

## Dynamic, Particularly Seismic Analysis of Vessel Internals

W. Elfmann

*NUCLEN — Nuclebras Engenharia S.A.,  
TM51, Av. Augusto Severo, 84-3º, Rio de Janeiro, RJ 20 021, Brazil*

In addition to the operation loads resulting from pressure and temperature, vessels are also strained by dynamic loads such as those resulting from emergency and faulted load cases. In addition to this the earthquake loads are also included, particularly in case of vessels which are used in nuclear power plants. Vessels are designed so that they can faultlessly perform tasks assigned to them following earthquakes or emergency and faulted load cases.

There will be the question to what extent these dynamic analysis has to be done also for vessel internals (for example for heat exchangers, steam generator). These are almost exclusively irrelevant for safety matters, but here it is necessary to define the internals availability in case of dynamic and particularly seismic loads. Taking a nuclear steam generator as an example a concept is explained which includes the stress analysis for dynamic and seismic strains.

## 1. General

The most important internals of the nuclear steam generator with economizer region are indicated in fig.1. These are the heating tubes, the flow distribution plate, the moisture separator support plate, the dryer system, the shroud as well as the components of the economizer region, i.e.: the baffle-anchoring-system, the water box and the secondary divider plate.

## 2. Dynamic loads

Dynamic excitation of the internals may result from loads caused by a hypothetically feedwater- and mainsteamlinebreak as well as those caused by an earthquake. These excitations are, according to the load case, pressure, accelerations and flow-induced forces (vortex shedding forces).

Table 1 shows which load cases are taken into consideration for the individual internals.

### 2.1 Feedwater- and mainsteamlinebreak

The loads from a feedwater- and mainsteamlinebreak are determined by means of thermohydraulic computer programs. For hypothetically assumed break locations and defined rupture opening times, time-dependent pressure and flow distributions are determined in the individual zones of the steam generator.

The zone division for example for the feedwaterlinebreak is shown in fig.2. For the majority of internals, the pressure loads are significant. Typical pressure curves for a feedwaterlinebreak at 10 % power are shown in fig.3. This figure shows the absolute pressure curve in different zones which facilitates recognizing the acting pressure differences at individual internals.

### 2.2 Earthquake (design- and safe shutdown earthquake)

The nuclear steam generator is part of the primary system located in the reactor building. For determining the seismic loads, a structure-dynamical computer model is set up, which takes into consideration the coupling between building, primary system and steam generator (fig.4). At the base point of the building, the soil spectra valid for the site

with the corresponding damping values are used as input. By means of structure-dynamic analysis, the response spectra (acceleration spectra) and the time-dependent displacements and accelerations are determined for all components of the primary system. The response spectra for the nuclear steam generator are applied appropriately to the individual internals. Typical response spectra for the horizontal and vertical directions are shown in figs. 5 and 6.

### 2.3 Flow-induced forces

In the case of a feedwater- and mainsteamline break, not only locally high pressure differences but also very high flow velocities will occur. The principle of the steam generator with economizer region consists in improving heat transfer by cross flow on the heating tubes. At tubes subject to cross flow from experience vortex shedding frequencies and lift forces are observed. The lift coefficient used for the determination of the acting forces at the tube is shown in fig. 7 as a function of the flow velocity. Consequently the stresses of the whole tube caused by flow-induced forces can be determined. At still higher flow velocities there appears the effect called "fluid-elastic coupling"; the velocities then occurring represent an upper limit (fig. 8).

## 3. Calculation methods and results

### 3.1 Calculation methods

Mainly two calculation methods are employed for the dynamic analysis: the "Time-History-Modal-Analysis" (THMA) and the "Response-Spectra-Modal-Analysis" (RSMA). For the loads caused by a feedwater- and mainsteamline break, the THMA method is used whereas, for seismic loads, the RSMA is preferred. Both methods are implemented in the finite element program STARDYNE, whereas the natural frequencies are calculated according to the LANCZOS method.

### 3.2 Natural frequency analysis

Computer models are set up for the individual internals and used subsequently for calculating the natural frequencies. All frequencies up to 100 Herz are determined. Table 2 shows in each case the first frequency in the horizontal and the vertical direction. For the various pressure-time sequences of the piping breaks, the "dynamic load factor"

(DLF) is determined so as to recognize orders of magnitude for the loads on the internals. Some typical mode shapes are shown in figs. 9-10.

### 3.3 Load case combinations and their classification

The loads caused by earthquake superposed with dead weight as well as the load case combination earthquake, mainsteam- or feedwaterline-break superposed with dead weight are classified as "faulted conditions" (level D), whereas the load case combination of mainsteam- or feedwaterlinebreak and dead weight are defined as emergency conditions (level C). The stresses are evaluated according to ASME-code NB-3224 (level C) and NB-3225 (level D).

