SKF @ptitude Exchange

Principles of bearing selection and application:

Selection of bearing size: using the life equations: load ratings and life

Summary

Using the Life Equations to determine bearing load ratings and life is an ISO-approved methodology for sizing bearings to applications. There are some clear boundaries to the process: don't choose a bearing any larger than necessary (engineering economy) and the bearing must survive to the expected design life of the application. Using well established, empirically proven methods, it's possible to choose the right bearing for the simplest consumer device, like a skateboard; to the largest rotating equipment, such as a Cement Kiln, over 100m long. The amazing part is that the same basic tools can be used: The "laws" of bearing life are well documented, and proven by over 80 years of empirical validation. These "bearing laws" have been refined several times over the years, as our understanding of bearings has improved. SKF continues to fund fundamental studies of bearing life: there is still plenty of research to be done.

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GC6000-2-3
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5 Pages
Published March, 2010

Basic Rating Life

The basic dynamic load rating, or "C" as you'll find it in bearing catalogs, is used only for bearings rotating under load. (Static, or non-rotating loads, use another ISO-approved process for selection). The value "C" that can be found in the SKF General Catalog expresses the ISO 281:1990 basic rating life for 1,000,000 (one million) revolutions. Later on we'll see how we convert from revolutions to hours of operation, which is often a more practical way to estimate bearing life.

There are some assumptions in determining bearing life:

1. The bearing load is constant in magnitude
2. The load is proper for the bearing; that is, radial loads for radial bearings (like deep groove ball bearings) and axial, centrally acting loads for thrust bearings (such as spherical roller thrust bearings. Many applications encounter combined loads, with radial and axial loads in the same machine1.
3. Standard materials: Chromium steel bearings hardened to 58 to 62 HRC (Rockwell Hardness, C Scale.) Using stainless steel components in bearings generally reduces the bearing life at least 10%.
4. "Normal" conditions: the environment doesn't have extreme temperatures or, humidity. Many of the newest bearing solutions are specifically designed to work in extreme operating conditions. In future articles we'll explore what can be done to extend bearing life in these extreme conditions.

The life of a bearing can be defined as

- the number of revolutions

or

- the number of operating hours at a given speed

which the bearing is capable of enduring before the first sign of metal fatigue (flaking, spalling) occurs on one of it's rings or rolling elements.

In the SKF research labs, fatigue life testing of bearings has been going on for decades. As life testing of thousands of bearings progressed, it became apparent that a statistical approach to bearing life was needed: a single bearing can fail early or late based on a number of factors, such as

[1] A centrifugal pump is a good example of combined loads: the impeller is offset in the housing (also called a "volute") and creates a radial load on the shaft that must be accommodated by the bearings. But the pump also produces thrust (axial) loads as the impeller applies suction to the pumpage, generally pulling the impeller and shaft towards the suction inlet, applying an axial load to the bearings.

variation in the steel quality or manufacturing variation of individual bearing components.
One of the first decisions was to assign a 90% reliability to life ratings, so the life of a bearing might be more practically defined as
the number of revolutions (or hours at a given speed) after which 90% of the bearings can be expected to survive without any sign of fatigue.
This means that we sometimes see a bearing fail from fatigue earlier than expected, and some last longer – they are statistical outliers.

As companies work machines harder, often well past the designed speed ratings or load capacities, bearings life can suffer greatly and lead to premature, often catastrophic failures.

So what affects bearing life, and is there anything I can do practically about it?

The L_{10m} life of a rolling bearing in a given application can be established using the ISO life equation:

$$L_{10m} = a_{SKF} \left(\frac{C}{P}\right)^{p}$$

Where
L_{10m} = SKF basic rating life, millions of revolutions
a_{SKF} = SKF life modification factor
C = basic dynamic load rating
P = equivalent dynamic bearing load
p = exponent of the life equation
p = 3 for ball bearings, 10/3 for roller bearings

The L_{10} life is what we are trying to estimate, so where do we get the other values? Where does the manufacturer get the value of C to put in their catalogs? The bearing manufacturer calculates the value of C from the sizes of the bearings components and the geometry of the bearing. Our understandings of fatigue failures are pretty sophisticated. We use advanced calculation tools to estimate the bearing rating life very well. In the 1920's and 30's – rating a bearing life was a complete unknown. Researchers set up large numbers of test stands and began to fail bearings under controlled loads and speeds. They carefully recorded the results. Statistical analysis found that for ball bearings, if the exponent, p, was three, the calculated results agreed closely with the actual data.

