Analytical and Experimental Investigations of the Dynamic Behaviour of the MAW-Evaporator Module

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INTRODUCTION

The structural concept of DWK's reprocessing plant at Wackersdorf provides a modular technique for remote operation in the middle and high active process areas (FEMO-technique). This new technique was tested on full scale models of modules at the Lahde test station.

In the framework of the DWK test project the MAW-evaporator module (fig. 1) was selected from a multitude of reprocessing modules containing evaporators, because this module contains the largest process component heated in operation. To achieve a most realistic method of analysis ensured by measurements, the module was constructed with the original stainless steel. The analyses are required for submission within the license procedure.

This paper gives an account of the calculations and tests carried out to investigate the dynamic vibration behaviour of the MAW-module. The calculations include free vibrations and earthquake loading. The corresponding tests are experimental modal analysis (EMA) and harmonic excitation (HE).

DYNAMIC CALCULATION DURING DETAIL ENGINEERING

In order to allow for the special demands of the special load case earthquake at construction, dynamic calculations of the module for this load case were carried out during the detail engineering phase.

For this purpose the module was modelled for a finite-element calculation (fig. 2). The model contains:

- the frame including all intermediate beams,
- all vessels and apparatus which interact with the frame because of their stiffness and mass,
- pipes of large nominal diameter DN 150 - DN 250, which are characteristic for this module.

All other components were taken into account with their masses including the maximal fluid filling during operation, so that the model reproduces the global general behaviour of the module.

As an intermediate result for the dynamic stress analysis the eigenfrequencies and mode shapes were determined. These modal parameters are especially suited to characterize the dynamic behaviour of the structure, because:

- they demonstrate an engineer-like account of the vibrational behaviour,
- the influence of all parameters of the calculation, for example stiffness, mass, material, boundary conditions and interaction between individual structural parts can be described by only two controlling quantities, which are eigenfrequency and mode shape.

Accelerations, displacements, stresses and strains were calculated for the load combinations earthquake by use of the response spectrum modal analysis (RSMA).

EXPERIMENTAL MODAL ANALYSIS

The model at Lahde differs from the calculation model due to the changes it underwent during construction, manufacturing and assembling. The aim of the experimental modal analysis was to document the actual state of the structure. Fig. 3 shows the measurement model. The mode shapes and eigenfrequencies were chosen again as a measure of comparison. They were determined by use of the experimental modal analysis with hammer impulse excitation.

ADJUSTED DYNAMIC CALCULATION

Contrary to the calculation model described above the following manufacture and test-station specific modifications were considered:

- overall weight reduction to meet the specific filling at the test-station,
- altered local flexibility of the supporting parts,
- larger wall thicknesses in the area of the bearings of the larger components.

With these modifications, the eigenfrequencies and mode shapes were calculated again. Furthermore, this calculation model was used for the modal analysis of the harmonic excitation (HE) tests. According to the results compared with earthquake calculations the required type of shaker for HE was determined.

SHAKER EXPERIMENTS

The aim of the harmonic excitation by shaker was the experimental simulation of the design earthquake (OBE). Therefore the frequency range of the driven sinus sweep was chosen from 1,5 Hz to 7,5 Hz according to the mean excitation range of the acceleration spectrum. The frequency change was slow enough to approach stationary vibrations at each frequency. Fig. 3 shows the measurement model with test load. Accelerations were measured to control the obtained excitation level in comparison with the calculations. Strain gauge measurements yielded the level of strength.

EVALUATION OF THE RESULTS

The relevant mode shapes of the calculations and the measurements were compared with each other for the vibrational analysis. The comparison of the first mode shape is illustrated in fig. 4. The mode shapes of the calculation and the measurement are in good agreement. Due to the model adjustments with mass reduction and increased stiffness, the calculated frequencies approach the measured frequencies.

The reason for the lower frequency of the calculation model is the stiffer system behaviour at the low loading level of the experimental modal analysis. In the shaker tests with high load level the resonance frequencies decreased (see fig. 5). Figure 5 shows acceleration responses from calculations and measurements at selected points. The comparison of the results shows adequate earthquake simulation by shaker excitation for the vibration sensitive module area between the module supports at the bottom and near the top. The experimentally attained accelerations exceed the aimed ones of the OBE-calculation.

CONCLUSIONS

The module bore the test loading repeatedly without any damage. The amount of calculated stresses was verified by strain measurements at selected parts of the structure. The stress values for earthquake loading are below the allowed values.

Fig. 1: MAW Module

Fig. 2: FE-Model

$$\begin{aligned} F(t) &= mr \Omega^2 \sin \Omega t \\ \Omega &= 2\pi f \\ mr &= 2 \div 8,9 \text{ kgm} \end{aligned}$$

Fig. 3: Measurement model, shaker load

Fig. 4: Free vibrations, comparison of first mode shape

Fig. 5: Comparison of accelerations $[m/s^2]$