# DETERMINATION OF CERTAIN PARAMETERS OF A BEARING

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The article deals with the development of a more accurate method for determining certain parameters of a bearing in the early stages of the engineering design process. Using the traditional approach, the parameters of the given parts are estimated by experience. Another method is to make a simple estimation of basic static or basic dynamic load rating, which is inaccurate if is applied. Following this step a potential bearing is chosen from a catalogue and is recalculated or replaced, which provides the inputs for optimization. The approach described in this paper can be used to estimate the mentioned parameters with regards to the load value and its duration.

**KEYWORDS**
ball bearing, load spectrum, optimization, determination, selection

## 1 INTRODUCTION

The traditional approach of the selection of a bearing is to select the bearing from a catalogue using experience or the minimum selected diameter of a shaft. After that the design is controlled by calculation. If parameters of the selected bearing are not acceptable, the bearing is replaced by another one and again controlled. These steps make designing more effective, but require a lot of time and energy to make changes and find an optimal solution. Determination of suitable parameters at an early stage is an opportunity to get a better product at the end of the design process. The aim of this paper is to estimate the parameters of a deep groove ball bearing loaded by fluctuating axial and radial loads. This approach is useful for calculation using a specially designed program without a database of bearing parameters. The selection is provided using basic dynamic load rating. The advantage of this approach over calculating using the database is speed, because results are not easily transferable between bearings due to nonlinear characteristics. Another benefit is the possibility to make a simple special program without the bearings database. This output is a part of a long-term research programme to develop new advances in the development and optimization of systems consisting of gears and shafts.

## 2 AN OVERVIEW OF METHODS USED BY MANUFACTURERS

Manufacturers of bearings suggest simple methods to estimate the parameters of bearings. This chapter introduces two methods presented in manufacturer's catalogues.

One of the SKF's recommendations [SKF 2013] is to select the bearing size by calculating the *basic static load rating*:

$$C_0 = s_0 P_0 \tag{1}$$

The static safety factor $s_0$ is given by the type of operation. The *equivalent static bearing load* ($P_0$) is given by equation [CSI 2008a]:

$$P_0 = X_0 F_r + Y_0 F_a \tag{2}$$

This method is simple, recommended only for low angular velocities. But the service life of a rotating bearing depends on the basic dynamic load. SKF generally recommends consideration based on many factors (service life, size of bearing, lubrication or service temperature).

Another approach can be selection using equivalent basic dynamic bearing load, despite SKF catalogue doesn't directly recommend it for selection.

A method provided by NSK is to calculate the basic dynamic load rating using a fatigue load factor $f_h$ [NSK 2013]. The principle of the fatigue load factor is similar to $s_0$, choosing $f_h$ from Operating Period table (Fig. 1).

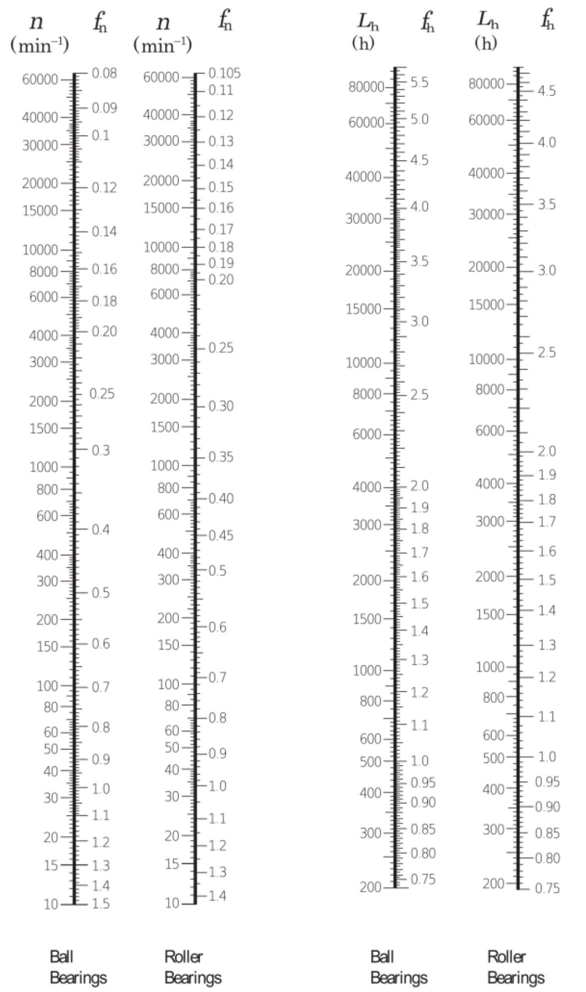


**Figure 1.** Operating Period Table [NSK 2013]

Recommended basic dynamic load rating can be calculated using by equation below:

