Analysis for Steam Separators in BWR

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Abstract

Steam seperators in BWR are thin walled pipes with special cyclons for seperating steam and water arranged in a hexagonal scheme and welded to the core cover head. The pipes are connected to each other in two planes by a gridwork of small upright sheets also arranged in a hexagonal scheme. At the level of these gridworks there are also shroud rings for holding long screws. The sheets of the gridwork run concentric to the tubes and are interrupted by the tubes. The interiour forces of the gridwork-members are transferred through the tubewalls by circumferential bending which causes extreme elastic ovalizing of the pipe crossection near to the gridwork connection. The height of these members may be constant or broader at the pipe connection (fig. 1d) for reducing the bending stresses in the pipe walls. If this ovalizing is involved in the elastic behaviour of the gridwork it works like a plate with a Poisson ratio $\nu \sim 1$. Such structures are extremely stiff against equal stresses in perpendicular directions and extremely weak for opposite stresses in both directions. Instead of this interrupted grid work the upper one may be a continues one, arranged tangentially to the tupes. The elastic behaviour of this gridwork is quite different to that of the interrupted one.

For analizing and designing the structure it is necessary to clarify how the stand pipes, the grid works and the external rings act with each other and to find simple models for the interpretation of the mechanical behaviour. The gridwork analysis becomes simple idealizing it as a plate, where the plate stiffnesses are determined by solving the stress concentration problem at the connection between the gridwork sheets and the pipes with the aid of a numerical shell analysis. Then the system is solved by steps splitting up the deformation pattern in the eigenmodes for the circumferential, the radial and the axial direction. In this way it is possible to idealize the stand pipes and the screws as beams which are elastically supported by the gridwork or the rings and elastically connected to each other.

Some results are given for the stress concentration problem at the connection between the gridwork and the pipes. Further more the first seperator eigenmodes and frequencies are discussed and compared with experimental results.

1. Introduction

Steam seperators in BWR consist of special standpipes arranged in a regular hexagonal scheme (fig. 1 a,b). These pipes are welded into the core cover head, a shallow spherical shell, and are connected to each other in two planes by a gridwork of small upright sheets with the same thickness as the pipes, also arranged in a hexagonal scheme (fig. 1b). At the periphery of these gridworks there are shroud rings for holding long screws. These rings are attached to the outer stand pipes (fig. 1 a,d). The sheets of the gridwork run concentric to the center of the tubes and are welded to the tubes. Since the grid work is interrupted by the tubes, the interiour forces of the gridwork-members are transferred through the tubewalls by circumferential bending, which causes an extreme ovalizing of the pipe crossection (fig. 1e). Instead of this interrupted gridwork the upper one may be a continuos one, arranged tangentially to the tubes (fig 1c). In this way the bending stresses in the pipe walls are avoided, since the forces are transferred directly by the grid members and not through the pipe walls. The interrupted gridwork has an unusual mechanic behaviour due to the extreme ovalizing of the pipe crossection in the surrounding of the gridwork connection. The interrupted gridwork acts like a plate with a Poisson ration $\nu \sim 1$. Such systems are nearly rigid if the normal forces in both directions are the same and they are extremely weak if the forces have an opposite sign.

The seperator is strained stationary by the temperature distribution within the surrounding water. Dynamic loads are produced by the steam seperating process within the cyclons and by vibrations in the core transferred through the core supporting structure to the seperator. The goal of this paper is to clarify the behaviour of the stand pipes, the gridwork, and the external rings, and then the interaction between these components both for statical and dynamical loads, and finally to give some guidelines for idealising this complex system by simple models. First we start with the gridwork.

