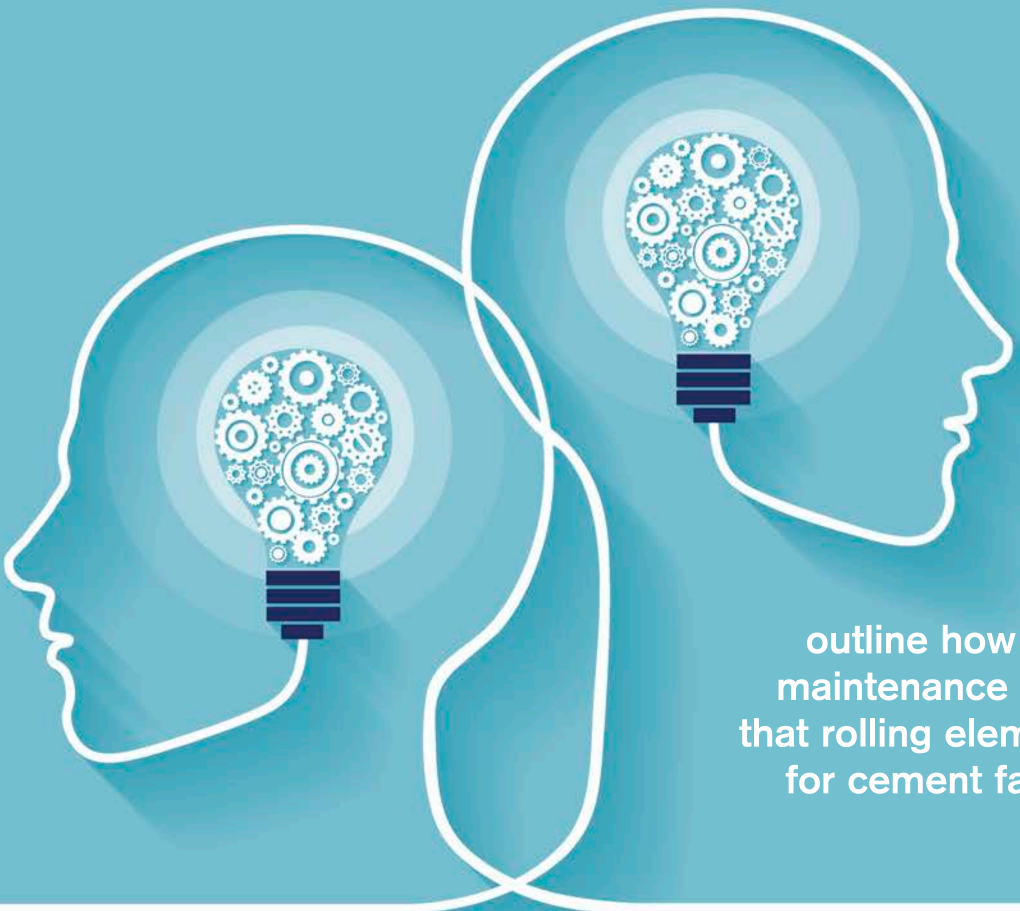


Dr John Irons, Halifax Fan UK, and Diane Wang, Halifax Fan China, **outline how proper design and maintenance can help to ensure that rolling element bearings used for cement fans achieve a good service life.**

Bearing it in mind

Fans are rotating machines and so need to use bearings. There are a variety of bearing types, lubrication methods and other features that can be employed to ensure that the fan runs with a good bearing life. The two main types of bearing are rolling element bearings and oil film bearings, with rolling element bearings being the more common type. This article considers rolling element bearings.

In some cases, fans have run for over 40 years with the original bearings. However, a more typical life for rolling element bearings on fans is 3 – 10 years. There are various factors that affect bearing life with some bearings having problems that lead to failure in less than one year.

There can be other issues such as excessive vibration. In addition, there are the changing requirements to consider for machinery, such as noise and pollution. Consideration and evaluation of the various factors involved increases the bearing life and results in a fan that will give years of trouble-free operation.

Types of bearing

Rolling element bearings rely on balls or rollers to transfer the weight of the rotating shaft to the support structure. The main types used for fans are deep groove ball bearings, roller bearings, self-aligning ball bearings and spherical roller bearings. The first two bearing types have little capability to cope with misalignment between the bearings. The second two bearing types can cope with significantly more misalignment between the bearings.