$$C_r = \frac{P f_h}{f_n} \tag{3}$$

where $f_n$ is a speed factor [NSK 2013]. The NSK method seems to be better, because the service life depends on the basic dynamic load factor. The *equivalent dynamic bearing load* is given by the expression [CSI 2008b]:

$$P = XF_r + YF_a \tag{4}$$

Coefficient *X* and *Y* depends on the ratio of axial and radial force (*X* and *Y* explained in the next section). There is no suggestion to determine *X* or *Y* (for NSK selection method).

Depends on use, the only disadvantage of NSK method can be Operating Table. For calculation using computer program is better to convert Operating Table to suitable equation with.

## 3 SUGGESTED METHOD FOR PARAMETER ESTIMATION

This method is developed for a load spectrum (fluctuating load). The load spectrum consist of events. Every event of the load spectrum is defined by radial and axial force, revolutions per minute and its duration. The mathematical model is based on ISO 281 [CSI 2008b] and ISO 76 [CSI 2008a] standards. The aim of this method is to estimate basic dynamic load rating by calculation directly from the load spectrum.

The first step is to estimate the basic static bearing load from the load spectrum. The equivalent static bearing load for event *i* is given by the expression:

$$P_{0i} = X_0 F_{ri} + Y_0 F_{ai} \tag{5}$$

The basic static load rating depends on the maximum load, $s_0$ is given by the type of operation:

$$C_{0min} = \max(s_0 P_{0i}) \tag{6}$$

The estimation of $C_{0min}$ is important for the calculation of $C_{min}$, because the value of *X* and *Y* depends on $C_0$. The calculation factor ($f_0$) depends on the specific bearing, for selection it is considered $f_0 = 12$.

The basic rating life of a bearing describes the service life in number of revolutions:

$$L = 10^6 \left(\frac{C}{P}\right)^p \tag{7}$$

The equivalent dynamic bearing load for event *i* (load spectrum):

$$P_i = X_i F_{ri} + Y_i F_{ai} \tag{8}$$

where $X_i$ and $Y_i$ is selected using the procedure described in ISO 281 [CSI 2008b]. The first step is to calculate ratio *k* (the *k* sign is used only for the purposes of this paper):

$$k = \frac{f_0 F_a}{C_{0r}} \tag{9}$$

The value of *k* is important for selection of *e* coefficient. In ISO 281, *e* is divided into intervals [CSI 2008b], so the calculation of *e* is simplified using approximation by the power function:

$$e = 0.283 k^{0.2329} \tag{10}$$

The *Y* parameter is divided into intervals in the same way as *e* [CSI 2008b]. The calculation of *Y* is solved by the power function using *e*:

$$Y = 0.56 e^{-0.975} \tag{11}$$

The value of the *X* coefficient is 0.56. For pure radial load, *X* = 1 and *Y* = 0.

From the previous calculation, the ratio ($z_i$) of realized revolutions and service life revolutions is:

$$z_i = \frac{n_i t_i}{10^6 \left(\frac{C}{P_i}\right)^p} \tag{12}$$

where $n_i$ is rotation speed and $t_i$ is duration of event.

Accumulation of a damage of a bearing loaded by fluctuating radial and axial forces is calculated using Miner's rule [SKF 2013]:

$$z = \sum_i z_i = \frac{1}{C^p} \sum_i \frac{{P_i}^p t_i n_i}{10^6} \tag{13}$$

The aim is to consume all available bearing life after loading by load spectrum, so *z* equals 1. The minimum basic dynamic load rating is given by the equation:

$$C_{min} = \left( \sum_i \frac{{P_i}^p t_i n_i}{10^6} \right)^{\frac{1}{p}} \tag{14}$$

The basic dynamic load rating of the selected bearing must be equal to or higher than $C_{min}$. And also the minimum value $C_0$ of the selected bearing must be higher than or equal to $C_{0min}$.
The method described in this section works well only for bearings loaded by pure radial forces. The problem is the dependency of the equivalent dynamic load rating on the basic static load rating. For combination of radial and axial load, firstly $C_{min}$ is calculated. Based on this value a bearing from a catalogue is selected. However, it is very likely that $C_0$ of this bearing is greater than $C_{0min}$ originally calculated. The higher value of $C_0$

requires a higher value of *C* therefore the selected bearing might not meet the bearing life criterion.

