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Stewart

(54) **U-BEND TUBE COMPRESSION/DISTORTION STABILIZATION SYSTEM (CDSS)**

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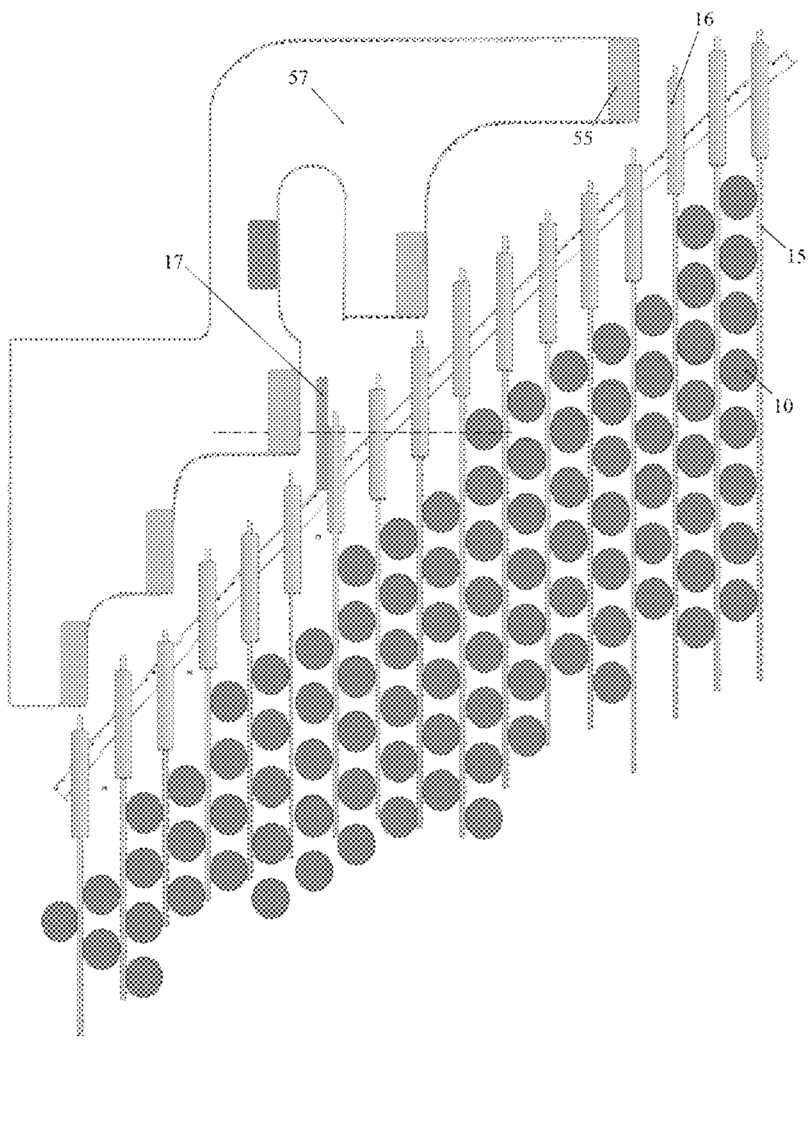
USPC **165/69**; 29/890.03

(57) **ABSTRACT**

This patent discloses and claims a system for providing in-plane stabilization to the tubes of a heat exchanger. The system increases the friction between the tubes and the existing anti-vibration bars by pressing the tube bundle together in the out-of-plane direction. The invention involves a structure that develops forces by reacting either off the inner diameter of the tube bundle wrapper, or off an assembled stressor hoop, which is self-supporting on top of the tube bundle, or involves purposely deforming connecting hoops to bias the anti-vibration bars in a way that the tube U-bend is no longer planar. It imposes a controlled clamping and/or deforming force on the tube bundle, either by direct contact with the outer tubes or indirectly via the existing anti-vibration bar structure.



