Vibration	Fluid Elastic Vibration occurred on Heat Exchanger	Plant
Self-excitation		

Object Machine

Thin tube bundle of heat exchanger (tube having fins, triangle arrangement, P/D=1.16)

Observed Phenomena

As shown in Fig.1, the equipment under consideration is a thin tube bundle provided with baffle plates at two positions. Previously, this equipment was operating normally, but at the time of each periodic inspection, contact parts of the tubes and the loose-supported baffle plates exhibited minute contacts or fine cracks that are assumed to have occurred due to fretting. No functional problem such as leakage was found, but for confirmation purpose, a modification work was performed to eliminate ratting (installation of a fixed support) at this position. However, during a time period of two months after resuming operation, two fine tubes were completely broken.

Cause Estimation

Changing the support conditions reduced the damping of tubes, resulting in the occurrence of fluid elastic vibrations.

Analysis and Data Processing

In order to verify the changes in damping due to different support conditions, a mimic testing apparatus was prepared to simulate actual tubes and the support, and damping ratio was measured through a minute vibration test by applying external excitation. In obtaining the damping ratio, the half power method was employed, with the results shown below (values in ( ) are rough indications given in the guideline of the Japan Society of Mechanical Engineers).

Loose support (before modification): 0.83% (1.0%-1.5%)
Fixed support (after modification): 0.094% (0.05%-0.2%)

By applying the fixed support after modification, the natural frequency increased from 16.3Hz to 31.9Hz, together with changes in the mode shape as illustrated in the figure.
In accordance with these points, a vibration evaluation was made as described in the reference literature. In order to perform a simplified evaluation, only one span out of the three spans in the figure was selected where flow from the inlet comes into contact directly, i.e., a model of a uniform flow on rigid body was applied. As the other two spans vibrate at the same time in case of the loose support, the unit weight of the fine tubes was tripled for evaluation. As shown in the figure, the resultant operation after modification falls in the unstable operation region.

Countermeasures and Results

Since fretting will cause no functional problems such as leakage for a time period of periodic inspections, the original design was set back. Also, a perforated plate was installed to reduce the local flow velocity at the downstream of the inlet tube, with a successful result that no breakage of tubes occurs since then.

Lesson

Sliding and collision contribute to damping of a vibration system. Enhancing the rigidity is a generally accepted method to prevent vibrations. However, it is necessary to keep in mind that increasing the support rigidity by welding reduces damping. This holds true especially when self-excited vibration is a problem as damping is a dominant factor.

References

Standard of the Japan Society of Mechanical Engineers "Guideline to prevent fluid elastic vibration at the U-shaped portion of steam generator heat transfer tubes; JSME S 016 2002"

Keywords

Fluid elastic vibration, bundle, fluid-related vibration, heat transfer tube, baffle plate, support rigidity, support, damping

