United States Patent [19]

Lenhardt

[11] **3,861,460**

[45] **Jan. 21, 1975**

[54] **CONDENSER CONSTRUCTION**

[75] Inventor: **Michael J. Lenhardt,** Trenton, N.J.

[73] Assignee: **De Laval Turbine Inc.,** Princeton, N.J.

[22] Filed: **May 23, 1973**

[21] Appl. No.: **362,948**

[52] **U.S. Cl.** ..... **165/111,** 165/134, 165/158, 60/95 A, 285/137 R

[51] **Int. Cl.** **F28b 1/02,** F28f 9/02

[58] **Field of Search** ..... 165/110–114, 165/134, 158, 159, 81; 60/95 A; 285/137 R

[56] **References Cited**

UNITED STATES PATENTS

2,181,704	11/1939	McNeal	165/114
2,196,641	4/1940	Morgan	60/95 A
2,496,301	2/1950	Meixl	165/159 X
2,552,416	5/1951	Farbas	165/111 X
3,139,926	7/1964	Tinber	165/111

Primary Examiner—Albert W. Davis, Jr.
Attorney, Agent, or Firm—Sandoe, Hopgood & Calimafde

[57] **ABSTRACT**

The invention contemplates a steam-surface condenser construction wherein an assembly of spaced tube sheets, associated tubes and water boxes is axially compliantly supported with respect to the condenser shell, and wherein the said assembly further includes elongate strain-proportioning mechanism extending between the tube sheets and effectively tying the water boxes to each other independently of tube-sheet connection via the tubes. The strain-proportioning mechanism may take the form of plural spaced elongate members which effectively span the assembly, these members being positioned in substantial alignment with the region of water-box connection to the respective tube sheets.

20 Claims, 6 Drawing Figures

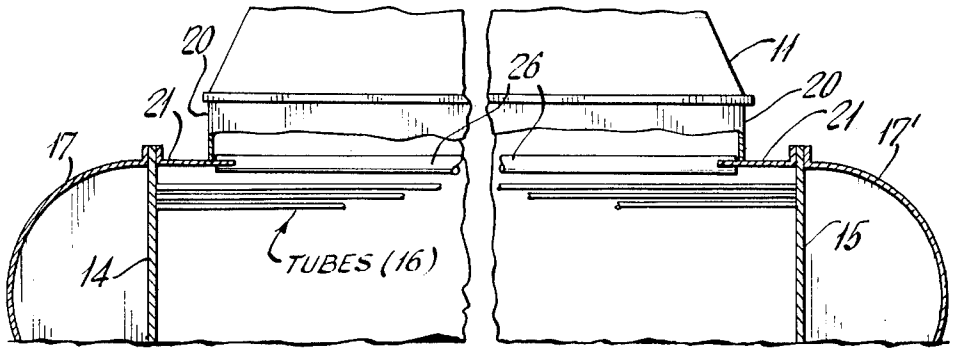


Fig. 1.