### 3.4 Results

A detailed evaluation of the stresses of the internals shows that the safety margin is for all load cases and load case combinations in some cases extreme above the allowable one. Besides the comparisons of stress intensities there were also considered stability cases like buckling. In case of very small safety margin, the question arises here whether, by means of more refined calculation methods (e.g. using THMA for seismic load cases) the existing conservativities in the analysis can be reduced or whether improving the design appears appropriate. This must be decided case-by-case. For the flow-induced loads of the heating tubes due to vortex shedding, the margin between forcing frequencies and natural frequencies is sufficiently wide. The forcing frequencies are much lower as the natural frequencies of the parts of the heating tube.

The danger of vibrations due to "fluid-elastic coupling", specially in the upper regions of the steam generator, does not exist, because the actual flow velocity is substantially lower than the critical one.

It has thus been shown that the steam generator internals are adequately dimensioned also for the very extreme accidents. Damage of the heating tubes caused by a failure of the internals can therefore be excluded.

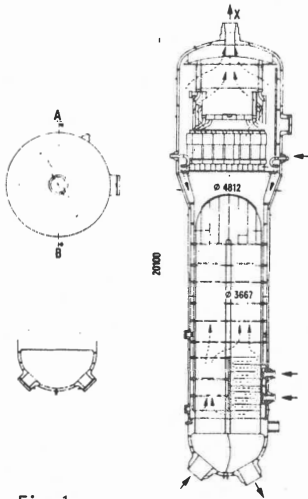


Fig. 1

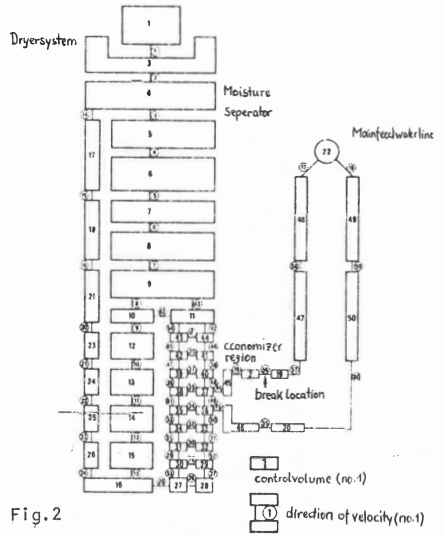


Fig. 2

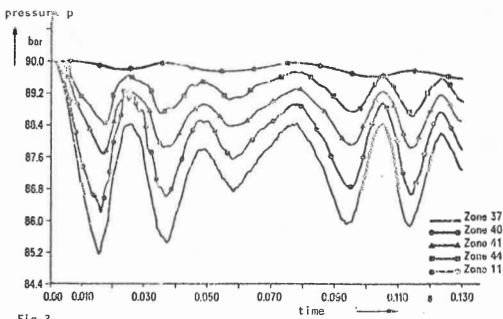


Fig. 3

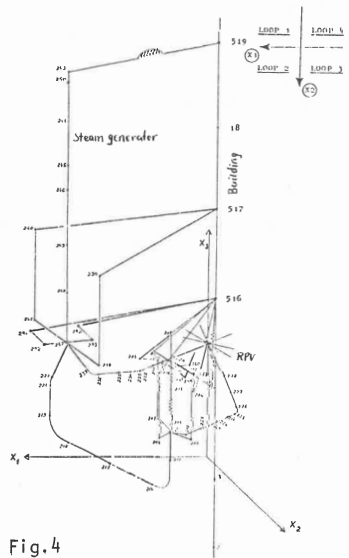


Fig. 4

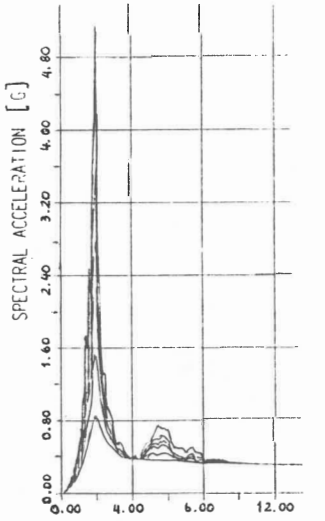


Fig.5 Horizontal direction

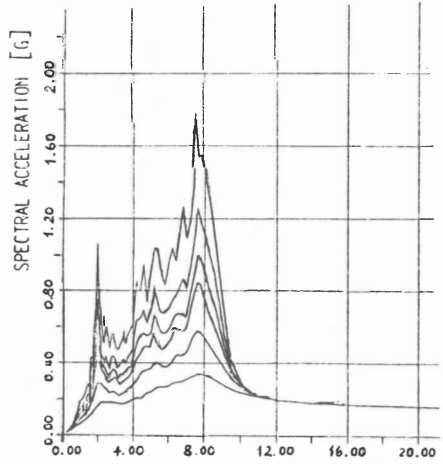


Fig.6 Vertical direction

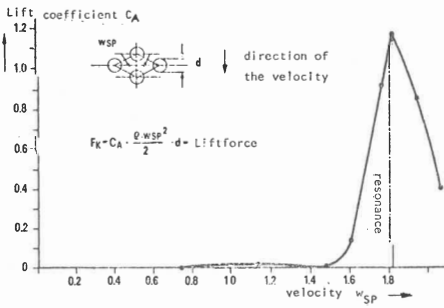


Fig.7

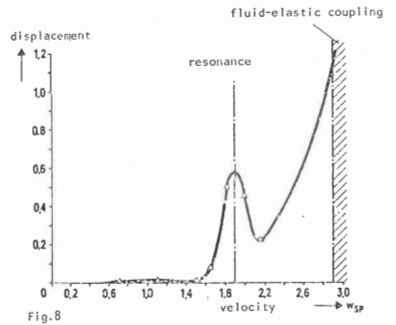


Fig.8

Mode shapes of the secondary divider plate

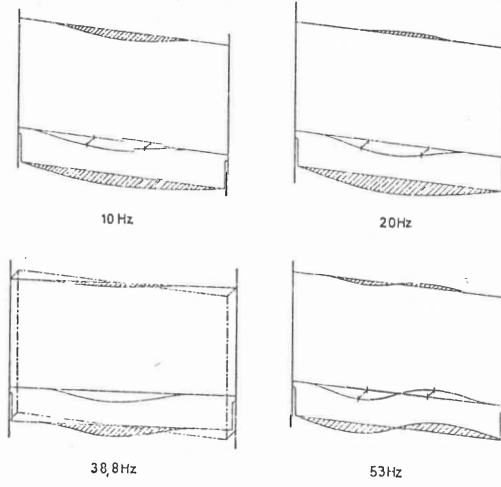


Fig.9

The fourth mode shape of the baffle-anchoring-system

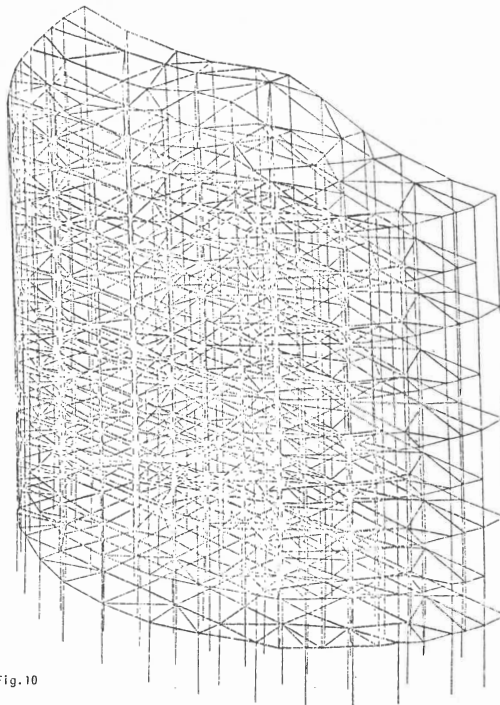


Fig.10

|                                  | FWLB <sub>p</sub> | MSLB <sub>p</sub> | FWLB <sub>f</sub> | MSLB <sub>f</sub> | EQ |
|----------------------------------|-------------------|-------------------|-------------------|-------------------|----|
| Heating tubes                    | X                 | X                 | X                 | X                 | X  |
| Flow distribution plate          | :                 | X                 |                   |                   | X  |
| Moisture separator support plate | :                 | X                 |                   |                   | X  |