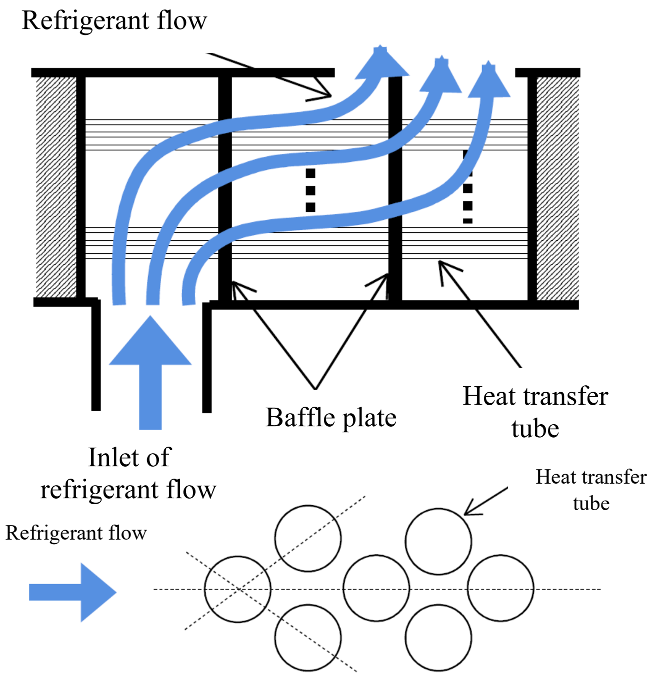

Fig.1 Overview of heat exchanger

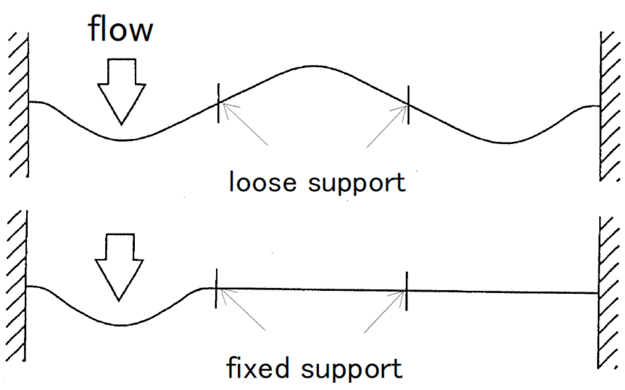

Fig.2 Vibration mode

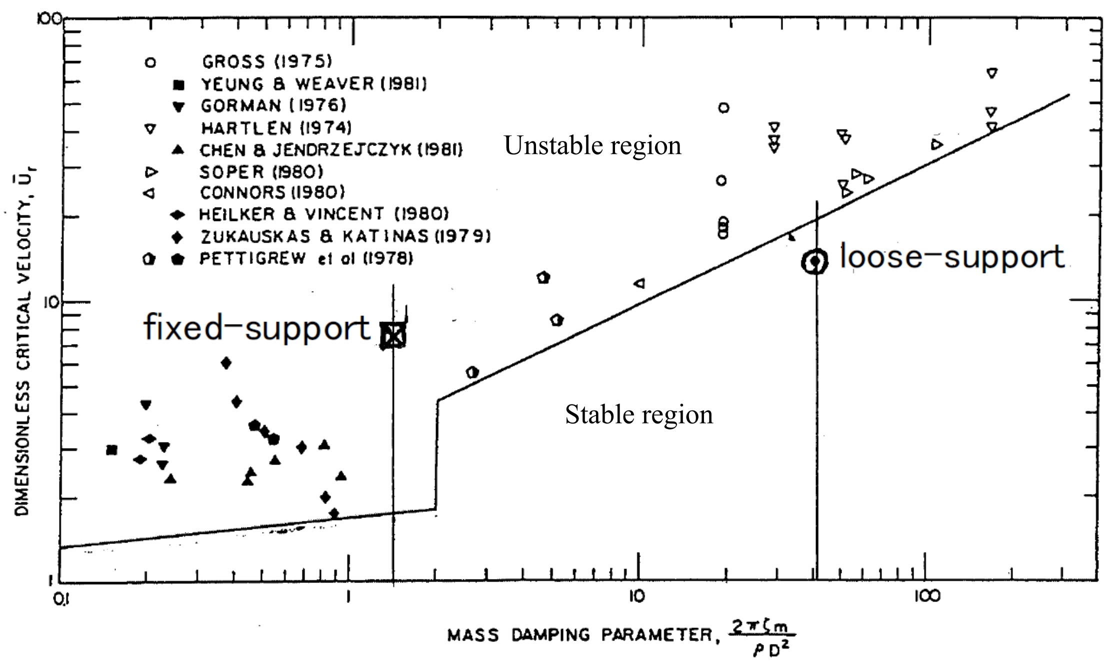

Fig.3 Stability map

Dimensionless flow velocity: $\overline{U_r} = \frac{U}{fD}$, $U = u\frac{P}{(P-D)}$	(u; Flow velocity, P; Tube pitch, D; Tube outer diameter, f; Natural frequency)
Mass damping parameter: $\frac{2\pi\zeta \cdot m}{\rho D^2}$	(ζ; Damping parameter, m; Mass of tube unit length, ρ; Fluid density, D; Tube outer diameter)