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(54) **Heat exchanger**

(57) A heat exchanger 302 comprising: an inlet manifold 304; an outlet manifold 306; and a tube matrix 310 comprising a plurality of tubes 308, each tube 308 being connected at one end to the inlet manifold 304 and at the other end to the outlet manifold 306; wherein each tube extends generally along a longitudinal axis defined between the connection of the tube 308 with the inlet manifold 304 and the connection of the tube 308 with the outlet manifold 306; and wherein a single portion 314 of each tube 308 is offset to one side of the longitudinal axis.

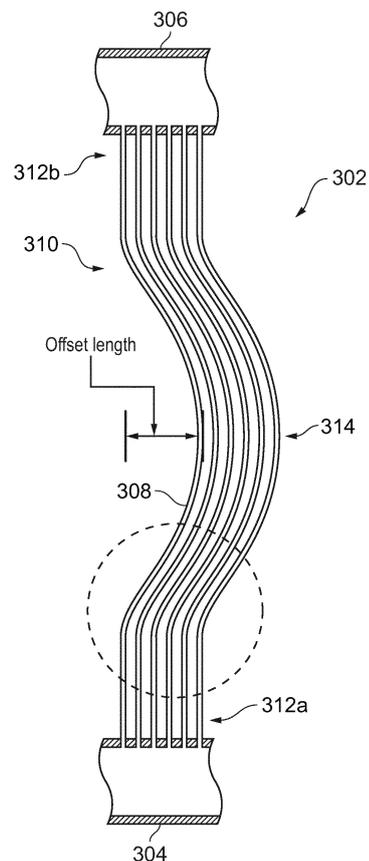


FIG. 10

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Description

[0001] The present invention relates to a heat exchanger, and particularly but not exclusively to a heat exchanger having a tube matrix which reduces thermal stress experienced by the heat exchanger.

[0002] Heat exchangers are widely used to transfer heat from a relatively hot fluid to a relatively cold fluid without direct contact between the fluids.

[0003] A conventional tube heat exchanger is shown in Figures 1 and 2. The heat exchanger 2 comprises an inlet manifold 4 and an outlet manifold 6. The inlet and outlet manifolds 4, 6 are fluidically coupled by a plurality of tubes 8 which together form a tube matrix 10. The tubes 8 of the tube matrix 10 are coupled at one end to the inlet manifold 4 and are coupled at the other end to the outlet manifold 6.

[0004] The tubes 8 of the tube matrix 10 are arranged such that their longitudinal axes are perpendicular to the longitudinal axes of the inlet and outlet manifolds 4, 6. A plurality of the tubes 8 are aligned in a plane of the longitudinal axes of the inlet and outlet manifolds 4, 6 to form a row, and several rows are disposed side-by-side to form columns of the tube matrix 10.

[0005] As shown in Figures 1 and 2, the tubes 8 of the tube matrix 10 are straight. Each tube 8 therefore follows a direct path from the inlet manifold 4 to the outlet manifold 6 without deviating from a longitudinal axis between its connection point with the inlet manifold 4 and its connection point with the outlet manifold 6.

[0006] The inlet and outlet manifolds 4, 6 and tube matrix 10 form a conduit for the passage of a first fluid through the heat exchanger 2. Accordingly, the first fluid flows into the heat exchanger 2 via the inlet manifold 4, passes through the tubes 8 of the tube matrix 10 and exits the heat exchanger 2 via the outlet manifold 6.

[0007] A second fluid flows over exterior surfaces of the tubes 8 of the tube matrix 10. The first and second fluids have different temperatures and therefore heat is transferred between the first and second fluids.

[0008] Figure 3 shows a simulated stress distribution for the heat exchanger 2 under large thermal and pressure loads. In this simulation, the ends of the inlet and outlet manifolds 4, 6 are assumed to have a fixed position.

[0009] As shown in Figure 3, the heat exchanger 2 experiences large stresses throughout as a result of thermal expansion of the inlet and outlet manifolds 4, 6 and the tubes 8 of the tube matrix 10. Increased loads are seen across those tubes 8 which are located towards the ends of the inlet and outlet manifolds 4, 6 due to the fixed position of the inlet and outlet manifolds 4, 6 at these locations.

[0010] Various tube matrix geometries have been proposed to reduce the stress experienced by heat exchangers under large thermal and pressure loads.

[0011] For example, Figures 4 and 5 show a heat exchanger 102 which has a tube matrix 110 which is formed of two portions 110a, 110b comprising U-shaped tubes

108. Each U-shaped portion 110a, 110b is connected at one end to the inlet manifold 104 and at the other end to the outlet manifold 106. The U-shaped portions 110a, 110b extend in opposite directions from the inlet and outlet manifolds 104, 106 to form an oval.

[0012] Figure 6 shows a simulated stress distribution for the U-shaped heat exchanger 102 under large thermal and pressure loads. As can be seen, the stress levels are far reduced for the tube matrix 102, since the U-shaped tubes 108 are not constrained by the inlet and outlet manifolds 104, 106. Accordingly, the U-shaped heat exchanger 102 is insensitive to the displacement constraints.

[0013] However, the U-shaped heat exchanger 102 requires more space and is heavier than the straight tube matrix 2.

[0014] Figures 7 and 8 show another example of a known heat exchanger 202. The heat exchanger 202 has an S-shaped tube matrix 210, with the tubes 208 of the tube matrix 210 following a serpentine path between the inlet manifold 204 and the outlet manifold 206.

[0015] Specifically, the tubes 208 of the S-shaped tube matrix 210 comprise first and second straight portions 212a, 212b adjacent the inlet and outlet manifolds 204, 206 respectively, and first and second curved portions 214a, 214b disposed between the first and second straight portions 212a, 212b. The first and second curved portions 214a, 214b deviate in opposite directions from the axis of the first and second straight portions 212a, 212b in a plane defined by the longitudinal axes of the inlet and outlet manifolds 204, 206 to form the S-shape.

[0016] The S-shaped nature of the tube matrix 210 acts to reduce the thermal stress placed on the heat exchanger 202, without considerably increasing the size and weight of the heat exchanger.

[0017] However, as shown in Figure 9, the gap between adjacent tubes 208 is reduced over the first and second curved portions 214a, 214b of the S-shaped tube matrix 210. Consequently, the tubes 208 must be spaced further from one another at the inlet and outlet manifolds 204, 206 in order to prevent the tubes 208 from contacting one another. This reduces the number of tubes 208 in the tube matrix 210 for a fixed size heat exchanger 202 or increases the size of the heat exchanger 202 for a fixed number of tubes 208. Furthermore, the curved portions 214a, 214b increase the complexity of the manufacturing process, thus increasing the cost of the heat exchanger.

[0018] Further tube matrix geometries are known which use tubes with additional curved portions; for example, see US Patent No. 5,058,663. However, although these matrices may reduce thermal stress, they exacerbate the reduction in the gap between the tubes and the increased complexity and cost of manufacturing.

[0019] Accordingly, it is desirable to provide a heat exchanger with a tube matrix which overcomes some or all of the problems described above.

[0020] In accordance with a first aspect of the invention

there is provided a heat exchanger comprising: an inlet manifold; an outlet manifold; and a tube matrix comprising a plurality of tubes, each tube being fixedly connected at one end to the inlet manifold and at the other end to the outlet manifold; wherein each tube extends generally along a longitudinal axis defined between the connection of the tube with the inlet manifold and the connection of the tube with the outlet manifold; and wherein a single portion of each tube is offset to one side of the longitudinal axis.

[0021] The tubes may be fixedly connected between the inlet manifold and outlet manifold independently from each other.

[0022] The tubes may each be separated from an adjacent tube by a substantially similar gap at corresponding portions along the longitudinal axis.

[0023] The tubes may be generally C-shaped.

[0024] The offset portion may comprise a curved portion which curves away from the longitudinal axis.

[0025] The curved portion may have a constant curvature.

