



AGMA Technical Paper

The Modified Life Rating of Rolling Bearings - A Criterion for Gearbox Design and Reliability Optimization

By A. Gabelli, A. Doyer, and
G. Morales-Espejel, SKF France

The Modified Life Rating of Rolling Bearings - A Criterion for Gearbox Design and Reliability Optimization

Antonio Gabelli, Armel Doyer, and Guillermo Morales-Espejel, SKF France

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Generally speaking, engineers learn that the bearing L_{10} life can be estimated using the so called “C/P method” also known as the “basic rating life” of the bearing. This method finds its root in the 1940s when Swedish engineers G. Lundberg and A. Palmgren developed their mathematical model for the bearing life calculation. In the following decades, this theory has been refined based on a better understanding of the fatigue life phenomena, as well as improvements in the material, design and manufacturing of the bearing. These findings were implemented in ISO 281 standard in 1977, under the title of “adjusted rating life”. Clearly, bearing manufacturers and industry acknowledged the need to adjust the basic rating life, taking into account the most important influencing factors affecting bearing performance. Since that time, further developments have led to what is called today the “modified rating life”, as released in ISO 281:2007, which includes the a_{iso} life modification factor. In the paper, the succession of equations used for bearing life ratings are reviewed and current bearing life rating practices are discussed in detail.

It is shown that despite the introduction of the adjustment factor of the basic rating life more than 30 years ago and the standardization of the a_{iso} modification factor in 2007, the use of these improved calculation methods for the ratings of bearing performance are not yet part of the calculation practices of every engineer. Indeed many users simply refer to the old model in order to comply with existing established practices. As a consequence those users may release technical specifications referring only to the requirements for the L_{10} basic rating life. This in turns leads to many gearbox manufacturers still making design decisions based on the old ISO 281:1977 “basic rating life” standard. The implication of not adopting modern rating life as described in ISO 281:2007 is, in a way, equivalent to disregarding 30 years of bearing technology development. This may lead to design selections that in some cases can be quite conservative whereas in others, by ignoring critical aspects absent from the simple “basic rating” model, may lead also to non-conservative design. The paper addresses these issues in the specific context of industrial gearbox bearing design. The discussion points are illustrated using an example of the design analysis of a helical gearbox application.

Copyright © 2014

American Gear Manufacturers Association
1001 N. Fairfax Street, Suite 500
Alexandria, Virginia 22314

October 2014

ISBN: 978-1-61481-108-4

The Modified Life Rating of Rolling Bearings - A Criterion for Gearbox Design and Reliability Optimization

Antonio Gabelli, Armel Doyer, and Guillermo Morales-Espejel, SKF France

Introduction

The concepts of rolling bearing rating life and basic load rating (load carrying capacity) were introduced by A. Palmgren in 1937 [1]. At that time and until the 1950s, most bearing manufacturers listed in their catalogues the load admissible on the bearing for thousands hours of operation at five different speeds. In those days the selection of a bearing size for a given application was rather a simple matter.

The concept of a single rating factor to characterize the dynamic capacity of the bearing was new and it was initially used only within the bearing company that developed this new technology. This rating method was backed by the theory of Lundberg and Palmgren (L-P) [2] and by the Weibull statistics [3]. It was found that it could provide a correct interpretation of the many series of endurance tests available at the time, [2], [4], [5]. This calculation method prevailed on all the others methods used at the time and it was adopted by ISO in 1962.

Before the ISO acceptance, the L-P model for life ratings was independently validated by Lieblein and Zelen 1956 [4] of the U.S. National Bureau of Standard using endurance test data provided from different bearing manufacturers. In total 213 test series were analyzed amounting to a total of 4948 endurance tested bearings. Furthermore, the statistical setting of the bearing life dispersion was also assessed by Tallian of the Philadelphia testing laboratories in 1962 [5]. In the Tallian investigation a composite sample for a total of over 2500 endurance tested bearings were analyzed. The original L-P model constituted the foundation, and it is still today the nucleus, of all national and international standards for fatigue life rating of rolling bearings including subsequent theories and developments. Basically the L-P theory [2] laid down the basis for the calculation of the dynamic load rating and equivalent dynamic load of rolling bearings as it is applied today in ISO 281 [8] basic rating life equation:

$$L_{10} = \left(\frac{C}{P} \right)^p \quad (1)$$

where

- L_{10} is rated fatigue life, at 90% reliability, in million revolutions;
- C is basic dynamic load rating of the bearing for a rated fatigue life of one million revolutions;
- P is standardized dynamic equivalent load of the bearing;
- p is life equation exponent.

The availability of a standard method for the dynamic rating of rolling bearings is useful to the mechanical industry as it allow streamlining product specifications for large-scale manufacturing and worldwide compatibility and exchangeability of rolling bearings.

The dynamic load rating allows bearing users to compare similar bearing types made by different manufacturers. Manufacturers, on the other hand, can profit from the ISO standards to rate their products, of any size and type, using just the internal nominal geometry of the bearing. Apparently the ISO standard for bearing load ratings provides a win-win situation to all parties and this explains the widespread use of this standard in the mechanical industry.