2. Elastic behaviour of the gridwork

For the analysis the standpipes are idealized as beams (with a rigid crossection). Since the flattening of the pipe crossection due to the interior forces of the gridwork members are limited to the immediate surrounding of the gridwork connection the elastical ovalizing of the pipe crossection may be combined together with the elastical deformations of the gridwork members. For deriving the stress strain relationships for this gridwork system it will be smeart out to a plate, since the gridwork has a regular scheme and the distance of the pipes is small in comparision to the measurements of the steam seperator. Stretching and bending of the gridwork is to investigate because normal and shearing forces and bending moments are transferred by the gridwork (fig. 1e).

In this paper only the stretching behaviour is considered (fig. 1e). To get a continuum the truss forces P_i in fig. 1e are smeart out on the pipe distance e to the continuum forces n_i and are transformed into the xy coordinate system:

$$n_x = n_1 + (n_2+n_3)\,c^2, \quad n_y = (n_2+n_3)\,s^2, \quad n_{xy} = (n_2-n_3)\,cs$$

or

$$n_1 = n_x - n_y\,c^2/s^2 \quad \text{with} \quad c = \cos \quad \text{und} \quad s = \sin. \tag{1}$$

The elongations u_i of the grid members including the bending deformations of the pipe wall will be presented by the deformations δ_i due to a unit force (fig. 1f): δ_1 in the force direction and δ_2 in a angle of 60° to the force

$$u_1 = P_1\delta_1 + (P_2+P_3)\,\delta_2, \quad u_2 = P_2\delta_1 + (P_3+P_1)\,\delta_2. \tag{2}$$
$$u_3 \qquad\qquad\qquad\qquad u_1 \qquad\qquad\qquad\qquad u_2$$

After dividing u_i by the elements length a (fig. 1b) the "plate strains" ε_i are yielded. If these strains are transformed also into the xy-system

$$\varepsilon_x a = u_1, \quad 2(\varepsilon_x c^2+\varepsilon_y s^2)a = u_2 + u_3, \quad 4\varepsilon_{xy} csa = u_2 - u_3 \tag{3}$$

and if the elongations u_i and the forces P_i are substituted by eq (2) and (1) we get finally the strain stress relationships, for example

$$\varepsilon_x = \frac{u_1}{a} = \frac{1}{a}\left[P_1\delta_1+(P_2+P_3)\delta_2\right] = \frac{e}{a}\,\delta_1\left[n_x - \frac{n_y}{s^2}\,(c^2 - \frac{\delta_2}{\delta_1})\right]. \tag{4}$$

For a hexagonal grid ($\alpha = 60°$) these equations coincide with those for an isotropic plate with the flexibility

$$f = \frac{e}{a}\,\delta_1 = \delta_1 tg\alpha = \sqrt{3}\delta_1 \tag{5}$$

and the effective Poisson ratio

$$\nu = \frac{c^2}{s^2} - \frac{\delta_2}{\delta_1 s^2} = \frac{1}{3}\,(1 - \frac{4\delta_2}{\delta_1}). \tag{6}$$

The Poisson constant depends on the ratio δ_2/δ_1. For a continous gridwork (fig. 1c) this ratio is zero and the corresponding Poisson constant becomes

$$\nu = c^2/s^2 = 1/3$$

as it is usual for metals. It is not zero since the forces P_2 and P_3 produce not only stretching forces in x direction but also such in y direction. If the part of the pipe within the height h of the grid member (fig. 1e) is idealized approximately as a circular beam (radius r, thickness t) the ratio δ_2/δ_1 for an interrupted gridwork becomes independent of the pipe measurements

$$\delta_2/\delta_1 = -(8-\sqrt{3}\pi - \pi^2/6)/(\pi^2-8) = -0{,}48,$$

to which belongs a Poisson constant ν (6) about 0,97, near to unity. If the pipe is considered more realistic as a cylindrical shell the ratio δ_2/δ_1 becomes smaller as for a circular beam and the corresponding Poisson ratio ν decreases to about 0,9. To this small modification in the Poisson ratio from 0,97 to 0,9 the stiffness of the plate