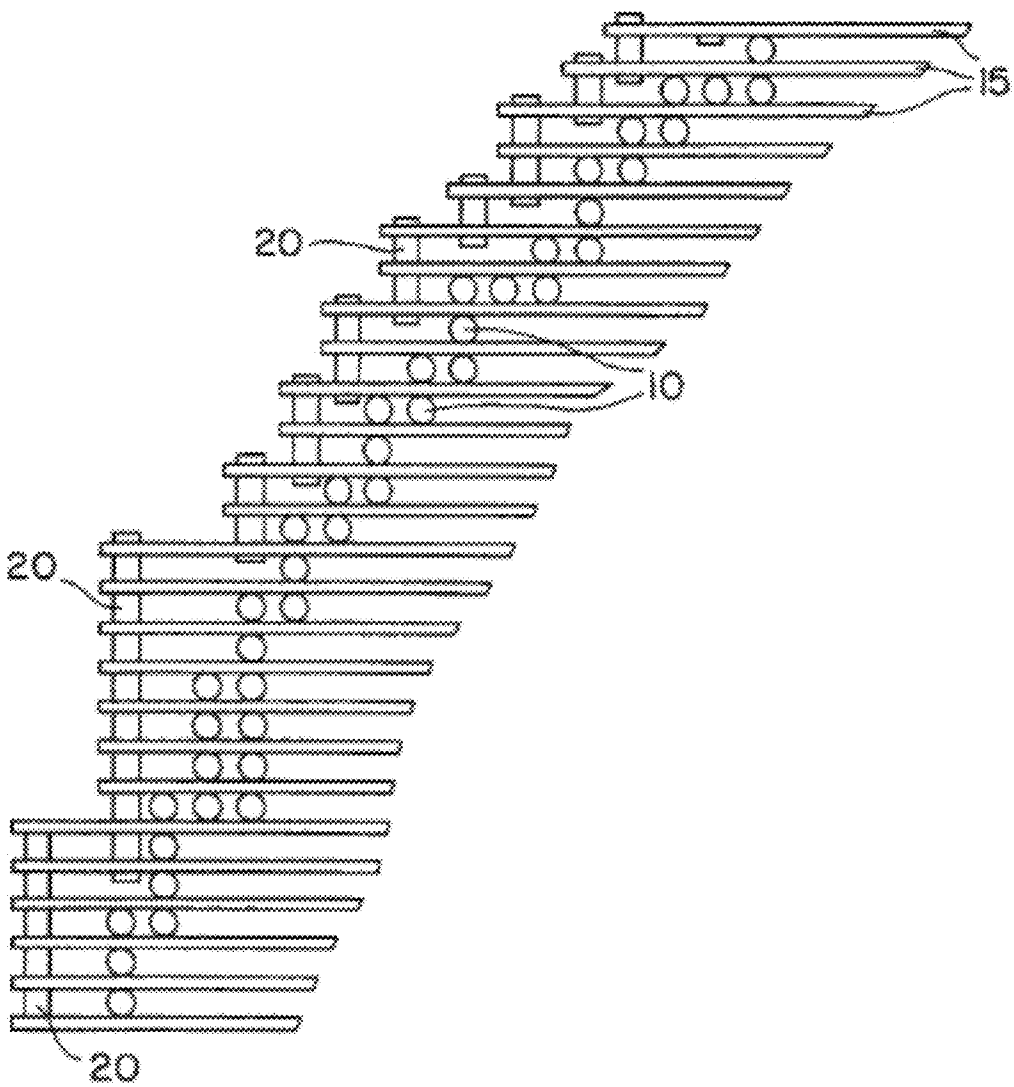


FIG. 1
Prior Art

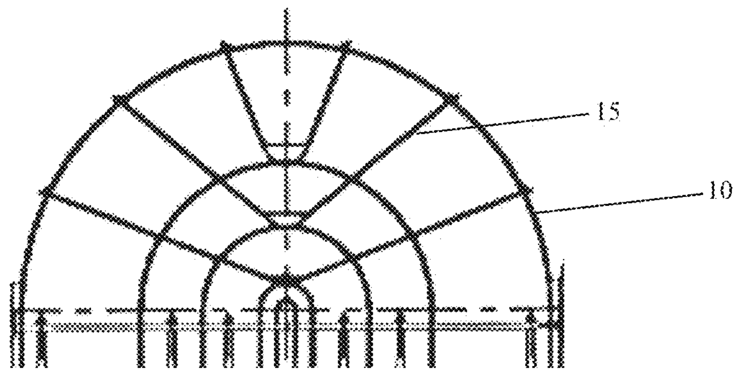


FIG. 2A
Prior Art

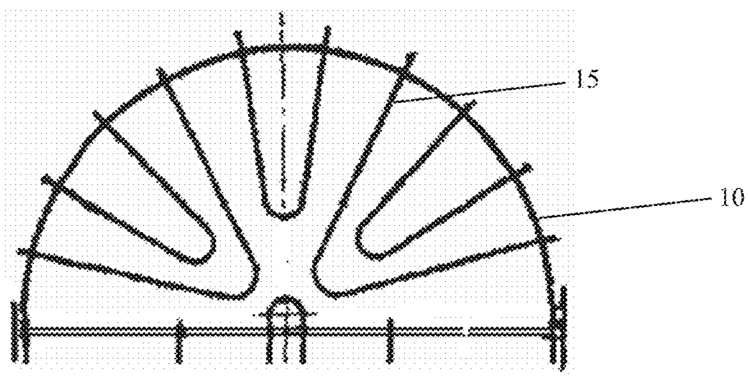


FIG. 2B
Prior Art

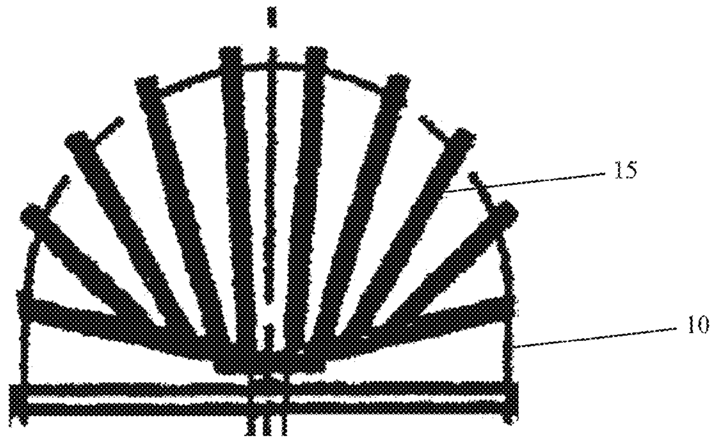


FIG. 2C
Prior Art

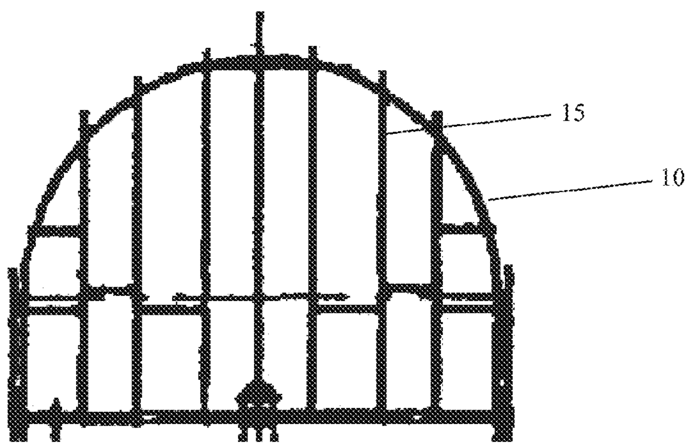


FIG. 2D
Prior Art