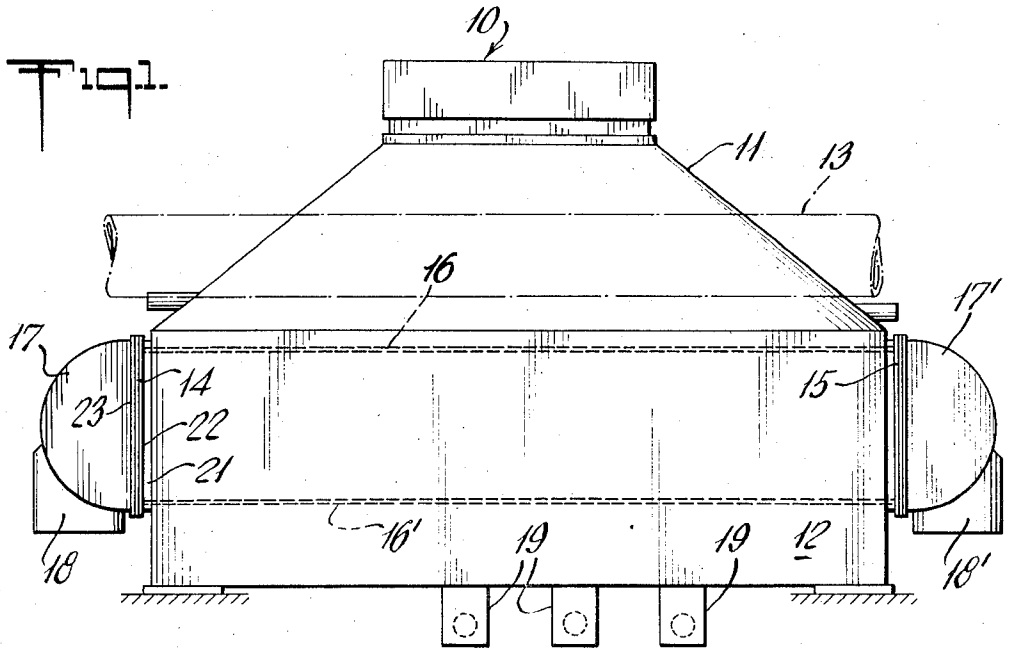


Fig. 2.

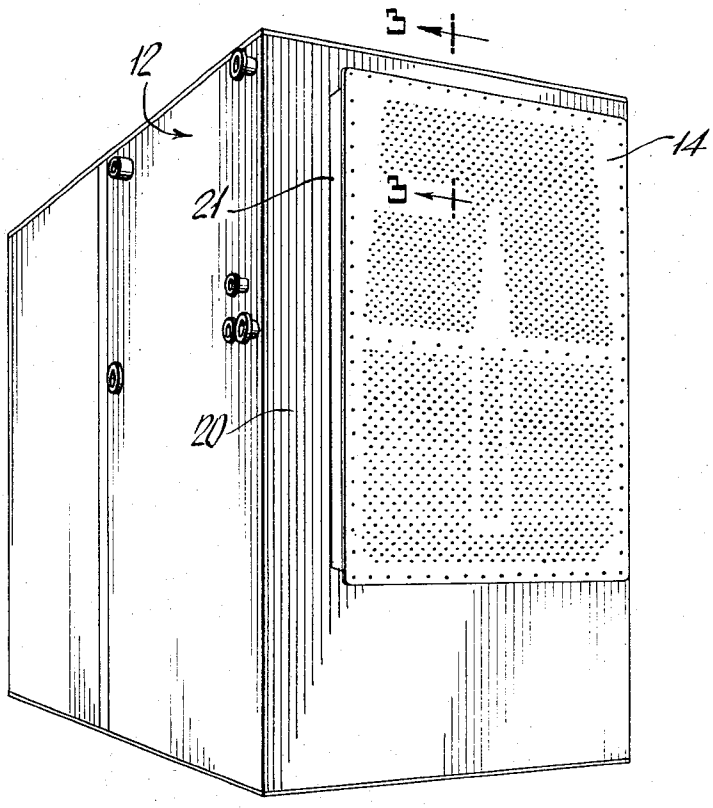


FIG. 3.