[0026] The offset portion may comprise a straight portion and pair of angled portions which offset the straight portion from the longitudinal axis.

[0027] The offset portion may be offset in a plane defined by a longitudinal axis of the inlet and outlet manifolds.

[0028] The tubes may be arranged in one or more rows in a plane defined by a longitudinal axis of the inlet and outlet manifolds.

[0029] A plurality of rows may be disposed side-by-side to form columns.

[0030] A minimum gap between adjacent tubes over the offset portion may be greater than 2/3 of the maximum gap between adjacent tubes at the inlet and outlet manifolds.

[0031] The offset portion may be 30-70% of the total length of the tube.

[0032] The offset portion may allow deformation of the tubes during thermal expansion, thereby reducing thermal stress experienced by the heat exchanger. Furthermore, the offset portion does not considerably affect the gaps between adjacent tubes. Consequently, the size of the heat exchanger is not significantly increased, if at all. This may make the heat exchanger of the present invention particularly suitable for installation in an aero-engine, where space is at a premium.

[0033] In addition, the manufacturing process for the single offset portion is simple and requires only one bending process. Accordingly, the manufacturing costs are minimised.

[0034] The present invention results in a high efficiency, high temperature, high pressure, lightweight and compact heat exchanger design.

[0035] According to another aspect of the invention there is provided a heat exchanger comprising an inlet manifold, an outlet manifold, and a tube array comprising a plurality of tubes, wherein the tube array generally ex-

tends along a longitudinal axis between the inlet manifold and the outlet manifold, and wherein the tube array comprises an offset portion that is offset from the longitudinal axis. There may be a single offset portion. Each tube may comprise an offset portion that is offset to the same side. The tube array may comprise at least one longitudinally extending portion and an offset portion. The tube array may comprise first and second longitudinally extending portions coupled to the inlet and outlet manifolds respectively, with the offset portion disposed between the first and second longitudinally extending portions. The single offset portion may be directly between the first and second longitudinally extending portions. The offset portion may be generally C-shaped.

[0036] For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made by way of example to the accompanying drawings, in which:

Figure 1 is a cross-sectional view of a conventional heat exchanger having a straight tube matrix in a plane defined by a longitudinal axis of the tubes;

Figure 2 is a cross-sectional view of the heat exchanger of Figure 1 in a plane defined by a longitudinal axis of the manifolds;

Figure 3 is a simulated stress distribution for the heat exchanger of Figures 1 and 2;

Figure 4 is a cross-sectional view through a conventional heat exchanger having a U-shape tube matrix in a plane defined by a longitudinal axis of the tubes;

Figure 5 is a cross-sectional view of the heat exchanger of Figure 5 in a plane defined by a longitudinal axis of the manifolds;

Figure 6 is a simulated stress distribution for the heat exchanger of Figures 4 and 5;

Figure 7 is a cross-sectional view through a conventional heat exchanger having a S-shaped matrix in a plane defined by a longitudinal axis of the tubes;

Figure 8 is a cross-sectional view of the heat exchanger of Figure 7 in a plane defined by a longitudinal axis of the manifolds;

Figure 9 is an enlarged view of a portion of Figure 8;

Figure 10 is a cross-sectional view through an embodiment of a heat exchanger in a plane defined by a longitudinal axis of the manifolds;

Figure 11 is an enlarged view of a portion of Figure 10;

Figure 12 is a simulated stress distribution for the heat exchanger of Figure 11;

Figure 13 is a comparative graph of thermal and thermo-mechanical stress for conventional heat exchangers and the heat exchanger of the present invention; and

Figure 14 is a cross-sectional view through another embodiment of a heat exchanger in a plane defined by a longitudinal axis of the manifolds.

Detailed Description

[0037] Figure 10 shows a heat exchanger 302 according to an embodiment of the invention. The heat exchanger 302 comprises an inlet manifold 304 and an outlet manifold 306. The inlet and outlet manifolds 304, 306 are fluidically coupled by a plurality of tubes 308 which together form a tube matrix 310. The tubes 308 of the tube matrix 310 are fixedly connected, for example, by welding, at one end to the inlet manifold 304 and are coupled at the other end to the outlet manifold 306.

[0038] A plurality of the tubes 308 are aligned in a plane defined by the longitudinal axes of the inlet and outlet manifolds 304, 306 to form a row, and several rows are disposed side-by-side to form columns of the tube matrix 310 arranged along a common plane.

[0039] Each tube 308 comprises first and second straight portions 312a, 312b adjacent the inlet and outlet manifolds 304, 306 respectively, and a single curved portion 314 disposed between the first and second straight portions 312a, 312b. The curved portion 314 deviates from a longitudinal axis of the tube 308 between its connection point with the inlet manifold 304 and its connection point with the outlet manifold 306. As shown in Figure 10, the curved portion 314 is offset in the plane defined by the longitudinal axes of the inlet and outlet manifolds 304, 306. The size of the offset from this longitudinal axis is defined as the offset length. The curved portion 314 follows a single curvature between the first straight portion 312a and the second straight portion 312b. Accordingly, the tube matrix 310 is generally C-shaped. Further, each of the tubes is separated from adjacent tubes by a similar gap at corresponding portions along the length of the tubes and are held between the manifolds independently of each other in the present embodiment, although supporting members may be incorporated between each of the tubes to help maintain a common gap therebetween.

[0040] The inlet and outlet manifolds 304, 306 and tube matrix 310 form a conduit for the passage of a first fluid through the heat exchanger 302. Accordingly, the first fluid flows into the heat exchanger 302 via the inlet manifold 304, passes through the tubes 308 of the tube matrix 310 and exits the heat exchanger 302 via the outlet manifold 306.

[0041] As shown in Figure 11, whilst the gap between

adjacent tubes 308 is reduced over the curved portion 314, the size of this reduction is minimised. Consequently, the spacing between the tubes 308 at the inlet and outlet manifolds 304, 306 is not significantly effected.

[0042] The curved portion 314 absorbs thermal expansion by elastically deforming. Thus, the curved portion 314 reduces the thermal stress experienced by the heat exchanger 302.

[0043] The geometry of the tube matrix 310 is optimised in order to minimise the thermal stress experienced by the heat exchanger 302. Accordingly, a design of experiment (DOE) analysis was performed using the Central Composite Design method and sensitivity analysis and response surface analysis was performed using the results of the DOE analysis.

[0044] From the results of the sensitivity analysis it was shown that the offset length and the length of the straight portions 312a, 312b (straight length) were found to be the most significant factors in reducing the thermal stress.

[0045] The response surface analysis was performed in order to find the optimum values for the offset length, the straight length and the curvature of the curved portion 314 which minimise the thermal stress, whilst maintaining a minimum gap between adjacent tubes over the curved portion 314 of 2/3 the maximum gap at the inlet and outlet manifolds 304, 306.

[0046] The result of this process showed that the thermal stress at the ends of the heat exchanger 302 (i.e. adjacent the inlet and outlet manifolds 304, 306) decreases as the straight length and the offset length increase. Furthermore, the thermal stress at the centre of the heat exchanger 302 (i.e. midway between the inlet and outlet manifolds 304, 306) was shown to decrease with increasing offset length and decreasing straight length.

[0047] The thermal stress was found to be at a minimum when the:

- inside diameter of the tubes 308 is approximately 0.9 times the outside diameter;
- the length of the tubes 308 is approximately 107 times the outside diameter;
- the offset length is approximately 13.3 times the outside diameter;
- the length of the straight portions 312a, 312b is approximately 23.3 times the outside diameter; and
- the radius of curvature between the straight portions 312a, 312b and the curved portion 314 is approximately 13.3 times the outside diameter.

[0048] Accordingly, the dimensions of the heat exchanger are preferably as follows:

- the diameter of the tubes 308 is approximately 1.0 to 5.0mm;
- the length of the tubes 308 is approximately 100-500mm;
- the length of the curved portion 314 is approximately 30-70% of the total length; and

- the offset length is approximately 10-100mm.