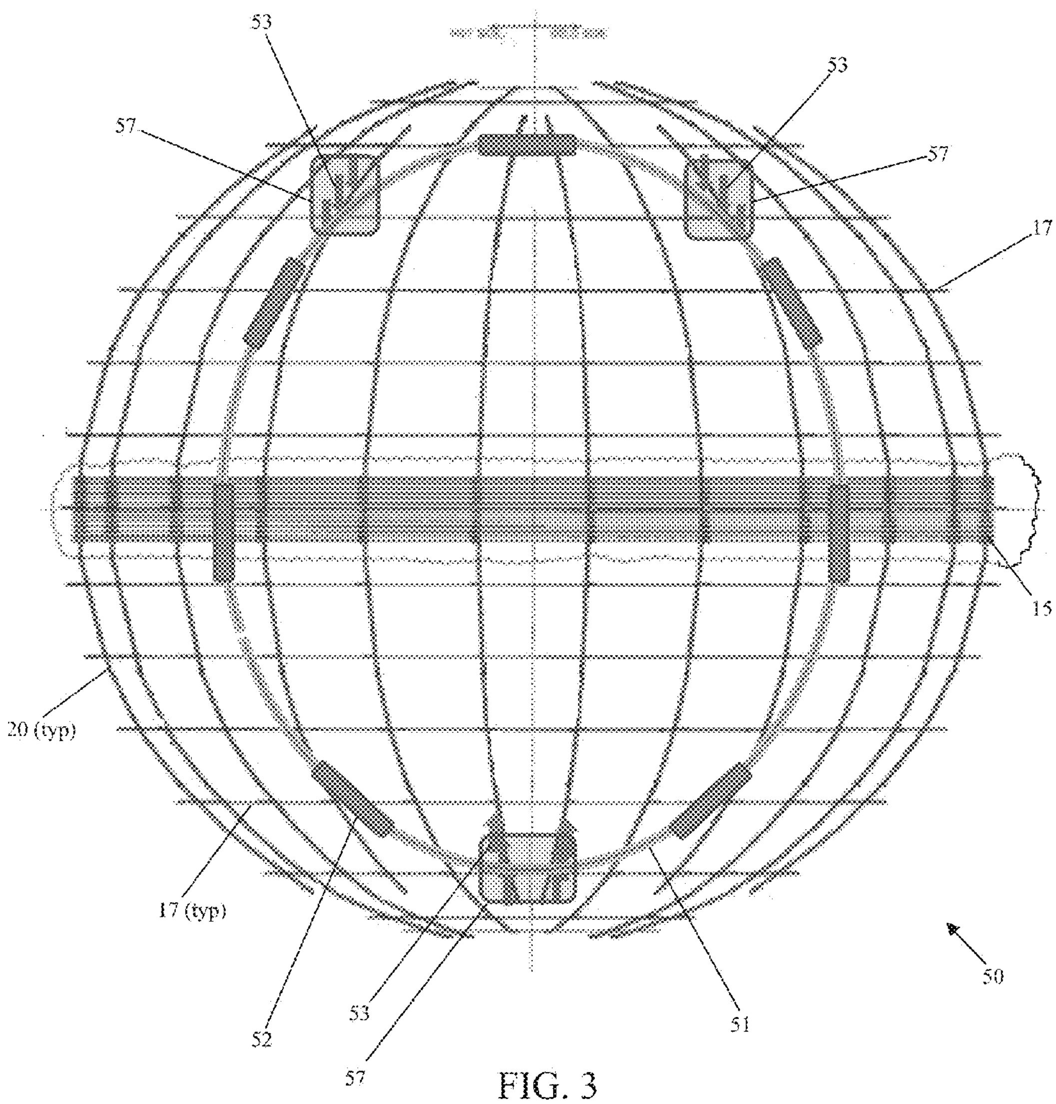


FIG. 3

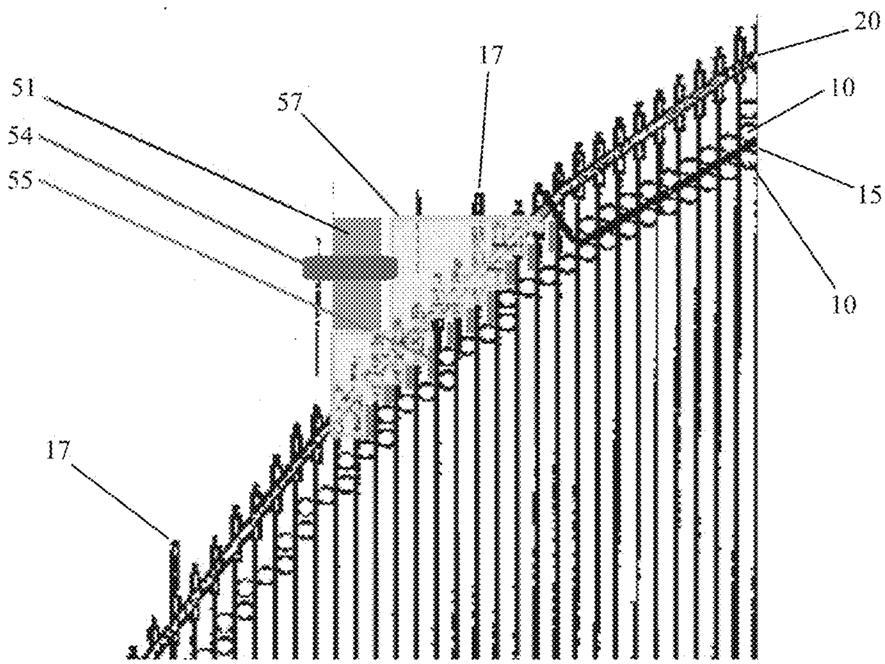


FIG. 4

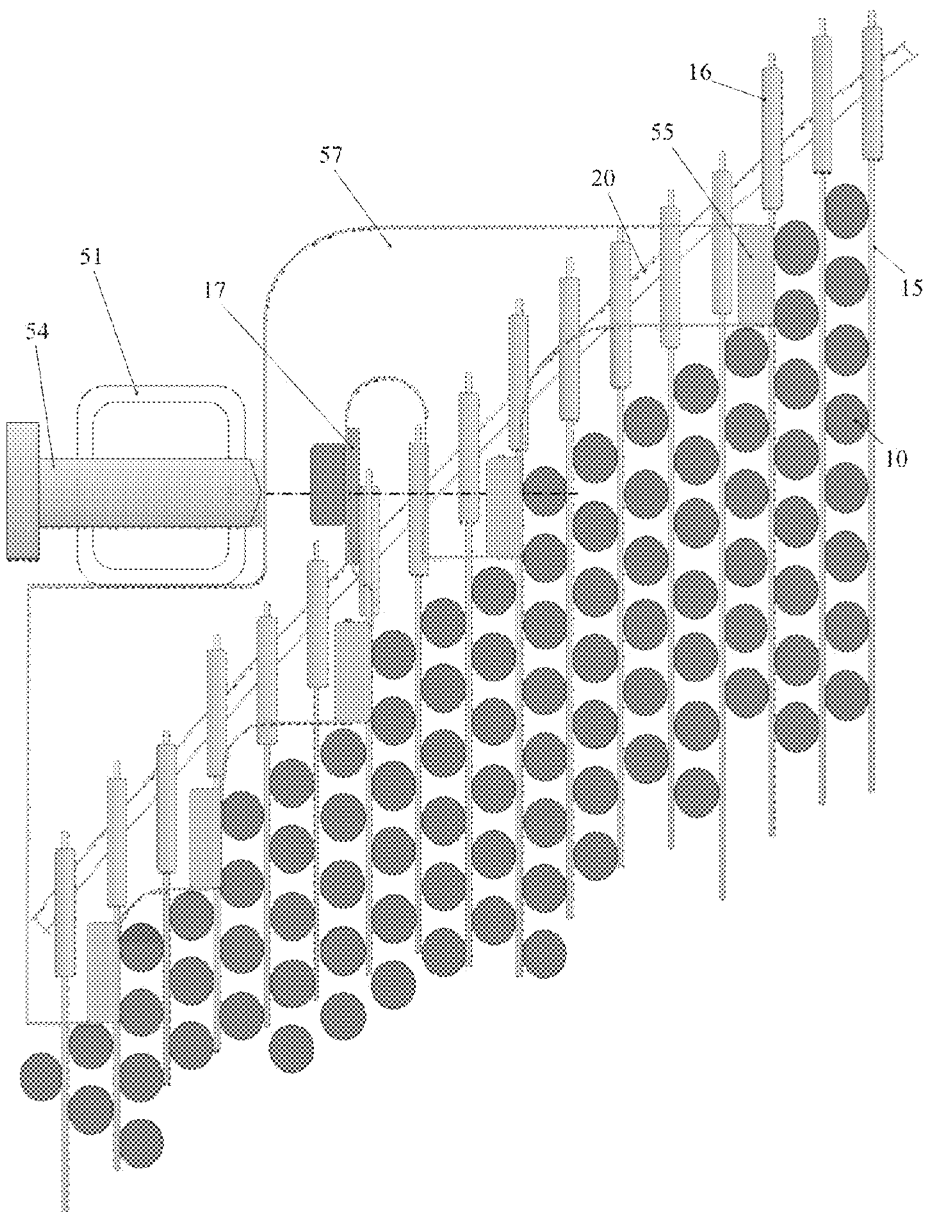


FIG. 5

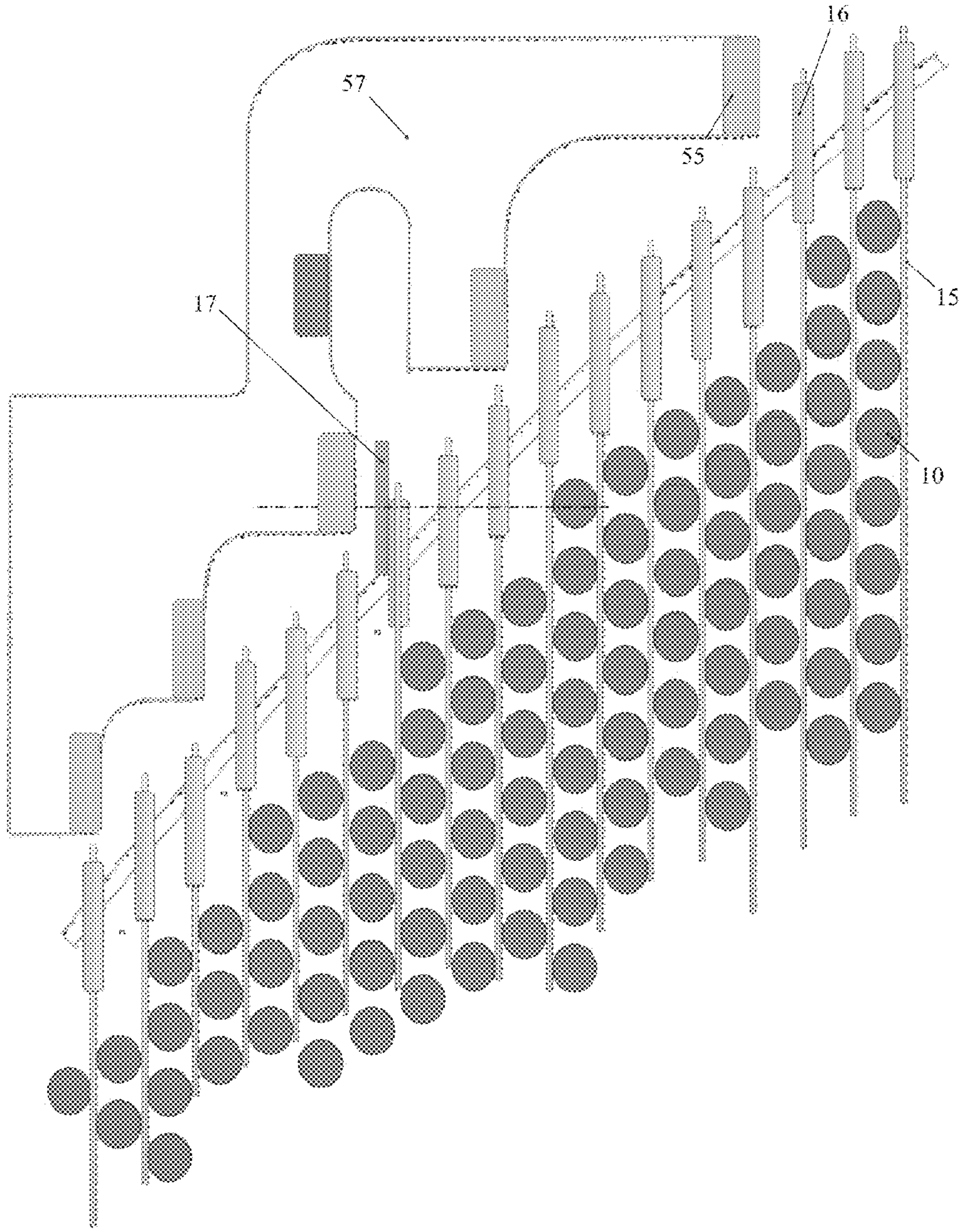


FIG. 6

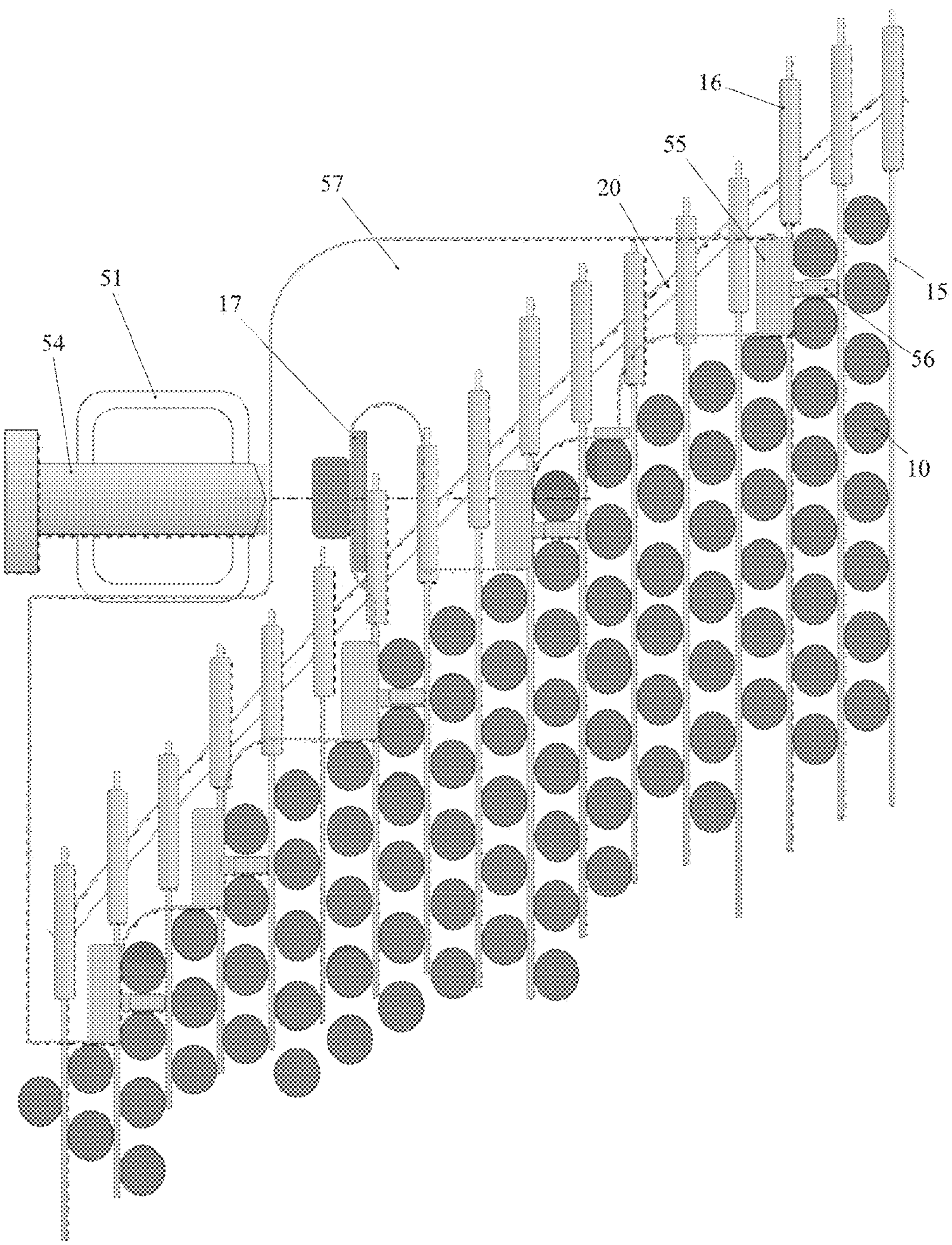


FIG. 7

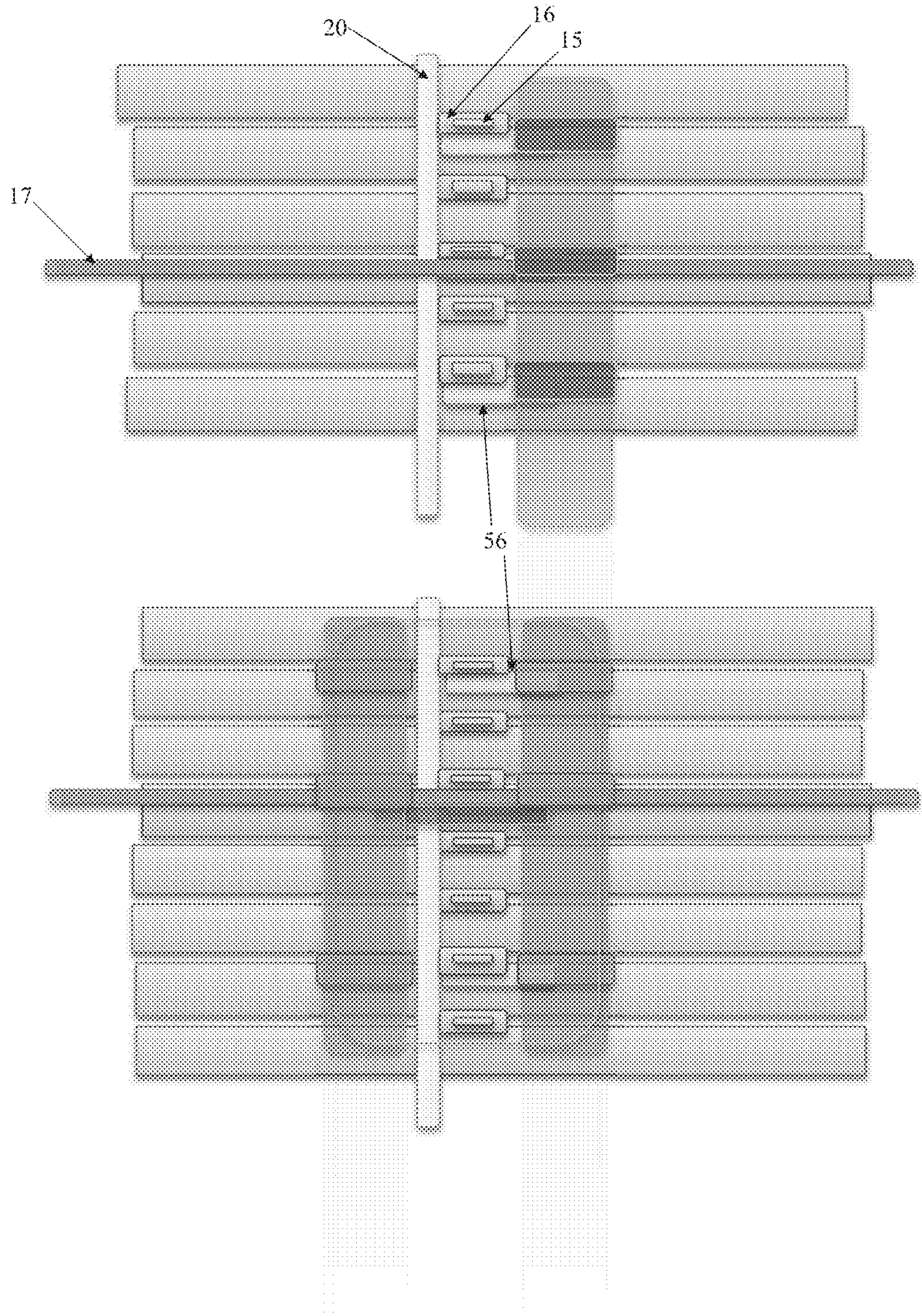