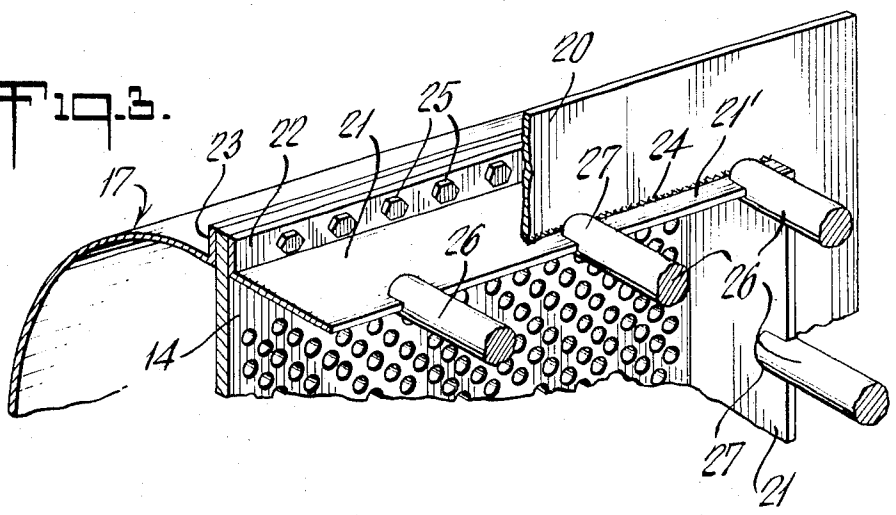
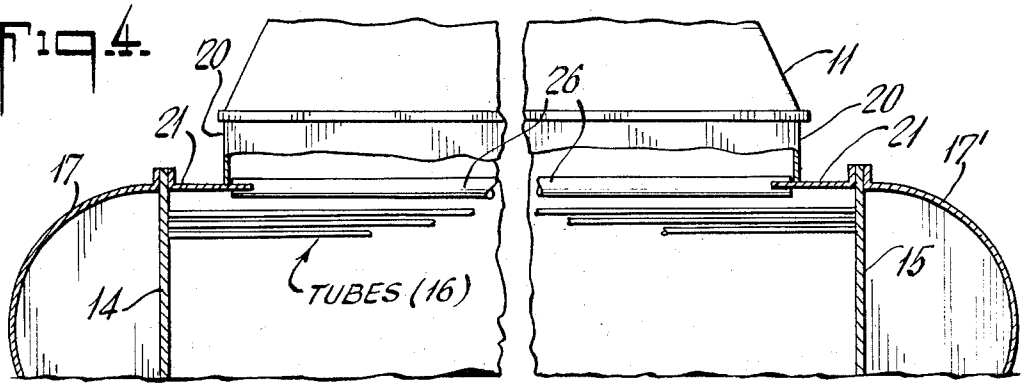


FIG. 4.



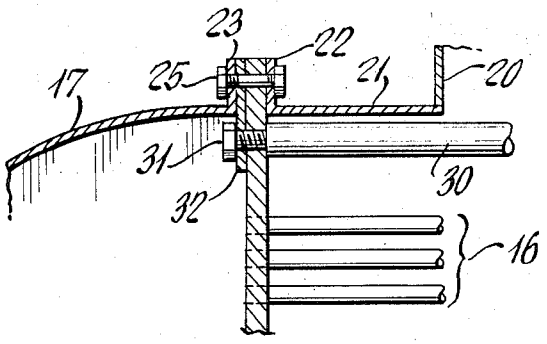
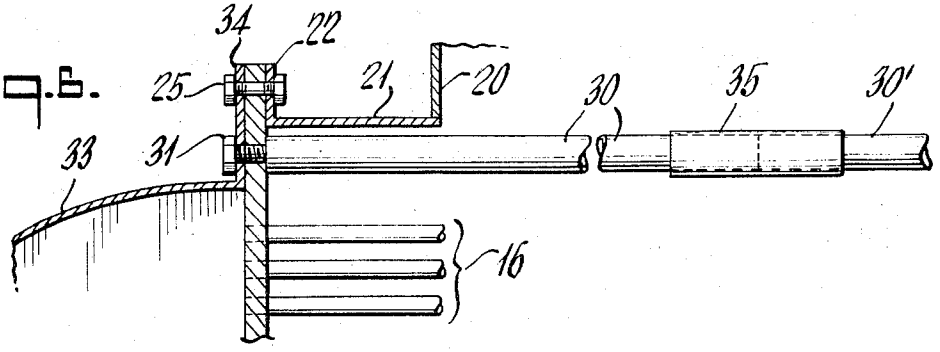


FIG. 5.

FIG. 6.



CONDENSER CONSTRUCTION

This invention relates to the construction of steam-surface condensers, of the type used to condense turbine-exhaust steam in large steam-electric power plants.

Modern steam-electric power-plant practice has been in the direction of producing ever-larger condensers, of operating at ever-higher pressures of water used to effect condensation, and at ever-higher flow rates. Choice of materials, section thickness and the like are the normal tools by which the condenser designer approaches the myriad structural problems raised by the power-plant trends, but the new materials introduce further problems; conventional techniques are not alone enough, for example, to achieve adequate compensation for differential thermal growth between shell and tubes and concurrently provide for assumption of the physical loads resulting from integration of hydraulic operating pressures.

It is, accordingly, an object of the invention to provide an improved construction and approach to the construction of condensers of the character indicated.

Another object is to provide improved compensation for differential thermal growth between shell and tubes, in such condensers.

