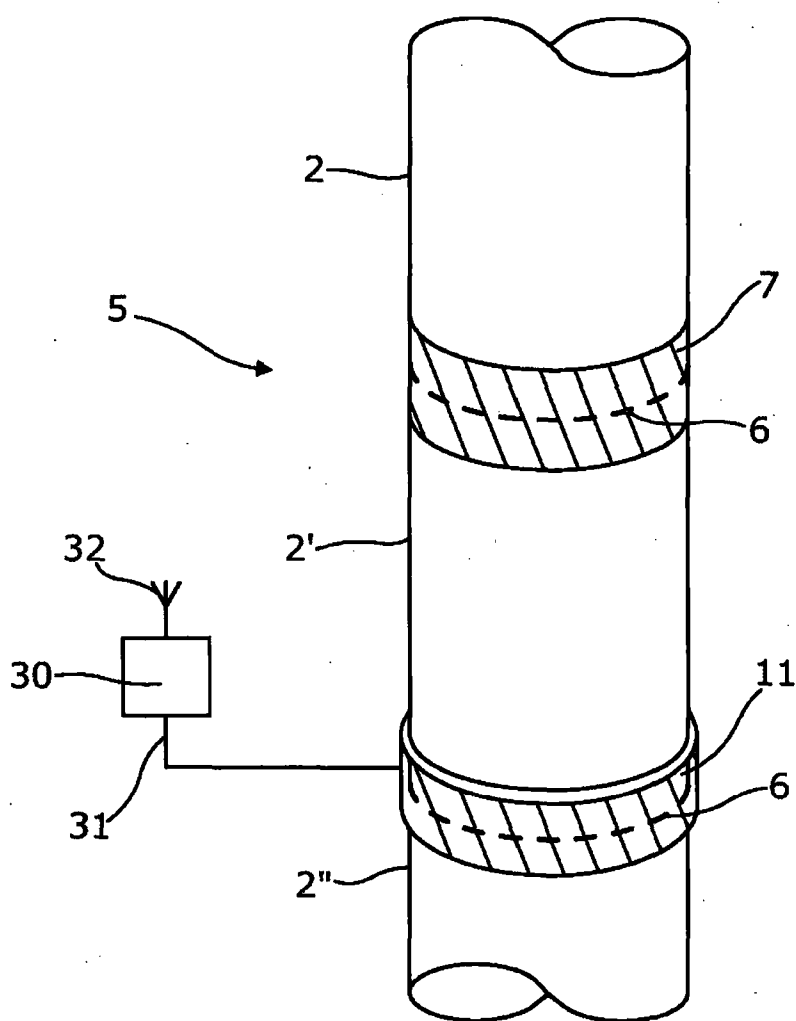


Figure 3

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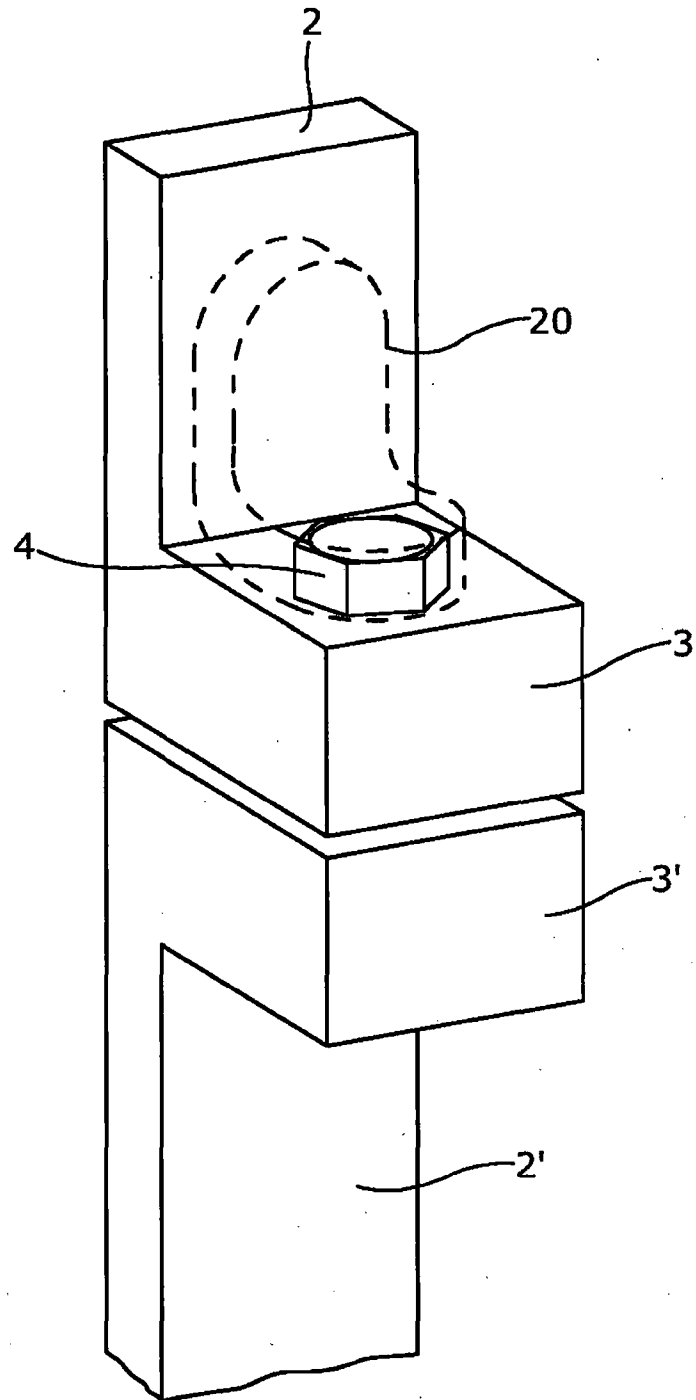