[0049] Figure 12 shows a simulated stress distribution for the heat exchanger 302 under large thermal and pressure loads. As shown, the heat exchanger 302 experiences larger stresses at its centre over the portion 314 as a result of thermal expansion and deformation of the tubes 308. However, as shown in Figure 13, the stress experienced at the centre and at the ends of the heat exchanger 302 is far lower than for the straight tube heat exchanger 2, and comparable to the U-shaped heat exchanger 102.

[0050] Figure 14 shows a heat exchanger 402 according to another embodiment of the invention. The heat exchanger 402 comprises an inlet manifold 404 and an outlet manifold 406. The inlet and outlet manifolds 404, 406 are fluidically coupled by a plurality of tubes 408 which together form a tube matrix 410. The tubes 408 of the tube matrix 410 are coupled at one end to the inlet manifold 404 and are coupled at the other end to the outlet manifold 406.

[0051] A plurality of the tubes 408 are aligned in a plane of the longitudinal axes of the inlet and outlet manifolds 404, 406 to form a row, and several rows are disposed side-by-side to form columns of the tube matrix 410.

[0052] Each tube 408 comprises first and second straight portions 412a, 412b adjacent the inlet and outlet manifolds 404, 406 respectively, and a single offset portion 416 disposed between the first and second straight portions 412a, 412b. The offset portion 416 deviates from a longitudinal axis of the tube 408 between its connection point with the inlet manifold 404 and its connection point with the outlet manifold 406. As shown in Figure 14, the curved portion 414 is offset in a plane of a longitudinal axis of the inlet and outlet manifolds 404, 406. The size of the offset from this longitudinal axis is defined as the offset length. The offset portion 416 comprises a third straight portion 418 which is connected to the first and second straight portions 412a, 412b by first and second angled portions 420a, 420b. The tubes 408 are curved at the intersections between the first/second straight portions 412a, 412b and the first/second angled portions 420a, 420b, and between the first and second angled portions 420a, 420b and the third straight portion 418. The third straight portion 418 is arranged such that it is offset from, but parallel with, the first and second straight portions 412a, 412b. Accordingly, the tube matrix 410 is generally C-shaped.

[0053] Again, whilst the gap between adjacent tubes 408 is reduced over the curved intersections of the offset portion 416, the size of this reduction is minimised. Consequently, the spacing between the tubes 408 at the inlet and outlet manifolds 404, 406 is not significantly effected.

[0054] The offset portion 416 absorbs thermal expansion by elastically deforming. Thus, the offset portion 416 reduces the thermal stress experienced by the heat exchanger 402.

[0055] The first and second straight portions and the

offset portion may be integrally formed or may be separate components which are subsequently joined together to form the tube 308,408.

[0056] It should be noted that the tubes need not have a circular cross-section and could have any other cross-section, so long as they provide a conduit for the passage of a fluid from the inlet manifold to the outlet manifold.

Claims

1. A heat exchanger comprising:

an inlet manifold;
 an outlet manifold; and
 a tube matrix comprising a plurality of tubes, each tube being fixedly connected at one end to the inlet manifold and at the other end to the outlet manifold;
 wherein each tube extends generally along a longitudinal axis defined between the connection of the tube with the inlet manifold and the connection of the tube with the outlet manifold, wherein a single portion of each tube is offset to one side of the longitudinal axis; and wherein the tubes are arranged in one or more rows in a plane defined by a longitudinal axis of the inlet and outlet manifolds and a plurality of rows are disposed side-by-side to form columns.

2. A heat exchanger matrix as claimed in claim 1, wherein the tubes are fixedly connected between the inlet manifold and outlet manifold independently from each other.

3. A heat exchanger matrix as claimed in claims 1 or 2, wherein the tubes are each separated from an adjacent tube by a substantially similar gap at corresponding portions along the longitudinal axis.

4. A heat exchanger as claimed in any of claims 1 to 3, wherein the tubes are generally C-shaped.

5. A heat exchanger as claimed in claim 1 or 4, wherein the offset portion comprises a curved portion which curves away from the longitudinal axis.

6. A heat exchanger as claimed in claim 6, wherein the curved portion has a constant curvature.

7. A heat exchanger as claimed in claim 1 or 4, wherein the offset portion comprises a straight portion and pair of angled portions which offset the straight portion from the longitudinal axis.

8. A heat exchanger as claimed in any preceding claim, wherein the offset portion is offset in a plane defined

by a longitudinal axis of the inlet and outlet manifolds.

9. A heat exchanger as claimed in any preceding claim, wherein a minimum gap between adjacent tubes over the offset portion is greater than $\frac{2}{3}$ of the maximum gap between adjacent tubes at the inlet and outlet manifolds. 5
10. A heat exchanger as claimed in any preceding claim, wherein the offset portion is 30-70% of the total length of the tube. 10

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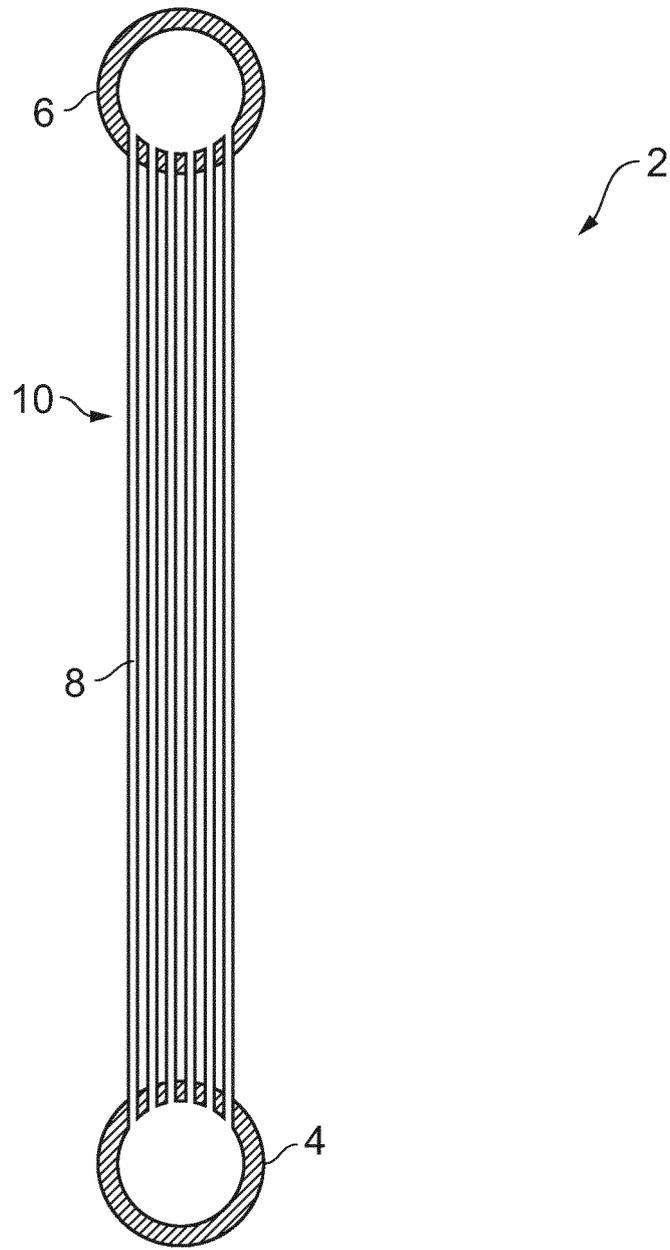