A specific object is to provide the foregoing by a technique whereby safe control and limitation are achieved, for physical hydraulic-reaction loads on tubes, or tube sheets, and on the joints between tubes and the tube sheets; such loads being for example the result of hydraulic thrusts of water heads and nozzles, weight of water heads and of water contained therein, and externally applied forces, or any combination of such loads and forces.

Another specific object is to achieve the foregoing objects in a manner to permit safe use of thinner, more flexible tube sheets and thin-wall tubes of higher heat-transfer efficiency.

A further specific object is to provide a condenser construction of such superior character as to assure virtually absolute and total protection from potential catastrophic failure, in the event of failure of a joint (or joints) between a tube sheet and one (or more) of the peripheral tubes connected thereto.

Another object is to achieve the foregoing objects with a construction which may be adapted, as to retrofit, to existing condenser installations, regardless of the source of original manufacture, such retrofit being a means of immediately and in relatively short time solving certain problems of existing installations.

It is also an object to eliminate the requirement for independent water-box support and for control rods on circulating water connections, where such control rods or supports may have been required by reason of physical limitations of the condenser.

A still further object is to provide an improved condenser construction wherein tube sheets and/or shell flanges are inherently better maintained in parallel planes, thus facilitating initial tubing assembly, as well as tube replacement operations.

Other objects and various further features of novelty and invention will be pointed out or will occur to those skilled in the art from a reading of the following specification, in conjunction with the accompanying drawings. In said drawings, which show, for illustrative purposes only, preferred forms of the invention:

FIG. 1 is a simplified view in side elevation, of a condenser to which the invention is applied;

FIG. 2 is an enlarged view in perspective, to show part of one end of the condenser of FIG. 1, with the water box removed from such end;

FIG. 3 is an enlarged fragmentary perspective view of the upper left corner of the tube sheet visible in FIG. 2, the fragment being taken at the vertical section 3—3 of FIG. 2, and with the associated tubes removed but water box in place.

FIG. 4 is a simplified diagram to illustrate basic elements of one form of the invention; and

FIGS. 5 and 6 are diagrams similar to FIG. 4 to illustrate other forms of the invention.

Referring to FIGS. 1 to 4, the invention is shown in application to a condenser for developing return-feed water from exhaust steam, such as the exhaust of a steam turbine in a power plant. Such exhaust steam enters with downward flow at an inlet 10 to an expansion hood or funnel 11 which covers and supplies the basic housing enclosure or shell 12; a feedwater heater-shell duct 13 is shown passing through hood 11. A set of horizontal condensing tubes is assembled to and extends between spaced vertical tube sheets 14–15, the tubes being generally indicated in FIG. 1 by limiting upper and lower elevations 16—16′ of the tube cluster. Each outer face of the tube-tube sheet assembly 14–15–16 is closed by a water box 17—17′ having a port 18—18′ through which cooling water is supplied (e.g., at 18) and exhausted (e.g., at 18′) after coursing all the tubes in the cluster 16—16′. Condensate accumulates in the shell volume beneath the tube cluster and in collection boxes 19 beneath shell 12, for boiler-feed recycled use.

Support for the tube-tube sheet assembly is by way of an axially compliant suspension of the tube sheets at each longitudinal end of shell 12. As shown, each of the shell ends is closed by a panel or diagragm 20 that is relatively thin and therefore axially compliant. A tubular member or neck 21 is carried at a central opening in panel 20 and projects axially outward to a radially outward flange 22, by which it is removably secured to the periphery of the tube sheet 14; a weld 24 (FIG. 3) unites panel 20 to neck 21, and the outer confines of panel 20 will be understood to be part of the welded completion of shell 12. A flange 23 on the water box 17 registers with the peripheral course of flange 22, so that a series of bolts 25 may rigidly unite flanges 22–23 to opposite faces of the tube sheet 14.

In accordance with the invention, elongate strain-proportioning members, such as tubes or rods 26 are provided to effectively and directly interconnect the water boxes 17—17′, thus relieving the joints between tubes and the tube sheets, and also relieving the tube sheets themselves, from having to sustain all axially directed forces. As shown, the neck 21 is sufficiently elongate to include a portion 21′ projecting axially inwardly of the panel 20, and strain-proportioning member connection is made to portion 21′, by diametrically slotting each rod end to define opposed fingers 27 which are securely welded to portion 21′. The neck 21 provides a convenient means whereby longitudinal strain-proportioning member forces are assuredly aligned with the peripheral region of water-box connection to the associated tube sheet 14, particularly since bolts 25 directly connect neck 21 to the water-box flange 23. And, of course, it will be understood that the sectional area of and spacing between strain-proportioning members 26 should be such as not materially to affect steam flow into the condensing-tube cluster.