$$d = 1/f\,(1-\nu^2) \tag{7}$$

drops to the half due to $(1-\nu^2)$. Thus we have to be carefully when calculating both, the unit deformations δ_i and the stresses, since it is a stress concentration problem. This will be done advantageously by the FEM. We use a special

finite method /2/ where the most interesting interior forces, the stretching forces and the plate moments are determined immediately. In fig. 2 the element grid and the distribution of the bending moments in some tube sections near to gridwork connection are given. At the connection there is a severe stress concnetration (section 1,2) which decreases rapidely with increasing distance from the connection, thus in some distance (section 3) only an ovalizing stress distribution remains. If the pipe walls are idealized as a circular beam the stress peak will be underestimated (fig. 2b).

Systems with a Poisson ratio $\nu \sim 1$ work quite different due to changing stress situations. If the normal forces in the axial and lateral direction are equal such systems become nearly rigid and if these forces have an opposite sign they are extremely weak. If the pipes and the gridwork members are idealized in a finite element analysis as beams (with rigid crossection) they are contracted to their center lines and the gridwork becomes automatically a continous one as in fig. 1c which works like a system with a Poisson ratio about 0,3. In this case it is indeed possible to involve the true plate stiffness (7) but not the true behaviour, belonging to a Poisson ratio about unity.

3. The interaction between the gridwork and the ring

Because the hexagonal scheme of the gridwork do not adjust with the ring geometry there are some irregularities in the length of the attachments between the outer stand pipes and the rings (fig. 1b). Since the attachments are arranged nearly radially and the rings are stiff enough within their plane the influence of these irregularities may be neglected by idealizing the gridwork as a continuum up to the rings. The deformations and the interior forces of the gridwork and the rings then are represented favourably by a Fourier series in the circumferential direction ϕ (fig. 3a)

$$u(r,\phi) = \sum U_m(r) \cos m\phi, \quad v(r,\phi) = \sum V_m(r) \sin m\phi. \tag{8}$$

The sine and cosine functions in eq (8) are orthogonal to each other, thus the gridwork may be analized for each order m seperately. The ring stiffness K_m that means the ratio between the amplitude of the radial force n and that of the radial deformation u is quite different for the different order m. In the axisymmetrical case (m =0) the rings are extremely stiff since they are only strained by normal forces

$$K_o = N_o/U_o = D/R^2, \tag{9a}$$

where D is the stretching stiffness and R the radius of the ring. In the order m = 1 the gridwork and the rings move like rigid bodies. Due to the higher order deformations ($m \geq 2$) the rings are strained by bending (bending stiffness B) and K becomes

$$K_m = B\,(m^2-1)^2/R^4, \tag{9b}$$

which is small for m = 2 and increases with the fourth power of m.

The pipes are elastically supported at the two gridwork levels and it is evident to idealize them as elastically supported beams (fig. 5a) where the stiffnesses of the supports have to involve the elastic behaviour of the gridwork. The supporting forces of the pipes which are proportional to the pipe deflection at the gridwork connection introduce radial and circumferential forces p_r, p_ϕ to the gridwork, which are also smeart out. To show the essentials we restrict ourselves to the axisymmetric case m = 0 for the stretching problem. From the equilibrium equation between the normal forces n_r and n_ϕ as well as the smeart out supporting forces p_r (fig. 3b)

$$(n_r r)' - n_\phi + p_r r = 0 \qquad (10)$$

and the stress strain relationship

$$n_r = d(u'+\nu u/r), \quad n_\phi = d(u/r+\nu u'), \quad p_r = cu \qquad (11)$$

we find the differential equation (Bessel type) for the radial deformation u

$$u''r^2 + u'r + (\frac{cr^2}{d} - 1)u = 0 \qquad (12)$$

Due to the boundary condition of our problem we get a complete set of eigenmodes $f_n(r)$. In the axisymmetric case (m =0) the radial deformation u vanish at the center point (r = 0) and the eigenmodes are fixed by the boundary condition at the ring (r = R). The first eigenmodes belonging to the limit boundary conditions: The rigid ring $[u(R) = o]$ and the weak ring or the extremely weak attached ring $[n_r(R) = 0]$ are given in fig. 3c also the eigenvalues,these are the non dimensional support stiffnesses cR^2/d. If the ring stiffness D is finite the support stiffness becomes approximately

$$\gamma_{o1} = \frac{cR^2}{d} = \frac{14,7(1+\nu+D/dR)}{4,1+\nu+D/dR} \quad (m = 0). \qquad (13)$$