FIG. 8

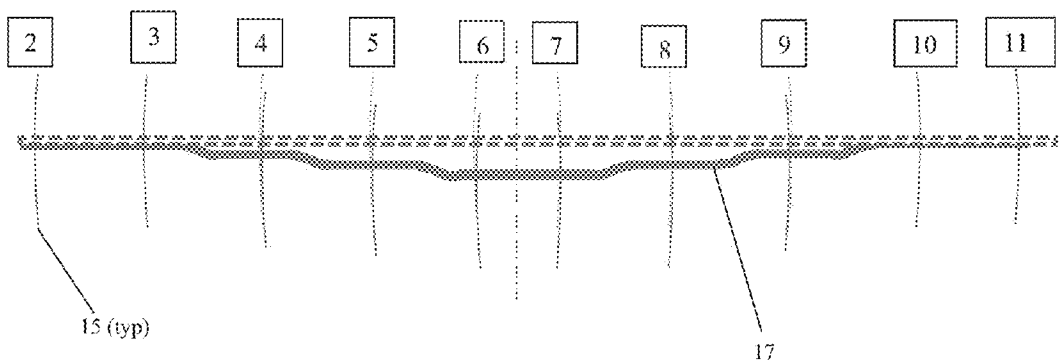


FIG. 9

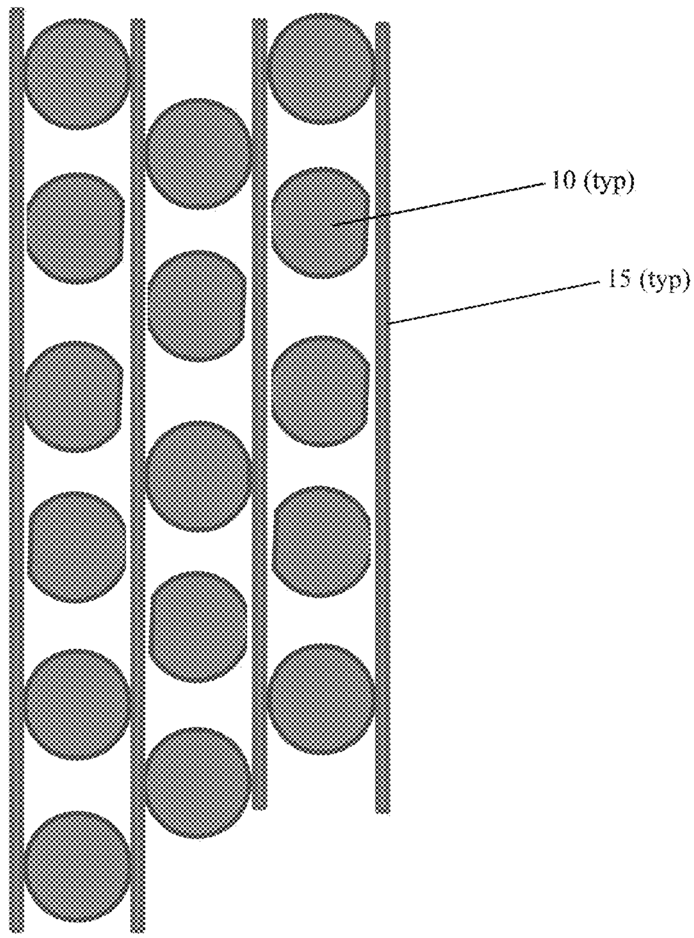


FIG. 10

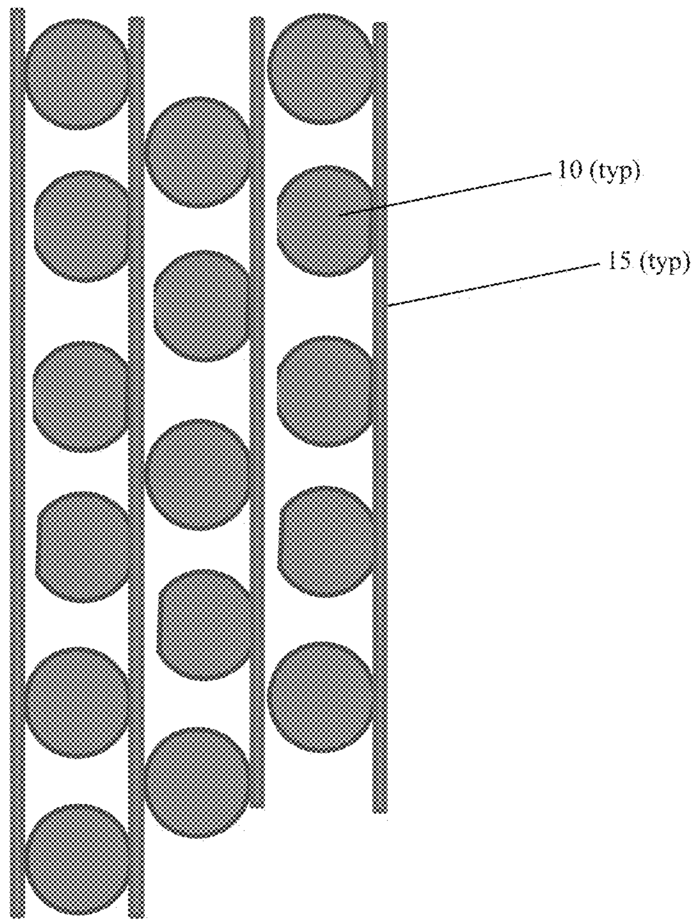


FIG. 11

U-BEND TUBE COMPRESSION/DISTORTION STABILIZATION SYSTEM (CDSS)

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims the benefit of U.S. Provisional Patent Application No. 61/671,636 filed on Jul. 13, 2012, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a stabilization system, and, more particularly, the present invention relates to a system for stabilizing the in-plane flow-induced vibration of U-bend tubes of a heat transfer device.