The arrangement of FIG. 5 resembles that which has

been described for FIGS. 1 to 4, except that strain-proportioning members **30**, of size and spacing analogous to those described at **26**, are employed as direct connections between tube sheets **14** (**15**). Thus, ends of members **30** are shown reduced and threaded, being drawn tight against a shoulder when secured by nuts **31**; preferably a plate **32** of width to accommodate the peripheral swath of securing means **25** and **31** substantially relieves the stress load on the tube sheet **14** and enhances the effectiveness of direct connection to the water box **17**. In the slight modification of FIG. **6**, the water box **33** and its flange **34** are of slightly altered radial proportions, so that direct strain-proportioning member connection to the water-box flange is assured, thus dispensing with any need for a stress-relieving plate **32**. It will be understood that, if desired, as in a retrofit application of the invention to an existing condenser installation, strain-proportioning members **30** or **26** may be initially formed at partial or fractional length to facilitate handling, being assembled in multiple as separate elements **30—30'** to their respective tube sheets and connected to each other as by a coupling sleeve **35** which overlaps and is welded to both adjacent portions of adjacent strain-proportioning member elements.

To provide some illustration of the significant effectiveness of the invention, consider a condenser construction wherein tubes **16** are 44 ft. long, having a capacity of 145,000 sq. ft., i.e., wherein this is the total outside surface area of all of the tubes **16**. The tube sheets **14–15** are 8 ft. wide, 12 ft. high, and 1 inch thick; in view of the nature of tube sheets to flex, it will be assumed that 780 1-inch diameter tubes, taken from the outer three peripheral rows of a normal construction (i.e., without the strain-proportioning members **26, 30, 30'**) of the invention, participate in sharing the annularly distributed axial load due to hydraulic thrust from the water boxes. Various comparative values are tabulated below for such a condenser, for the three conditions of (a) past practice, without strain-proportioning members, (b) strain-proportioning member practice with aluminum-brass tubes, and (c) strain-proportioning member practice using titanium tubes, all taken for an assumed water-box pressure of 45 psi, meaning a 533,000-lb. axial load to be sustained between tube sheets **14–15** due to water pressure alone. Strain-proportioning members **26** are assumed to be of low-alloy steel, providing a total effective sectional area of 27 sq. in., distributed over 12 suitably spaced strain-proportioning members **26**.

Generally speaking, from the safety viewpoint it is not desirable to permit the operating dynamic axial load per tube to exceed thirty percent of the theoretical strength of a tube-tube sheet joint. For the joint of an aluminium-brass tube to a 1-inch thick muntz-metal tube sheet, this strength, the "pull-out" strength, is conservatively approximated at 2,000 lbs.; the above-indicated maximum axial-load conditions for such tubes, protected by the invention, are less than 20 percent of 2,000 lbs. and are thus well within the desired safety design limit. Additionally, field hydrostatic pressures at 150 percent of design capacity can be safely sustained. For the joint of a titanium or stainless-steel tube to a similar muntz-metal tube sheet, this strength is about 1,300 lbs.; and again, it is seen that the above-noted maximum axial-load conditions for such tubes, when protected by the invention, are safely held within the thirty percent level for hydraulic-thrust loads, and to approximately the 10 percent level for the thermal condition which might result from loss of coolant water.

It will be seen that the invention meets all stated objects and permits material improvement in the safety factor which can be designed into a given installation or which can be provided as the up-grading retrofit of an existing installation. Not only is safety realized by reducing the danger of tube-tube sheet "pull-out," but the invention also makes it possible to avoid or substantially reduce the large force differentials which can severely warp the tube sheet, with resultant damage to local effectiveness of tube-tube sheet joints, particularly in the peripheral region of the tube bundle. Additionally, any tendency for cooling water to leak via one or more of the tube-tube sheet joints is materially reduced.