The eigenvalues γ are marked by the doubleindex mn, since to each mode cos mϕ in the circumferential direction belongs a complete set of modes $f_n(r)$ in the radial direction. But we need only the first values since the support stiffness increases extremely with the order n. The eq. (13) is only valid if the traverses are arranged at the same level as the gridwork (fig. 1d). Similar relationships we get also for the higher orders m - 2 and for the bending problem.

4. Results (Eigenmodes)

Stationary loadings come from a temperature field within the surrounding water. Temperature gradients induce warping of the core coverhead, which causes stretching of the gridwork, and different elongation of the stand pipes, which cause gridwork bending. Further more two dynamic loading types are to be expected namely impact loads induced by the changing of the steam flow in the pipes when opening the valves and a random input due to the steam seperating process and to the vibrations of the core which are transfered by the core support structure. The corresponding measured horizontal motions of the upper ring are given in fig. 4. For the dynamic loads the deformation pattern will be described favourably by the eigenmodes. Since the system acts

for each eigenmode like a mass spring oscillator where the generalized masses, the eigenfrequencies and the load functions change from mode to mode. We restrict us to the eigenmodes since most of the structural behaviour is involved into the eigenmodes. They are influenced by the two partial systems: The shroud rings with the screws and the stand pipes with the two gridworks. These systems interacts with each other by the attachments between the pipes and the rings. The mechanical behaviour may be described by two beams (fig. 5a), one for the screws and the other for the standpipes each elastically supported and elastically connected to each other, where the lower pipe end is elastically built in at the cover core head.

Two types of eigenmodes are to be exspected: "Torsional" modes with significant deformations in the circumferential direction and small deformations in radial direction and "bending" modes with appreciable deformations in the radial direction and small ones in circumferential direction which will be discussed in the following. For a steam seperator drawn in fig. 1 we get the lowest frequencies due to bending of the whole seperator (m = 1), where the pipes are deflected, the rings and the grid work move like rigid bodies with small strains in the gridwork and the rings. In the first bending mode (p = 1, f_{11} = 6 Hz) the screws and the stand pipes oscillate in the same sense (mode 1 in fig. 5b). In the next mode (p = 2, f_{12} = 18,1 Hz) the screws oscillate in two half waves with small motions of the stand pipes (mode 2 in fig. 5b). Since the ring stiffness (9b) due to the ovalizing mode m = 2 (in circumferential direction) is small, the eigenmodes in the vertical direction (fig. 5c) are similar to the bending modes (m = 1, fig. 5b) the lower frequency (p = 1, f_{21} = 11 Hz) increases more as the second frequency (p = 2, f_{22} = 20 Hz). With increasing order m the rings stiffness (9b) increases more and more and also the eigenfrequencies (f_{31} = 16,4 Hz). In the range up to 20 Hz there are a large distance between the eigenfrequencies. But in the range above 20 Hz the rings becomes more and more rigid and the lowest eigenfrequencies to m = 0,4,..and the higher frequencies to m = 2,3,.come close together. The analytical results for the eigenfrequencies agree very well to the measured ones up to 20 Hz. The index at the eigenfrequencies should be a triple one mnp, since to each mode mn belongs a complete set p of modes in the vertical direction. The order n is cancelled since the eigenfrequencies to the higher modes (n ≠ 2) are also in the range beyond f = 20 Hz. If the upper ring attachment is more stiff as in fig. 1a the first frequencies f_{21} and f_{31} increases since the upper ring deflection decreases (fig. 5c).