The tests were repeated using roller bearings, and the exponent that worked best was 3+1/3, or 10/3.[2] This result tells us that to increase application life, switching from ball bearings to roller bearings of the same size should result in a life increase.

So the experimenters found the exponents that seemed to work in this newly found "Law of Bearing Life." They continued their investigations using the new "law" to predict the life of another bearing. Under the same controlled conditions, the failure rates of the newly tested bearings matched the life predictions very closely. To this day, SKF continues to validate our *predicted* bearing life data by testing factory produced bearings in our research centers. This gives SKF the confidence to back up the data we put in our catalogs – we've tested our bearings to make sure.

For bearings operating at constant speed it may be more convenient to deal with a basic rating life expressed in operating hours using the equation:

$$L_{10mh} = \frac{1\,000\,000}{60\,n}\left(\frac{C}{P}\right)^{p}$$

Where n = rotational speed, r/min

[2] Ball bearings have "point" contact with the bearing raceways, while roller bearings have "line" contact with the raceways. The load is distributed over a greater contact volume in roller bearings, hence their longer life.

Some general conclusions

Now we can make more general conclusions about the life of bearings. Let's use an inclined conveyor as an example. The conveyor belt is supported by three idlers, each idler supported by two ball bearings on each side. The design life of the idler bearing was specified at 40,000 hours, and the machine manufacturer chose bearings with the proper size to reach the expected life. This week, your company has received orders to increase production. You decide to speed up the conveyor belt 10%. The changes are made, and higher production is achieved. But at what cost? If the loads remain constant, and the speed (n) increases 10%, L_{10} life is reduced by 10%. Speed affects life proportionally.

The next week, you're ordered to convey even more material than before. Production must be increased. This time, you decide to increase the volume of material (weight) on the belt on the belt by 25%, but shortly thereafter, you begin to encounter bearing failures. Replacing the bearings doesn't help – the life, originally designed for 40,000 hours, is much shorter. What's happening?

By conveying more material , you placed a much greater load on the bearings. You have increased "P" – the equivalent dynamic bearing load - significantly. Even though the bearing load from increasing the weight on the belt is only 25% higher, the life on the ball bearings will be reduced at an exponential rate.

The basic dynamic load rating (C) for the bearings is the same, but P, the equivalent dynamic bearing load, has increased 25%.

$(C/P)^p = (C/P)^3$
$= (C/P) \times (C/P) \times (C/P)$
$= (1/1.25) \times (1/1.25) \times (1/1.25)$
$= (.8) \times (.8) \times (.8)$
= .512, or only 51% of the original life.

Multiply this by the 25% life reduction from the speed increase and we get 12.8% of the original design life. The application that was originally designed for 40,000 hours life (about 5 years) will now have a potential bearing failure about every six months. Fairly small changes to P, the equivalent bearing load, have *significant* effects on bearing life.

The basic rating life equation also points the way toward improvement opportunities: what can I do locally to increase the service life of my bearings? Manufacturers almost never include the effects of unbalance or misalignment on machines: they assume you install and run machines in perfect alignment and with zero unbalance. Improving the balancing and alignment condition of your machines can be an easy way to increase bearing life by reducing unwanted, parasitic bearing loads.

These calculations account for life under ideal conditions only. We haven't considered the influence that contamination and ineffective lubrication, have on bearing life. These factors can reduce actual bearing life well below that predicted by the basic life equation.

Lubricant and sealing selection is very important for bearing life.

In our next article, we'll use the general catalog to perform bearing life estimation using the SKF rating life method, as well as advanced strategies for life extension.