Figure 4

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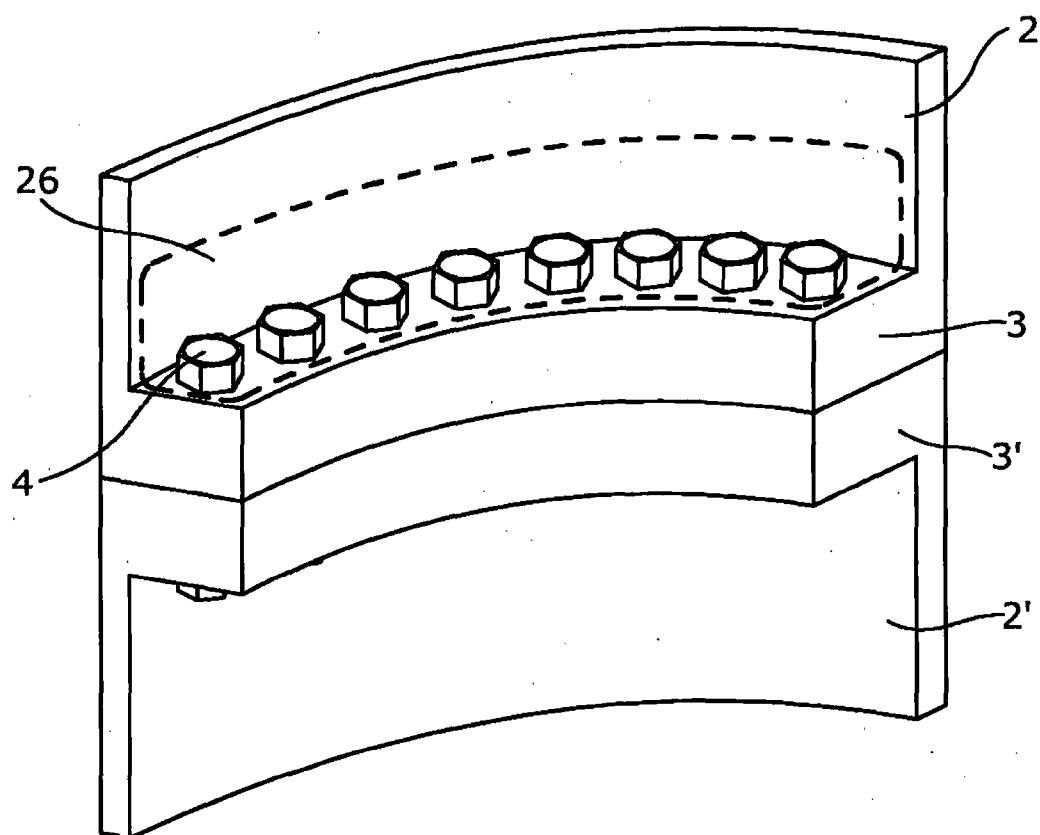