5. References

/1/ GIENCKE, E.: Über ein Tragsystem mit einer Querkontraktionszahl $\nu \sim 1$. ZAMM 61, T 155-156 (1981).

/2/ GIENCKE, E.: A simple mixed method for plate and shell problems. Nucl. Eng. Design 29, 141-155 (1974).

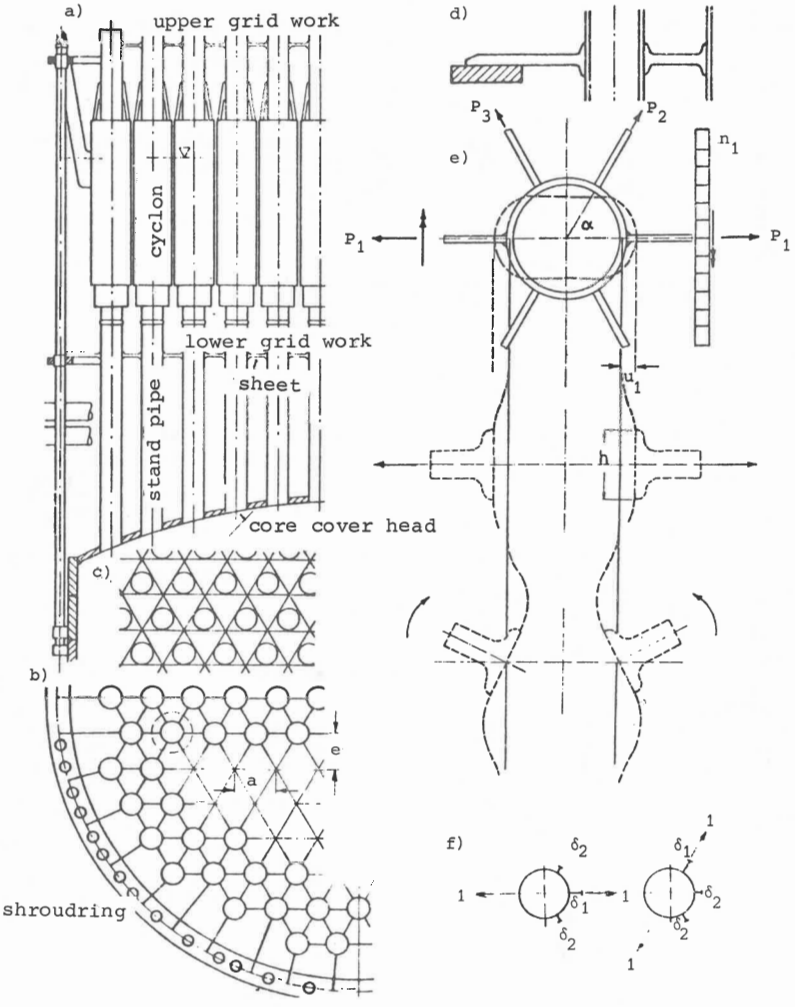

Fig.1: Steam seperator
a) vertical section
b) horizontal section (with an interrupted gridwork),
c) contineous gridwork,
d) attachment of the rings to the outer pipes,
e) deformation pattern of a gridwork unit due to stretching,
f) deformations δ_i due to a unit load at point 1 and 2.