[0004] 2. Description of the Related Art

[0005] While the present invention may be used in a variety of industries, the environment of a pressurized water reactor (PWR) nuclear power plant will be discussed herein for illustrative purposes. There are two major systems utilized in a PWR to convert the heat generated in the fuel into electrical power. In the primary system, primary coolant is circulated past the fuel rods where it absorbs the emitted heat. The heated fluid, which is in liquid form due to the elevated pressure of the primary loop, flows to the steam generators where heat is transferred to the secondary system. After leaving the steam generators, the primary coolant is pumped back to the core to complete the primary loop. In the secondary loop, heat is transferred to the secondary coolant, or, feedwater, from the primary side in the steam generators, producing steam. The steam is used to rotate a turbine, generating electricity. The wet steam leaves the turbine, passes through a condenser to remove residual heat, and the liquid feedwater is pumped back to the steam generators.

[0006] Inside of the steam generator, the hot reactor coolant flows inside of the many tubes and the feedwater flows around the outside of the tubes. There are two forms of steam generators: once-through steam generators, in which the tubes are straight, and U-bend steam generators, which are more common and in which the tubes contain a U-shaped bend.

[0007] The typical heat exchanger, steam generators in the nuclear industry in particular, are susceptible to vibration-induced wear on the internals. Vibration is due to flow-induced forces on tubing during normal operation, particularly in the U-bend region of the tubes where flow is much more cross-flow than axial. The normal industrial practice is to analyze, design, and construct the heat exchanger with specific supports, called anti-vibration bars, that directly and positively act against instability in the out-of-plane direction (that is, against the plane defined by the U-bend tube). Commonly, anti-vibration bars, however, are not designed with specific features to prevent instability in the in-plane direction (that is, within the plane defined by the U-bend tube).

[0008] Recently, tube-to-tube wear has been detected in the U-bend region of steam generators. This wear is indicative of tube-to-tube contact during power operation, and has been attributed to tube instability in the U-bend area. The tube motion is in the in-plane direction (movement back and forth parallel to the anti-vibration bars). It has been concluded that the in-plane instability is due to a lack of sufficient friction between the anti-vibration bars and the tubes, which renders the anti-vibration bars ineffective at preventing in-plane motion of the tube.

[0009] Several classic repair approaches exist tier recovery from out-of-plane instability, but those approaches do not work optimally for in-plane repair. They can require extensive disassembly of the steam generator to effect the repair, and are very labor-intensive. Additionally, most U-bend steam generators are not currently designed and fabricated to guarantee resistance to in-plane instability by mechanical restraint.

[0010] Thus, what is needed is a stabilization system that specifically counteracts induced in-plane vibration of heat exchanger tubes.

SUMMARY OF THE INVENTION

[0011] The inventive tube stabilization system increases the friction between the steam generator tubes and the anti-vibration bars by pressing the tube bundle together in the out-of-plane direction and/or distorts the plane of the U-tubes. The invention involves a structure that reacts either off the inner diameter of the tube bundle wrapper, or off an assembled "hoop," which is self-supporting on top of the tube bundle. it imposes a controlled pushing force on the tube bundle, either by direct contact with the outer tubes and/or indirectly via the existing anti-vibration bar structure.

[0012] The invention creates a controllable distortion geometry and loading on the U-bends of a heat exchanger, providing a unique means to create stability against excessive tube vibration, whether it be in-plane and/or out-of-plane. By creating a controllable side load and/or elastic tube axis distortion, the tube is heavily damped against any vibration movement in the in-plane direction. It also becomes more damped against out-of-plane vibrations.

DESCRIPTION OF THE DRAWINGS

[0013] The present invention is described with reference to the accompanying drawings, which illustrate exemplary embodiments and in which like reference characters reference like elements. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than restrictive.

[0014] FIG. **1** shows an example of the tubes and anti-vibration bars of a known pressurized water reactor steam generator.

[0015] FIGS. **2**A, **2**B, **2**C, and **2**D show examples of various anti-vibration bar support designs.

[0016] FIG. **3** shows a first example of a system of the current invention in place atop the U-bend region of a steam generator.

[0017] FIG. **4** shows a detailed view of the system of FIG. **3**, illustrating the connection to the existing anti-vibration bars of the steam generator.

[0018] FIGS. **5**, **6**, **7**, and **8** each show detailed views illustrating configurations of the load blocks and how the load can be distributed to a multiplicity of tubes and anti-vibration bars.

[0019] FIG. **9** shows a rotated view of an anti-vibration bar hoop and illustrates another example of the current invention,

[0020] FIG. **10** shows anti-vibration bars and steam generator tubes prior to being stabilized according to the present invention.

[0021] FIG. **11** shows anti-vibration bars and steam generator tubes being stabilized according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0022] The inventive tube stabilization system counteracts induced in-plane vibration of heat exchanger tubes. According to one aspect of the system, existing anti-vibration bars (AVBs) are used to counteract in-plane vibration. FIG. **1** shows an example of the tubes and anti-vibration bars of a known pressurized water reactor steam generator, and FIGS. **2**A, **2**B, **2**C, and **2**D show examples of various anti-vibration bar support designs uses in the industry. The view of FIG. **1** is a partial cut-away showing a cross-section view collinear with the longitudinal axis of the steam generator tubes **10**. The AVBs **15** are bars that extend in between the tubes **10**, thereby resisting out-of-plane movement of the tubes **10** (only a representative portion of which are shown). The AVBs are connected and retained in place by a plurality of connecting devices **20**, or even singular rods welded to AVB terminators **16**, as seen in FIG. **5**. Additionally, AVB hoops **17** (see FIG. **3**) extend across the U-bend at intervals to interconnect the connection devices **20** and support the AVBs as they span through and across the tubes **10**. As will be appreciated, the flat AVBS **15** do not resist in-plane motion of the tubes **10**. As the flow-induced forces imparted by normal use of the steam generator can be different for each tube **10**, adjacent ones of the tubes **10** may come into contact, potentially causing damage.

[0023] FIG. **3** shows an overhead view of the U-bend region of a steam generator (for clarity, the tubes themselves are not shown in the figure, just some of the AVBs and the "mesh" of external structures that hold all of the AVBs in place are shown). The AVBs **15** are designated. by horizontal lines, only a few of which are shown in the bubbled region and with only these being referenced in the figure so that the figure will not be cluttered. (Similarly, only two AVB hoops **17** are referenced in FIGS. **3** and **4**.) The inventive system **50** includes a stressor hoop **51** that is assembled by a plurality of connectors **52** (if the assembly must be constructed in place with limited access) and in turn is connected to load blocks **57**, which in turn connect to some of the AVBs **15** or connecting structures **17**, **20**. Preferably, the number of connectors **52** is minimized. If multiple connectors **52** are used, they preferably are symmetrically spaced about the hoop **51**. By tightening the hoop **51** in known manner, such as forcing of load developing device **54**, inward-directed force **53** is imparted to the AVBs via the load blocks **57** and pressure-point tugs **55** and, as needed, load fingers **56**. The magnitude of this force **53** can be varied by adjusting the compressive load generated by device **54**; increasing the compressive load will impart a force **53** of relatively greater magnitude. Alternate means of using the system **50** are also available; for example, shortening or lengthening the hoop **51** (like a turn-buckle) will impart a force **53** of relatively greater or lesser magnitude, respectively. Preferably, the hoop **51** may be chosen to safely withstand loads of 1000 to 9000 lbs or more, and be thermally compatible with the operating components. Differential thermal expansion of the various components is logically important to consider the net loads applied to the tube U-bend assembly at operating conditions.

