Functions of Heavy Bearing Cages (Part I)

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Abstract
In the context of global economy the development capacity and innovation of products is the key to modern society in order to ensure sustainable development. They are known and apply a significant number of research methods and design that are using both technical and economic criteria. They help to perpetuate and stimulate creative, so that in the design or development phase of existing products to ensure optimal correlation between quality and cost. Value engineering as a method of research and design is used herein to identify the functions of a bearing cage which is an important component in a bearing assembly. Identification of the cage functions lead to the identification of the optimization potential in terms of the production, costs and energy consumption involved in the entire life cycle of the cage (manufacturing, operation and post-operation). In the present paper the principal period of interest is the operating period because it has the most significant impact, if not the biggest regarding the energy consumption and costs. The analysis extends also to the period of manufacturing and post-use, periods with significant impact on consumption and costs. The study is part of a major ongoing research and it aims primarily to identify the right paths / directions of research in order to develop reliable and efficient new technological and constructive solution according to the concept of sustainable development and eco-design.

Keywords
heavy bearing, cage, value engineering, functions, sustainable development, eco-design

1. Introduction

Development of the global industry boosts awareness so as to ensure continues development and innovation of products. Competition within the bearings industry determines a positive influence on how the products are redesign and innovated according to the concept of sustainable development [1] and eco-design [2]. This fact has determined a significant increase in recent research in this area due to the European sustainable development strategies and due to massive investments in renewable energies.

The main products of bearing industry are linear rolling and plain bearings, spherical plain bearings, bearings and other adjacent products. Bearings in the usual sense of this term [3] are independent assemblies which are composed of two rings that contains raceways, a number of rolling elements (balls, rollers, needles), a cage and in some cases elements which assure protection and the sealing (Fig. 1).

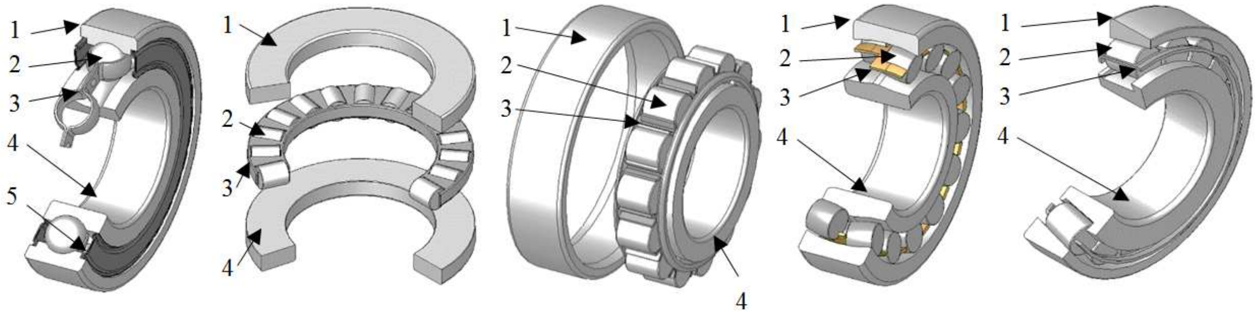

Fig. 1. Types of bearings and their components
1 – outer ring; 2 – rolling elements; 3 – cage; 4 – inner ring; 5 – protection and sealing elements

The bearings are designed to replace the sliding friction with rolling friction, which causes a significant reduction in friction, with all the positive consequences known [4].

Classification criteria for bearings are known [4]. Regarding heavy bearings was not identified a clear delimitation based on the diameter. In this paper will be considered as part of heavy bearings category those bearings that have the $d_m \geq 430$ mm (d_m = medium diameter).

Bearings cages are design mainly to ensure the equidistance of "rolling elements on the circumference of the raceways and to prevent the rolling elements to touch with the neighboring ones thereby avoiding important sliding friction effects" [3].

In order to identify the main potential for optimization and futures directions of research regarding the cages integrated in heavy bearings, in the first stage, it is necessary to identify the main, secondary and eventual the particular function. It appeals to value engineering, research and design method commonly used to study industrial products.