Figure 5

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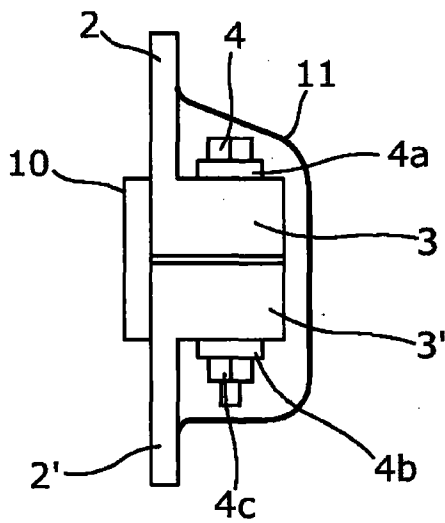


Figure 6a

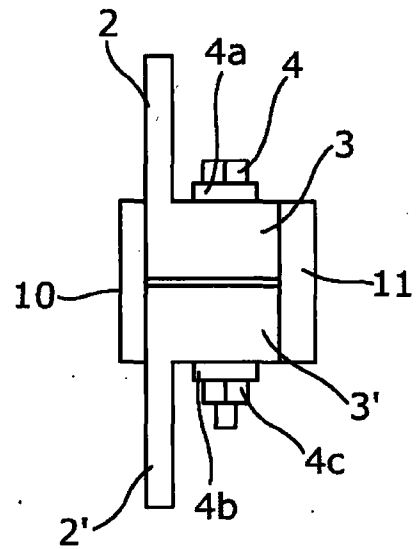


Figure 6b

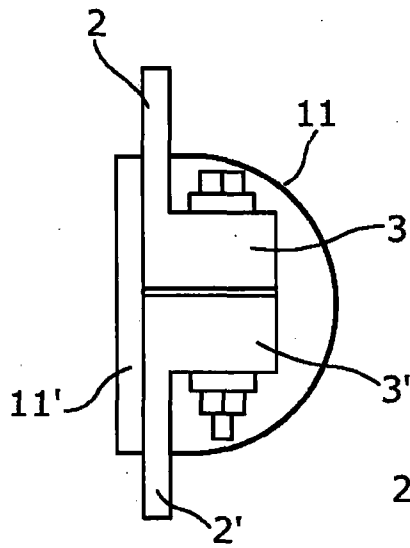