Good alignment can be achieved between the bearings by putting them in the same bearing housing – a mono-block. With modern five axis machines, it is possible to machine bores with good concentricity. Using a co-ordinate measuring machine (CMM) it is possible to carry out cross-concentricity measurements between the housing bores to confirm the alignment. This ensures maximum life for deep groove ball bearings and roller bearings. However, using a mono-block bearing unit requires the rotor to be overhung.

Some designs of deep groove ball bearings and roller bearings have a spherical outer surface and sit in a housing with a matching spherical surface. This allows the bearing to swivel in the housing to give concentricity. The most common type of bearing using this technique has a saddle housing, with the bearing protruding beyond the housing. Split roller bearings use rollers to maximise bearing life so are one of the main types of bearing with a spherical seat. With a spherical seat, the bearing seal has to be part of the bearing.

Large rotor being installed on site – oil film bearings.

Cement cooler fan – monoblock bearing unit.

Cement cooler fan – plummer block bearings.

Spherical roller bearings and self-aligning ball bearings have a spherical outer race to allow the bearings to align themselves to each other. The inner race has to be concave, which means that one row is unloaded with an axial load. Therefore, these bearings employ two rows of the rolling elements. Although spherical roller bearings and self-aligning ball bearings have a tolerance for lack of concentricity, it is not very large. This is due to the effect of misalignment on the bearing shaft seals and the movement that can happen within the bearing.

Effect of bearing load

Rolling element bearings have a localised surface stress concentration where the load goes through a point (ball) or line (roller). All rolling element bearings will eventually fail due to surface fatigue associated with the stress concentration. This is known as spalling. Fatigue life for rolling element bearings is based on well-established formulas and the dynamic load rating. Fatigue is grounded in statistics, and for bearings, the fatigue life is based on the point at which 10% of the bearings will fail – the L10 life.

When calculating bearing L10 lives the typical convention is that 1 year is 10 000 hours. There are various requirements for a suitable L10 life. End users can specify values between 20 000 hours and 100 000 hours. API 673 gives a minimum required life of 65 000 hours at design operation. Due to the effects of the environment, a life of over 100 000 hours is not usually achievable. Taking this and the effect of light load into consideration, a requirement for an L10 life in excess of 100 000 hours is not very common.

All bearings require a minimum load to work effectively. If rolling element bearings are not properly loaded, or there is insufficient load to make the balls or rollers rotate, they will skid. Roller bearings can tilt through loading on one side, so are more prone to skidding than ball bearings. This means that roller bearings require a higher load. Bearings with long rollers, needle roller bearings and CARB bearings require more load to prevent skidding.

There is always some fluctuation of the thrust load of fans, resulting in micromovement of the balls/rollers perpendicular to the direction of rotation. With no skidding, a bearing track on the race will be frosted. However, with fan applications, there is typically some skidding from the load, so the track tends to experience some polishing. The amount of polishing depends on the degree of skidding. Since there is a tendency for skidding in fan applications, the minimum load should be higher than that specified by the bearing manufacturers – a value based on a steady load. As a general rule, bearings in fan applications should not have a predicted life of more than 1 million hours.

The clearance of the bearing affects the ability of a bearing to skid. The tighter the clearance, the less likely a bearing is to skew and skid. This means that when there are skidding problems, as well as changing from a roller bearing to a ball bearing, reducing the bearing clearance can be considered.

Skidding results in thermal cycling of rolling element bearings. Thermal cycling from skidding is caused by the outer race being constrained and cooled by the housing. Heat from skidding expands the balls/rollers and reduces the clearance in the bearing, reducing the skidding. So, the bearings cool down, opening the clearance, and the skidding starts again. Thermal cycling from slight skidding typically lasts between 30 minutes and 1 hour and involves a temperature fluctuation of up to 5˚C. Many fans are run with a good bearing life and this level of thermal cycling.

In some cases, the thermal effects from skidding can lead to unstable loss of clearance. This occurs when the heat being generated by the balls/rollers at the boundary of the loaded zone cannot be dissipated. When this happens, the loss of clearance can result in one or more balls/rollers sticking and the cage collapsing or breaking. If the cage breaks, there will be a run-away thermal effect resulting in the bearing seizing. This can be prevented by following a cycle of running and stopping that allows the grease, races and balls/rollers to establish a stable running condition prior to prolonged running. External cooling can also prevent this.

Lubrication

Rolling element bearings require lubrication. The lubricant has three beneficial effects:

- Minimising the wear from non-ideal rolling or skidding.
- Increasing the load through the hydrodynamic wedge effect.
- Transmitting heat away from the contact zone.