FIG. 1

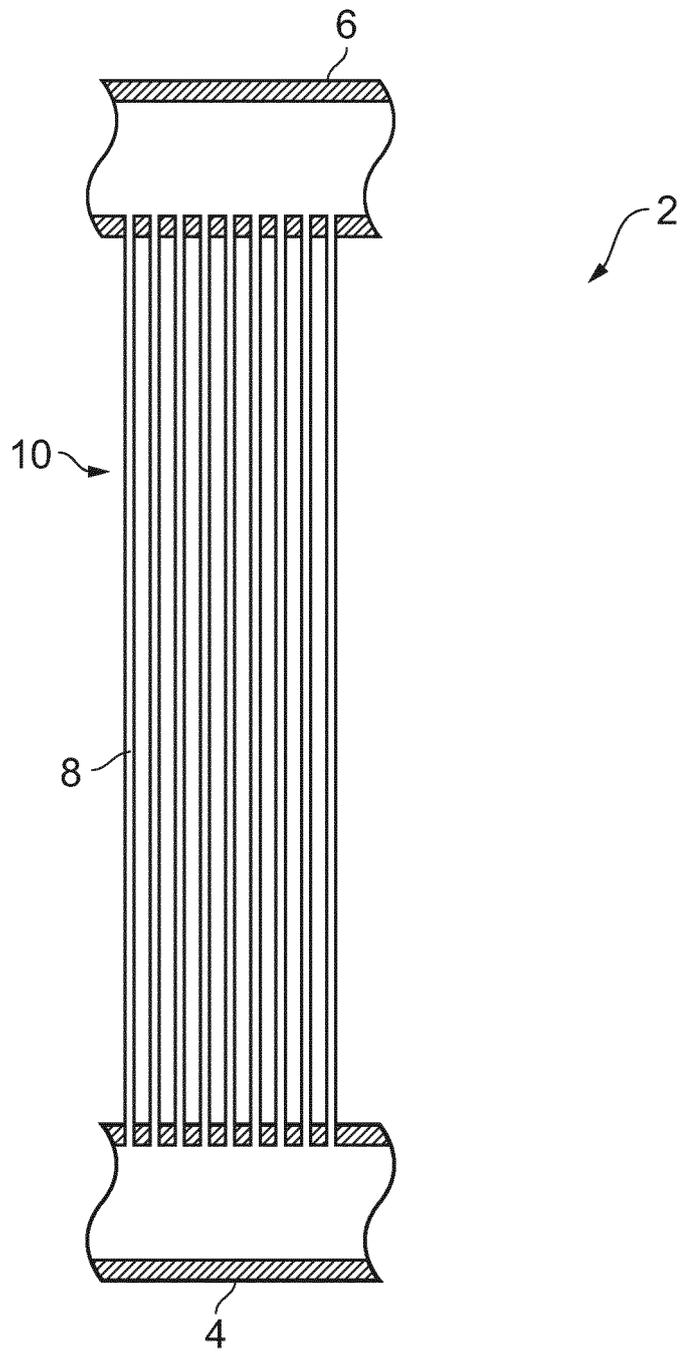


FIG. 2

NODAL SOLUTION
STEP=1
SUB =1
TIME =1
SEQV (AVG)
PowerGraphics
EFACET=1
AVRES=Mat
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SMN =1.398
SMX =3929
XV =-.711218
YV =-.637251
ZV =.296784
DIST =183.756
XF =-.11441
YF =192.057
ZF =79.925
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2620
3056
3493
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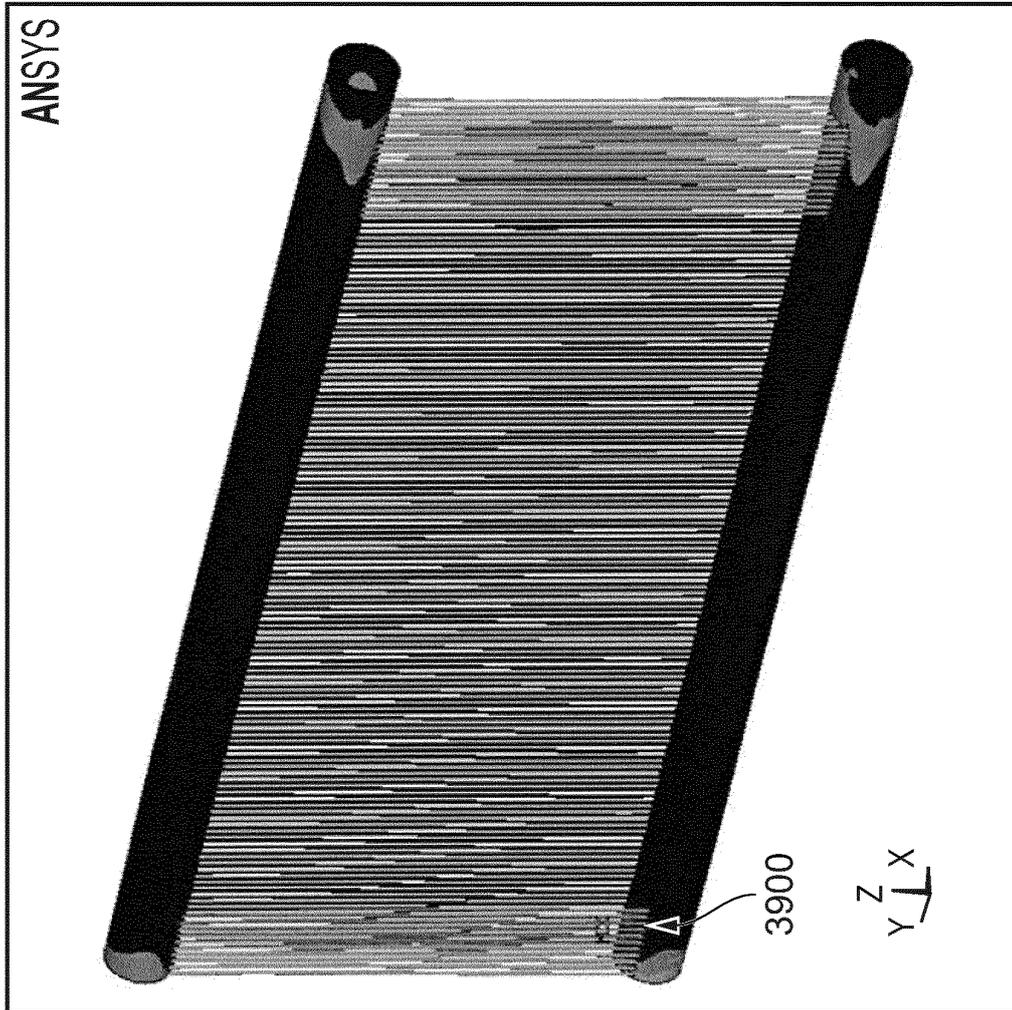


