(54) Titre : MOYENS ET METHODE DE REPARATION DE TUBE CHAUFFANT DE GENERATEUR DE VAPEUR
(54) Title: STEAM GENERATOR HEATING TUBE REPAIR MEANS AND REPAIR METHOD

(57) Abrégé/Abstract:
The invention relates to a steam generator heating tube repair sleeve (50, 70), which at one end has an encircling flange (36, 52, 72), which merges into a conical region (38, 54, 74) that tapers on the outside in the direction of the other sleeve end and which is
Adjoined by a straight region (56, 76). The invention also relates to a steam generator heating tube repair method for a steam generator heating tube (12, 32, 86, 88, 90) which is installed in a steam generator (80) and has a defective tube end, wherein the ends of a multiplicity of steam generator heating tubes (12, 32, 86, 88, 90) are passed through respective clad tube plates (18, 44, 82) and welded to the cladding (20, 46, 84), comprising the following steps: 1. conical milling out (14) of the defective tube end and milling a depression (16) into the cladding (20, 46, 84) around the defective tube end; 2. insertion of a steam generator heating tube repair sleeve (50, 70) according to the invention into the conically milled-out (14) defective tube end, wherein the outer sleeve contour is matched, at least in the conical (38, 54, 74) region, to the inner contour of the milled-out tube end; 3. rolling in the steam generator heating tube repair sleeve (50, 70) in the straight region (56, 76) thereof; 4. welding the flange region (36, 52, 72) of the rolled-in steam generator heating tube repair sleeve (34) to the cladding (20, 46, 84) to form a sealing seam.
Abstract

The invention relates to a steam generator heating tube repair sleeve (50, 70), which at one end has an encircling flange (36, 52, 72), which merges into a conical region (38, 54, 74) that tapers on the outside in the direction of the other sleeve end and which is adjoined by a straight region (56, 76). The invention also relates to a steam generator heating tube repair method for a steam generator heating tube (12, 32, 86, 88, 90) which is installed in a steam generator (80) and has a defective tube end, wherein the ends of a multiplicity of steam generator heating tubes (12, 32, 86, 88, 90) are passed through respective clad tube plates (18, 44, 82) and welded to the cladding (20, 46, 84), comprising the following steps: 1. conical milling out (14) of the defective tube end and milling a depression (16) into the cladding (20, 46, 84) around the defective tube end; 2. insertion of a steam generator heating tube repair sleeve (50, 70) according to the invention into the conically milled-out (14) defective tube end, wherein the outer sleeve contour is matched, at least in the conical (38, 54, 74) region, to the inner contour of the milled-out tube end; 3. rolling in the steam generator heating tube repair sleeve (50, 70) in the straight region (56, 76) thereof; 4. welding the flange region (36, 52, 72) of the rolled-in steam generator heating tube repair sleeve (34) to the cladding (20, 46, 84) to form a sealing seam.

Significant figure: Fig. 2
Steam generator heating tube repair means and repair method

Description

The invention relates to a steam generator heating tube repair sleeve, which at one end has an encircling flange, which merges into a conical region that tapers on the outside in the direction of the other sleeve end and which is adjoined by a straight region. The invention also relates to a steam generator heating tube repair method for a steam generator heating tube which is installed in a steam generator and has a defective tube end, wherein the ends of a multiplicity of steam generator heating tubes are passed through respective clad tube plates and welded to the cladding, wherein, according to the method, a steam generator heating tube repair sleeve according to the invention is to be used. The invention also relates to a steam generator repaired in accordance with the invention.

It is a matter of common knowledge that steam generators are used, inter alia, in power stations, especially in nuclear power stations. Steam generators are heat exchangers, through which a heated primary medium flows in a first circuit during operation, wherein the heat is then transferred to a secondary medium, in particular water, which flows in a second circuit separate from the first. After flowing through the steam generator, the water has then changed to a gaseous state of aggregation and is then available to drive a power station turbine. Especially in the case of nuclear
power stations, where the primary medium is radioactively contaminated, strict and absolutely reliable separation between the first and second circuits in the steam generator must be preserved.