The choice of lubricant is important if a bearing is to run effectively. The choice is between oil and grease.

Oil is not held in the bearing. Therefore, oil in the reservoir is used to constantly replenish the lubricant in an oil lubricated bearing. This means that the bearings can typically withstand more contamination and will run cooler compared to grease lubricated bearings. To improve the oil circulating round the bearing, some bearing designs use an oil ring. This is a ring that sits on the shaft and rotates with it. It picks up oil from the oil reservoir and transfers it to the shaft where it should migrate to the bearings. Most rolling element bearings rely on the rolling elements and cage to transport the oil round the bearing.

A cooling coil can be located in the bearing oil reservoir to cool the oil and extend the bearing life. With a pumped oil system it is also possible to have an external tank with cooling and/or filtration to extend the bearing life. For fans, there is typically an overflow gate in the return line. The oil is pumped into the bearing and flows over the gate. This means that the bearing will not lose lubrication if the oil pump fails.

Although oil has advantages, it also has a major disadvantage. It is difficult to retain the oil in the

Spherical roller bearing – grease black from wear.

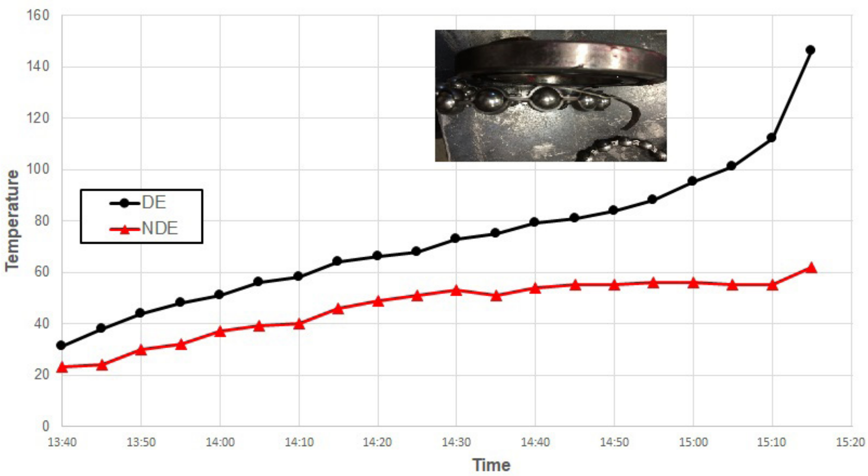
bearing, whilst oil loss occurs through the shaft seal. In part, this is caused by the shaft rotation leading to windage. Windage with oil evaporation will pressurise the housing. Shaft seal leakage can be minimised by using complex shaft seals that involve a series of labyrinth arrangements and O-rings. There will also be oil loss through the vent in the housing, which is used to minimise windage and oil evaporation pressure effects on the shaft seals. With modern environmental requirements, the effect of this oil loss has to be considered. Halifax Fan has been working with a steel manufacturer to change oil lubricated roller bearings to grease lubricated roller bearings because the manufacturer was using gallons of oil per week in order to keep the bearing oil at an acceptable level. In some facilities, a move away from oil is also being introduced because it is seen as a fire hazard.

The main lubrication method for fan rolling element bearings is grease. If the bearing was filled with the grease, the bearing would get too hot. However, when the fan is running, the bearing has maybe 10% of its space filled with grease. To ensure that the bearing surfaces are fully greased, they are initially packed with grease and the space either side partially filled with grease, between 25% and 50%. When the bearing initially runs, it will run hot due to the excess grease. This will then migrate out of the bearing but only if there is space for the excess grease to go.

Mono-block bearing units have a large cavity between the bearings that will hold the grease. Therefore, there is no requirement to empty old grease out of the bearing units. For other bearing housings there is a requirement to remove grease, typically once every couple of years. For larger motors, a port is opened so that grease is pushed out as it is pushed in. Due to additional grease being pushed into the bearing from the cavity, it is typical for bearing temperature to increase for up to a couple of hours after re-greasing.

Bearing failure – lost lubrication.

Red bearing grease turned pink by water contamination – water in the bottom of the bearing housing.



Bearing failure from thermal instability – cage broken.

