Vibration / Resonance	Excessive Vibration of Impeller and blade due to Mistuning	Rotating Machinery

Object Machine

Impeller and blade in general of turbo-machinery

Observed Phenomena

Since resonance between the blades or impellers of a turbo-machinery and various excitation sources has a risk of leading to damaged blades due to excessive vibrations, examinations are made in the design stage to avoid a resonance as much as possible within the operation range. However, due to various restrictions, it is often difficult to perform adequate examinations. In such a case, the level of danger is evaluated by grasping a stress to occur by means of analysis or measurement. In such a case, measured vibration levels may often vary depending on each blade even within the same impeller, resulting in a maximum value much higher than the expected level.

Cause Estimation

Various analyses of impellers are usually conducted the basis of an ideal condition, wherein the characteristics of each blade are identical and that disk parts constitute a periodic symmetrical structure (tuning system). However, actual blades have slight variations or heterogeneity within the manufacturing allowance in terms of dimensions and materials (mistuned system) (Fig.1). A mistuned system has frequency separation of multiple root mode (in a tuned system, two multiple root modes have the same frequency), or inclusion of plural nodal diameter components within the mode (a vibration mode in a tuned system can be represented by a single nodal diameter component). As a result, periodic symmetry of vibration characteristics peculiar to the tuned system will be lost. Therefore, excessive vibrations occur due to variations response variation of each blade or vibration energy concentration on several specific blades.

Analysis and Data Processing

As an example of variations in the frequency response between blades, vibration measurements of all the blades were conducted for the secondary mode resonance of the supercharger turbine impeller having 9 blades and nozzles excitation as shown in Fig.2, with the results given in Fig.4. As for the same impeller, the excitation forces (Fig.3 (b)) having identical phase difference between blades corresponding to the nozzle excitation were applied to an FEM modelling with varied Young modulus of the blades in response to the measured natural frequencies (Fig.3 (a)). Amplitude ratios of each blade thus obtained by the frequency response analysis are shown in Fig.4, which indicates that both the measurement and analysis of frequency response level of each blade have variations in magnitude of several times between the maximum and the minimum values. The analysis provided a tendency (maximum amplitude blade & minimum amplitude blade, with their ratio) that agrees fairly well with the measurements, and it was also verified that variations only of several percent in the blade natural frequency is a cause to generate fluctuations in blade vibrations several times greater in level in terms of vibration response; and that a maximum response value in a mistuned condition will be larger than that in a tuned condition.

Countermeasures and Results

From the viewpoint of quality control and security ensuring, it is important to know the so-called magnification factor, that indicates the ratio of the maximum vibration value of all products in the market with respect to the predicted value under an assumption of no variation. Examination of all products in the market requires the combinations of an enormous amount of target blades, so that direct application of the above FEM analysis is not a good measure. An alternative solution is a method to use theoretical equations (Figs.5 and 6) that provide an upper limit value introduced by Monte Carlo simulation or Whitehead by means of a model with a reduced freedom of calculation. In this case, theoretical values are based on a simplified assumption (only one blade mode group is treated; both the amount of mistuning and damping are small), so that, when applying this method, it is necessary to fully bear in mind if the omitted portions are allowable for the target in question.

Lesson

- Actual impellers involve various uneven elements within manufacturing tolerance cannot be regarded as a complete periodic symmetrical structure.
- Even a small amount (several percent) of variations of uneven elements within tolerance may cause vibration level several times larger upon resonance, and on the upstream side of variations, the response will be slow compared to a tuned condition.
- Prediction of maximum value of vibrations of all products in the market involves several theoretical upper limits, thus attention shall be paid in consideration of portions that are omitted in the assumption made.

References

- H.Hattori, et.al, Mistuned Vibration of Radial Inflow Turbine Impellor, Proc. of the 9th Asian International Conference on Fluid Machinery, AICFM9-224, October 16-19, 2007, Jeju, Korea
- For instance, Whitehead, D.S., 1998, The Maximum Factor by Wich Forced Vibration of Blades Can Increase Due to Mistuning, J. of Engineering for gas turbine and power, 120, 1, pp.115-119.