Steam generators essentially have a generally cylindrical vessel, which has respective clad tube plates at the axial ends thereof, wherein the interior space formed in this way is traversed by a multiplicity of steam generator heating tubes, which are joined to the cladding. In this way, as large as possible a contact area for heat exchange is formed between the two cooling circuits.

Steam generator heating tubes are welded leak-tightly to the cladding on the lower edge of the tube plate. If this weld seam is damaged, e.g. by foreign bodies, the leak-tightness of the seam is no longer assured, and there may be a leak between the primary and the secondary medium. The damaged weld seams must be repaired in order to re-establish the separation between the primary and secondary media.

Hitherto, this has been accomplished by installing welded plugs. In this case, the standard practice is for steam generator heating tubes that have a leak at the weld seam to be sealed by means of welded plugs. To install welded plugs, a specific milled contour is first of all introduced. The bottom flange of the welded plug is used as filler material and is welded to the cladding of the tube plate by means of a TIG method (Tungsten Inert Gas). The seam serves both as a load bearing seam and as a sealing seam.

The disadvantage here is that the sealed steam generator heating tube no longer contributes to heat exchange between the primary and secondary circuits, and therefore there is a reduction in the efficiency of the power station. Since the steam generator also has a safety function in the case of incidents or accidents, the proportion of sealed tubes must not exceed a certain value, e.g. 10%. If the number of damaged weld seams in a steam generator is very high, installing welded plugs is no longer suitable as a repair measure.

Another prior art method consists in re-welding. By re-melting the material, it is possible to close up defects in the seam, such as cracks or pores. In the case of re-
welding, however, only small and superficial defects can be eliminated. Since no filler material is introduced, it is not possible to compensate for a lack of welding material. Moreover, the impurities in the original weld seam may be melted in again during re-welding, thereby possibly impairing the quality of the new seam. Re-welding damaged weld seams is therefore not a reliable and long-term repair method.

Repair methods that involve repair sleeves are furthermore also known. Thus, a repair sleeve for insertion into a defective tube end of a steam generator is disclosed in US Patent 4592577. A repair sleeve for insertion into a defective tube end of a steam generator is likewise disclosed in GB 1141239, wherein subsequent expansion by means of a rolling process is performed, giving a leak-tight joint with the tube end.

Taking this prior art as a starting point, it is the object of the invention to provide a repair means and a repair method which, on the one hand, avoid the sealing of the steam generator heating tubes affected and, on the other hand, allow long-term and reliable repair of the damaged tube ends.

This object is achieved by a steam generator heating tube repair sleeve which at one end has an encircling flange, which merges into a conical region that tapers on the outside in the direction of the other sleeve end and which is adjoined by a straight region.

The basic concept of the invention consists in the installation of a short tubular sleeve or steam generator heating tube repair sleeve - also referred to as a "sleeve" - on the respective tube end that is damaged. The steam generator heating tube repair sleeve is fixed in the steam generator heating tube by being rolled in mechanically, and its lower edge is welded in a milled contour to the cladding of the tube plate. On the one hand, this ensures continued operation of the repaired steam generator heating tube, thus enabling continued problem-free operation of the respective steam generator, even after a large number of repairs. On the other hand, this also allows a high-quality and therefore durable repair of defective tube ends.

The defective weld seam is completely removed by prior conical milling of the tube end concerned and the milling in of a depression into the cladding around the defec-
ative tube end. Any impurities that may have contributed to the defect in the previous weld seam are thus eliminated in an advantageous manner.

The lower edge of the steam generator heating tube repair sleeve has a flange that serves as filler material during the welding process. The manual introduction of filler material during the welding process is thus avoided in an advantageous manner. The melted flange material is distributed in an advantageous manner into the milled depression, thus ensuring that the surface of the cladding remains virtually smooth. In addition to the necessary high quality of the weld seam, this also allows an accelerated repair process.

The conical region of the steam generator heating tube repair sleeve is matched accurately to the conically milled-out region of the tube end, thus allowing an accurate fit. This can be achieved, in particular, through the choice of an appropriate milling tool with the desired taper angle.

The outside diameter chosen for the straight region of the sleeve should be no greater than the respective minimum inside diameter of the defective tube end in order, in this way, to allow problem-free insertion of the steam generator heating tube repair sleeve according to the invention into the milled-out tube end. In a rolling-in process, the straight region of the inserted steam generator heating tube repair sleeve is then expanded, thus giving a leak-tight and secure joint with the tube plate.

