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MORE RECENT DEVELOPMENTS FOR THE ULTRASONIC TESTING OF LIGHT WATER REACTOR PRESSURE VESSELS

DERNIERS DEVELOPPEMENTS POUR LE CONTROLE ULTRASONORE DE REACTEURS NUCLEAIRES A EAU BOUILLANTE ET PRESSURISEE

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SUMMARY: The development of an ultrasonic testing method for the inspection from the outside of the areas close to the cladding of the spherical fields of holes of light water reactor pressure vessels is described.

RESUME : Il s'agit d'une description du développement d'un procédé de contrôle ultrasonore de l'extérieur pour les régions se trouvant à proximité de la plaqué des zones sphériques perforées de réacteurs nucléaires à eau bouillante et pressurisée.

The German RSK guide lines for pressurized and boiling water reactors require, amongst other things, ultrasonic basic and in-service inspections on reactor pressure vessels (1). To the areas which are to be tested there also belongs the spherical field of holes, i.e. the bottom of the boiling water reactor and the top of the pressurized water reactor. Vertical rods are inserted in these fields of holes which have an austenitic cladding on the inner surface. The webs between neighbouring nozzles should be tested in the greatest possible quantity using the ultrasonic pulse-echo method. For both the boiling water and pressurized water reactor these tests must be done from the outside in accordance with present conditions.

The confirmation of the existence of cracks in the area of the web near the cladding between two nozzles is made more difficult by the austenitic cladding. This is due to strong back scattering of ultrasonic energy from the relatively coarse grained and strongly anisotropic cladding.

We report on examinations on the spherical bottom for the nuclear power plant Philippsburg II for developing an ultrasonic testing method for the web area close to the cladding using a single probe operation from the outside. These tests were carried out within the framework of a reactor safety research programme required by the German BUNDESMINISTERIUM FÜR FORSCHUNG UND TECHNOLOGIE, by the KRAFTWERK UNION AG, MASCHINENFABRIK AUGSBURG-NÜRNBERG AG and KRAUTKRÄMER GMBH. In addition the BUNDESANSTALT FÜR MATERIALPRÜFUNG was also involved in the planning.

Before our measurements were taken the spherical bottom of the nuclear power plant Philippsburg II had only a few holes in the vicinity of the crown - the majority of the intended holes had not been produced. The existing holes still didn't have the intended diameter but were only preliminary holes. As shown in fig. 1 this is why test flaws could be made on nozzle holes and also further away from the already existing holes at future hole locations without damaging the component, because the test flaws disappear due to further processing. A total of 42 test flaws, 20 on holes and 22 others were produced from the cladded inner surface in the appr. 200 mm thick wall by spark erosion. The smallest 7 mm deep grooves are consequently in the cladding, i.e. they do not enter into the ferrous base material. They are 14 mm wide. The depths of the test flaws extend from 10 and 14 mm up to 20 mm, wherefrom always appr. 7 mm is in the cladding. The widths of the grooves are between 10 and 40 mm.

The results of fracture mechanics do not allow a clear statement regarding the orientation of probable cracks developing in the web area between the nozzles. Crack orientation is possible between the extreme case of a crack which is parallel to the axis of the nozzle and one which is perpendicular to the curved surface. With todays usual type of spherical bottom dimensions the deviation between both extreme positions is appr. 30^o i.e. deviations can occur which are 30^o from the vertical position.

For the ultrasonic confirmation of the existence of such near surface reflectors from the opposite side the angle effect can be used as shown in fig. 2. The angle ε gives the deviation of the position of the test flaw from the perpendicular plane. For $\varepsilon \neq 0$ there are always two different testing possibilities with the angle effect - namely acute and obtuse angles. For $\varepsilon = 0$, that is the perpendicular groove, these are apparently both identical. The ultrasonic energy reflected to the probe depends, amongst other things, upon the depth of the crack t, the angle of tilt ε and the impingement angle δ of the acoustic axis or the incidence angle α .

The aims of the test

1) Determining the optimum values for the crystal area, the testing frequency and the incidence angle α for this application of the angle effect.