Figure 6c

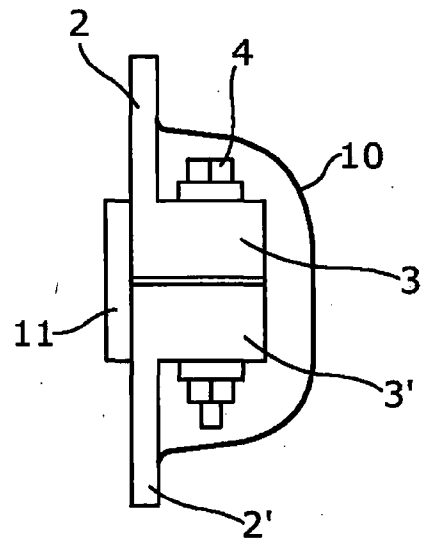


Figure 6d

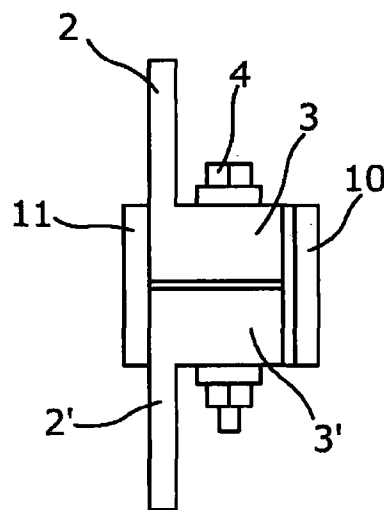


Figure 6e

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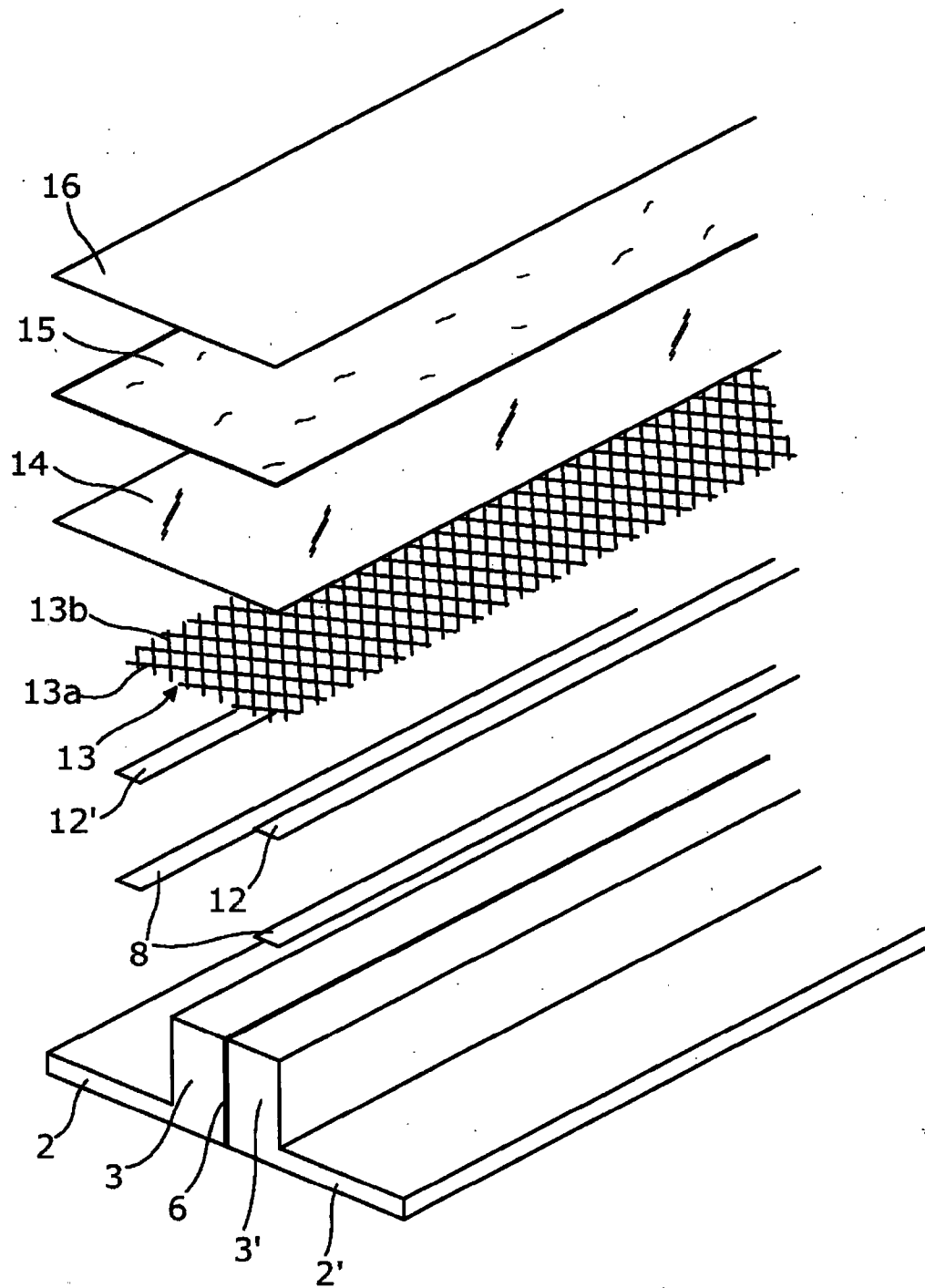