Premature lubricant failure most often occurs due to environmental effects. Water contamination results in a clear change in the consistency of the oil or grease. Typically, grease will become much whiter with water contamination. Electrostatic discharge is often reported as the leading cause of bearing damage. However, at a weaker arc level there can be localised carburisation of grease, leading to rapid ageing. Cases have been noted where grease has failed in less than six months. Using an elastomer coupling prevents arcing and more frequent greasing compensates for rapid ageing.

The part of the bearing that fails first from temperature is the lubricant, with most greases becoming liquid above about 120˚C. Typically, bearings are not allowed to run hotter than about 90˚C without risk of temperature transients leading to failure. With grease lubrication, there is no cooling effect from changing lubricant. This means that external cooling has to be applied (either cooling of the housing or the use of a cooling disc to take heat away from the shaft). The typically higher viscosity of grease compared to oil means that there is more focus on cooling by design for grease lubricated bearings.

With both oil and grease, compatibility must be considered, with reports of grease becoming stiff from being mixed with another that is incompatible. Thus, it is important to ensure that compatible greases are used. Halifax Fan uses lithium complex-based grease, either with a mineral oil or synthetic oil for most applications, but may use others depending on the application. Some end users seek to minimise greases used on site or have a preferred supplier. If that is the case, they need to let the fan manufacturer know so that the bearings can be re-greased with grease that suits their requirements.

Vibration

Rolling element bearings are not rigid. The smaller a bearing is and the less a bearing is loaded, the less stiff it is. There are standard formulae for working out bearing stiffness that take these factors into account. The stiffness these formulae give is the stiffness in the load direction. For the located bearing, this also tends to be the stiffness perpendicular to the load but for the non-located bearing, the stiffness perpendicular to the load direction is about 33% of the stiffness in the load direction. If the bearings are assumed rigid there can be fan vibration problems due to an unexpected proximity of the rotor natural frequency to running speed.

The most common vibration problem is

skidding due to light loading of bearings. The vibration of shafts whirl like a skipping rope. Forward whirl is driven by out of balance and occurs in the direction of the shaft rotation. Reverse whirl is driven by skidding and moves in the direction opposite to the shaft rotation. Typically, the reverse whirl mode is not considered due to the fact that it is only weakly excited by being out of balance, so can be close to running speed. This becomes a problem when there is excessive bearing skidding and can lead to high vibration levels at running speed. When this happens, the solution is usually to change to a bearing that can take the light load without skidding. For example, a spherical roller bearing may be changed to a self-aligning ball bearing.

ATEX Fan – Mechanical shaft seal, bearing unit with temperature and vibration monitoring.

Where there is thermal cycling of the bearing from skidding there can also be vibration cycling if the reverse whirl's natural frequency is close to running speed. This produces a rotation vibration superimposed on the vibration from out of balance. In effect, there is an offset circle on a balance chart with the centre of the circle being the out of balance effect. The size of the circle indicates the skidding effect. Since this is a skidding thermal phenomena, the cycle can last between 30 minutes and 1 hour.

Failure of a bearing does not always lead to high vibration. There have been cases of larger fans with badly spalled bearings, and about 50% of the track damaged, with a vibration level of less than 5 mm/s. This has led to an interest in high frequency vibration measurements to detect bearing failure. In the 1980s, shock pulse monitoring was used as a method to detect bearing failure using a single value. However, it fell out of fashion due to good bearings that were found to be running more noisily, being condemned over others. This was due to users not trending the value to detect deterioration. More recently, acceleration envelope methods have been gaining popularity for assessing bearings. This is a modern equivalent of shock pulse monitoring that uses more complex methods to generate a single number. Like shock pulse monitoring, it is difficult to differentiate between a noisy, but acceptable bearing and a bearing that is starting to fail based on isolated readings. Halifax Fan has been involved with a number of end users where this method has been used to condemn good bearings. With an acceleration envelope, as with shock pulse monitoring for lower value readings, it is necessary to trend the value over time to assess if the bearing is failing.

Summary

Rolling element bearings are the main bearing types used for fans. They have their challenges but with proper design and maintenance, can give years of good fan service. ■

Assessing bearing vibration.

About the authors

Dr John Irons has had over 25 years of fan design and development experience, having joined Halifax Fan in 2015 as the Chief Engineer from Howden Group Technology. He has extensive experience of fan design, including noise, vibration and fluid dynamics.

Diane Wang joined Halifax Fan China in 2007 and has worked closely with customers to drive product development through providing solutions to customer needs. She is now the Manager of the Shanghai office, with a key focus on serving the cement industry. Last year Diane received her MBA from the University of Liège, Belgium.