2) The study of the reflection characteristics of the test grooves preferred for the previously chosen optimum testing parameters.

Measured values were, amongst other things, flaw echoes, noise level values (cladding noise) and the dynamic behaviour of the reflector indications. For determining the reflector characteristics of the different test grooves the impingement angle δ and thereby the incidence angle α must be varied. This is given in fig. 3. For different incidence angles between 37^o and 70^o the sound entry points (interface) were calculated and marked for all the test flaws. Proceeding from these points the ultrasonic echoes of the grooves were measured. Thus the reflector echo was measured for the maximum acoustic excitation i.e. for impinging in the centre of the groove. This was checked by measuring the sound path. After this measurement of the reflector echo a noise level value (back scattering from the cladding) was measured at the respective reflector location. Proceeding from the sound entry point as shown in fig. 4 , the dynamical behaviour of the echo was measured by means of an XY-recorder. The X-coordinate of the recorder controlled a path-coder which was connected to the probe. Further measurements were taken using a mechanically guided probe not only going from the marked sound entry point but also with "blind guiding" along previously determined testing paths.

Results

1) Crystal area: for 1 MHz and 2 MHz and for all incidence angles a sufficiently large ultrasonic crystal of, say, 20 x 22 mm^2 or more must be used in order to obtain a signal-to-noise ratio sufficient for a mechanical test. Smaller crystals often deliver considerably worse and, for mechanical measurements, a signal-to-noise ratio which is too small.

2) Frequency: at appr. the same sufficiently sized crystal areas of, e.g. 20 x 22 mm^2 the testing frequency of 1 MHz for small incidence angles of e.g. 45° results in a considerably larger signal-to-noise ratio than 2 MHz (≈6 dB). This advantage, as compared to 2 MHz, decreases with an increasing incidence and impingement angle and, vice versa, with an incidence angle of appr. 70° one obtains for 2 MHz a greater signal-to-noise ratio than for 1 MHz.

3) Incidence angle: the angle range of appr. 40° to appr. 50° or 55° is most suited in practically all cases, i.e. for all 42 test flaws examined. That applies especially for the small incidence angles (40°, 45°). Large incidence angles e.g. 70° only show themselves to be suitable with large reflectors (large in the sense of our test flaws).

4) The reflection characteristics of the test grooves for the most favourable test parameters: representative of the designated range we consider the test results with the 1 MHz - 45° probe with a crystal area of 25 x 25 mm^2. In fig. 5 the results (FE) for reflectors of the same size are marked as black squares and triangles over the X-axis which shows the incline of the reflector. Noise level values (SP) are also marked by open squares and triangles. The squares indicate beaming from the acute-angled side and the triangles denote beaming from the obtuse-angled side. A non-monotonic dependency from the incline of the groove can be seen. The perpendicular groove delivers the maximum flaw echo. This also applies for all other groove depths. Variations of up to 20 dB from the maxima occur as a function of the incline. Essential differences in the reflection characteristic between beaming from the acute and obtuse angled side cannot be determined because the measured deviations of appr. 6 dB also occur from perpendicular grooves with beaming from both sides, probably due to the interfering influences from the cladding. The consequence of the non-monotonic trend means: even with the knowledge of the reflector size a conclusion regarding the incline of the groove cannot be obtained from the maximum echo amplitude alone.

Fig. 6 shows the flaw echo above the X-axis which shows the flaw area F for perpendicular grooves. In addition noise level values are marked. The black squares and triangles represent flaw echoes, the open ones represent noise level values. Test flaws 10 and 12 are each represented twice as squares and triangles according to the beaming from both sides. These test results agree with the assumption of a monotonic increase of the echo amplitude with increasing reflector size. It does not apply however for the corresponding results of the inclined grooves. An example of the 25°-grooves is given in fig. 7. Although test flaw 5_1 is four times larger than test flaw 7_3 the reflector echoes are practically the same! From which follows: a conclusion regarding the depth of the groove cannot be based on the echo amplitude alone. In any event with perpendicular grooves and with perpendicular beaming of the flanks of optionally inclined grooves, within certain limitations, an almost monotonic increase of the echo amplitude with increasing reflector area can be expected. With inclined grooves and even if knowing the inclination nothing can be deduced regarding the depth of the groove based on the echo amplitude alone - as shown in fig. 7. This agrees with the results in (2) about the reflection characteristics of grooves published in 1971. As a result we establish that the maximum echo alone generally is not sufficient for determining the depth and/or incline of the groove.