Figure 7

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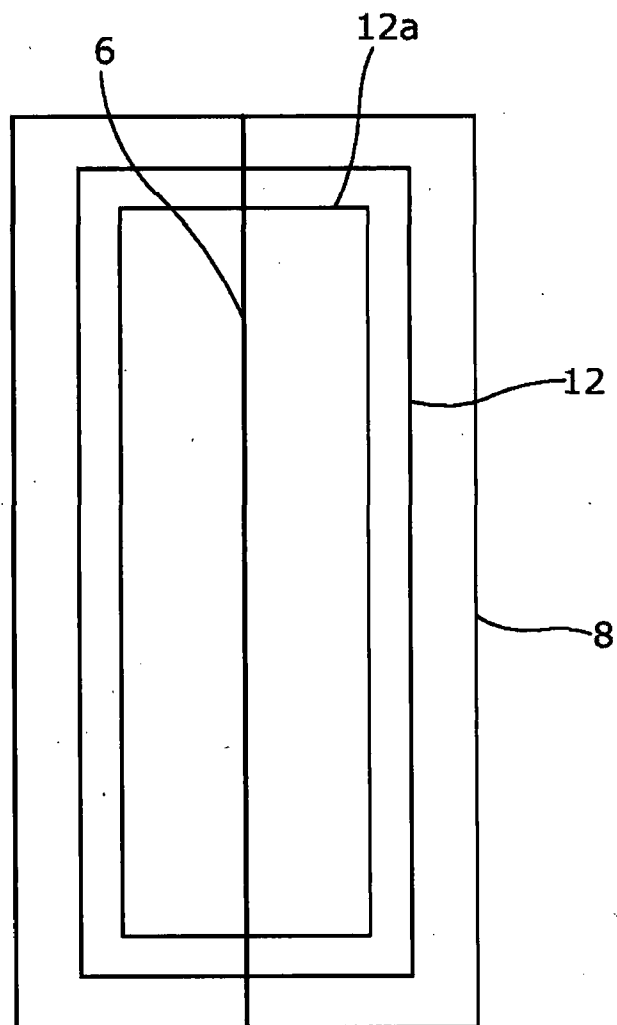