FIG. 3

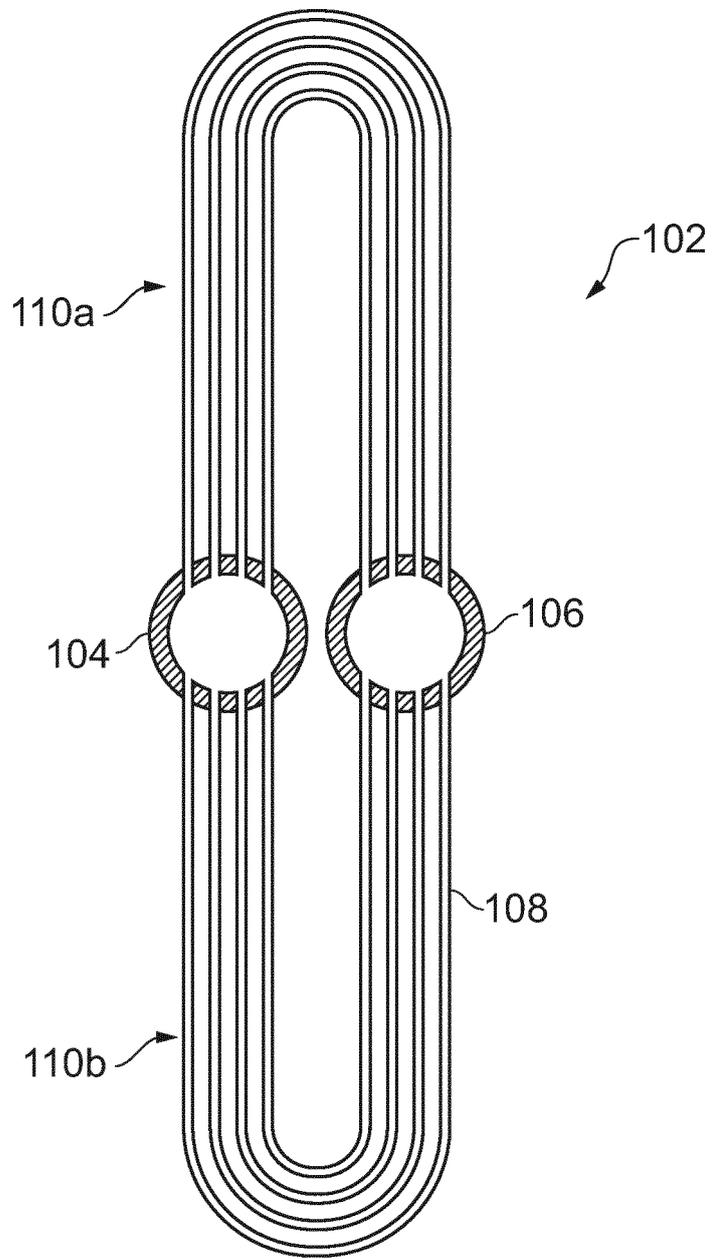


FIG. 4

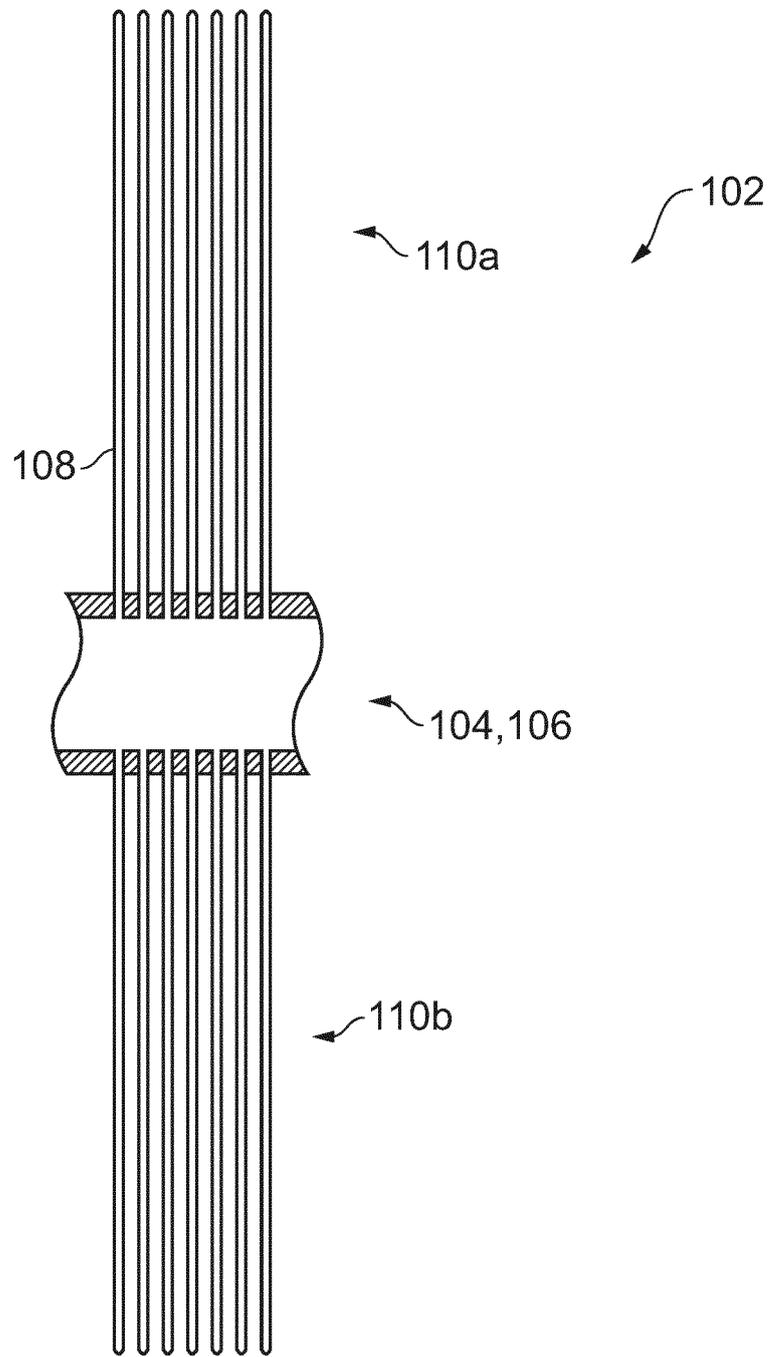


FIG. 5

NODAL SOLUTION

STEP=1
 SUB =1
 TIME =1
 SEQV (AVG)
 PowerGraphics
 EFACET=1
 AVRES=Mat
 DMX =4.12
 SMN =5.174
 SMX =134.101

XV =-.548178
 YV =-.797381
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 XF =-1.123
 YF =176.004
 ZF =50.403
 A-ZS=66.726
 Z-BUFFER

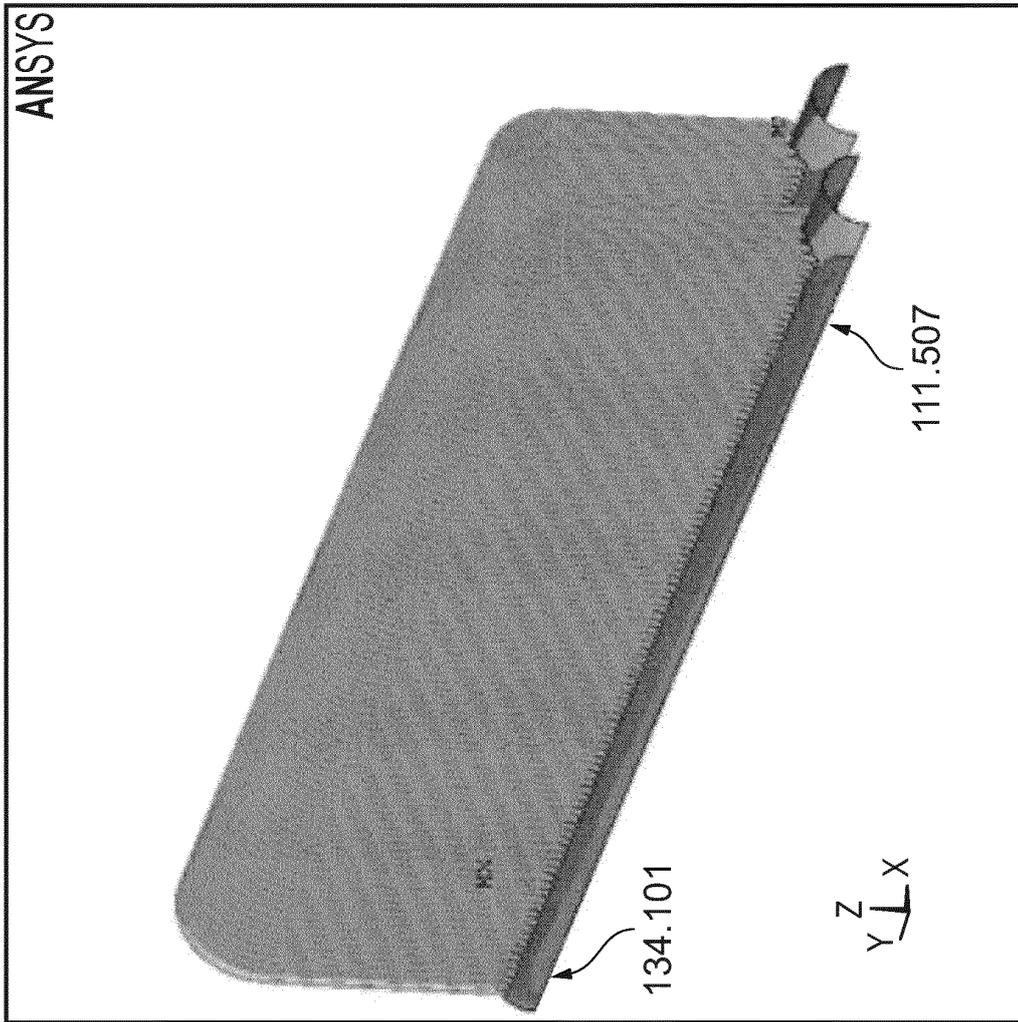
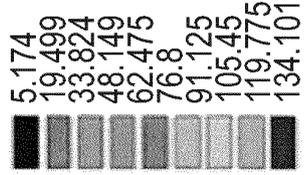


