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ACOUSTIC SYSTEM FOR PIPE RUPTURE MONITORING AND LEAK DETECTION

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INTRODUCTION

As a safety aspect pipe rupture and leakage effects are of particular interest in nuclear power plants where severe consequences for the reactor may result. Counter measures against postulated pipe breaks and leakages in nuclear power plants are necessary whenever the main safety goals: safe shut-down, safe afterheat removal and retention of radioactivity, are endangered.

Against the mechanical effects of pipe breaks (e.g. shock wave, jet and reaction forces) passive devices such as pipewhip restraints, physical separation of safety systems, or shielding structures are employed.

In such cases where the leaking fluid itself affects plant safety, e.g. due to its high temperature, chemical reactions, or radioactivity, active devices are needed to stop the leak and/or shut the plant down. To activate such devices it is necessary to detect that a leak has occured and - in many cases - to identify the leaking system. If the leak is small early detection and counter actions may help to avoid immediate activation of safety systems with resulting plant shut-down.

The requirements to be met by a leak detection system depend on the time available for counter actions. If this time is short so that automatic actions are necessary the German safety criteria for nuclear power plants (Criterion 6.1) require two physically diverse signals to be monitored.

One fairly obvious possibility of leak detection is to monitor process parameters (pressure, flow). As a diverse signal physical parameters outside the process may be employed: pressure, pressure transients temperature, humidity are principally suitable. In practical application, however, it is difficult to predict these parameters by way of calculation in order to establish the required set-point of the monitoring system. Experimental determination is possible only in special cases.

A study of several ways of diverse leak detection methods lead to the very promising acoustic method. We investigated experimentally the feasibility of monitoring the sound created by a leakage. Air borne sound as well as body borne sound was analyzed.

MONITORING OF AIR BORNE SOUND, ACOUSTIC SIMULATION OF PIPE LEAKAGE

For an acoustic pipe rupture monitoring system a concept has been conceived which allows to design and test the system before the plant is put into service. To verify this concept the sound level of a steam jet discharging into open air was mapped in various distances from the discharge opening, and tape recordings of the noise were taken. The recordings were played back at a somewhat reduced level in an operating power station, thus simulating a pipe rupture or leakage. It could be shown that the simulated steam leak can reliably be detected against the background noise simply by monitoring air borne sound level.

The open air experiments were performed at the heating plant of the Kernforschungsanlage Jülich (KFA). Steam of 1.3 MPa and 250 °C was discharged horizontally about 2.3 m above the ground from a 130 mm pipe through orifices ranging from 3 to 100 mm diameter. Figure 1 shows a photograph of such a 100 mm leak.

An example of the sound field for the 100 mm leak is shown in Fig. 2. The characteristical 45° angle of the sound pressure maxima is distinctly seen. At greater distances, where velocities become lower, this angle reduces to about 30°. The characteristic is explained by Lighthill's theory of the quadrupole source of flow induced noise which cannot be discussed within the scope of this paper. The disturbance created by reflection at the lateral building diminishes with increasing distance, as expected.

The simulation of a leak was tested against strong background noise at the AVR reactor in Jülich and at the fossil fired power station Großkraftwerk Mannheim (GKM). The test set-up is shown schematically in Fig. 3. Simulation of the leak is performed by playing back the noise recordings from the KFA heating plant through powerful loudspeakers. The "leak detection" set-up consists of microphone, sound pressure meter, filter and recorder. An additional tape recording is taken for an off-line frequency analysis. To test the directional sensitivity, i.e. the systems capability to localize the leak, two additional channels are used with microphones at different distances from the noise source.

The advantage of the acoustic leak simulation is obvious from Fig. 4, which shows the signal received from the two additional microphones. The left trace, reflecting the microphone placed farther away from the source, shows a distinct time lag and lower amplitude. These two differences are easily utilized to localize the "leak", i.e. left-right distinction, by means of a "first-in" circuit. By placing the loudspeakers in varying locations throughout the area to be monitored the optimum microphone location can be determined and the monitoring system tested without creating an actual leak.