Figure 8

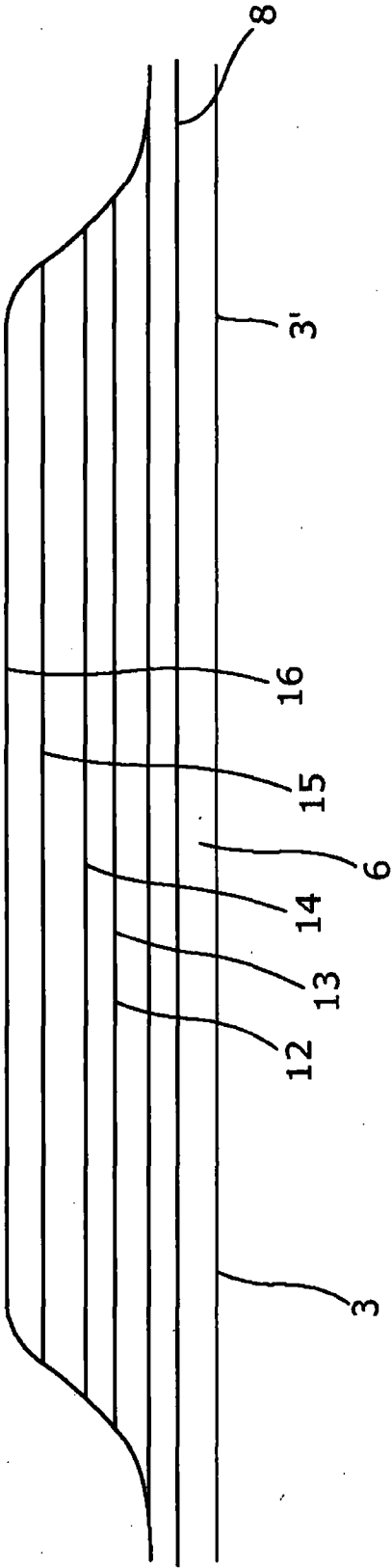


Figure 9

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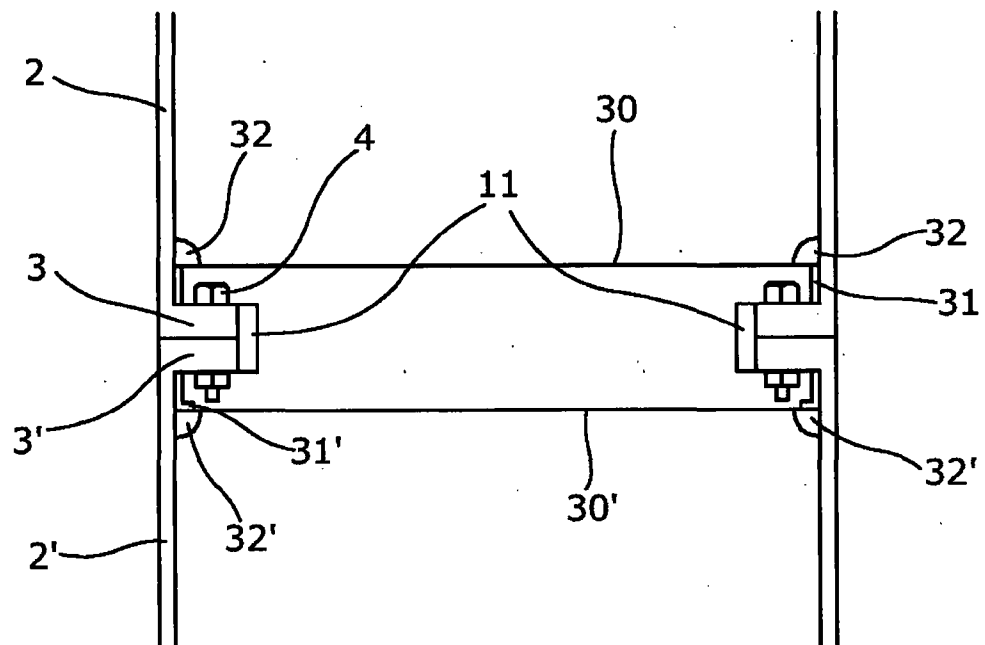