[0024] FIG. **4** shows a detailed view of the system **50** of FIG. **3**, illustrating the connection thereof to the existing AVBs of the steam generator. The stressor hoop **51** is linked to the load block **57** by a sliding connection at the interface and by load developing device **54**. The load block **57** is the structure that holds and positions the pressure point lugs **55** that contact one or more AVBs **15** and/or tubes **10**. Preferably, each load block **57** contacts a plurality of AVBs **15** such that the force **53** imparted by the hoop **51** is transmitted to a great many of the AVBs **15**. This may be achieved, as shown in the illustrated example of FIG. **4**, by providing multiple pressure point lugs **55**. The force imparted by the system **50** can be adjusted via load adjustment screw **54**. Tightening or loosening this screw **54** adjusts the force imparted by the load block **57** to the AVBs **15**.

[0025] FIGS. **5**, **6**, **7**, and **8** contain more explicit sketches to illustrate some of the ways that loads can be readily imparted to multiple tubes **10** and AVBs **15** such that contact stress levels are reduced but the total loads per load block **57** can be amplified. In FIG. **5** the pressure point lugs **55** are shown pressing on pairs of tubes **10**, taking advantage of any natural steps its the tube-bundle geometry. The geometry is chosen as desired to allow use near the AVB connecting hoops **17** and to provide for system elasticity. One can press directly on the AVBs **15**, or on tube-pairs which then press on the adjacent "underlying" AVB **15**. FIG. **6** is provided to aid in comprehension of the concept of using pre-assembled load blocks **57** and how they may be installed. FIG. **7** illustrates a further variation of loading which embodies load fingers **56** to develop direct contact on event more AVBs **15** and tubes **10**. Here, the lug **55** again rests on two tubes **10**, but the finger **56** projects through and dog-legs to rest on an AVB **15**. This approach has the advantage of further developing successful interlock with the tube bundle to aid in lift-off resistance during any main steam tine break event; such events develop high ejection loads on AVBs **15** and connecting structures.

[0026] FIGS. **5**, **6**, **7**, and **8** further illustrate how the blocks **57** can be fashioned to accommodate and even take advantage of individual geometries of a given AVB support structure. AVBs **15**, AVB terminators **16**, AVB hoops **17**, and connecting devices **20** are shown since they are commonly used elements in steam generator U-bend configurations. (FIG. **1** shows an alternate design used for connecting device **20** which would require appropriate modification to the load block **57**.)

[0027] FIG. **8** shows example variations of the load block **57**. The upper sketch shows loading with offset load fingers **56**, and the log ser sketch shows loading on tubes **10**, balanced across the AVBs **15** to minimize bending stress, plus the offset load fingers **56**. All figures are used as example configurations that can be applied to develop loading on a multiplicity of tubes **10** and AVBs **15**, reducing peak point loading as needed.

[0028] This imparted force **53** causes the AVBs to move, such that they make firm contact with the adjacent steam generator tubes **10**. Thus, the system **50** causes the existing AVBs to provide resistance to in-plane motion of the tubes **10**, such as vibration caused by normal operation of the steam generator when the PWR is in use. Furthermore, if the force applied to the AVBs **15** on one side of the U-bend is reacted by pushing on a different set of AVBs **15** on the opposite side of the tube bundle, then the U-bends of the tubes **10** are forced into a slight curvature. In-plane motion of those tubes **10** are thus further restricted because they are not allowed to move without elastically "turning the curves," and thus must absorb more energy themselves, and impart desirable rubbing friction against the AVBs **15**.

[0029] An important advantage gained by this use of non-collinear forces (that is, not applying the balance load to the same set of AVBs **15** on the opposite side of the tube bundle) is that the bundle is typically much less stiff so that significant bundle deflection can occur with less load, and the peak side loads on tubes are much reduced. This has the advantage of allowing some relative sliding of the tube **10** against the AVB **15**. Tubes **10** that are highly pinched between both adjacent AVBs **15** may be excessively locked and may then deform in-plane excessively at other areas where pinch loads are lower.

[0030] The AVBs **15** further "domino" by the connectivity of the connecting devices **20**. This AVB-to-tube contact causes friction against and resistance to in-plane motion of a large number of the tubes **10**. This domino effect has the added effect of moving most of the AVBs **15** in essentially the same displacement such that even in the presence of pre-existing tube-to-AVB wear, there is still movement of every related AVB **15**, and there is no significant accumulation of the effects of wear on multiple columns of wear. This is the effect present when the entire column of tubes is not worn; it is observed that some level of wear may occur in five to perhaps fifteen or more consecutive tubes **10**, however the tubes **10** outboard of that, not showing wear, or the tubes **10** with minimal wear will transfer the load to the next AVB **15** once the nominal gap is taken up by displacement. The relatively short spans between those tubes **10** that have no or insignificant wear in a given column means that the unsupported span of the associated AVB **15** is also short, and thus remaining relatively quite stiff. The AVB **15** then has the ability to impart side load on the worn tubes **10** once further bundle displacement has occurred.

[0031] A further advantage gained by the domino effect is that the tube **10** is not necessarily pinched between adjacent AVBs **15**, as excessive pinch could lock the tube U-bend, which may have undesirable effects under operating conditions.

[0032] In further explanation of this feature, FIG. **10** illustrates that simple compaction of stacks of tubes **10** and AVBs **15** does not impart side loading onto those tubes that have pre-existing wear. With true distortion of the U-bend and domino of the AVBs **15**, as shown in FIG. **11**, all tubes **10** are pushed, regardless of wear and regardless of wear in adjacent columns of tubes.

[0033] FIG. **3** illustrates the case where load blocks **57** are not a aligned on directly opposing ends of the same AVB **15** set, but rather are shown offset by three on each side.

[0034] The components of system **50** may be interconnected and connected to the existing plant equipment such that any threat of it coming loose during plant operation is minimized or eliminated. It is also preferable that system-**50** is adjustable, such that added or reduced U-bend distortion can be made should there be a desire to change operating characteristics. This is readily achieved, for example, by unlockable bolting on the load developing device **54**.

[0035] Additionally, it is preferable that the system **50** and its components be readily removable. These goals may be achieved, for example, by using tack welds, straps, or unlockable bolting to removably lock them in place. Rather than affixing the pressure point lugs **55** to each AVB **15** they are in contact with, the lugs **55** may simply hook into the AVBs **15** by being under the AVB terminators **16** and thus be held in place by geometry, and also the load block **57** would be positively engaged into the stressor-hoop **51**. Other means of retaining the system **50** and its components in place during plant operation will be apparent to those of skill in the art.

[0036] According to another aspect of the invention, the forces **53** can be generated by "jacking" against structures inside the pressure vessel; in terms of a steam generator, a good surface would be the inside of the wrapper. In this aspect, the stressor hoop **51** need not be installed and is replaced and/or augmented by a foot which braces to the inside of the wrapper, and toad developing device **54** is modified to span the distance from the foot to the load blocks **57**. Such loading approaches may be more suitable for developing higher loads.

