Case History / Forced Vibration	Low Frequency Whirl by Rotating Stall in Multi-Stage Turbine Pump	Rotating machinery (pump & water turbine)

Object Machine

Multi-stage turbine pump for boiler feed (general arrangement shown in Fig.1)
Rotational speed of pump = 2,980 (rpm), pump head = 850 m, and rated discharge rate of pump = 3.8 (m^3/min)

Observed Phenomena

About three months after commencement of operation of the boiler feed pump, steam leakage occurred from the pump shaft sealing equipment. This was caused by whirling of shaft at a low speed (3.75 Hz) during mini-flow operation, which was able to be visually identified by watching the shaft rotation. Thus, the rotor vibration was measured, and at the same time vibration frequency analysis was conducted. The results are shown in Fig.2.

Cause Presumed

As indicated in Fig.2 "Frequency analysis of rotor vibration", it was found that (1) whirl occurred when the pump discharge rate was at about 30% or less of the design flow rate, (2) the direction of whirl matched the direction of rotation, and (3) the period of whirl is as low as 7.5% of the rotational speed of the pump, while the shaft system had no such natural frequency. Judging from the above observations, it was estimated that the problem was not a self-excited vibration, but a forced vibration of the shaft due to a dynamic radial thrust caused by diffuser rotating stall.

Analysis and Data Processing

Based on the above cause estimation, the following investigations were conducted.

(1) The impeller wear ring was replaced with another shaped one having a large supporting force. As a result, the amplitude of swirl decreased together with a slight reduction in sliding flaw on the rotating body and the fixed part. However, this did not prove to be a radical solution for whirl at minimum flow.

(2) Investigation of hydraulic force acting on the impeller due to rotating stall:
Fig.3 illustrates an example of measured data on hydraulic force acting on the impeller upon occurrence of a rotating stall. Estimation of a radial thrust applied to the actual pump rotor based on these data indicated that the thrust force would be 520 kgf when all forces on the impellers were in synchronism. Given the pump shaft system span, it was understood that shaft deformation could cause leakage from the shaft sealing equipment, if such a thrust force was applied.
Fig. 4 shows the relationship between the area where diffuser rotating stall developed and the diffuser shape. The diffuser of this pump lies within the rotating stall area, which is believed to be the cause.

Countermeasures and Results

(1) Examination of change of diffuser design
  (a) To have intentional eccentricity of the center of hydraulic force of the diffuser and the impeller.
  (b) To make asymmetric along the shaft center the inlet shape of the diffuser vane.

Based on the above, countermeasures were planned not to allow rotating stall to occur. Before applying these countermeasures to the actual pump, their effect was checked by means of a model test, which revealed that, although the whirling force of the impeller was reduced, it was not completely eliminated. Accordingly, instead of changing the pump hydropower unit, the minor piping around the pump was modified, thus increasing the mini flow rate.

(2) Modification of the shape of impeller wear ring
As for the pump body, the shape of the wear ring was modified to enhance the shaft stiffness.
In consequence, the problem in using the pump was solved.

Lesson Learned

(1) Hydraulic force acting on the pump rotor is quite large, which should be taken advantage of when planning.

(2) Rotating stall to occur on a pump diffuser will not be eliminated just by some modification of an impeller or a diffuser.

(3) The use of a pump at points other than the design point shall also be taken into

consideration.

References

(1) Ohashi, H. et al. “Lateral Fluid Forces of Whirling Centrifugal Impellers with Various Geometries”. The 3rd Japan-China Joint Conf. on Fluid Machinery, Osaka (1990)
(2) Hergt, P.; and Krieger, P. “Radial Kräfte in Leitrad Pumpen”. KSB Technische Berichte Heft 16 (1973)

Keyword

Rotating stall, forced vibration, boiler feed pump

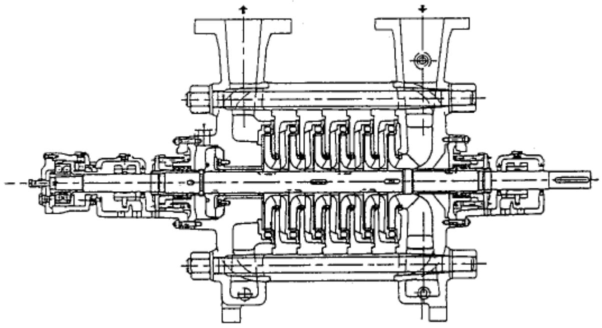


Fig.1: General arrangement of pump
* Rotating stall appeared on all the stages.

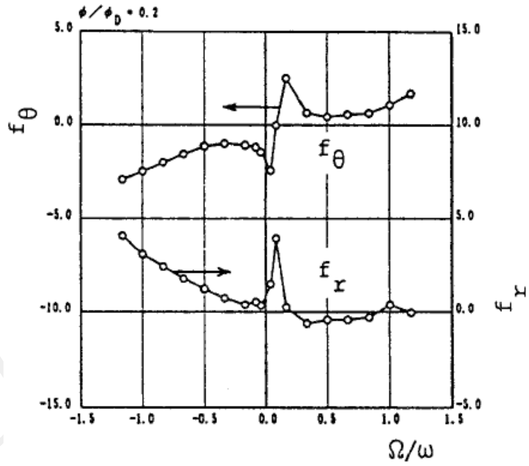
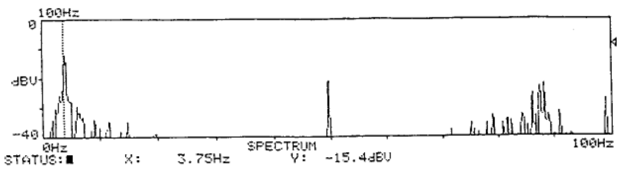
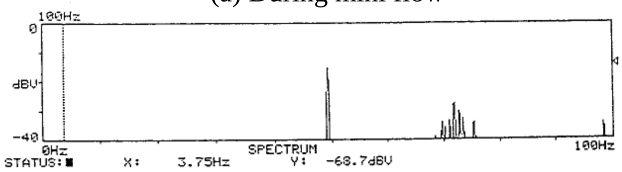


Fig.3: Impeller excitation force



(a) During mini flow



(b) Design flow rate

Fig.2: Frequency analysis of rotor vibration

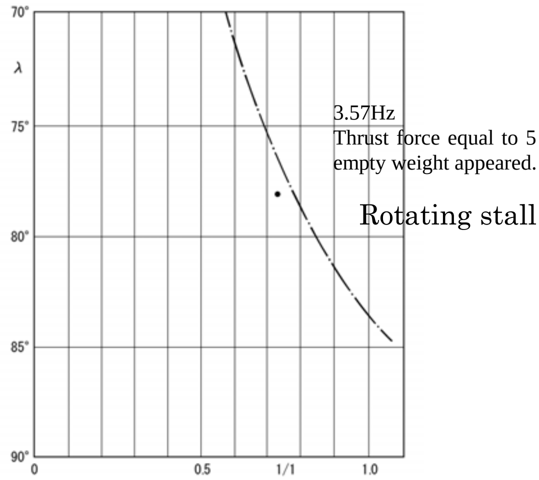


Fig.4: Relationship between rotating stall and diffuser parameters