Case History	Axial Compressor Vibration due to Rotating Stall
Forced	

Object Machine

Multistage axial compressor with variable stator vane systems (for blast furnace) (Fig.1)
Maximum flow rate: 10,000 Nm^3/hr, maximum pressure: 5.7 kg/cm^2·G,
nominal power: 60 MW, rated rotational speed: 3,600 rpm (steam turbine driven)

Observed Phenomena

When the rotational speed reached 2,750 rpm during startup of the machine, vibration suddenly increased (measured at the bearing), but at 2,900 rpm after further speed increase, the vibration showed a sharp decline (Fig.2).

Cause Presumed

In this vibration phenomenon, a large excitation force that occurred at a specific rotational speed excited the rotor, but the force disappeared soon thereafter. The reason for such an abrupt occurrence and disappearance of an excitation force is often related not with the machine but with fluid.
In this Case, the machine was an axial compressor, and considering the fact that the compressor was started with the stator vane angle fixed and that noise did not increase even during a large vibration, it was thus estimated that the cause was a rotating stall.

Analysis and Data Processing

(1) Observation of vibration waveforms (Fig.3)
Compared to the normal operating condition, the frequency obviously varied when the vibration grew.
(2) Examination of the result of frequency analysis: vibration
During normal operation, the predominant frequency was the synchronous component N (rotational speed), but about 0.436 N when the vibration was large (Fig.2).
(3) Observation of pressure waveforms on the casing inner wall
The generation and disappearance of vibration corresponded to large and small pressure variations (Fig.3).
(4) Examination of the result of frequency analysis: pressure waveforms (Fig.2)
The predominant frequency was 0.436 N for large pressure variations, but in other cases, 0.8 to 0.9 N frequencies developed from time to time.

Judging from the above,
1) As variable frequency is proportional to the rotational speed, the pressure variations represent rotating stall.
2) One cell rotating stall occurred for large vibration, while two cells rotating stall occurred for other cases. (One cell rotating stall and two cells rotating stall could be distinguished by the empirical values on the relationship between turning rotational speeds and rotor rotational speeds, but measurements at two positions enables distinction as indicated in Fig.4)
3) Since the frequency for large vibration agreed with that of one cell rotating stall, one cell rotating stall generated an aerodynamically induced unbalance excitation force, which acted on the rotor.
4) In case of two cells rotating stall, the two cells were at positions nearly symmetrical on the circumference inside the compressor, so that the forces acting on the rotor are balanced.

In this phenomenon, the excitation frequency due to rotating stall was (2,750~2,900) × 0.436=1,199~1,264 rpm, which corresponded to the rotational speed immediately after passing the first critical speed of the shaft system. Thus, it is considered that the vibration became large upon occurrence of one cell rotating stall.

Countermeasures and Results

In case of axial flow compressors, it is difficult to restrain the generation of rotating stall for the entire operation range. Since rotating stall occurs in low speed and low flow rate regions, the variable stator vanes were controlled in this Case, so as to avoid the condition causing rotating stall, and thus eliminating the generation of vibration.
In case of fixed stator vanes, a countermeasure of maintaining the flow in the casing by opening a bypass may also be taken.

Lesson Learned

- Countermeasures include avoiding the operation range where vibrations are liable to occur by adjusting the operation, in which case consultations should be held with the customer to explain the situation and win the customer's understanding.
- Once after completion of assembling a machine, it would be extremely difficult to modify the machine in terms of performance. Countermeasures against vibration of fluid machines often encounter this sort of difficulty.
- Even if causes are unknown, operation ranges to avoid vibration may be found after repeated trial operations. Yet it would be a thorough measure to clarify the cause and control the operation conditions. By so doing, the manufacturer's reliability will be enhanced, while the customer's reassurance will be ensured.
- Although rotating stall of two cells or more will not be an excitation force for rotors, it always poses a risk for blades (both blades and stator).

References

Nothing in particular

Keyword

Rotating stall, axial compressor, axial blower, one stall cell, two stall cells, low flow rate region

The Japan Society of Mechanical Engineers (No.940-26 IV) "Examples of Mechanical Vibrations for Designers" "v-BASE" forum materials (July 12, 1997, Akita City)

