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Reduction of operational vibration and seismic design of the feed-water piping system of the VVER-440/213 at PAKS

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ABSTRACT

The feed-water piping system in unit 3 of the nuclear power plant in Paks was suffering strong operational vibration. To reduce this vibration and also to increase the seismic safety, the piping was analysed and optimised. In order to solve the problem measurings and calculations were combined efficiently: Vibrations measured were used both for a first evaluation of the damaging potential of the operational vibrations as well as for the optimisation of a calculation model. The reduction of the operational vibrations and the improvement of the strength during earthquake were achieved by means of viscous dampers, the parameters of which were determined by a strategy of maximising the energy dissipation in the relevant frequency range. The calculation showed a significant reduction of the operational vibrations for the system with dampers. The vibration amplitudes are reduced to 1/10 of the original values. The measurements designed have in the meantime been partially carried out and the measurements confirm the favourable prognosis of the calculation.

INTRODUCTION

The entire feed-water piping system in unit 3 of the nuclear power plant in Paks was exposed to great operational vibrations. The task was to evaluate the operational vibrations with regard to their permissibility an to reduce them through improvement measures where necessary. At the same time operational loads and earthquakes for the original system and for the improved system were to be evaluated.

Operational vibrations in piping systems are a rather frequent cause for damages. Due to the practically unlimited load frequency connected with these vibrations the strength of the material is very reduced. For the ferritic material of the feed-water piping system the decisive fatigue strength is at only 1/5 of the tensile strength. For this reason visually rather unnoticeable vibrations can lead to cracks in the piping system after some time, especially at those parts which show stress concentrations due to their construction.

METHOD OF SOLUTION

First of all the feed-water pipe in the inspectable area of the engine house was evaluated according to the usual, simple and conservative method as described in /1/: Vibrational velocities were measured for the total length of the pipes and were evaluated with regard to their permissibility. Thus, it could be shown that a big part of the feed-water pipe is not stressed unpermissibly by operational loads.

For the pipe on the 15.5 m level, however, the vibrational speeds measured exceeded the permissible values. Therefore, a more exact and realistic evaluation was carried out based on a structure-dynamic calculation. The information available from previous measurements of operational speeds was used for the qualification of the calculation.
After locally measuring the dimensions and location of the system, the dynamic behaviour of the pipe system was simulated with a piping programme. A simulation consisting of pressure pulses with statistically varying parameters in certain areas was applied for the load. Due to some adaptations to the results measured, a very realistic calculation model was set up.

With this calculation model the stresses caused by operational vibrations can now be evaluated realistically for each part of the pipe. In this way parts of the pipe, for which measurements do not exist due to bad accessibility, can be evaluated. This was the case for the pipe system in the reactor building.

If the calculated stresses are inadmissable - compared to the fatigue strength of the material - hardware adjustments for the reduction of the vibrations become necessary. The adjusted calculation model is now also suitable for the conception, optimisation and realistic judgement of the efficiency of improvement measures.

The example of the feed-water pipe in Paks showed that an improvement with viscous dampers is extraordinarily effective. The calculation in the time area of the system with local viscous damping was done by means of the calculation programme KWUROHR /3/. The values for the viscous dampers were determined with a specially developed optimising strategy to maximise the dissipated energy. The viscous dampers also have a very load-reducing effect for the load case earthquake which resulted in the improvement of the pipe regarding operational vibrations and earthquake at the same time.

RESULTS

The entire feed-water piping system has a pipe length of 930 m, however, due to fixed points it was analysed in three sections. As an example the results for the system on the 15.15 m level in the engine house are shown. Figure 1 shows this system. The parts at which the measurings were carried out are marked. Acceleration versus time functions were measured from which velocities and amplitudes were derived. Figure 2 gives a survey of the vibrational velocities measured and the permissible values according to /1/. The values measured are partly
considerably higher than allowed.

In order to determine in a less conservative manner whether improvement measures are inevitable or to elaborate these measures, the calculation model and its load functions were adapted to where the measurements were reproduced rather well. Figure 3 shows the result of these adaptations at the measured and calculated displacements. At three measuring points high deviations occur, which could, however, be lead back to deficiencies during measuring. At all other places the results are good.