FIG. 6

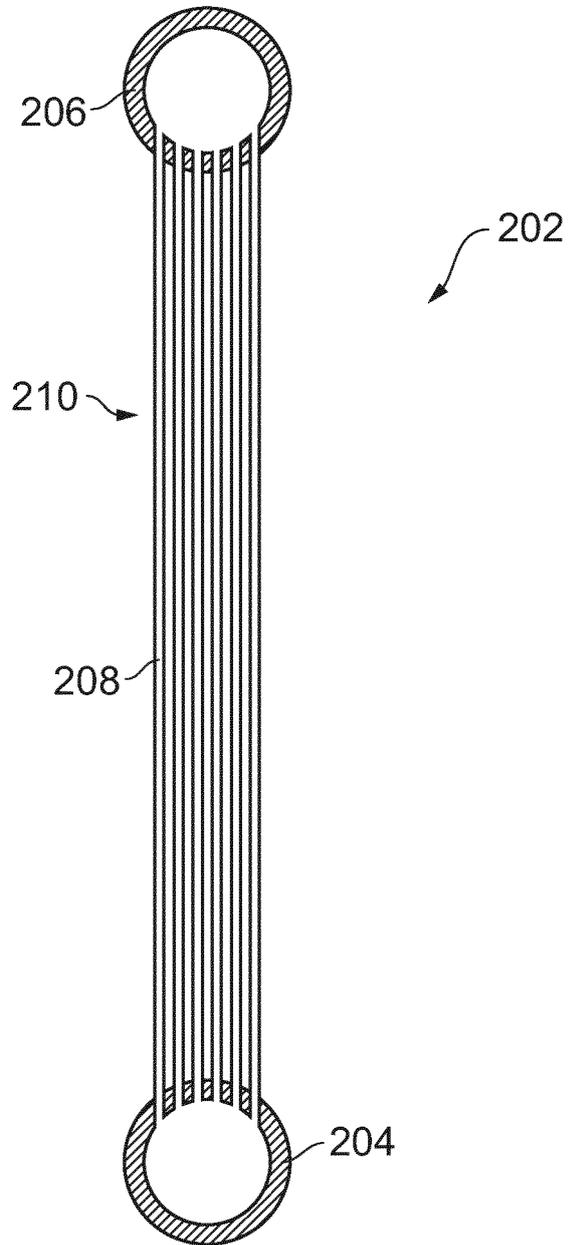


FIG. 7

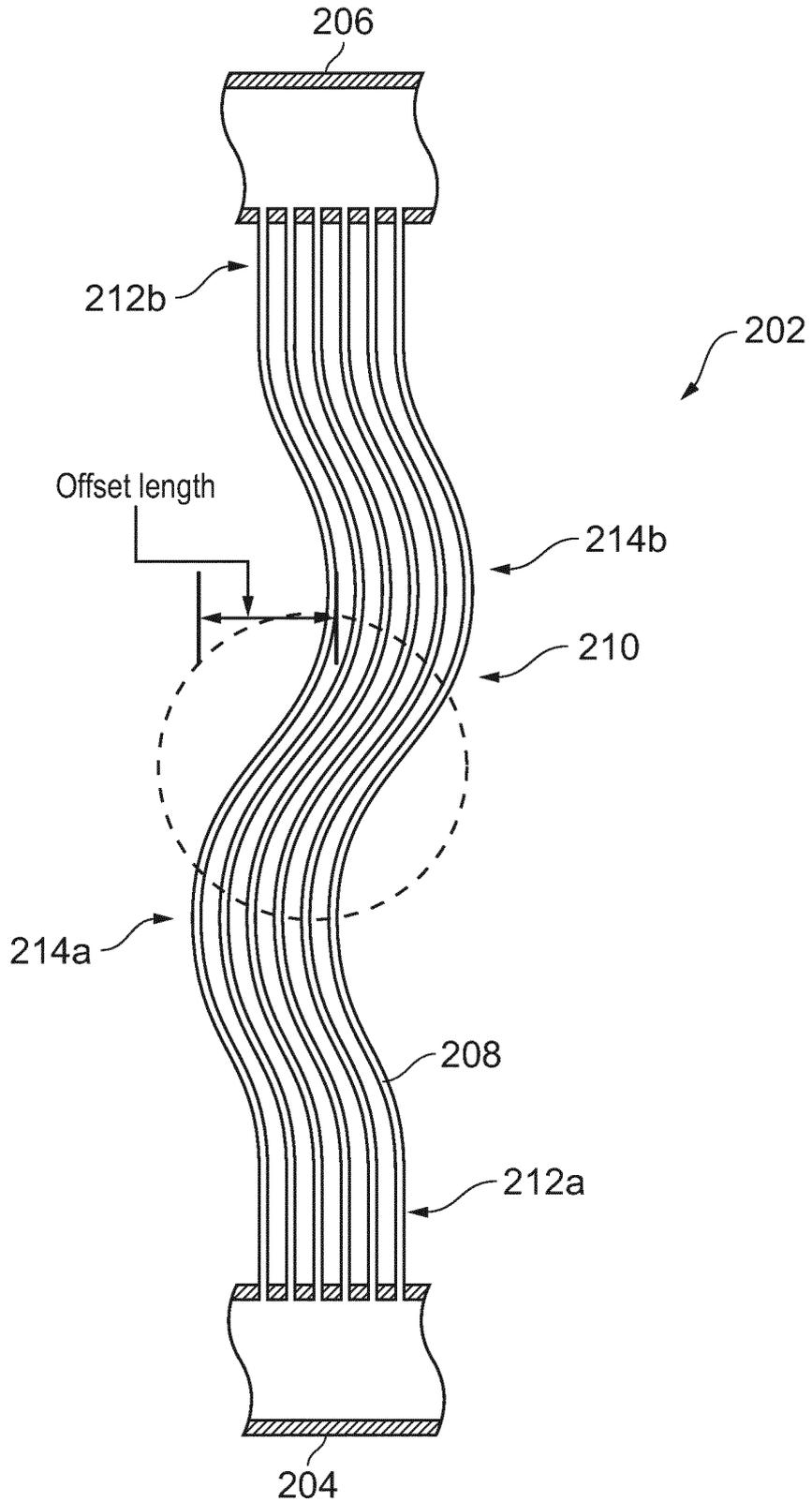


FIG. 8

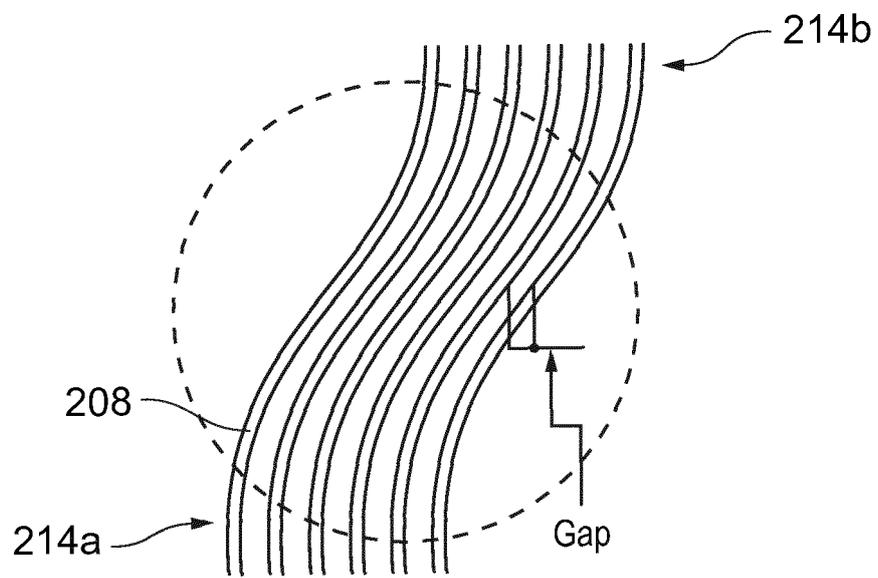


FIG. 9

