Vibration	Damage of Reducer due to Self-excited Torsional Vibration during Starting of Induction Motor	Rotating Machinery
Self-Excitation		

Object Machine

Reducer of fan for cooling tower (motor output power 220kW, rated rotational speed 1,490rpm (input shaft)/119rpm (output shaft)) (Fig.1)

Observed Phenomena

During operation of the cooling tower for test operation of a petrochemical plant, several months after commencement of operation, the reducer pinions of 14 fans out of 16 units experienced heavy damage (Fig.2). (two units out of 16 are for stand-by, while 14 units are for normal operation)

Cause Estimation

Not only a possibility for defects during the design, manufacture, and installation of the reducer itself, but various other possibilities for the application of excessive torque due to torsional resonance and instantaneous voltage drop during operation were examined, but these possibilities were denied. Thus, the only possibility was narrowed down to transient conditions during starting of the motor, followed by the occurrence of torsional vibrations. Thus, it was assumed that the resultant excessive torque was applied to the gear teeth, resulting in the reducer damage. Synchronous motors always pose problems at the time of starting due to torque pulsations, but in case of induction motors, almost no attention has been paid to torque pulsations upon starting, so that the above assumption was fairly bold.

Analysis and Data Processing

Measurement of the transmission torque by attaching a strain gage on the drive shaft revealed that large torque pulsations occurred at the time of motor starting, whose maximum value reached four times the rated torque (Fig.3). It was also found that the torque pulsations caused tooth hitting of the gear, resulting a shock load to be applied to the gear face (Fig.4). Moreover, a non-steady torsional vibration analysis was conducted that reflects the motor starting characteristics, and the analysis result agreed well with the measurements (Fig.5). If the negative damping of a transient torsion due to the positive gradient of an induction motor starting torque curve is superimposed on the large inertia moment of a driven machine and a soft torsional stiffness of the drives shaft, a torsional self-excited vibrations will occur. And a series of examinations proved that these vibrations were the above-mentioned self-excited torsional vibrations. Following is a mechanism for torsional vibrations to grow as if self-excited in the rotating area where a motor starting torque curve has a positive gradient (Fig.6).

- Increase in output torque => increase in the rotational speed => further increase in output torque (as the torque curve has a positive gradient) => infinite increase in output torque and the rotational speed
- Decrease in output torque => decrease in the rotational speed => further decrease in output torque (as the torque curve has a positive gradient) => infinite decrease in output torque and the rotational speed

Countermeasures and Results

The essential solution would be to replace the motor with another one having a more moderate starting characteristics or to replace the reducer with a larger one, so as to have a larger design margin, but from the viewpoint of time and cost, it was unpractical to incorporate such a large-scale modification to a plant near completion. On the other hand, as an analysis proved that stiffening of the drive shaft can restrict the development of torsional vibrations, this alternative plan was adopted, together with measurement for verification (Fig.7). After effectuating this countermeasure, no gear damage has occurred.

Lesson

If the inertia moment of a driven machine is large, induction motors may generate torsional vibration phenomenon at the time of starting, due to its starting torque characteristics. This phenomenon is different from a torsional resonance (forced vibration) to occur on synchronous motors, and occurs by a mechanism of self-excitation mode.

References

Adachi, A. Murphy, B, “Torsional Instability of Cooling Tower Fan During Induction Motor Startup”. Proceedings of the 45th Turbomachinery Symposium. Turbomachinery Laboratories, Texas A&M Engineering Experiment Station. (2016)

Keywords

Torsional vibration, self-excited vibration, torque pulsation, starting torque characteristics, gear damage, torsion analysis, induction motor, cooling tower, fan, reducer

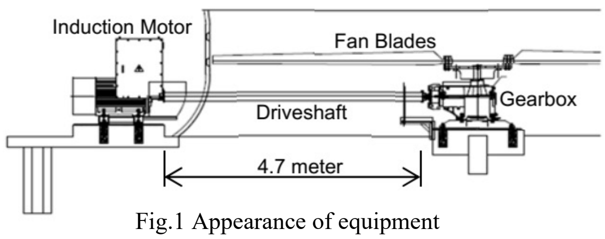

Fig.1 Appearance of equipment

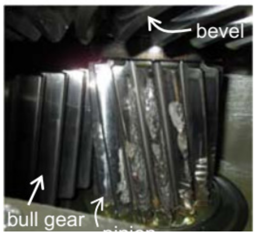

Fig.2 Damaged pinion gear

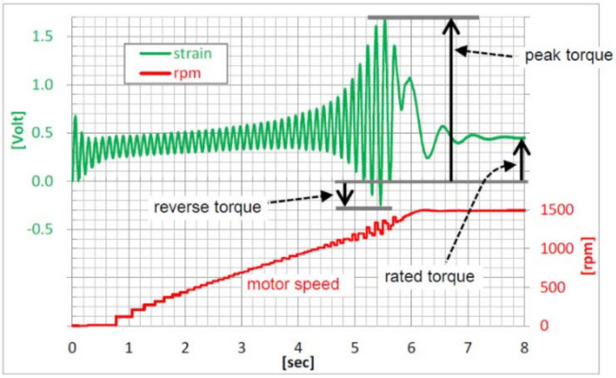

Fig.3 Measurements of strain gage output (green) and rotational speed (red)