The stresses calculated by means of the calculation model which was adapted to the measuring results show that the permissible values were exceeded at some parts. This concerned component parts which were given very conservative stress concentration values in the calculation programme. These stress concentration values could have been reduced by applying a Finit-Element-Analysis. Regarded in this way, the simulation of operational vibrations produced permissible results. Pre-damaging of the feed-water system does not necessarily have to be expected and improvement measures are not urgently necessary.

However, in order to reduce the visually quite considerable vibrations, an improvement with viscous dampers was designed /4/. Thus, a bigger distance from the permissible stresses was reached, which is desirable as operational vibrations may slightly change through the course of time. The dampers also have a very positive effect on the earthquake endurance of the pipe system.

When determining the parts at which the dampers are to be attached, the constructional conditions and possibilities have to be taken under consideration. In this case it seemed reasonable to attach the dampers where elastic supports already existed. Thus, the possibility of load reduction into the building was ensured and neither new anchor plates nor any special proof was necessary, as the load of the damped system is generally lower than the load of the undamped system. This is a great advantage of the viscous dampers.

Figure 4 shows the 4 highest stresses for the system without dampers (variant 0) and for 4 slightly different configurations of dampers. The variants 2 to 4 resulted from variant 1 - which was achieved by estimation - and were then optimised according to /2/. It is clearly shown how important the optimum determination of the dampers' parameters is in order to achieve really good results. The stress level shown in picture 6 could be reduced - as already mentioned - by less conservative stress concentration values. Figure 5 shows the effects of the damper configuration - planned for the realisation according to variant 4 - on the effective values of the vibrational amplitudes. The global easing of the vibrating system can be seen more clearly than for the stresses.

Figure 6 clearly shows the vibration-reducing effect of the viscous dampers as well. The transfer functions for one part of the system (30RL25, 15.5 m level) are shown here, on the left without dampers and on the right with dampers. With respect to the undamped original piping there is an essential reduction of the amplitudes in the damped case.

CONCLUSIONS

By means of an efficient combination of measurements and calculations a realistic evaluation of the operational vibrations in the feed-water pipes in the nuclear power plant Paks 3 was possible. By means of a calculation model adjusted to the measurements it was shown that the operational vibrations were not able to cause any pre-damaging.

Viscous dampers, the parameters of which were determined by means of a special optimising strategy, were planned in order to reduce the operational vibrations and to improve the strength of the pipe system during earthquake. In the meantime these dampers have been partly installed and measurements confirm the improvement predicted by the calculation: The vibrational amplitudes reduced by approximately 1/10 of the original values.

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Fig. 1: Piping on 15.15 m Level

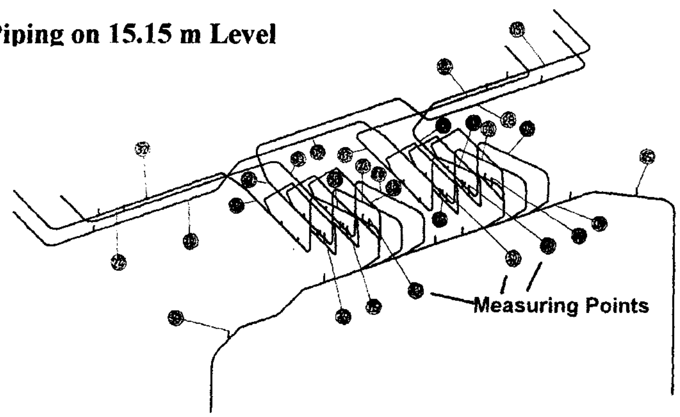


Fig. 2: Measured and Allowable Peak Velocities

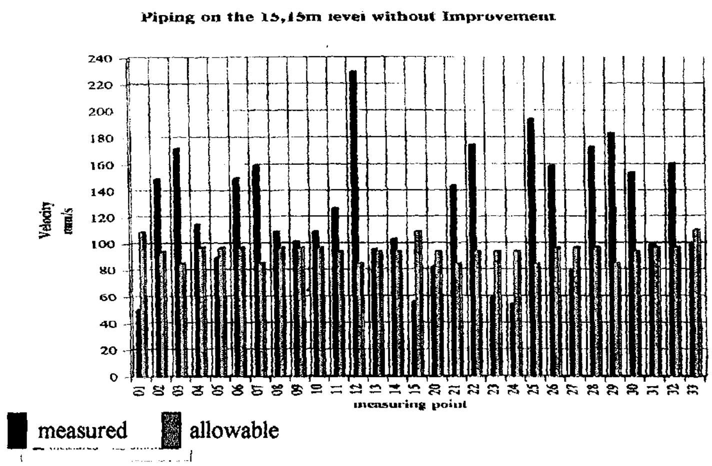


Fig. 3: Effective Values of Displacements Calculated and Measured without Damping