Conclusions regarding the depth and incline of a groove could be possibly obtained from the structure of the complete dynamic behaviour of an echo indication. The measured echo dynamics are at present compared with the groove dynamics calculated in the BUNDESANSTALT FÜR MATERIALPRÜFUNG. The basis for these calculations is given in (3). Fig. 8 shows such a comparison. It involves the X-dynamics of a large steeply inclined reflector when being beamed from the acute-angled side. The black points have been calculated, the open circles in this fig. are transferred characteristic points of the measured dynamic behaviour. The two curves are adapted with their maxima. Both have two maxima and appr. the same half-value width, the structures therefore agree. If these incompleted comparisons turn out to be successful we can give data on the depth and inclination of grooves in this way, which, as we have seen, is not possible based purely on the echo amplitude.

Finally a few words on carrying out a practical test on the spherical field of holes of a reactor pressure vessel: The test results show that it is advisable to use large 1 MHz crystals and small incidence angles for ultrasonically testing the web area near to the cladding. This apparently simple solution, namely <u>one</u> incidence angle and <u>one</u> frequency, however still leads to considerable expense. This is due to the geometric conditions which change from web to web and also to the fact that on the spherical bottom of a boiling water reactor only every other passage between the rows of nozzles can be used as a testing passage and that these passages which are parallel to each other are unsymmetrical on the outer surface and in addition that perpendicular passages cannot be used. When using rigid crystals one therefore needs a great number of individual crystals, for testing the spherical bottom of a boiling water reactor, which can be accommodated in large multi-crystal probes. These probes, which are matched to the curvature of the spherical bottom, are mounted on a trolley which runs on rails through the passages on the surface of the bottom.

ULTRASONIC TESTING OF REACTOR PRESSURE VESSELS

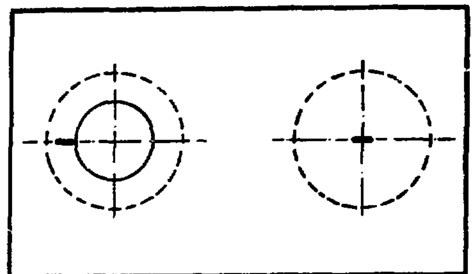
The spherical bottoms of the Isar and Philippsburg I power plants were tested in this manner this year by the KRAFTWERK UNION AG and the MASCHINENFABRIK AUGSBURG - NÜRNBERG AG.

(1) RSK - Leitlinien für Druckwasserreaktoren

RSK - Leitlinien für Siedewasserreaktoren
Institut für Reaktorsicherheit der TÜV e.V. Köln

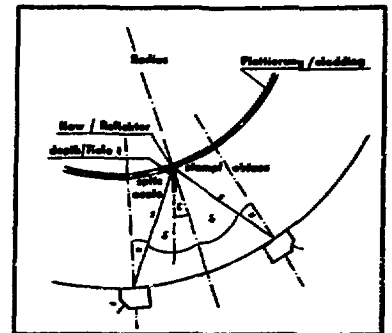
(2) R. Werneyer, U. Schlengermann: Über die Reflexion von Ultraschallwellen an Oberflächenrissen und nutförmigen Testfehlern.
Materialprüfung 13 (1971) Nr. 7, p.213 and
Nr. 9, p.298

(3) H. Wüstenberg, U. Völkel, J. Kutzner: Reflexionsverhalten von flächigen Trennungen in festen Körpern bei der Ultraschallprüfung.
Materialprüfung 16 (1974) Nr. 10, p. 323



Testfehler Rißentstehung und Stegmitte / testflaws for starting cracks and cracks between the nozzles

