Vibration	Flow-Induced Vibration of Heat Exchanger Cooling Water Piping	Plant
Resonance		

Object Machine

Seawater piping line for heat exchanger is shown in Fig.1. This line is used for feeding seawater to the heat exchanger after taking in seawater from the system A header or the system B header. In order to prevent fluctuations of the readings of an orifice type flowmeter caused by flow disturbance, a flow straightening plate is installed immediately after the flow confluent part where large disturbance exists.

Observed Phenomena

Vibrations and abnormal noises occurred on the piping near the straightening plate. The seawater flow speed in the piping was about 3m/s, with the major component of the piping vibration being about 30Hz, and the magnitude of acceleration being 1 to 2m/s^2. The abnormal noise was similar to a drum beating sound whose level is about 80 dBA. The noises consist of a low frequency component of 30Hz and a high frequency component of drum sounds, and these noises occur when the piping vibrations are large. The vibrations are large when operating the system A than the system B. Investigations made thereafter proved the existence of cracks on the welds to fix the straightening plate.

Cause Estimation

It is considered that the straightening plate vibrated to a large extent when the natural frequency of the straightening plate and vortex shedding frequency come close to each other. As this is a highly disturbed place, disturbance-induced vibration might have occurred. It is thus estimated that vibrations of the straightening plate caused cracks on the welds, and grazing or collision with the cracks resulted in the occurrence of abnormal noises.

Analysis and Data Processing

As it is impossible to directly measure the vibrations of the straightening plate in the seawater, FEM analysis using a general purpose structure analysis code NASTRAN was conducted to estimate the natural frequency characteristics. Also, in order to evaluate the influence of added mass of seawater in the piping, a virtual mass method was utilized. Comparison with the spectrum of piping vibrations shown in Fig.3 indicates a good agreement between the natural frequency of the straightening plate and the vibration peak measured on the piping, thus it is assumed that the vibrations under consideration are of the third mode.

Relationship between the average flow speed and the piping vibrations is given in Fig.4, which leads us to assume that, as the increase in the flow speed causes changes peak frequency, the vibration is excited by vortex around the straightening plate. Thickness of the plate h including the lining is 17mm (steel plate thickness; 9mm). The vortex shedding frequency f is calculated by $f=S_t \cdot V/h$, where V=flow speed, S_t=Strouhal number. The number S_t varies depending on the aspect ratio and inflow angle in case of a rectangular shape. Assuming that S_t is 0.2 for example, the frequency will be 35Hz for V=3m/s, which is close to the third-order natural frequency, while for V=3.6m/s, the frequency will be 42Hz, approaching to the fourth-order or the fifth-order natural frequency.

Countermeasures and Results

Examination was made to avoid resonance by increasing the natural frequency; as shown in Fig.5, the construction was changed such that two straightening plates, each for the horizontal and vertical direction, were crossed at one position. Consequently, it was confirmed that even the first-order natural frequency exceeds 60Hz. As Fig.4 indicates, the countermeasures greatly reduced the piping vibrations, with abnormal noises perfectly eliminated.

Lesson

Like a cylindrical structure, one plate located in a flow shall be designed in consideration of vortex vibrations. Inside a liquid, the natural frequency of a plate changes to a great extent, but the use of the virtual mass function of NASTRAN allows a simple and precise calculation of a natural frequency.

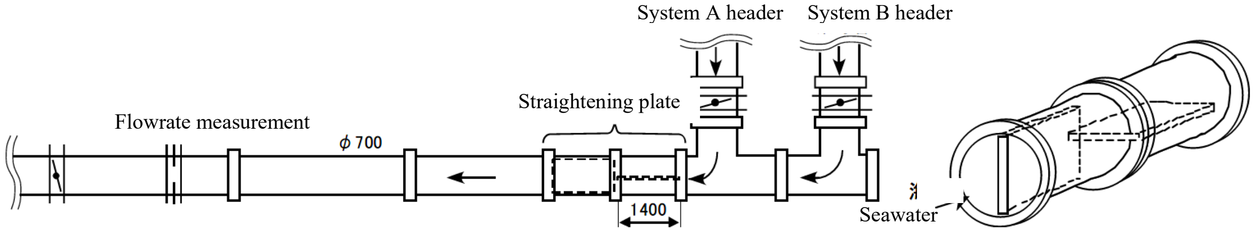
References

The Japan Society of Mechanical Engineers; Flow-induced vibrations based on examples, Gihodo Publishing Company, 2003, pp74-84