| Dryer system                     | :                 | X                 | X                 |                   | X  |
| Shroud                           | X                 | X                 |                   |                   | X  |
| Baffle-anchoring-system          | X                 | :                 |                   |                   | X  |
| Water box                        | X                 | :                 |                   |                   | X  |
| Secondary divider plate          | X                 | :                 |                   |                   | X  |

: loads are covered by other linebreaks

FWLB<sub>p</sub> Feedwaterlinebreak(pressure)

MSLB<sub>p</sub> Mainsteamlinebreak(pressure)

FWLB<sub>f</sub> Feedwaterlinebreak(flow-induced forces)

MSLB<sub>f</sub> Mainsteamlinebreak(flow-induced forces)

EQ Design- and safe shutdown earthquake(acceleration)

Table 1

First frequencies of the internals in horizontal  
and vertical direction  
Dynamic load factor

|                                  | horizontal<br>frequency(Hz) | vertical<br>frequency(Hz) | DLF <sup>3)</sup>  |                    |
|----------------------------------|-----------------------------|---------------------------|--------------------|--------------------|
|                                  |                             |                           | feedwaterlinebreak | mainsteamlinebreak |
| Heating tubes                    | 1,8                         | 10,5                      | 1,00               | 1,00               |
| Flow distribution plate          | 18,1                        | >100,0                    | -                  | -                  |
| Moisture separator support plate | 31,9 <sup>1)</sup>          | 27,8                      | 1,14               | -                  |
| Dryer system                     | 64,4                        | >100,0                    | 1,22               | -                  |
| Shroud                           | 41,2                        | >100,0                    | 1,06               | 2,32               |
| Baffle-anchoring-system          | 28,8                        | 135,0                     | 1,01               | 1,10 <sup>2)</sup> |
| Water box                        | 38,9                        | 154,0                     | -                  | 1,46               |
| Secondary divider plate          | 10,0                        | >100,0                    | 1,01               | 2,18               |

1) Vibration of the separators

2) one baffle, not the system

3) Dynamic load factor

Table 2