Figure 10

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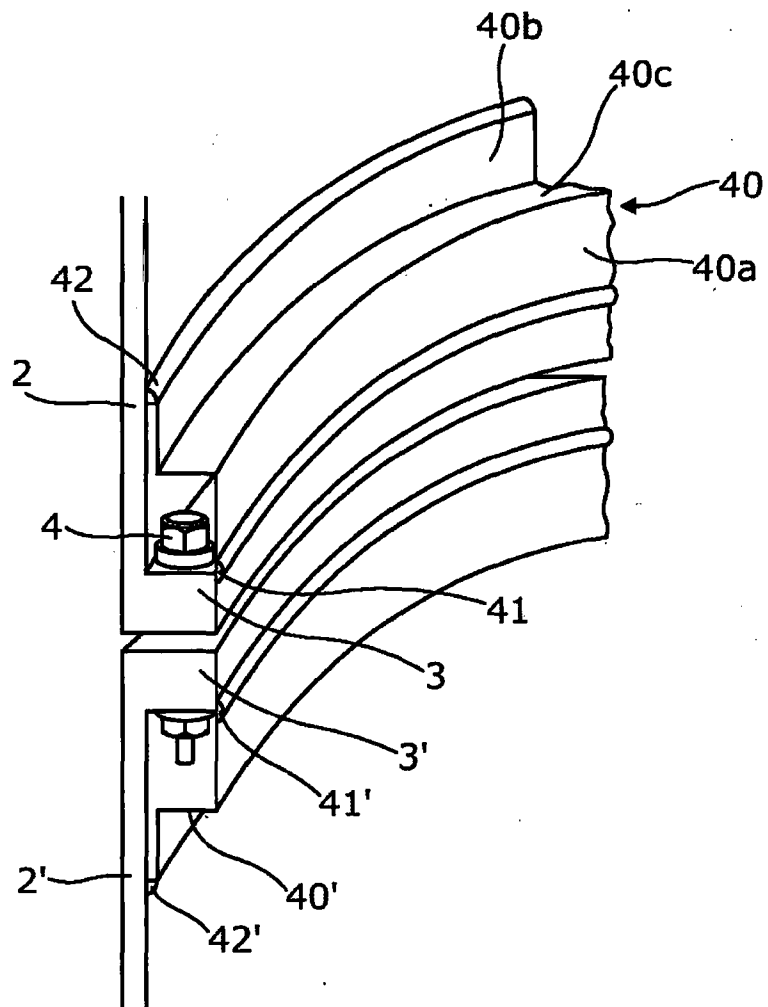


Figure 11

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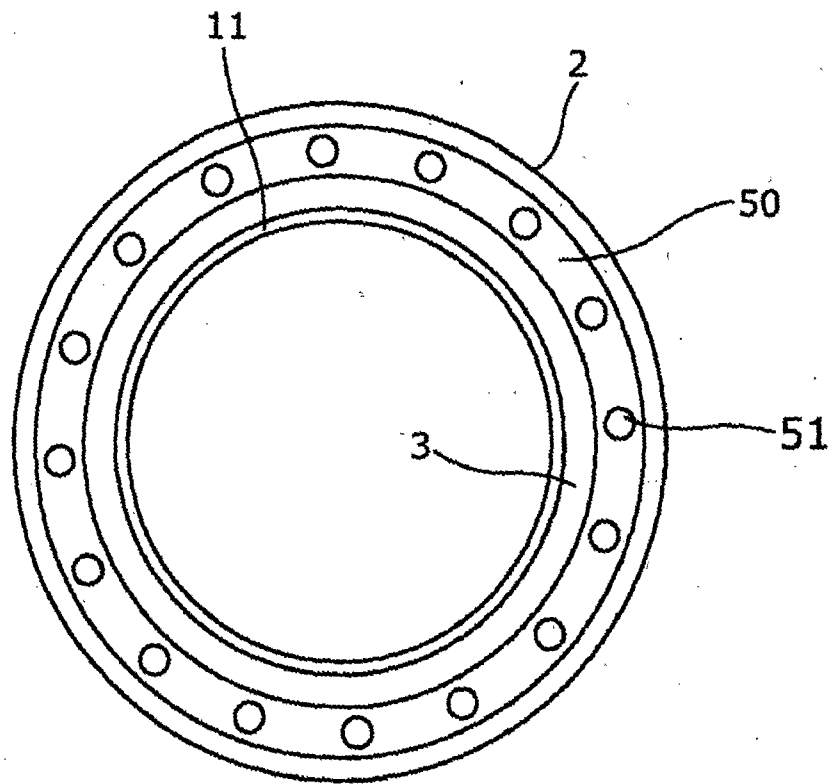