The steam generator heating tube repair sleeve according to the invention furthermore allows particularly rapid repair of defective tube ends. This is of great importance, especially in the case of steam generators in nuclear plants, owing to the radiation to which the maintenance personnel are exposed. This is thereby reduced in an advantageous manner.

According to a preferred embodiment of the steam generator heating tube repair sleeve according to the invention, the thickness of the sleeve wall in the conical region is increased as compared with the straight region. The conical region as the essential and critical part of the repair zone is advantageously reinforced by such an increased wall thickness. The conical region is not necessarily provided for the roll-
ing-in process, since there is a high accuracy of fit in any case in the conical region owing to the matching of the conical milling thereto. However, it is possible to achieve a further increase in the stability of the repair joint by rolling in in the conical region. An increased wall thickness does not present a problem during rolling in inasmuch as the wall material is not subjected to any major deformation during rolling in, owing to the high accuracy of fit of the sleeve. An increased wall thickness in this region thus also leads to increased stability of the joint to be created between the steam generator heating tube repair sleeve and the tube plate.

In the straight region, which is likewise provided for rolling in if required, a thinner sleeve wall can be chosen because, to this extent, the steam generator heating tube does not have a weak point in this rear region. In any case, either the conical or the straight region or, if appropriate, both should be rolled in. An illustrative thickness of a sleeve wall is, for example, 1-2 mm in the conical region and <0.5 mm in the straight region, this depending to a great extent on the respective boundary conditions and on the choice of material for the steam generator heating tube repair sleeve. The length of the steam generator heating tube repair sleeve should be designed in such a way that installation is possible even in the edge positions of the steam generator, and it is 10 to 15 cm, for example.

According to a particularly preferred embodiment of the steam generator heating tube repair sleeve according to the invention, the length of the conical region corresponds to at least one and a half times the sleeve inside diameter at the flange end, which, for its part, is 2.5 cm, for example. A relatively long conical region of this kind makes it possible to produce a stable repair joint simply by rolling in the conical region. Owing to the high accuracy of fitting of the steam generator heating tube repair sleeve into the conical bore, and even in the state before rolling in, an increased wall thickness can also be rolled in without problems, and the resulting joint is of particularly high quality.

According to another variant of the steam generator heating tube repair sleeve according to the invention, the thickness of the sleeve wall in the conical region is reduced towards the straight region. Overall, an approximately constant wall thickness of the steam generator heating tube repair sleeve and the conically milled steam
generator heating tube is thus obtained in the conical region, with an ideally constant inside diameter of the repair joint.

According to another embodiment of the steam generator heating tube repair sleeve according to the invention, a thin rough layer is provided at least on partial areas of the outer surface. This layer, also referred to as a microlock, improves the anchoring of the steam generator heating tube repair sleeve in the steam generator heating tube and avoids rotation of the repair sleeve during the installation thereof, especially during rolling in. An insignificant partial increase in the outside diameter of the repair sleeve caused thereby is immaterial because a slight clearance is envisaged in any case for inserting the repair sleeve into the milled-out tube end without problems. The clearance is then completely eliminated by the rolling-in process.

According to a particularly preferred embodiment, the steam generator heating tube repair sleeve according to the invention is produced at least predominantly from the material Inconel 690®. This is distinguished by good corrosion resistance and suitability for welding to the cladding material. Likewise suitable, on the basis of these properties and its good behaviour when rolled in, is the material Incoloy 800®. It is thereby also possible to achieve rolling in of relatively high wall thicknesses, in the region of 1 mm and above, without cracking.

The object is also achieved by a steam generator heating tube repair method for a steam generator heating tube which is installed in a steam generator and has a defective tube end, wherein the ends of a multiplicity of steam generator heating tubes are passed through respective clad tube plates and welded to the cladding, comprising the following steps:

- conical milling out of the defective tube end and milling a depression into the cladding around the defective tube end,
- insertion of a steam generator heating tube repair sleeve according to the invention into the conically milled-out defective tube end, wherein the outer sleeve contour is matched, at least in the conical region, to the inner contour of the milled-out tube end,
- rolling in the steam generator heating tube repair sleeve in the straight and/or conical region thereof,
• welding the flange region of the rolled-in steam generator heating tube repair sleeve to the cladding to form a sealing seam.