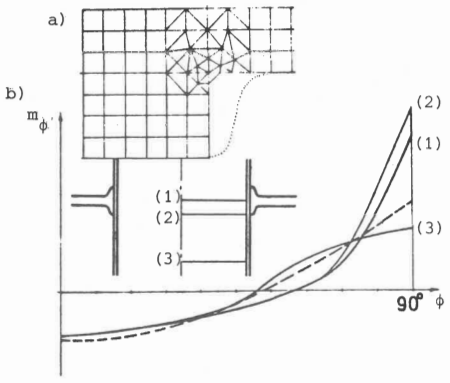

Fig.2: Bending of the pipe walls due to the normal force in the grid work
a) grid of finite analysis
b) circumferential bending
—— shell, --- beam analysis

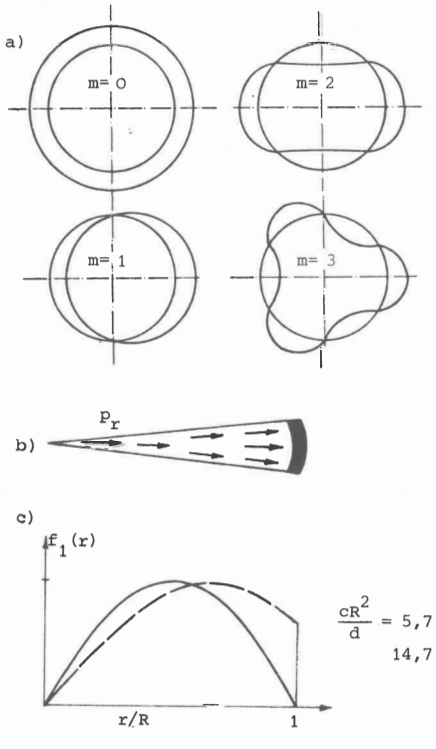

Fig.3: Deformation pattern of the gridwork
a) eigenmodes in circumferential direction
b) distributed supporting forces p_r (m=0),
c) eigenmodes in radial direction (m=0),
—— rigid ring, --- weak ring

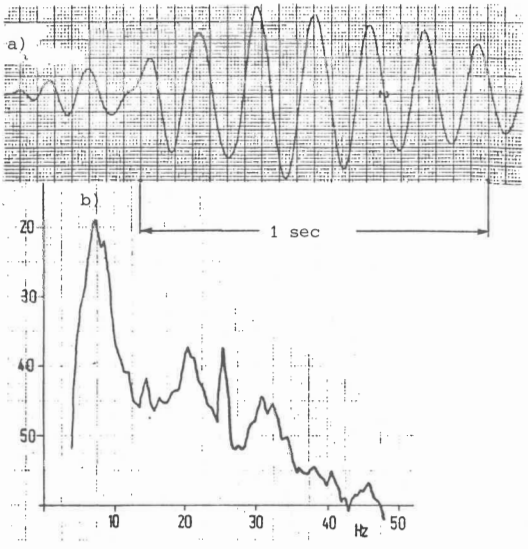

Fig.4: Horizontal motion of the upper ring
a) impact loads, b) random loads

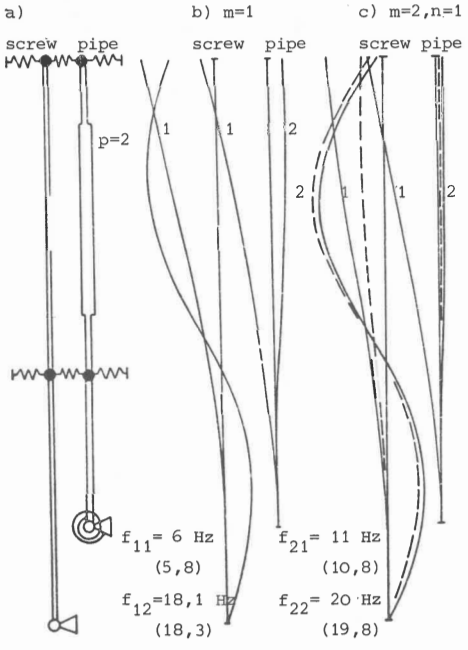

Fig.5: Eigenmodes in the vertical direction
a) model
b) bending eigenmodes (m=1)
c) ovalizing modes (m=2)
—— weak, --- stiff upper ring attachment, ( ) measured eigenfrequencies