[0037] According to another aspect of the invention, and as an alternative method to elastically deforming the AVBs **15** by installing the added hardware of structure **50**, small plastic deformations may be made to many or all of the AVB linking hoops **17**. The net effect is similar for peripheral tubes **10**, although it may not have much penetration effect deep into the bundle if the AVBs **15** are relatively thin, thus being relatively flexible over long spans. No new tooling is however left inside the steam genera or vessel. Preferably, the plastic deformations are implemented in a stepped fashion. This stepped deformation could be implemented, for example, by hydraulic pressing tools temporarily clamped onto the AVB hoop **17**. The installer can enter the steam generator vessel with several hydraulic forming tools, clamp them onto several places on one of the AVB hoops **17**, activate them to deform that AVB hoop **17**, and then move them to the next AVB hoop **17**.

[0038] When finished, the entire AVB bundle ends up somewhat deformed but no tooling remains inside the steam generator. The tube-to-bundle deforming loads are generated by the sum of the small deformations on each of the AVB hoops **17**. A representative deformation value for each step might be small and on the order of 0.020 inch, for a total of about 0.06 inch for three steps. The range of peak total deformation targeted will be a function of the steam generator size and the needed amplitude of average tube-to-AVB contact force.

[0039] FIG. **9** shows a rotated view of one of the AVB hoops **17**. The boxed numbers above the illustrated AVB hoop **17** correspond to sets of AVBs. It is contemplated that all or most of the AVB hoops **17** would be step-deformed to collectively build large forces. The impact of the stepping is to displace the sets of AVBs **15** indirectly attached to the AVB hoops **17** by connecting devices **20** and to create deformation of the central AVB sets **15** relative to the outer AVB sets **15**. In the illustrated embodiment of FIG. **9**, AVB sets **4** through **9** have been displaced relative to the others. The original position of the AVB hoop **17** is shown by dashed lines and the AVB sets **15** by dotted lines.

[0040] As will be appreciated by the illustrated embodiment of FIG. **9**, the AVB hoop **17** is subjected to multiple deformations that, preferably, are made in pairs. This results in a stepped appearance of the AVB hoop **17** with each stepped portion being substantially parallel to the other stepped portions. Additionally, the inside portion of the AVB hoop **17** is more displaced than outside portions thereof, relative to a center of the heat exchanger.

[0041] While being quite applicable to new steam generators, the aspects of this invention beneficially can be assembled inside an already-fabricated steam generator using normal manway openings. This eliminates expensive and time-consuming efforts to temporarily cut apart the steam generator shell or some of its internals. In this feature, the inventive system is highly useful as a repair tool for pre-installed steam generators, and may be applicable tier other heat exchangers which have adequate secondary side access.

[0042] This system does not require removal of the existing AVBs, and thus likely eliminates extensive reanalysis of vibration and wear calculations. This also eliminates large costs and risks of damaging the steam generator tubing **10** during the removal and installation process of replacement AVBs **15**.

[0043] This invention also provides a means to create controlled side forces on the tubing **10**. This eliminates the assumption of adequate side loads during operating conditions.

[0044] The forces generated by the system **50** on the tubing **10** can be adjusted as described above after installation, for example should there be a need to increase or decrease loading or deformations.

[0045] Local areas or large zones of the U-bend can be controlled by the system **50**. High void fraction regions or high velocity regions are typically quite localized, and may be deep in the tube bundle **10**. A single tool-system under this invention can impart the needed loading over a large volume of the U-bend.

[0046] When applied to a new steam generator design, the inventive system **50** may allow reduction of the need and cost of high tolerance machining of AVBs and other AVB structure subcomponents, and assembly tools, since it will absorb and accommodate variable tolerances.

[0047] The invention may significantly improve tube bundle stability during vessel handling and shipping and may eliminate the need for anti-liftoff devices if sufficient resistive friction is generated.

[0048] The invention accommodates the existence of wear marks at tube-to-AVB intersections, which may otherwise interfere with many other repair concepts. Further, it is observed that this inventive system **50** does not loosen gaps to existing AVBs **15** within the compression/distortion zone. This removes concern that would arise otherwise: increased gaps can promote tube wear rates created by out-of-plane vibration, which is generally a stronger phenomenon than in-plane vibration. Careful attention would of course need to be taken for tube columns outboard of the compression zone, to assure those tubes are adequately supported for their flow conditions.

[0049] While the preferred embodiments of the present invention ha re been described above, it should be understood that they have been presented by way of example only, and not of limitation. It will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. Thus the present invention should not be limited by the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents. Furthermore, while certain advantages of the invention have been described herein, it is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment of the invention. Thus, for example, those skilled in the art will recognize that the invention may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

What is claimed is:

1. A system imparting in-plane stability to a heat exchanger having U-bend tubes with anti-vibration bars running therebetween, comprising:

a plurality of load blocks positioned so as to be in contact with at least some of the anti-vibration bars;

a hoop coupled to each of said load blocks;

wherein said hoop is tensioned to provide an inwardly directed force to the U-bend tubes through the load blocks and anti-vibration bars.

2. The system of claim **1** wherein said hoop is tensioned so as to apply forces to said load blocks, said forces being balanced across opposite sides of the U-tubes and located to both compress and controllably deform the U-bend region such that controlled contact forces are generated between the anti-vibration bars and the U-bend tubes.

3. The system of claim **1**, wherein said hoop is tensioned so as to induce contact bets teen at least one of the U-bend tubes and an adjacent one of the anti-vibration bars.

4. The system of claim **3**, wherein said hoop is adjustably tensioned.

5. The system of claim **4**, wherein said hoop is designed to support a load of approximately 1000 to 9000 lbs.

6. The system of claim **1**, wherein at least one of said load blocks includes a body having a stepped profile such that each of said steps contacts a separate one of the anti-vibration bars.

7. A method of providing in-plane stability to a heat exchanger having U-bend tubes with anti-vibration bars running therebetween, comprising:

attaching a plurality of load blocks to the heat exchanger;

attaching a hoop to each of said load blocks; and

tensioning said hoop to provide an inwardly directed force to the U-bend tubes.

8. The method of claim **7**, wherein said attaching said plurality of load blocks to the heat exchanger includes attaching a least one of said plurality of load blocks to one of the anti-vibration bars.

9. The method of claim **7**, said tensioning includes tensioning said hoop such that at some of said U-bend tubes contact an adjacent anti-vibration bar.

10. A method of providing in-plane stability to a heat exchanger having U-bend tubes arranged in bundles and having tube wrappers and further having anti-vibration bars running between the U-bend tubes, comprising:

attaching a plurality of load blocks to the heat exchanger; and

attaching a restrictive foot to each of said load blocks, said restrictive foot positioned against the associated wrapper or other steam generator structure so as to compress its associated load block to provide an inwardly directed force to the U-bend tubes.

11. The method of claim **10**, wherein said attaching said plurality of load blocks to the heat exchanger includes attaching a least one of said plurality of load blocks to one of the anti-vibration bars.

12. The method of claim **10**, wherein said attaching a restrictive foot includes compressing said foot such that at least some of said U-bend tubes contact an adjacent anti-vibration bar.

13. A method of providing in-plane stability to a heat exchanger having U-bend tubes with anti-vibration bars running therebetween, the anti-vibration bars being connected by a plurality of hoops, comprising plastically deforming at least one of the hoops such that at least some of said anti-vibration bars contact an adjacent U-bend tube.

14. The method of claim **13**, wherein said deforming includes making multiple deformations such that an inside portion of said at least one of the hoops is more displaced than outside portions of said at least one of the hoops, relative to a center of the heat exchanger.

15. The method of claim **14**, wherein said deforming includes making pairs of multiple deformations such that said at least one of the hoops has a stepped appearance, with each stepped portion of said at least one of the hoops being substantially parallel to the other stepped portions.

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