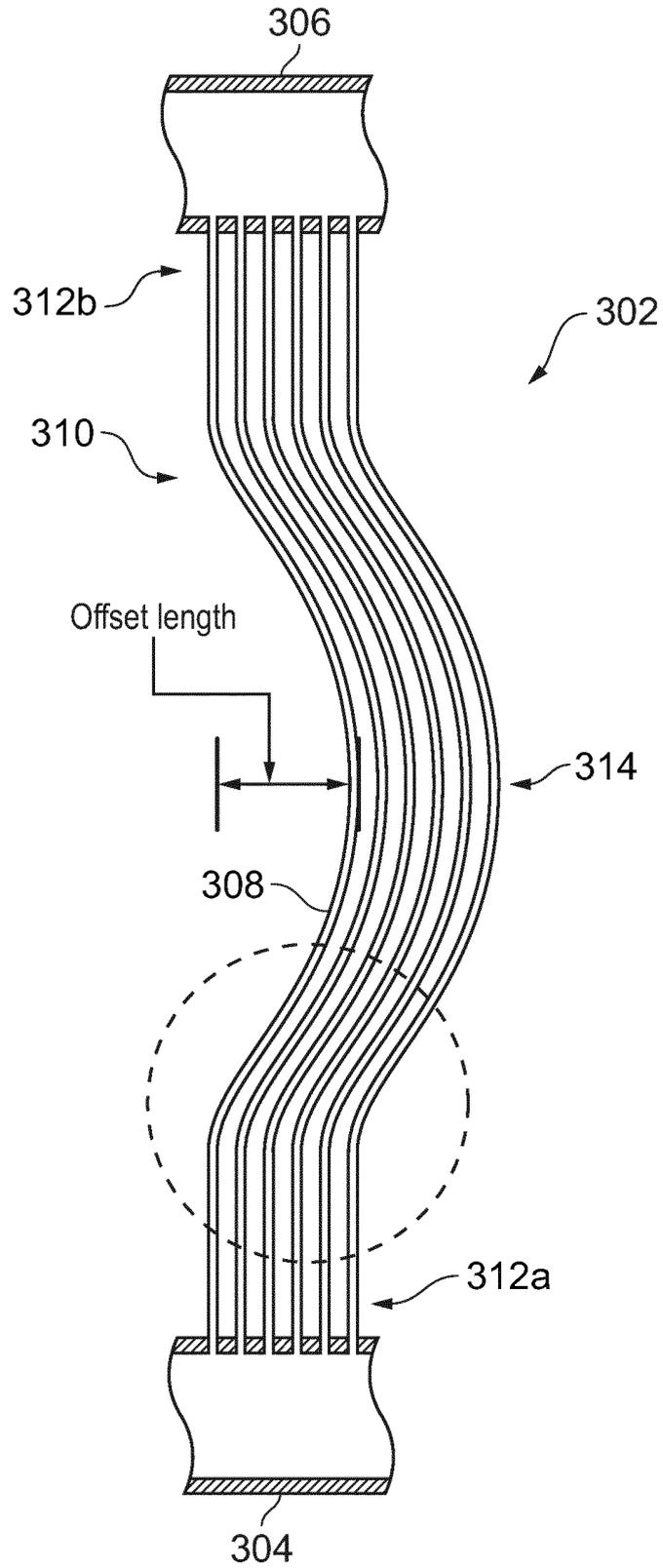


FIG. 10

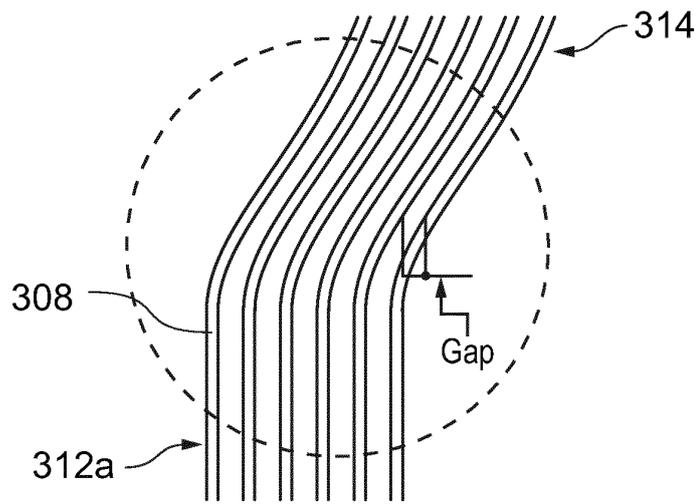


FIG. 11

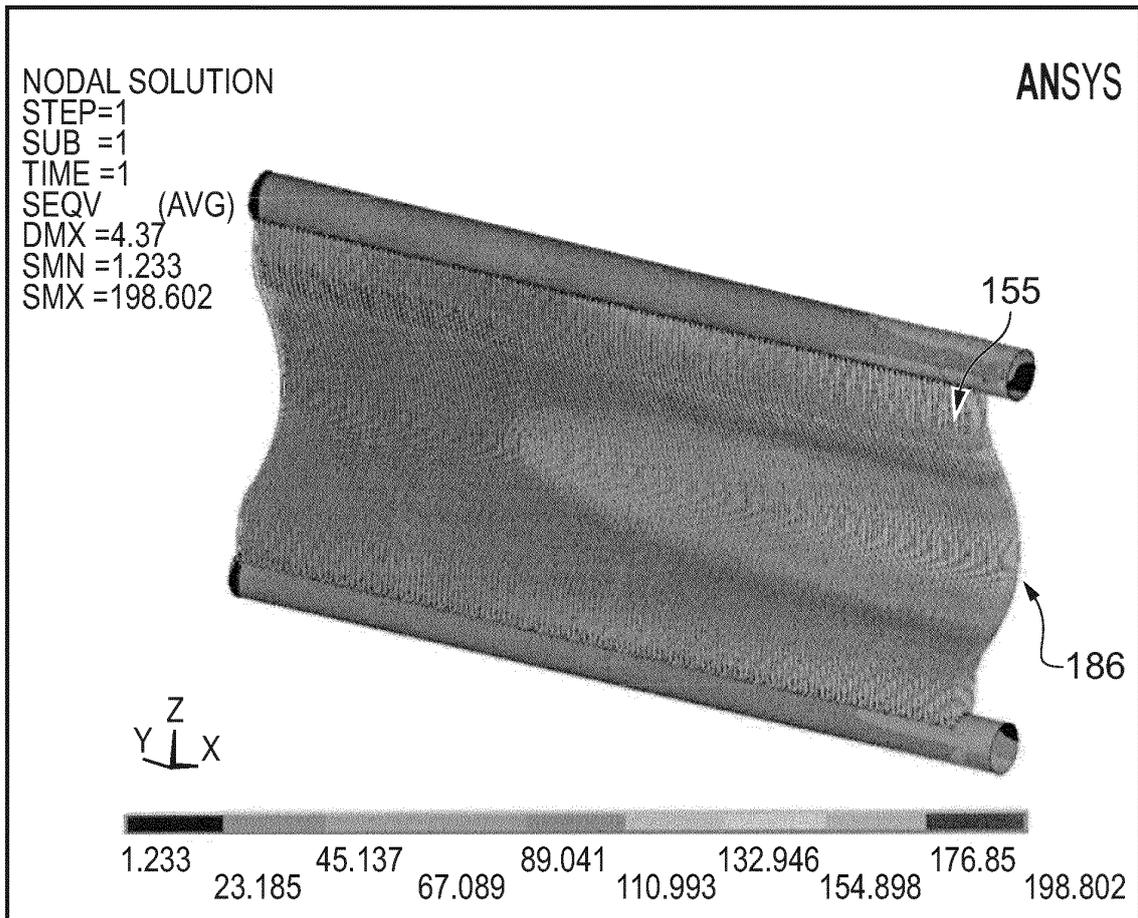


FIG. 12

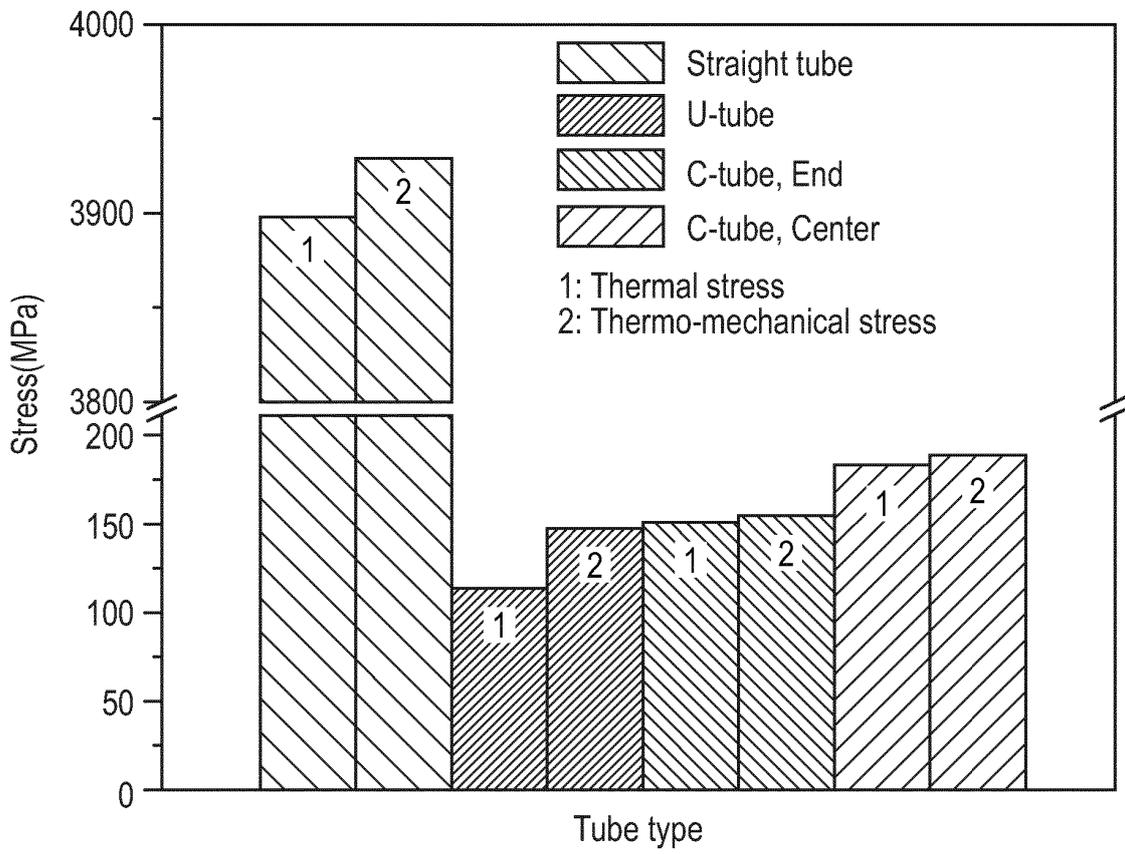


