Vibration	Fluid-elastic Vibration of Heat Exchanger Tube	Plant
Self-excitation		

Object Machine

Heat exchanger for heating exhaust gas

Observed Phenomena

At the time of periodic inspection and disassembling the heat exchanger for heating exhaust gas from a combustion furnace, it was found that several tubes were perfectly broken at their fixed parts, and fracture face observation has proven that they were due to fatigue. On the other hand, site measurement of vibrations of other heat exchangers at their casings during operation revealed that their frequencies were 15Hz or 10Hz, and that cracks in the tubes reduced their natural frequencies.

Cause Estimation

These phenomena led us to assume that they are vibrations of tube bundles due to Karman vortex, or fluid elastic vibrations. Measured natural frequencies of tubes were in the range of 30Hz to 32Hz, which Karman vortex frequency is fairly higher than these. Instead, a calculated dimensionless flow velocity is close to a critical one. Then, assuming that the cause of fracture was due to fluid elastic vibrations, and appropriate measures were taken.

Analysis and Data Processing

(1) Measurement of natural frequency and damping of tube (refer to Fig.1)
Fig.1 shows the vibration waveforms of a tube by impact test where the natural frequency is in the range of 30Hz to 32Hz, with a damping ratio of about 1%, while a calculated natural frequency (both ends fixed) is 32.6Hz.

(2) Frequency of Karman vortex (refer to Fig.2)
$f=St\cdot Vg/D=$223Hz (St=0.31 Vg=15.6m/s D=0.0217m)
which is fairly higher than the tube natural frequency, thus no possibility for this vortex to be a cause.

(3) Criterion of the stability of fluid elastic vibration (refer to Fig.3, by S.S.Chen)

1) Obtain dimensionless critical flow velocity Vc from dimensionless mass damping parameter M_D.
$M_D=2\pi\zeta m_s/(\rho_f D^2)$=183
Thus, from the figure of S.S.Chen, the dimensionless critical flow velocity V_c is fairly equal to 30.

> ζ: *damping ratio*=0.01
> m_s: *mass of tube*=0.137kgs^2/m^2
> ρ_f: *air density*=0.1kgs^2/m^4
> D: *tube outer diameter*=0.0217m

2) Dimensionless critical flow velocity of current tube Vr
$Vr=Vg/(fs\cdot D)$=24.0
which is below the critical value of 30. However, the gap flow speed may become higher due to attachment of ash on the tube outside, so there is a high possibility of the occurrence of fluid elastic vibrations.

> fs: natural frequency of tube=30Hz

Countermeasures and Results

A countermeasure was taken wherein a baffle plate was inserted at the center of a tube, so as to increase the natural frequency and thus to reduce the dimensionless flow speed (refer to Figs.3 and 4).
$Vr=Vg/(fs\cdot D)$=8.0
This countermeasure of inserting a baffle plate solved the problem of breakage of tubes.

> fs: calculated natural frequency of tube after taking countermeasures= 90Hz

Lesson

As for heat exchangers for general industrial machinery, the occurrence of fluid elastic vibrations is a rare phenomenon, and the designers themselves were unaware, which is one factor of this trouble. It is just a consolation in a bad luck that an important clerical error was found. The explanation in his literature “an approaching speed should be used” is a mistake, and gap flow speed should be used in Fitz-Hugh’s diagram.

References

Chen, S.S., 1987, Flow-Induced Vibration of Circular Cylindrical Structures, Sprinder-Verlag, P424.

Keywords

Heat exchanger, tube, fluid-induced vibration, self-excited vibration, fluid elastic vibration, natural frequency