The monitoring system should not only be able to detect steam leaks, but also leaks from feedwater pipes. In addition to the experiments with steam jets, feedwater jets were therefore analyzed. Marked differences to the steam jets were observed: The shape of the feedwater jet shows a much stronger expansion near the origin (Fig. 5). This may be explained by the spherical velocity components caused by evaporation of the feedwater. The sound pressure levels, especially in the higher frequency range, are lower for feedwater than for comparable steam leaks (Fig. 6). The lower overall sound level is, however, partly compensated by a more uniform sound field.

Even with the comparatively lower sound pressure levels created by feedwater jets, feedwater leakages can be reliably detected against plant background noise, assuming an alarm level of about 110 db(lin). This was shown by additional experiments at the GKM plant, where feedwater at 13 MPa was available. Plotted in Fig. 7 are the sound pressure levels of feedwater leaks at different pressures, measured at KFA and GKM. An extrapolation of the sound pressure level to feedwater pressures found in modern power plants shows that a monitoring system set at an alarm level of 110 db(lin) can reliably detect leakages of feedwater and steam, with leakage areas down to 80 mm^2 at distances of 10 m.

The experiments presented here concentrate around audio-frequencies, with peaks in the 1 to 10 kHz range. Commercial leak detectors utilizing the sound monitoring principle operate in the 30 to 45 kHz range. However, sound attenuation increases with higher frequencies. At longer distances it is advantageous to monitor the audio range, where the signal-to-noise ratio is better, despite higher background noise.

MONITORING OF BODY BORNE SOUND

Simultaneously with the steam jet discharge experiments the body borne sound generated by the jet was measured by piezo electric detectors mounted against the pipe wall at a distance upstream of the leak. Fig. 8 shows the results, plotted against piping length. (Total length between leak and boiler is about 80 m.). The significant drop of the noise signal near the leak is explained by damping due to a valve flange gasket. Similarly, damping occurs at concrete pipe supports.

Monitoring body borne sound has some advantages if entire pipe systems are involved. Especially to localize a leak from a distance less equipment is needed compared to the method of monitoring air borne sound. A disadvantage is the intensive background noise during plant operating transients, e.g. start-up, shut-down, or load changes. A good solution seems to be the combination of both methods.

ACOUSTIC DETECTION OF SMALL LEAKS

Considering the detection limit for small leaks process parameters (pressure, temperature) and damping are of importance, however, the main parameter is leakage area.

At the KFA heating plant tests were conducted - under a different task - with steam leakages through orifices of 1 to 5 mm diameter. Measuring body borne sound the leaks were reliably detected against considerable background noise over a pipe distance of 5 m. Further test series on feedwater lines are planned at the AVR reactor in Jülich, with leakage diameters below 1 mm, to closer evaluate detection limits.

On high temperature reactors the detection of helium leaks is of particular interest.During the start-up phase of the Hochtemperatur-Helium-Versuchsanlage(HHV) in Jülich it was successfully attempted to determine such leakages: At the shaft seal system of the turbo set an increasing external helium leakage had occured, estimated to be about 30 - 50 m^3/h (STP). This leakage could be diverted to a second seal system. Using common sound emission analyzing channels to monitor body borne sound this change could be registered, see Fig. 9. The detectors were placed at the main gas duct at the inlet to the turbo set (I), the outlet (II), and at the hot gas duct (III). Channel II clearly shows the switch-over to the second seal system by a signal drop of about 80 % (log scale). The operation is repeated after 10 minutes. Channel I, away from the leak, shows some reaction, however with large oscillations. Channel III shows no noticeable change. The high signal-to-noise ratio is remarkable considering the size of the entire unit and the helium velocities of up to 120 m/s in the hot gas duct. Beside the leakage other characteristic effects could be registered, e.g. rotor vibrations during a turbine trip.