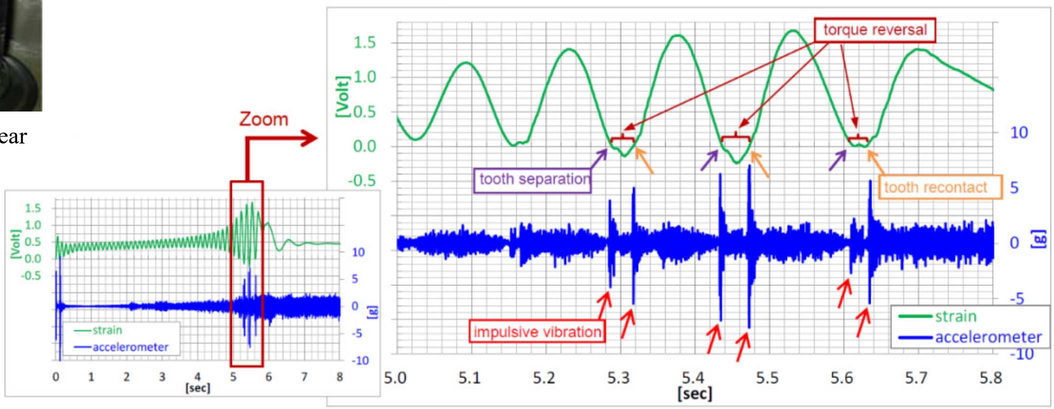

Fig.4 Measurements of strain gage output (green) and vibration acceleration of reducer casing (blue)

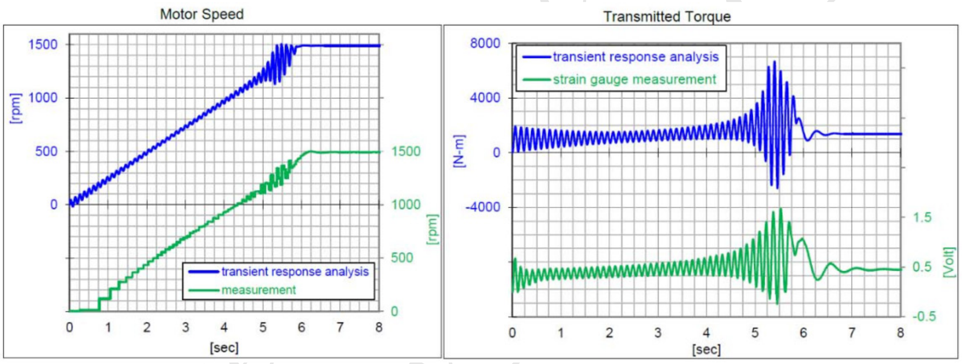

Fig.5 Comparison of analysis results (blue) against measurements (green) of rotational speed (left) and transmitted torque (right)

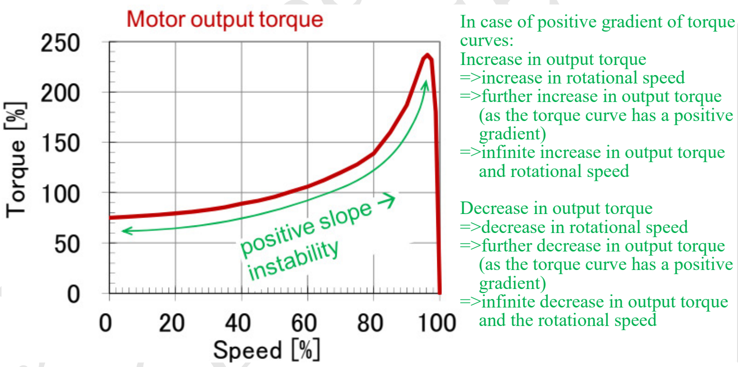

Fig.6 Motor starting torque characteristics
(instable in the positive gradient area)

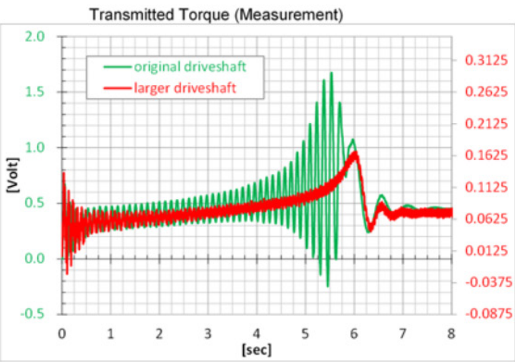

Fig.7 Transmitted torque before modification (green)
and after modification (red)