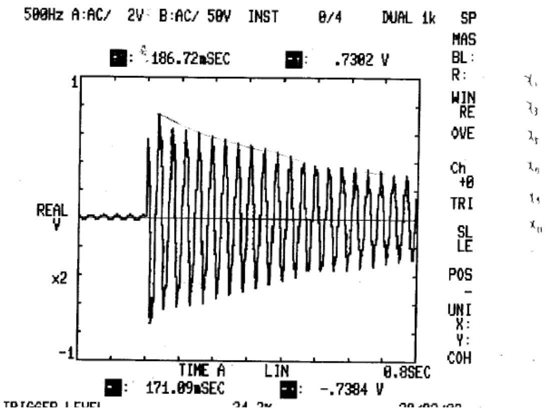

Fig.1 Measurement of natural frequency and damping of tube by impact test

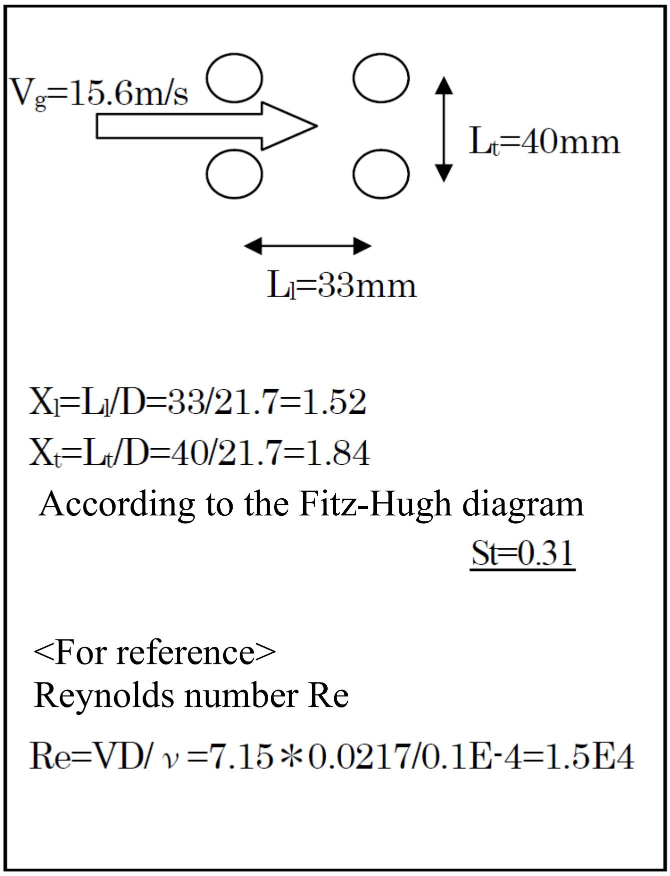

Fig.2 Arrangement of tubes and Strouhal number

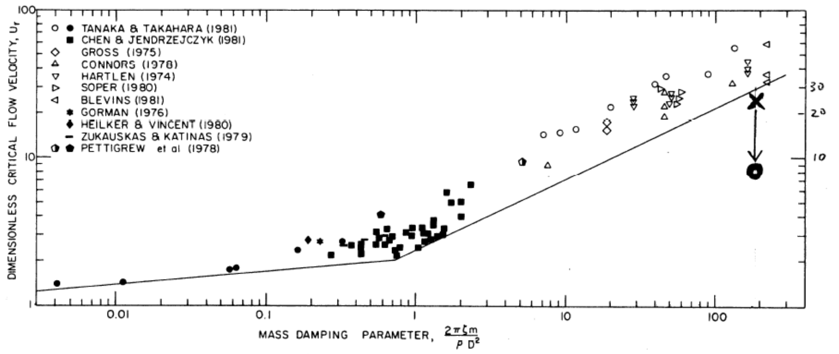

FIGURE 10.18. Stability map for square arrays (Chen 1984)

Fig.3 Criterion of stability (S.S.Chen 1987 Flow-Induced Vibration of Circular Cylindrical Structures, Sprinder-Verlag, p424.)

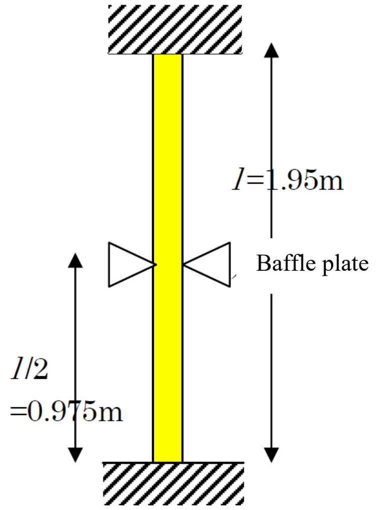

Fig.4 Countermeasures taken (insertion of a baffle plate at the center of a tube)