Mechanical designers however need to be well informed in order to take full advantage of the opportunities offered by standardized bearing load ratings. In particular they must be aware of the many aspects and changes that have taken place in this field through the years and how these changes have impacted gearbox performance and design practices.

In this paper we will examine at first the evolution of standardized bearing life rating that has taken place after ISO 281 was first instituted in 1962. The technical justifications behind each different change will be explained, showing also the impact that variation of bearing life ratings had on gearbox design and product performance through the years.

Present use of the standard will also be discussed showing that there are different interpretations and some misuses of the present standard in the marketplace. This introduces distortions and uncertainty to the rather straightforward task of selecting the proper bearing size for a given application.

Methods to avoid possible misleading situations and risks are suggested and explained using an example of a bearing design analysis of a helical gearbox application. The limitations implicit in the definition of standard load rating are also considered and discussed in detail. Finally, the concept of robust design based on the latest rating rules and the modified life, i.e., ISO 281 [8] is introduced with reference to the performance and reliability optimization of industrial gearboxes.

Standardization and evolution of bearing life

The increase of transmitted torque, the decrease in overall dimensions and weight together with the increased reliability and service life are undoubtedly the technical aspects that have dominated the rapid progress in the design of mass produced gearboxes and mechanical transmissions over the last fifty years.

Previous analysis have shown that the ratio between the transmitted torque and the mass of a typical industrial gearbox has increased up to a factor twelve since the fifties [6], see Figure 1.

This progress can be assessed also by looking at the power density of the gearbox that is particularly relevant in case of automotive transmissions. An analysis of automotive gearboxes [7] shows that this parameter approximately doubled during the last thirty years. During the same time period the reliability of rolling bearings for gearboxes also increased by a factor three [7], allowing for a 70% improvement of the torque density of automotive transmissions [37], see Figure 2.

This real progress would not have taken place if gearbox designers could not benefit from the simultaneous continuous progress in rolling bearing technology that have characterized the same time period. Indeed, due to the stress concentration of the rolling contact and the number of rolling elements, rolling bearings are in general the heaviest stressed and the highest fatigue cycled component of a mechanical system.

The fact that the life expectancy of the whole system depends on its weakest link, makes the reliability of a few critical bearing components vital for the reliability of the whole transmission and it pushes for the development of bearings with an extended life. The progress achieved in increased rolling bearing reliability can be visualized in the development of the ISO 281 rated life relative to the original ISO 281:1962 level, as shown in Figure 3.

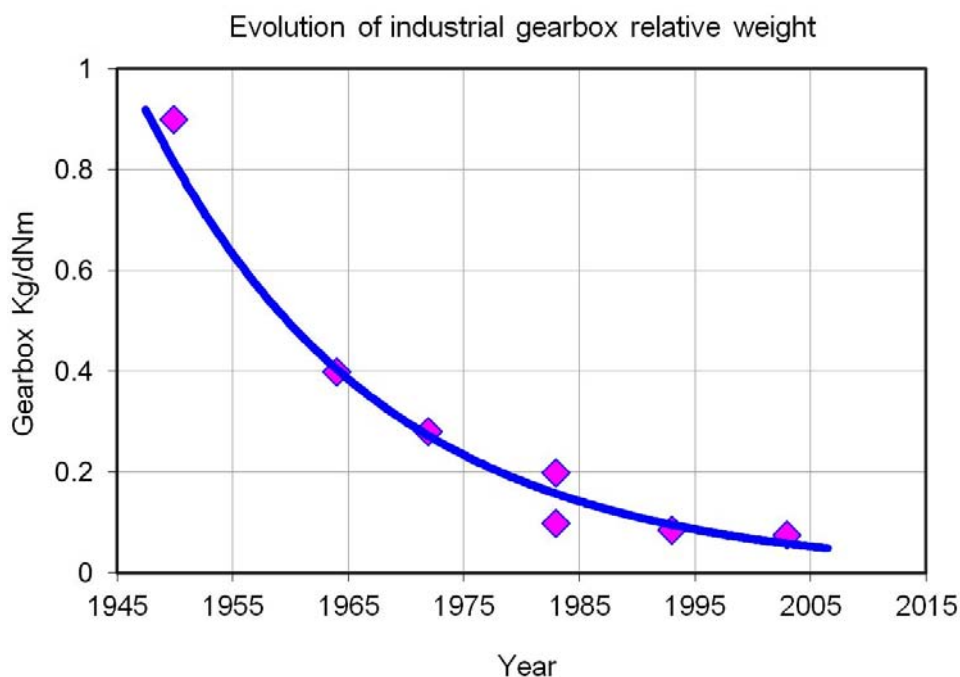


Figure 1. Typical relative weight evolution in industrial gearboxes during the last fifty years [6]