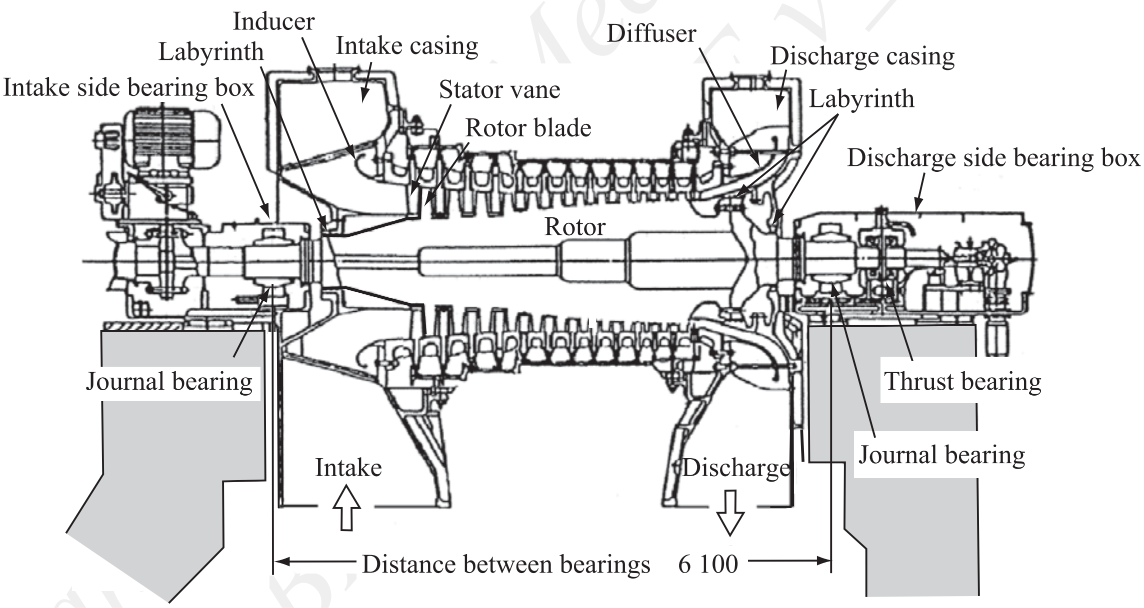


Fig.1: Axial compressor

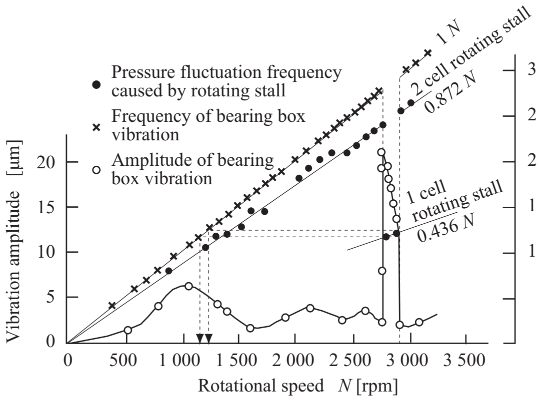


Fig.2: Amplitude and frequency of vibration displacement and fluctuating pressure

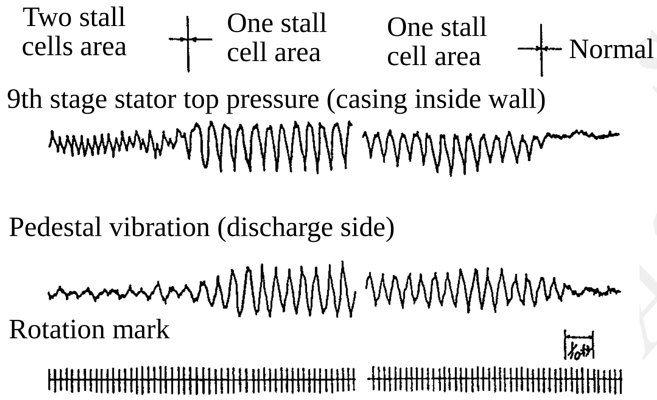
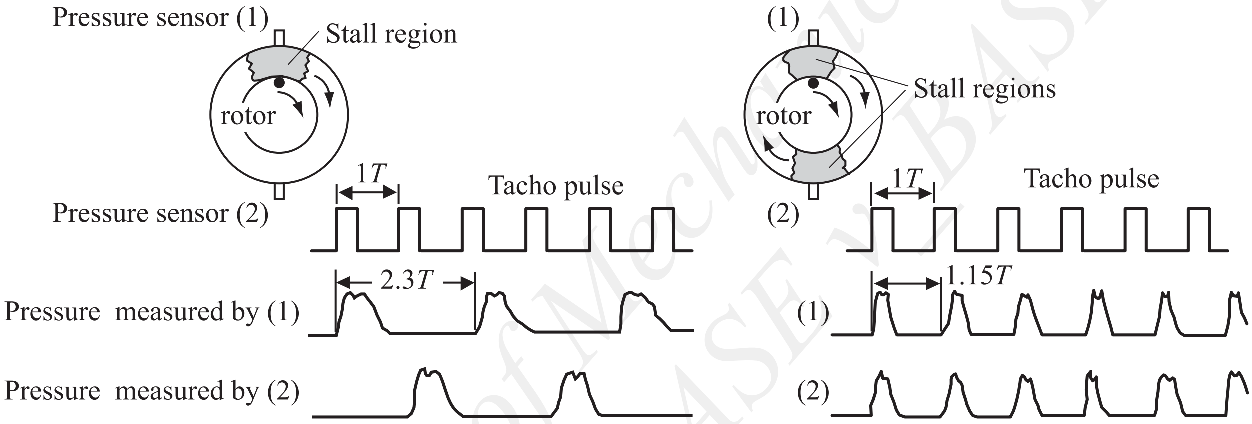


Fig.3: Vibration waveforms and pressure waveforms



(a) In case of one stall cell (b) In case of two stall cells

Fig.4: Distinction between one cell and two cells (schematic diagram)