The defective tube end is milled with the aid of a conical milling cutter. The milling cutter centres itself in the steam generator heating tube by means of its tip. The diameter and the angle of the conical region of the milling cutter are designed in such a way that the old, defective weld seam is completely removed. A new milling contour is formed, with a depression for accommodation and subsequent welding of the steam generator heating tube in the flange region thereof. A high accuracy of fit of the conical region of the steam generator heating tube repair sleeve with the conically milled tube end is thereby achieved.

Apart from the advantages already mentioned in connection with the steam generator heating tube repair sleeve, this method proves not only to provide a joint between the repair sleeve and the tube plates which is necessarily of very high quality but also to be very rapid, a great advantage especially in respect of minimized radiation exposure of the repair personnel.

According to another embodiment of the method according to the invention, welding is carried out by a TIG welding method (Tungsten Inert Gas). This has proven particularly suitable and leads to high-quality weld seams.

According to another variant of the method, welding of the inserted steam generator heating tube repair sleeve is carried out even before the latter is rolled in. This avoids rotation of the repair sleeve during the rolling-in process.

According to another variant of the method, the steam generator heating tube repair sleeve is rolled in in a plurality of processing steps. Particularly in the case of an internal steam generator heating tube diameter that is stepped axially towards the rear, a different rolling-in tool may be necessary for each step, thus requiring a further processing step.

According to a particularly preferred variant of the method, this is performed on a defective end of a steam generator heating tube of a radioactively contaminated steam
generator of a nuclear plant. Owing to the extremely high safety requirements applying in that case, the high quality and long life of the outcome of repair achieved in accordance with the method is particularly significant. Moreover, the radiation exposure of the repair personnel is advantageously reduced, owing to the short time required for the method according to the invention. The sequence of steps mentioned may also be interchanged within certain limits, provided this has no effect on the end result.

The advantages according to the invention also extend to a steam generator comprising a multiplicity of steam generator heating tubes, the two ends of which are passed through respective clad tube plates and welded to the cladding, wherein the repair method according to the invention has been employed on at least one tube end. Owing to the continued use of a steam generator heating tube repaired in accordance with the invention, the efficiency of a steam generator does not in fact fall, even when repaired many times, and the steam generator can advantageously be operated reliably over a longer period of service by virtue of the high-quality and long-life repair.

These advantages extend especially to a radioactively contaminated steam generator, the replacement and disposal of which after a foreshortened service life is particularly expensive.

Further advantageous possibilities for embodiments can be found in the other dependent claims.

The invention, further embodiments and further advantages will be described in detail with reference to the illustrative embodiments shown in the drawings, in which:

Fig. 1  shows an illustrative steam generator heating tube in a clad tube plate,
Fig. 2  shows an illustrative repaired steam generator heating tube,
Fig. 3  shows an illustrative first steam generator heating tube repair sleeve,
Fig. 4  shows an illustrative second steam generator heating tube repair sleeve,
Fig. 5  shows an illustrative steam generator, and
Fig. 6 shows an illustrative second repaired steam generator heating tube.

Fig. 1 shows an illustrative steam generator heating tube 12 in a clad 20 tube plate 18 in a view 10. The steam generator heating tube 12 has been subjected to conical milling in the front end region thereof, as indicated by reference numeral 14. A depression 16 has furthermore been milled in at the surface of the cladding 20 of the tube plate 18. The previous, defective weld seam (not shown) has thereby been completely removed, as have therefore also any impurities that may have led to the defect in the weld seam. The steam generator heating tube 12 is shown with an inside diameter that decreases in steps and with a wall thickness that increases in steps in the rear region thereof. A greater wall thickness is necessary as the steam generator heating tube emerges from the tube plate because the stabilizing effect of the latter is then lost. The steam generator heating tube 12 shown is thus prepared for the insertion of a steam generator heating tube repair sleeve or "sleeve" according to the invention.