Figure 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/050016

A. CLASSIFICATION OF SUBJECT MATTER INV. E04H12/08 F03D13/20 F03D13/25 G01M3/02 G01M3/18 G01M3/28 B32B37/00 ADD. 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) E04H F16L F03D G01M B32B 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, WPI Data																										
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Category*</th> <th style="width: 70%;">Citation of document, with indication, where appropriate, of the relevant passages</th> <th style="width: 20%;">Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">X</td> <td>US 2016/258832 A1 (HARITOU CHRISTOS SOTIRIOUS [GB] ET AL) 8 September 2016 (2016-09-08)</td> <td style="text-align: center;">1-14</td> </tr> <tr> <td style="text-align: center;">Y</td> <td>the whole document</td> <td style="text-align: center;">15-24</td> </tr> <tr> <td style="text-align: center;">Y</td> <td>US 2013/327412 A1 (DEGEORGE JOSEPH P [US] ET AL) 12 December 2013 (2013-12-12) abstract; figures 1-8</td> <td style="text-align: center;">15-18</td> </tr> <tr> <td style="text-align: center;">Y</td> <td>EP 1 318 300 A1 (GEN ELECTRIC [US]) 11 June 2003 (2003-06-11)</td> <td style="text-align: center;">19-24</td> </tr> <tr> <td style="text-align: center;">A</td> <td>paragraph [0024]; figure 3</td> <td style="text-align: center;">1-18</td> </tr> <tr> <td style="text-align: center;">A</td> <td>DE 20 2018 100604 U1 (KTW UMWELTSCHUTZTECHNIK GMBH [DE]) 2 March 2018 (2018-03-02) paragraph [0026] - paragraph [0030]; figure 1</td> <td style="text-align: center;">1-24</td> </tr> <tr> <td></td> <td style="text-align: center;">----- -/-</td> <td></td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	US 2016/258832 A1 (HARITOU CHRISTOS SOTIRIOUS [GB] ET AL) 8 September 2016 (2016-09-08)	1-14	Y	the whole document	15-24	Y	US 2013/327412 A1 (DEGEORGE JOSEPH P [US] ET AL) 12 December 2013 (2013-12-12) abstract; figures 1-8	15-18	Y	EP 1 318 300 A1 (GEN ELECTRIC [US]) 11 June 2003 (2003-06-11)	19-24	A	paragraph [0024]; figure 3	1-18	A	DE 20 2018 100604 U1 (KTW UMWELTSCHUTZTECHNIK GMBH [DE]) 2 March 2018 (2018-03-02) paragraph [0026] - paragraph [0030]; figure 1	1-24		----- -/-	
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X	US 2016/258832 A1 (HARITOU CHRISTOS SOTIRIOUS [GB] ET AL) 8 September 2016 (2016-09-08)	1-14																								
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Date of the actual completion of the international search 15 May 2020		Date of mailing of the international search report 28/05/2020																								
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Vecchio, Giovanni																								

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/050016

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 032 562 A (MARSH D) 8 May 1980 (1980-05-08) abstract page 2, line 5 - line 51; figure -----	1-24
A	US 4 620 731 A (RUSHING BENDEL S [US]) 4 November 1986 (1986-11-04) abstract; figures -----	17,18
A	WO 2012/107741 A1 (AIRBUS OPERATIONS LTD [GB]; DOBBIN RICHARD [GB]) 16 August 2012 (2012-08-16) abstract; figures -----	18
A	US 2010/127460 A1 (BENNETT BARTON E [US]) 27 May 2010 (2010-05-27) abstract; figures -----	1-24
A	JP H08 128586 A (MITSUBISHI HEAVY IND LTD) 21 May 1996 (1996-05-21) abstract; figures -----	1-24

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2020/050016

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016258832	A1	08-09-2016	NONE
US 2013327412	A1	12-12-2013	NONE
EP 1318300	A1	11-06-2003	DE 10160022 A1 18-06-2003 EP 1318300 A1 11-06-2003
DE 202018100604	U1	02-03-2018	NONE
GB 2032562	A	08-05-1980	NONE
US 4620731	A	04-11-1986	NONE
WO 2012107741	A1	16-08-2012	EP 2673193 A1 18-12-2013 EP 3366593 A1 29-08-2018 US 2013322982 A1 05-12-2013 US 2016076574 A1 17-03-2016 WO 2012107741 A1 16-08-2012
US 2010127460	A1	27-05-2010	US 2010127460 A1 27-05-2010 WO 2010062890 A1 03-06-2010
JP H08128586	A	21-05-1996	NONE