FIG. 13

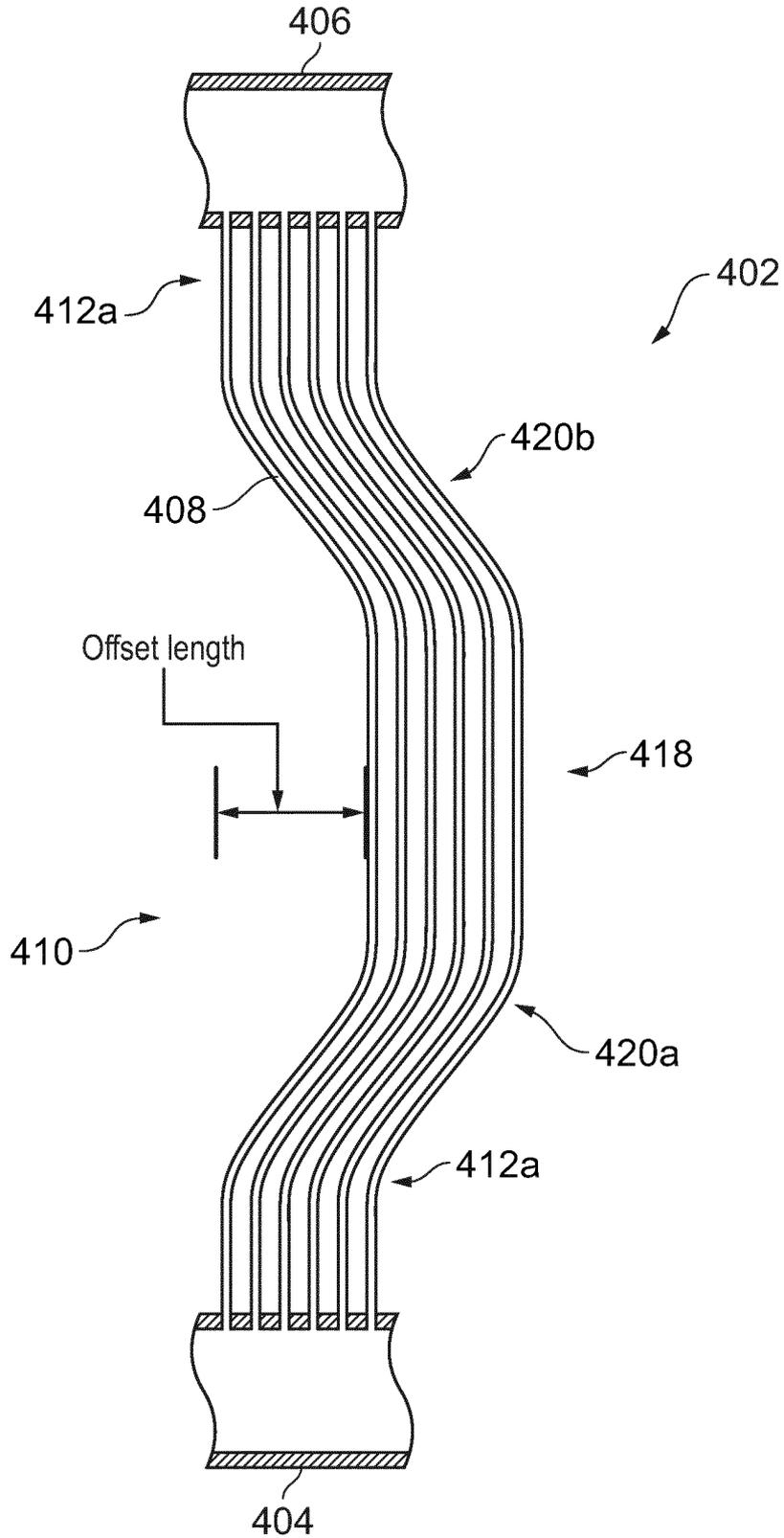


FIG. 14

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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