Although shown and described for preferred forms and an illustrative example, the invention is not to be considered thus limited. For example, in certain existing condensers of the above-indicated proportions, the tube population in the peripheral region of the tube bundle may be substantially less, for example, 30 percent less, than indicated, in which case employment of the same number and size of strain-proportioning members **26** will still hold the aluminum-brass tube situation within tolerable safety limits; however, for the titanium-tube situation, it may be necessary, still within the teachings of the invention, to augment from 12 to 16, the number of strain-proportioning members to safely cover the hydraulic-thrust load condition.

It will be appreciated that bolted connections at **25**

	Conventional (without members 26)	Invention, with members 26 Al.-Brass Tubes (18 BWG)	Invention, with members 26 Titanium Tubes (23 BWG)
A. Due to hydraulic thrusts, normal flows:			
Axial load/tube	672 lbs.	380 lbs.	290 lbs.
Tube stress:			
Al.-Brass Tubes	4,600 psi	3,200 psi	—
Titanium Tubes	8,800 psi	—	4,600 psi
Strain-member stress	—	6,000 psi	9,400 psi
B. Due to thermal excursion, assuming the extreme case of loss of coolant water:			
Total strain (e), in./in.		6.15×10^{-4}	2.85×10^{-4}
Tube strain (e_t), in./in.		1.85×10^{-4}	1.34×10^{-4}
Strain-member strain (e_m), in./in.		4.30×10^{-4}	1.51×10^{-4}
Tube stress, psi		2,900 (compression)	2,000 (tension)
Strain-member stress, psi		12,900 (tension)	4,500 (compression)
Axial load/tube*		370 lbs.	130 lbs.

* I.e., reflecting difference between combined load in peripheral tubes, as opposed to combined axial load sustained by strain members.

(31) are purely illustrative of fastening the various members together. And in other situations, other fastening techniques may be employed, wherein the strain-proportioning members serve at least an equally beneficial function. For example, should the neck, and adjacent tube-sheet and water-box parts be strength-welded about their peripheries, the tube sheet will be deriving less radial-plane support at its location of fastening to the adjacent water-box and neck regions, so that the strain-proportioning function of members **26** will provide an even more important contribution to the maintenance of a flat tube sheet which will not be likely to degrade the nearby tube-tube sheet joints, under the most adverse conditions.

What is claimed is:

1. A steam-surface condenser, comprising an elongate shell, an assembly of two spaced tube sheets and associated tubes, longitudinally spaced means supporting spaced parts of said assembly within said shell, one of said supporting means being axially compliant, first and second water boxes defining chambers over the respective outer faces of said tube sheets and communicating with the respective outer ends of said tubes, said boxes being secured to said tube sheets over a peripherally continuous mounting region, and a plurality of spaced elongated strain-proportioning members securely interconnecting correspondingly spaced locations along said mounting regions.

2. A condenser according to claim **1,** in which a peripherally continuous neck member is interposed between and connects said compliant supporting means to the nearby tube sheet.

3. A condenser according to claim **2,** in which the peripheral course of said neck member substantially conforms to and registers with the mounting region of said nearby tube sheet.

4. A condenser according to claim **2,** in which said strain-proportioning members are connected to the axially inner end of said neck member.

5. A condenser according to claim **2,** in which the other supporting means includes a second peripherally continuous neck member connected to the other tube sheet in substantial registration with the mounting region of said other tube sheet, and in which said strain-proportioning members interconnect the axially inner ends of said neck members.

6. A condenser according to claim **5,** in which said other supporting means includes an axially compliant connection between said second neck member and said shell.

7. A condenser according to claim **2,** in which said strain-proportioning members are directly connected to said tube sheets within and substantially independent of said neck member.

8. A condenser according to claim **2,** in which said one supporting means includes a flat generally radial annular axially compliant plate having an inner edge peripherally secured to said neck member at a location between the axial ends of said neck member, said strain-proportioning members being connected to the axially inwardly extending portion of said neck member.

9. A steam-surface condenser, comprising an elongate shell, an assembly of two spaced tube sheets and associated tubes, said assembly being axially compliantly supported within and near the respective ends of said shell, water boxes defining chambers over the respective outer faces of said tube sheets and communicating with the respective outer ends of said tubes, said boxes being secured to said tube sheets over a peripherally continuous mounting region, and a plurality of spaced elongated strain-proportioning members securely interconnecting correspondingly spaced locations along said mounting regions.