MSC/NASTRAN Users' Manual; Structural modelling edition / Analytical function edition 67, 1991

Keywords

Piping vibration, vortex excitation, rectangular cross-section, straightening plate, fluid added mass, FEM analysis



(a) Layout of seawater tube (b) Straightening plate portion (17mm thick, end R)

Fig.1 Target piping system

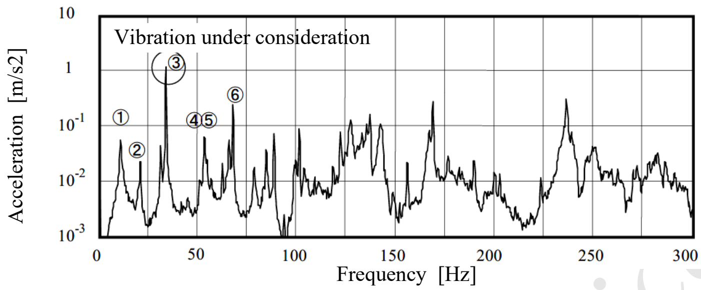


Fig.2 Measurements of spectrum of piping vibrations (straightening plate portion)

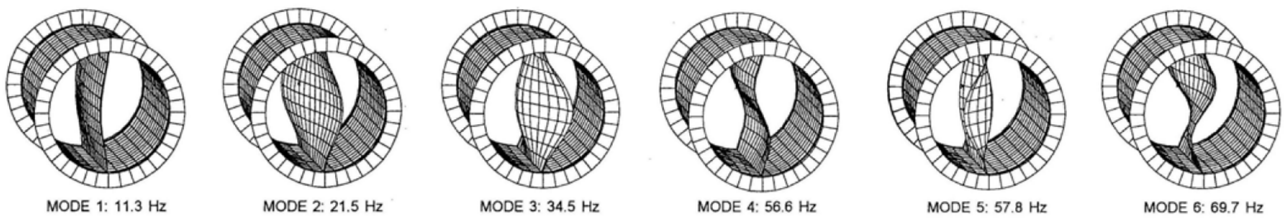
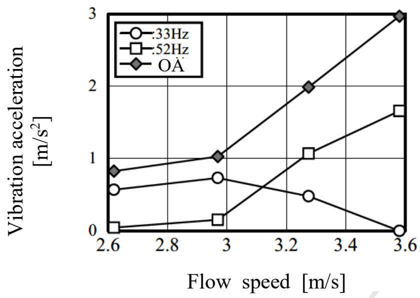


Fig.3 Eigenvalue analysis results in consideration of fluid added mass on the straightening plate



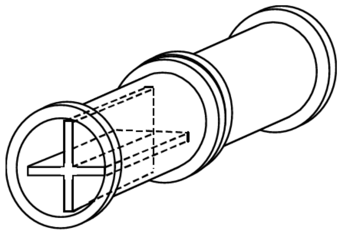
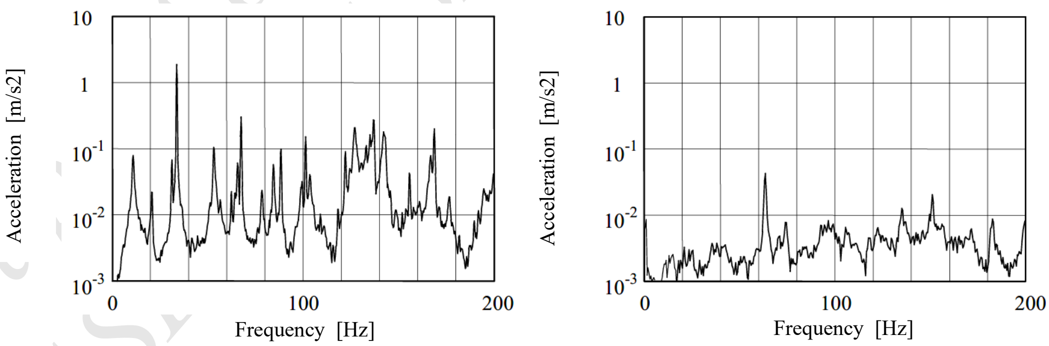


Fig.4 Relationship between flow speed and generated piping vibration

Fig.5 Method taken in the countermeasures



(a) Before taking countermeasures (b) After taking countermeasures

Fig.6 Characteristics of piping vibrations before and after taking countermeasures