CONCLUSIONS

The results of the experiments conducted allow the conclusions that the method of monitoring air borne sound in the audio range up to 20 kHz is suitable for leak detection. Its particular advantage is the possibility of installing and testing the system by simulating the leak acoustically. The method of monitoring body borne sound is more sensitive where larger piping systems are to be monitored under steady state conditions.

Both methods do not require noise analysis, simply monitoring signal level is sufficient. Plant operating transients result in different background noise bands for the two methods. In practical application a combination of both methods is indicated, if erroneous trip signals are to be avoided.

Fig. 1

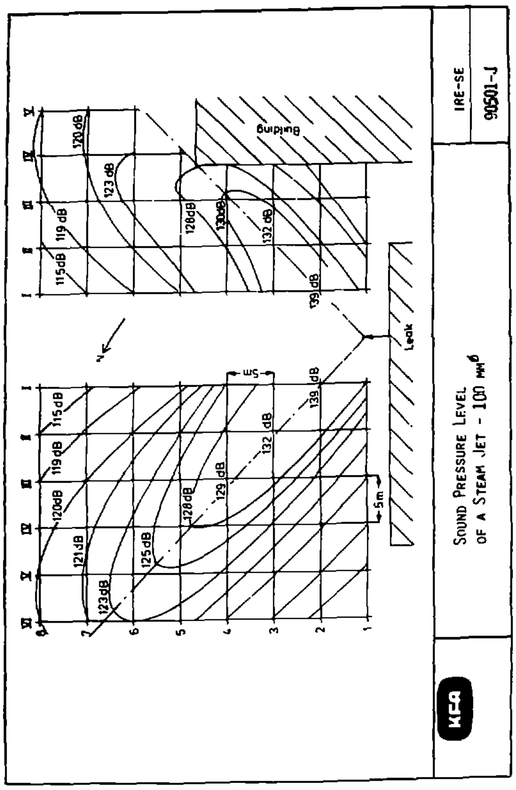

Fig. 2

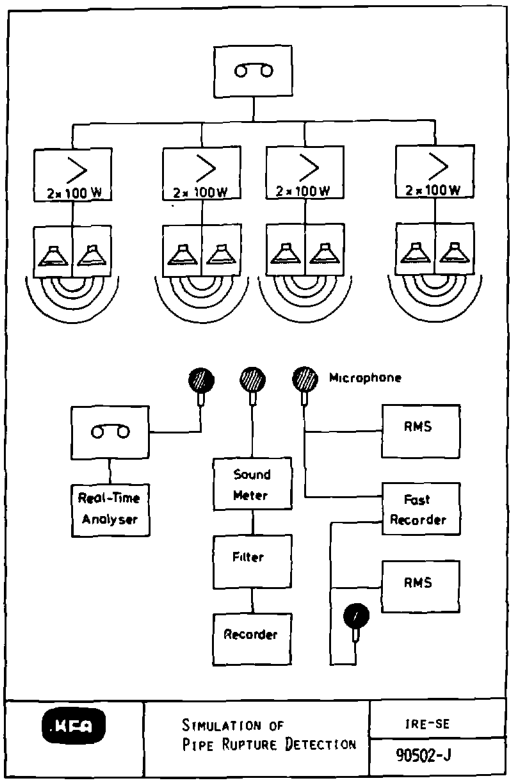

Fig. 3

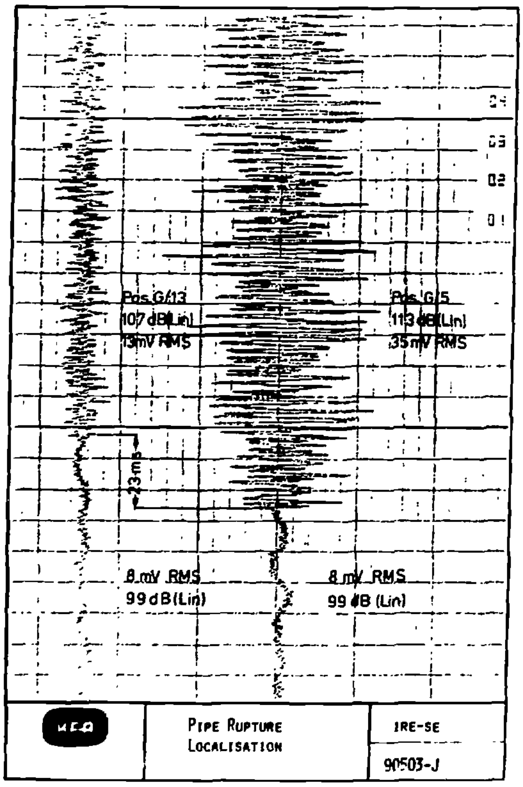

Fig. 4

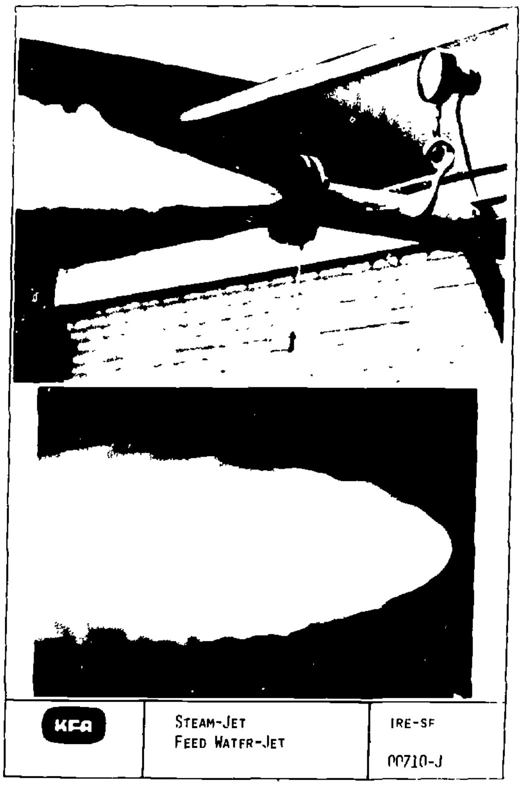

Fig. 5

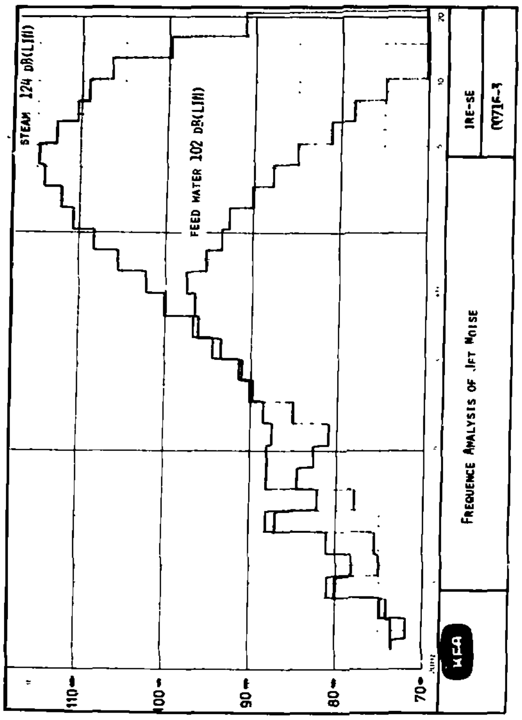

Fig. 6

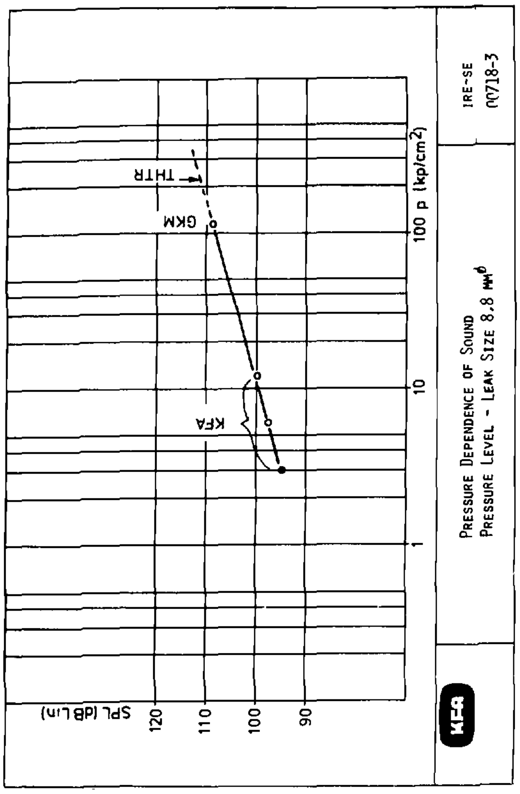

Fig. 7

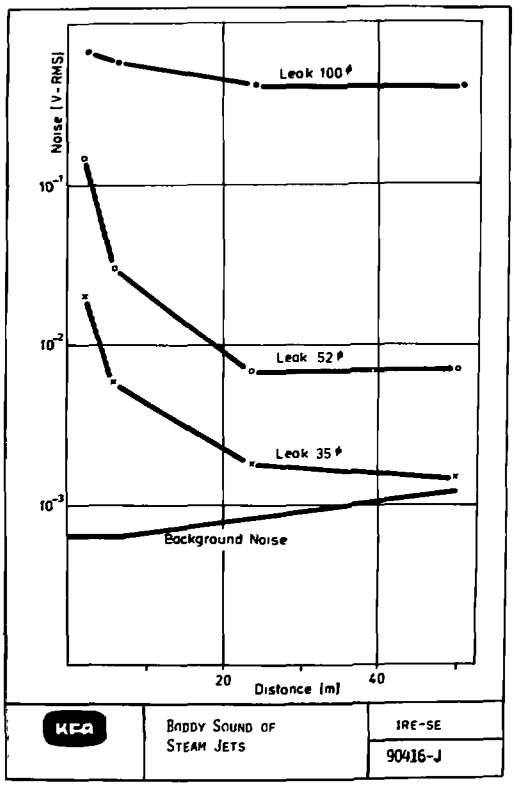

Fig. 8

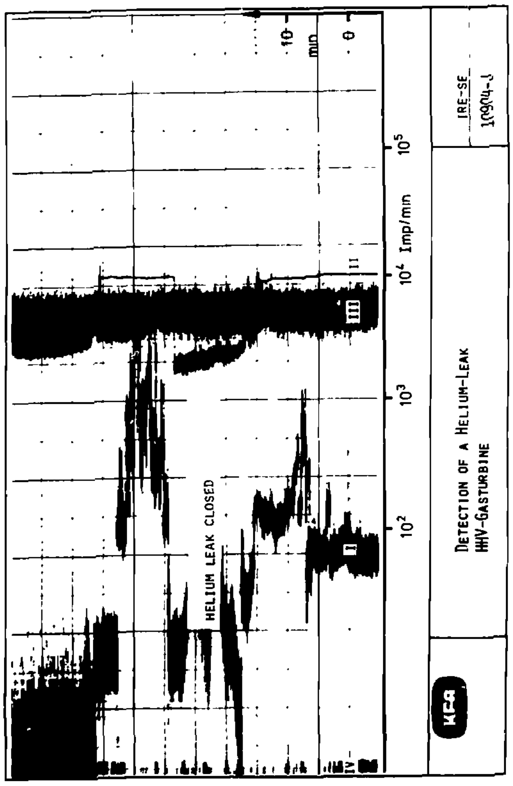

Fig. 9