## 4 IMPROVING PRECISION OF DYNAMIC RATING ESTIMATION

The solution to the problem described above with $C_{0min}$ is to determine $C_0$ more precisely. So the next step is to determine basic static load rating on $C_{min}$. The relationship between *C* and $C_0$ depends on the design of a bearing. It can be calculated very precisely based on a theory of bearing design. But this approach requires to know a large amount of information about bearings (at least number and size of elements, material of elements, races design and material). For a purpose of selection a bearing from catalogue, the relationship must be based on data from manufacturers.

The determination is based on $C/C_0$ dependency derived from SKF catalogue [SKF 2013]. From this catalogue, we selected a group of bearings which represents all the series of bearings and we created a graph of ratio $C/C_0$ (Fig. 2). For the sake of simplicity, the relationship is approximated by a linear function, a large variance is caused by the inclusion of both light and heavy series bearings.

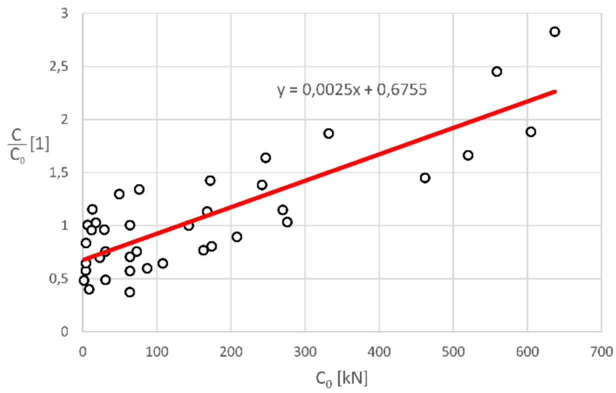


**Figure 2**. Dependency $C/C_0$ based on $C_0$

The estimated basic static load rating $C_{0E}$ is given by the equation ($C_{min}$ [N]):

$$C_{0E} = C_{min} \cdot \left( \frac{10^{-5}}{4} \cdot C_{min} + 0.6755 \right) \text{ [N]} \qquad (15)$$

The next step is to calculate the $P_{Ei}$ ($P_i$ based on $C_{0E}$) and estimate basic dynamic load rating:

$$C_E = \left( \sum_i \frac{{P_{Ei}}^p t_i n_i}{10^6} \right)^{\frac{1}{p}} \qquad (16)$$

The basic dynamic rating of the selected bearing must be close to $C_E$. The basic static load rating of the selected bearing must be higher than $C_{0min}$.

## 5 COMPARISON OF METHODS

This chapter compares the results from the methods suggested by SKF, NSK and the approach described by this paper. The results described below are only examples to demonstrate basic differences. The parameters of the bearings are from the SKF catalogue [SKF 2013], calculations made by our special program, there is no preference for the inner diameter of a bearing. The coefficient $s_0$ equals 2.5 for all examples.

### 5.1 *Example 1 – pure radial load*

First example is only one event consist of pure radial load.

| Radial Force [N] | Axial Force [N] | Speed [rev/min] | Duration [hrs.] |
|---|---|---|---|
| 4000 | 0 | 1600 | 10000 |

**Table 1.** Load spectrum of Example 1

The solution was calculated using own script written in Python 3.

| CE [kN] | Cmin [kN] | Cr [kN] (NSK) | C0 (SKF) [kN] |
|---|---|---|---|
| 39.5 | 10 | 39.5 | 10 |

**Table 2.** Results (Example 1)

Considering the result of $C_E$ and $C_{min}$, the selected bearing is SKF 6015 ($C$ = 41.6 kN, $C_0$ = 33.5 kN). The service life $L_h$ of selected bearing is 11717 hours, static safety factor $s_0$ is higher than 8. The results $C_E$ and $C_r$ are very close to the required duration.

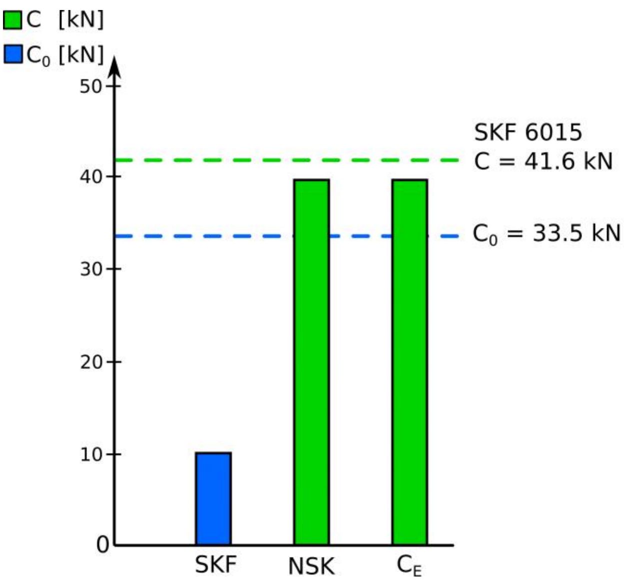


**Figure 3.** Ex. 1: Comparison of results and selected bearing parameters

Booth NSK and recommended method give the same results with 6% deviation. Method from SKF catalogue is far away from basic static load rating of selected bearing.