Fig. 1



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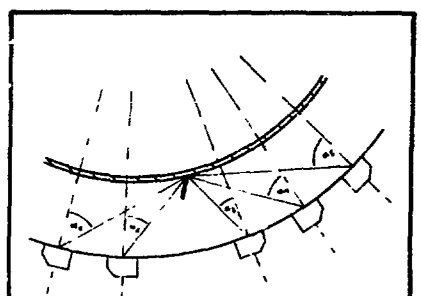
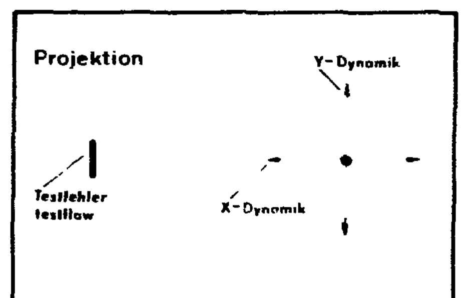
Ultrasonic testing using the angle-effect

Fig. 2



Winkelspiegeleffekt mit versch. Schallwinkeln
angle-effect using different angles of incidence

Fig. 3



Messung der Echo-Dynamik
measuring the dynamic characteristic of the echo

Fig. 4

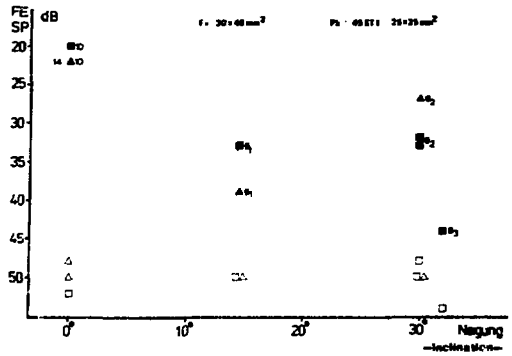


Fig. 5: Flaw echo (FE) and noise level (SP) values for reflectors of the same size

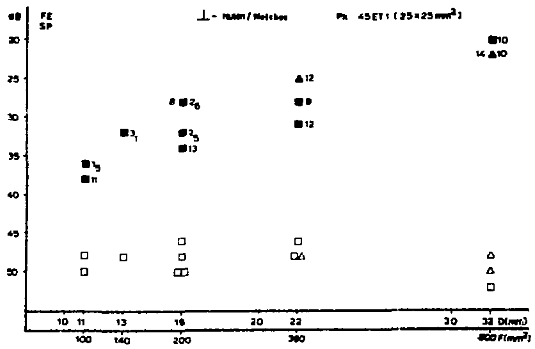


Fig. 6: Flaw echo (FE) and noise level (SP) values for perpendicular grooves

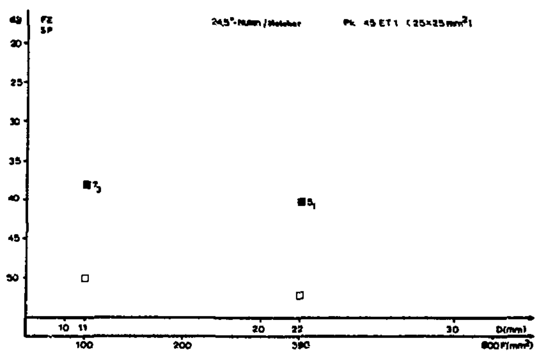


Fig. 7: Flaw echo (FE) and noise level (SP) values for inclined grooves ($\varepsilon = 25^{o}$)

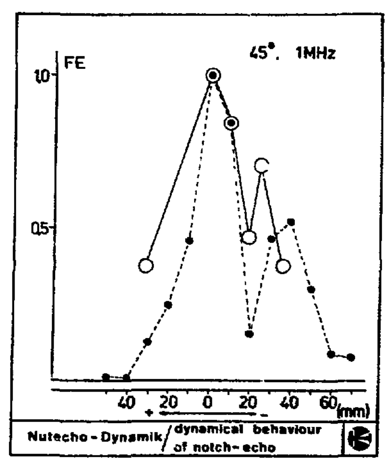


Fig. 8