Keywords Blade vibration, nozzle excitation, mistuning, impeller, bladed disk vibration

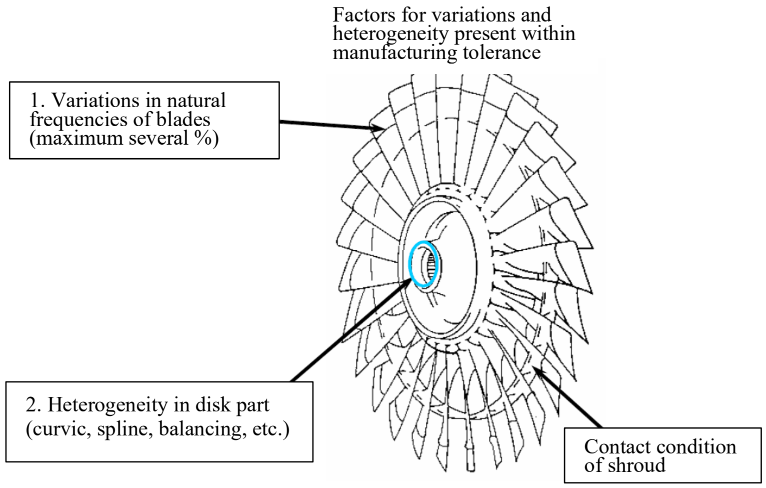


Fig.1 Conceptual factors for variations and heterogeneity present in turbo-machinery impeller

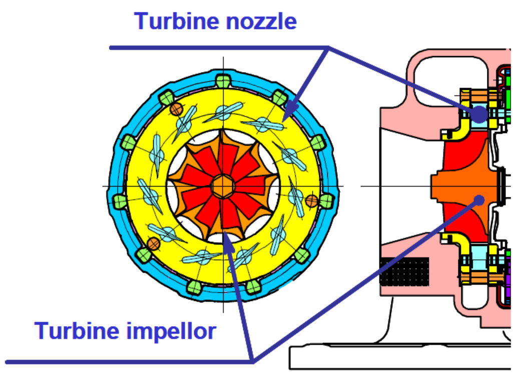
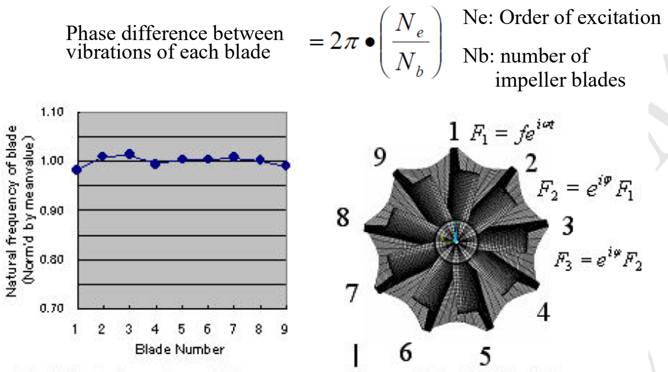


Fig.2 Cross section view of supercharger turbine impeller subjected to entire blade vibration measurement against nozzle excitation



(a) Blade's natural frequency **(b) Applied force**

Fig.3 Condition for mistuned frequency response analysis

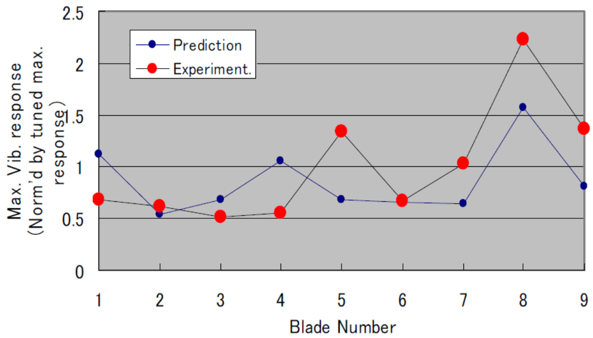


Fig.4 Maximum vibration value of each blade at resonance point

The following is a typical theoretical equation to determine the upper value with the number of blades N as a parameter.

$$Mag.Factor \leq \frac{1}{2}(1 + \sqrt{N})$$

(Whitehead 1966, 1998)

In addition to the above, upper limits are also proposed, where order of excitation is also considered as a parameter. (Kenyon & Griffin 2002, GT-2002-30426)

Fig.5 Theoretical equation to determine upper limit of variations

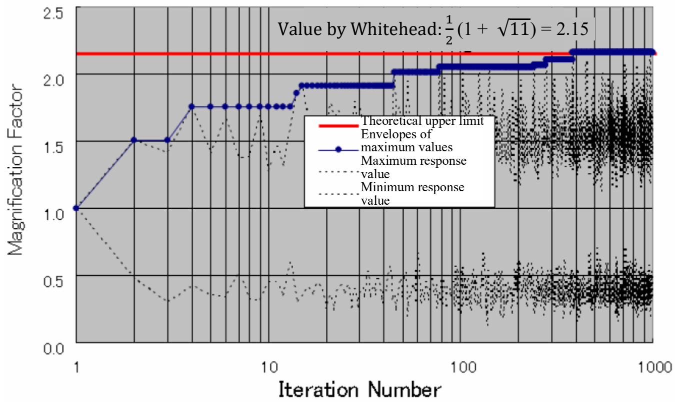


Fig.6 Monte Carlo simulation of vibration variations for 1000 units of impellers having 11 blades (comparison with the upper limits by Whitehead)