Fig. 2 shows an illustrative repaired steam generator heating tube 32, which is passed through a tube plate 44 and a cladding 46 arranged thereon, in a view 30. A steam generator heating tube repair sleeve 34 is then inserted into the tube end prepared in accordance with Fig. 1, said sleeve having already been rolled in in the upper, straight region 40 thereof, i.e. expanded in diameter to the respective inside diameter of the tube end. As a result, a hermetic joint between the steam generator heating tube 32 and the steam generator heating tube repair sleeve 34 is ensured. Owing to the stepping of the steam generator heating tube 32, several rolling-in steps were necessary. In a conical region 38, the conical external shape of the steam generator heating tube repair sleeve 34 and the conical internal shape of the milled tube end are matched precisely to one another, thus giving an accurately fitting joint in this location. In a flange region 36, a flange surrounding the steam generator heating tube repair sleeve 34 rests in a milled-in depression, which is designed in such a way that the flange material approximately fills the depression as it melts in the subsequent welding process. The steam generator heating tube repair sleeve 34 and the steam generator heating tube 32 extend in a rotationally symmetrical manner around an imaginary centre line 42.
Fig. 3 shows an illustrative first steam generator heating tube repair sleeve 50 (not yet rolled in) in section. An encircling flange is provided in the lower flange region 52, said flange being melted during the subsequent welding operation and joined to the cladding of a respective tube plate. A conical region 54 is embodied with an increased wall thickness, with this region not being provided for rolling in. An adjoining straight region 56 is provided for rolling in and therefore has an outside diameter which is marginally smaller than the inside diameter of a respective steam generator heating tube to be repaired. A thin rough layer 58, referred to as a microlock, is provided over a certain area of the outer surface of the straight region 56 in order to avoid rotation of the steam generator heating tube repair sleeve 50 during the subsequent rolling-in process. This extends in a rotationally symmetrical manner around an imaginary centre line 60 and is preferably produced from the material Inconel 690, which has proven particularly suitable for this application.

Fig. 4 likewise shows an illustrative second steam generator heating tube repair sleeve 70 but in a three-dimensional view. A flange region 72 is provided at the bottom end, adjoining which flange region in the direction of the other sleeve end is a conical region 74 and then a straight region 76. The straight region 76 is surrounded at the outer surface thereof by a thin rough layer 78, which prevents rotation of the steam generator heating tube repair sleeve 70 during the rolling-in operation.

Fig. 5 shows an illustrative steam generator 80 in a schematic diagram. Walls 92 and a clad 84 tube plate 82 form a closed interior space, through which a plurality of steam generator heating tubes 86, 88, 90 is passed. The respective ends of said tubes are passed through holes in the bottom plate and the adjoining cladding 84 and are welded to the cladding. During the operation of the steam generator, there is a flow of a first medium through the interior space thereof, while there is a flow of a second medium through the steam generator heating tubes 86, 88, 90. The two media must be separated completely and reliably from one another, and mixing must be avoided at all costs. In the event of a repair, the repair method according to the invention is applied to the respective defective tube end.

Fig. 6 shows an illustrative second repaired steam generator heating tube in a sectional view 100. A steam generator heating tube repair sleeve 106 has a conical re-
region 102, which corresponds to approximately twice the inside diameter 104 of the flange end of said sleeve. The steam generator heating tube repair sleeve 106 has been inserted into a milled-out steam generator heating tube and rolled in in its conical region. By virtue of the relatively long design of the conical region 102, rolling in in the straight region adjoining at the rear is not necessary. The wall thickness of the steam generator heating tube repair sleeve 106 decreases towards the rear by the same measure as the wall thickness of the steam generator heating tube subjected to conical milling increases, with the result that, overall, an approximately constant wall thickness of the steam generator heating tube repair sleeve and the steam generator heating tube is obtained in the conical region.
List of reference signs