### 5.2 *Example 2 – radial and axial load*

The second example consist of three different events. There is one pure radial load and two events with combination of radial and axial load.

| Radial Force [N] | Axial Force [N] | Speed [rev/min] | Duration [hrs.] |
|---|---|---|---|
| 2000 | 0 | 1200 | 2000 |
| 4000 | 1000 | 1600 | 4000 |
| 6000 | 2000 | 2400 | 4000 |

**Table 3.** Load spectrum of Example 2

The solution was again calculated using Python 3, arrays was implemented with Numpy library.

| CE [kN] | Cmin [kN] | Cr [kN] (NSK) | C0 (SKF) [kN] |
|---|---|---|---|
| 60.4 | 15 | 51.8 | 15 |

**Table 4.** Results (Example 2)

For the NSK method *P* is estimated for $C_0$ = 15 kN (based on NSK catalogue [NSK 2013]). The axial and radial forces are calculated separately, then *P* is determined by calculating the equivalent load.

Considering the result of $C_E$ and $C_{min}$, the selected bearing is SKF 6018 ($C$ = 60.5 kN, $C_0$ = 50 kN). The service life $L_h$ of the selected bearing is 10599 hours, static safety factor $s_0$ is higher than 8. The result $C_E$ is very close to the required duration. The NSK result can be usable, but the evaluation is complicated due to the estimation of *P*. As mentioned, NSK method doesn't suggest any solution for fluctuating load. The method based on static load (SKF) is applicable only for low angular velocity.

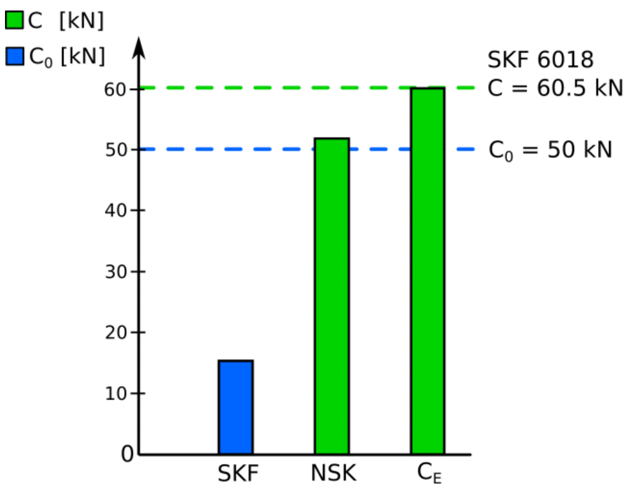


**Figure 4.** Ex. 2: Comparison of results and selected bearing parameters

## 6 CONCLUSION

The approach described in this paper is an attempt to select bearings using the basic dynamic loading rating. The goal was to create a mathematical model to estimate the parameters of deep groove ball bearings loaded by fluctuating radial and axial forces. This method requires only simple characteristics based on selection of a representative group of bearing parameters. Only disadvantage of the method is necessity to use computer program. The benefits are relatively simple implementation and accuracy for using in own program. The method described in this paper seems to be more accurate for fluctuating load than the basic methods suggested by the manufacturers of bearings. In the future we would to like to focus on the possibility of optimization.

**ACKNOWLEDGMENTS**

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**REFERENCES**

**[CSI 2008a]** CSN ISO 76, 2008. Rolling Bearings – Static load ratings. Prague: Czech standards institute, 2008 (in Czech)

**[CSI 2008b]** CSN ISO 281, 2008. Rolling Bearings – Dynamic load ratings. Prague: Czech standards institute, 2008 (in Czech)

**[NSK 2013]** Rolling Bearings [online]. NSK Ltd., 2013 [20.05.2016]. Available from <http://www.jp.nsk.com/app01/en/ctrg/index.cgi?rm=pdfDown&pno=E1102>

**[SKF 2013]** Rolling Bearings [online]. SKF Group, 2013 [20.05.2016]. Available from <http://www.skf.com/binary/138-121486/SKF-rolling-bearings-catalogue.pdf>

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