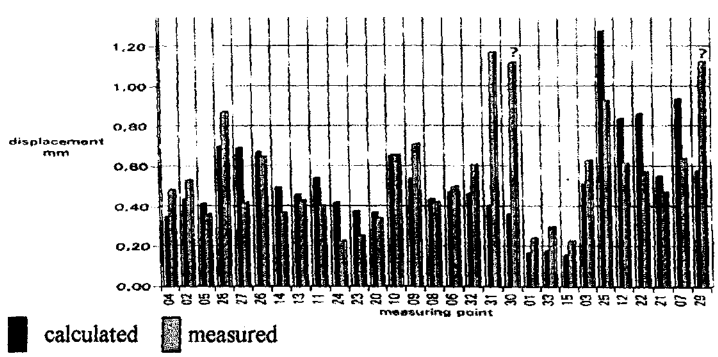


Fig. 4: Effect of Viscous Dampers for Different Configurations

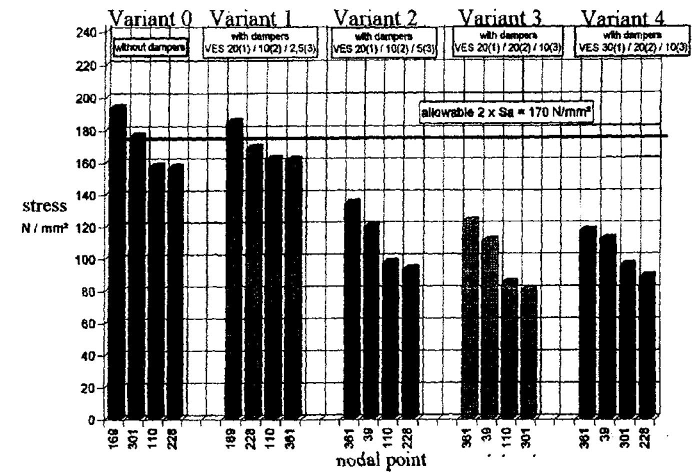
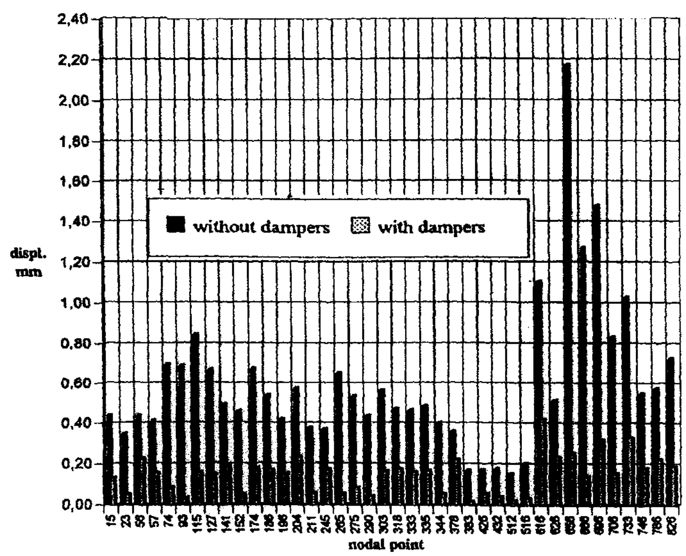


Fig. 5: Effect of Viscous Dampers on Displacements



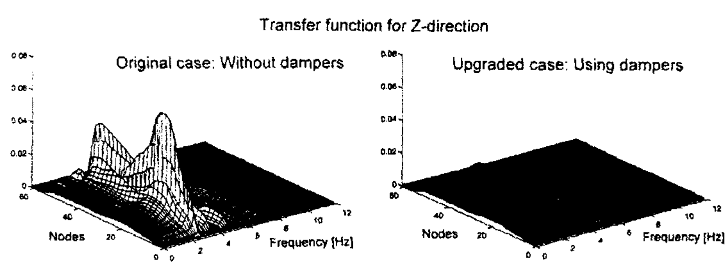


Fig. 6: Transfer Function Comparison