10  illustrative steam generator heating tube in clad tube plate
12  steam generator heating tube
14  conically milled-out tube end
16  milled-in depression
18  tube plate
20  cladding
30  illustrative repaired steam generator heating tube
32  steam generator heating tube
34  rolled-in steam generator heating tube repair sleeve
36  flange region of the steam generator heating tube repair sleeve
38  conical region of the steam generator heating tube repair sleeve
40  straight region of the steam generator heating tube repair sleeve
42  centre line
44  tube plate
46  cladding
50  illustrative first steam generator heating tube repair sleeve
52  flange region of the steam generator heating tube repair sleeve
54  conical region of the steam generator heating tube repair sleeve
56  straight region of the steam generator heating tube repair sleeve
58  thin rough layer
60  centre line
70  illustrative second steam generator heating tube repair sleeve
72  flange region of the steam generator heating tube repair sleeve
74  conical region of the steam generator heating tube repair sleeve
76  straight region of the steam generator heating tube repair sleeve
78  thin rough layer
80  illustrative steam generator
82  bottom tube plate of the steam generator
84  cladding of the bottom tube plate
86  first steam generator heating tube
88  second steam generator heating tube
90  third steam generator heating tube
92  wall
100   illustrative second repaired steam generator heating tube
102   conical region of the steam generator heating tube repair sleeve
104   inside diameter at the flange end
106   illustrative third steam generator heating tube repair sleeve
Patent claims

1. Steam generator heating tube repair sleeve (50, 70), which at one end has an encircling flange (36, 52, 72), which merges into a conical region (38, 54, 74, 102) that tapers on the outside in the direction of the other sleeve end and which is adjoined by a straight region (56, 76), characterized in that the thickness of the sleeve wall in the conical region (38, 54, 74, 102) is increased as compared with the straight region (56, 76).

2. Steam generator heating tube repair sleeve according to Claim 1, characterized in that the length of the conical region (38, 54, 74, 102) corresponds to at least one and a half times the sleeve inside diameter (104) at the flange end.

3. Steam generator heating tube repair sleeve according to Claim 1 or 2, characterized in that the thickness of the sleeve wall in the conical region (38, 54, 74, 102) is reduced towards the straight region (56, 76).

4. Steam generator heating tube repair sleeve according to one of the preceding claims, characterized in that a thin rough layer (58, 78) is provided at least on partial areas of the outer surface.

5. Steam generator heating tube repair sleeve according to one of the preceding claims, characterized in that said sleeve is produced at least predominantly from the material Inconel 690®.

6. Steam generator heating tube repair sleeve according to Claim 1 or 2, characterized in that said sleeve is produced at least predominantly from the material Incoloy 800®.
7. Steam generator heating tube repair method for a steam generator heating tube (12, 32, 86, 88, 90) which is installed in a steam generator (80) and has a defective tube end, wherein the ends of a multiplicity of steam generator heating tubes (12, 32, 86, 88, 90) are passed through respective clad tube plates (18, 44, 82) and welded to the cladding (20, 46, 84), comprising the following steps:

- conical milling out (14) of the defective tube end and milling a depression (16) into the cladding (20, 46, 84) around the defective tube end,
- insertion of a steam generator heating tube repair sleeve (50, 70) according to one of Claims 1 to 6 into the conically milled-out (14) defective tube end, wherein the outer sleeve contour is matched, at least in the conical (38, 54, 74) region, to the inner contour of the milled-out tube end,
- rolling in the steam generator heating tube repair sleeve (50, 70) in the straight (56, 76) and/or conical (38, 54, 74, 102) region thereof,
- welding the flange region (36, 52, 72) of the rolled-in steam generator heating tube repair sleeve (34) to the cladding (20, 46, 84) to form a sealing seam.

8. Steam generator heating tube repair method according to Claim 7, characterized in that welding is carried out by a TIG welding method (Tungsten Inert Gas).

9. Steam generator heating tube repair method according to either of Claims 6 and 8, characterized in that welding of the inserted steam generator heating tube repair sleeve (50, 70) is carried out even before the latter is rolled in.

10. Steam generator heating tube repair method according to one of Claims 7 to 9, characterized in that the steam generator heating tube repair sleeve (50, 70) is rolled in in a plurality of processing steps.

11. Steam generator heating tube repair method according to one of Claims 7 to 10, characterized in that said method is carried out on a radioactively contaminated steam generator (80) of a nuclear plant.

12. Steam generator (80), comprising a multiplicity of steam generator heating tubes (12, 32, 86, 88, 90), the two ends of which are each passed through respective clad tube plates (18, 44, 82) and welded to the cladding (20, 46, 84), characterized in
that the repair method according to one of Claims 7 to 11 has been employed on at least one tube end.

13. Steam generator according to Claim 11, characterized in that said generator is radioactively contaminated.