10. A condenser according to claim **9,** in which each axially compliant support comprises a flat generally radial annular plate having an inner edge connected to the nearby tube sheet and an outer edge connected to said shell.

11. A condenser according to claim **10,** in which a peripherally continuous neck member is interposed between and axially connects the inner edge of one of said plates to the nearby tube sheet.

12. A condenser according to claim **11,** in which said neck member substantially conforms to and registers with the mounting region of the nearby tube sheet, and in which said strain-proportioning members are connected to said neck member.

13. A steam-surface condenser, comprising an elongate shell, an assembly of two spaced tube sheets and associated tubes, longitudinally spaced means supporting spaced parts of said assembly within said shell, one of said supporting means being axially compliant and comprising an annular plate secured at its outer edge to said shell, a tubular neck having a radially outward flange at its axially outer end and secured to the inner edge of said plate at a location axially offset from said flange, first and second water boxes defining chambers over the respective outerfaces of said tube sheets and communicating with the respective outer ends of said tubes, said boxes being secured to said tube sheets over a peripherally continuous mounting region, said neck having a peripheral contour which substantially conforms to the course of said mounting region and the water box near said neck having a radially outward flange substantially conforming and being secured to said neck flange, and a plurality of spaced elongated strain-proportioning members securely interconnecting spaced locations along the axially inner end of said neck with correspondingly spaced locations along the mounting region at the opposite axial end of said assembly.

14. In a steam-surface condenser, two spaced apertured tube sheets, plural tubes extending between said sheets and having end support at corresponding openings of said sheets, first and second radially outwardly flanged water boxes defining chambers over the respective outer faces of said tubes, the flanges of said boxes defining corresponding peripherally continuous mounting regions in axially registry at outer faces of said tube sheets, means including a plurality of spaced elongated strain-proportioning members securely interconnecting said water-box flanges at correspondingly spaced locations along said mounting regions, a condenser shell surrounding said tubes and strain-proportioning members, and peripherally extending means connecting said mounting regions to axially spaced parts of said shell, at least one of said last-defined means being axially compliant.

15. A condenser according to claim **1,** in which said strain-proportioning members are bars having ends passing through said tube sheets and secured directly to said water boxes.

16. A condenser according to claim **1,** in which at least one of said strain-proportioning members com-

prises at least two fractional lengths, one of which is connected to the mounting region at one longitudinal end, the other of which is connected to the mounting region at the other longitudinal end, and means rigidly coupling the other ends of said fractional lengths.

17. A condenser according to claim **1,** wherein the material and effective total sectional area of said strain-proportioning members are selected, in reference to the materials and sizes and peripheral population density of said tubes, such that normal hydraulic load is substantially borne by said strain-supportioning members to the substantial relief of tube-tube sheet joints and of the tube sheets themselves for the regions of peripheral tubes, and such that, in the event of water supply failure during a capacity steam exposure of said condenser, the thermal expansion of said strain-proportioning members and tubes will so nearly correspond that the difference between axial-load forces on peripheral tubes and on said strain-proportioning members will be held within limits at least no greater than substantially fifty percent of the tube-tube sheet joint strength.

18. A condenser according to claim **1,** wherein the material and effective total sectional area of said strain-proportioning members are selected, in reference to the materials and sizes and peripheral population density of said tubes, such that normal hydraulic load is substantially borne by said strain-proportioning members to the substantial relief of tube-tube sheet joints and of the tube sheets themselves for the regions of peripheral tubes, and such that, in the event of water supply failure during a capacity steam exposure of said condenser, the thermal expansion of said strain-proportioning members and tubes will so nearly correspond that the difference between axial-load forces on peripheral tubes and on said strain-proportioning members will be held within limits at least no greater than substantially the level of axially load per tube achieved by said strain-proportioning members for a full-capacity hydraulic coolant flow from one to the other of said water boxes.

19. A condenser according to claim **18,** in which said level of axial load per tube is at least no greater than substantially 30 percent of the tube-tube sheet joint strength.

20. A condenser according to claim **18,** in which said level of axial load per tube is at least no greater than substantially 20 percent of the tube-tube sheet joint strength.

* * * * *