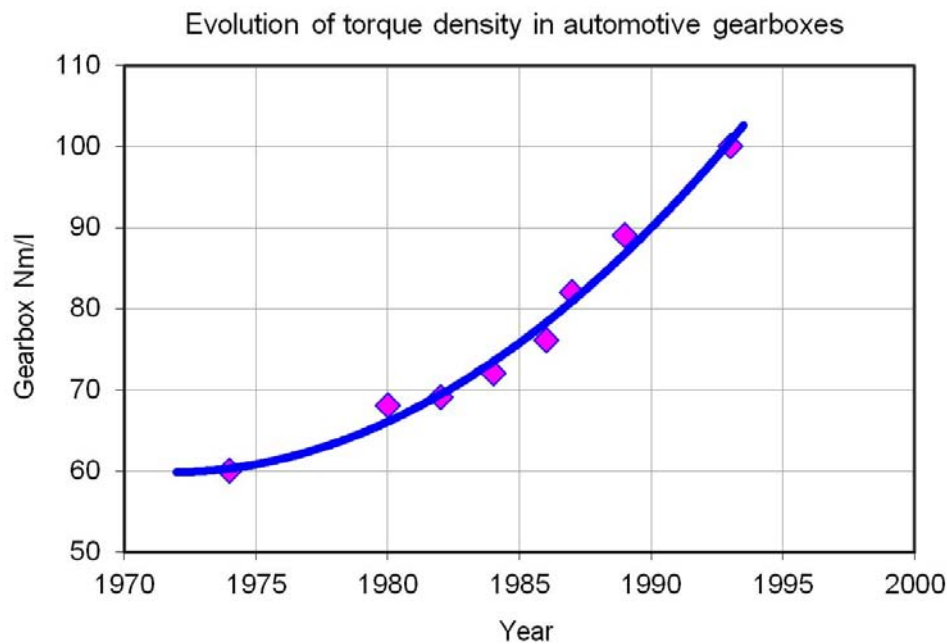


Figure 2. Progress in automotive gearbox design in term of increased torque density [37].

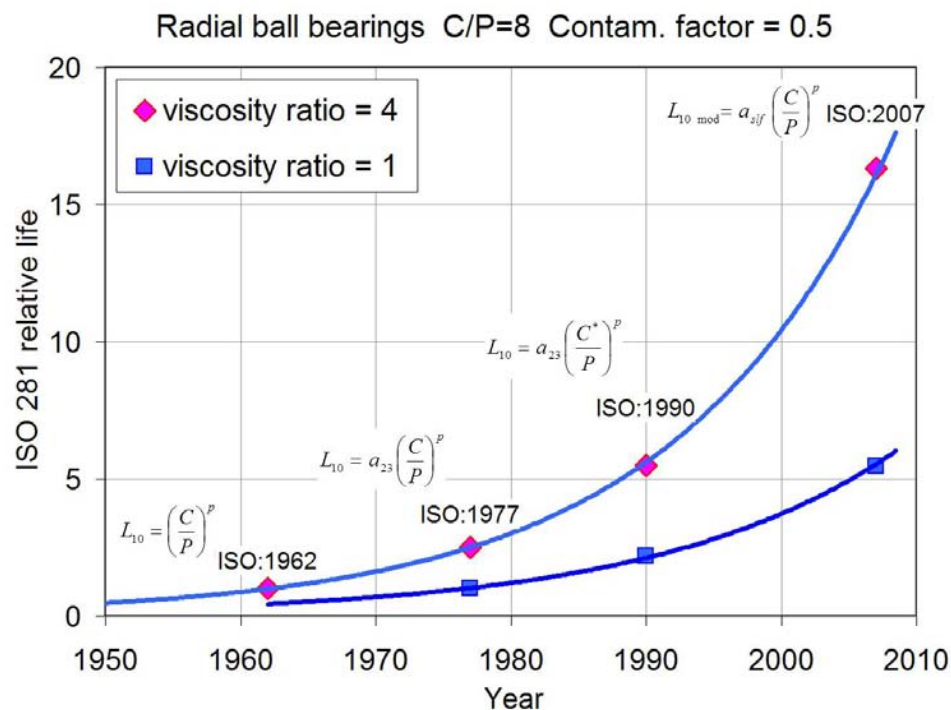


Figure 3. Typical progression of the ISO rated life of a radial ball bearing, loaded at $C/P = 8$, contamination factor = 0.5, viscosity ratio of lubrication = 1 and 4

Figure 3 shows normalized rated lives to the initial ISO 281:1962 rating. As discussed in the introduction, the ISO 281:1962 was the direct result of a draft proposed by the Swedish delegate A. Palmgren to the ISO Technical Committee in 1952. This draft basically contained the bearing rating rules developed in SKF during the previous two decades of research.

In the following period, thanks to the newly discovered elastohydrodynamic lubrication (EHL) mechanism the effect of the lubrication quality on the expected bearing life could be addressed and an intensive research program was initiated in SKF. This research work was carried out with the prominent contribution of T.E. Tallian in Philadelphia [9], [10], [11] and by S. Andréason in Gothenburg [12], [13], [14]. The results of this work were also made available in SKF catalogs [15] [16] and to the ISO