framatome

Assessment of thermal loads and resulting fatigue in closed pipe branches

Multidisciplinary approach to evaluate the effects of thermal oscillations on the integrity of closed pipe branches

Framatome's multidisciplinary approach predicts the possibility and intensity of thermal fluctuations in closed pipe branches and evaluates them with regard to thermal fatigue and fracture mechanics

Challenge

In power or industrial plants, numerous pipe branches on hot flow main lines are shut off during normal operation.

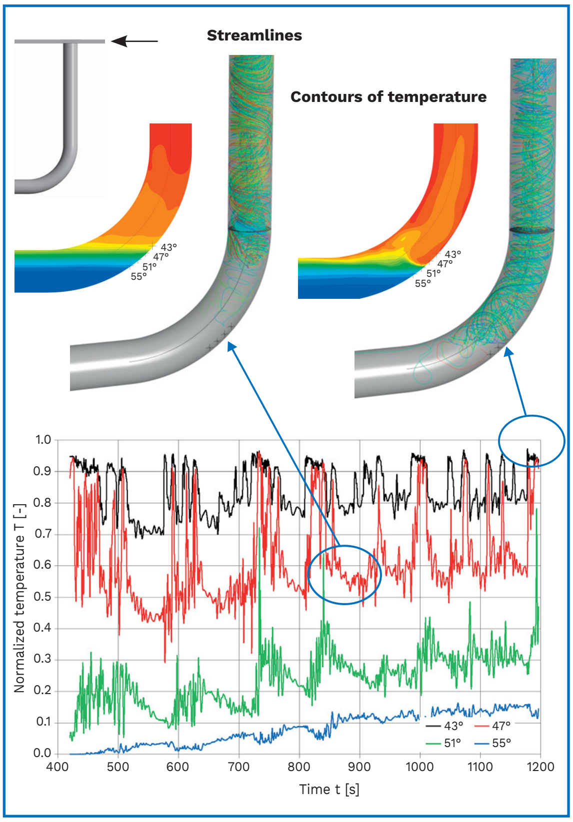
Under certain conditions the hot fluid of the main pipe penetrates into the closed branch and forms a spiral vortex, which interacts with the cold fluid in the closed branch pipe. The fluctuating penetration depth of the spiral vortex leads to thermal shock loads and may initiate thermal fatigue cracks followed by subsequent crack growth in the branch pipe.

Solution

Framatome's methodology predicts whether thermal fluctuations occur in the closed pipe branch as well as the order of magnitude of their frequencies and amplitudes. The simulation of the complex transient three-dimensional turbulent flow is performed with a state-of-the-art Computational Fluid Dynamics (CFD) code and includes the heat transfer through the pipe wall and through any existing insulation towards the environment.

Based on the calculated three dimensional time dependent temperature field of the pipe, a Finite Element Model (FEM) is used to analyze the resulting stresses including the loads caused by pressure and dead weight.

Finally, the stresses are evaluated with regard to their thermal fatigue relevance and can be used for further fracture mechanics analysis.



Temperature distribution and stream lines (top) and time dependent temperature progress at the pipe bend out side (bottom)

Customer benefits

- Gain confidence over the integrity of the pipe branch
- Optimize inspection interval for the pipe branches to improve plant safety and availability

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is **our** everyday **commitment**

Technical information

When hot fluid flows over a closed pipe branch, an unstable spiral vortex penetrates into the branch. This vortex transports in its outer area adjacent to the branch wall the hot fluid from the main line into the pipe branch while inside it sucks the colder fluid out of the pipe branch to fulfill the mass conservation. Since the penetration depth of the vortex is time dependent the branch pipe wall encounters unsteady thermal loads, which may initiate thermal fatigue cracks.

A one-way coupled approach between the fluid- and thermodynamics of the flow and the structural mechanics of the pipe is used to evaluate the relevance to thermal fatigue.

The three-dimensional unsteady temperature distribution of the pipe branch is simulated with a state-of-the-art Computational Fluid Dynamic (CFD) code including conjugate heat transfer and buoyancy forces. To resolve the fluctuations in the flow a high resolution discretization of the fluid domain is necessary using a Detached Eddy Simulation (DES) for turbulence modelling.

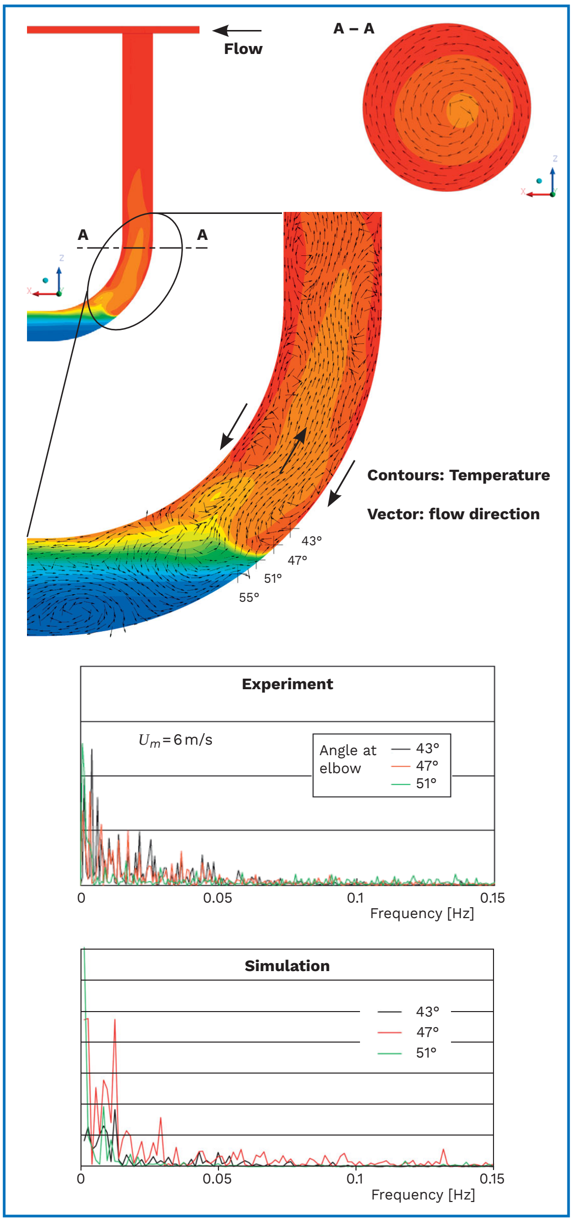
The resulting temperature field is used as input for a Finite Element Model (FEM) to calculate the stresses and evaluate their relevance to thermal fatigue, critical crack size and crack growth.

The Fluid dynamic approach has been validated against experimental data from Nakamura et al, published in:

- Nuclear Engineering and Design (2014)

The fatigue method has been published at:

- NAFEMS DACH conference (2016)



Simulation of temperature and flow distribution with CFD (top). Comparison of measured and simulated frequency spectrum (bottom).

References

- Safety injection line of a Swiss Nuclear Power Plant [2020]

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