2. Theoretical Elements of Value Engineering

Value engineering it is a method developed during the Second World War by General Electric, used to develop or replace certain materials. Research conducted by Lawrence D. Miles at General Electric Company contributed to the development of a methodology, which aims to study the material in order to enhance the quality of products and to reduce the cost with row material.

Value engineering can be used both in conceptual and design phase but also in the operating phase of the products [5]. L. W. Crum, a well-known specialist in the field of value engineering, defines it as "series of systematic procedures oriented towards the achievement of the required functions with minimal costs without neglecting the quality, reliability, performance and delivery" [6], a definition that applies in the current industrial practice.

Value engineering has two characteristic phases. Phase I presume the analysis of the designed or an existing product and it assumes to dignify the unnecessary functions and high costs of an product or a subset of sub-assemblies of the product in comparison with other products or sub-assemblies from the same category of products with superior features and low cost. Phase II involves the development of new solutions, superior to the product analyzed, ensuring increased quality, more efficient energy consumption, lower production costs and exploitation etc.

From the perspective of product development, value engineering is based on the need identified and studies (analyze) the functions and costs of products, after which the costs of functions are optimized resulting the improved product (Fig. 2). The classical perspective of product development assumes that the product is developed based on the need identified without taking into consideration in the design-manufacturing phase the costs of functions and the cost of the product, subsequently the cost of the product is determined(Fig. 3).

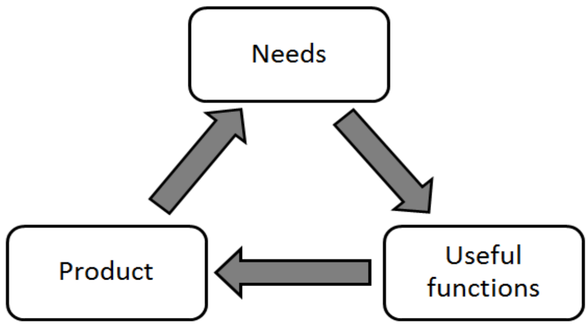

Fig. 2. Product development in terms of value engineering

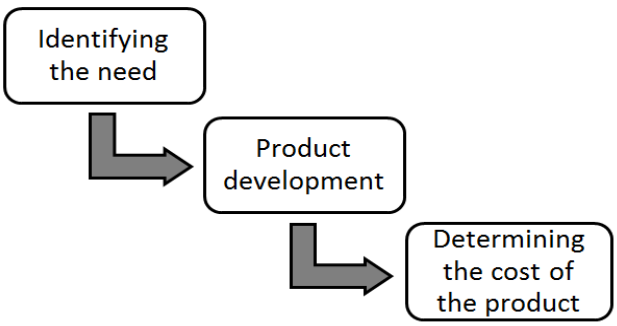

Fig. 3. Classic product development perspective

It turns out that the main object of value engineering is to maximize the ratio between the utilization value (V_i) and the production cost (C_p) so that the required global market value expressed by the multitude of users to be complied [7]:

$$\frac{V_i}{C_p} \rightarrow \max \tag{1}$$

Utilization value is defined as the totality of function of a product that contributes to the social needs (requirements), the final product in some cases could be a necessary component for the manufacturing of other products [7].

3. The Value of a Cages and Bearing

Since determining the value of a product or component provides essential information, especially regarding the repartition costs of the components in the assembly, the paper will refer both to the value of the cage and to the value of the heavy bearing in which the cage is incorporated. To highlight the net values and the cage shared value across the heavy bearing, are given below in Tables 1 and 2, several realistic information for a heavy bearing with massive brass cage used in wind farms.

Table 1. Main dimensions of the heavy bearing and bearing cage

	External diameter	Internal diameter	Width
Bearing	2200 mm	1760 mm	320 mm
Brass cage	2060 mm	1924 mm	247 mm

Table2. Data regarding the lifetime and the cost of the bearing [8]

Bearing lifetime (guaranteed)	20 years
Total availability	175,320 hours
Lifetime in hours	136,970 hours
Operating degree during the period of 20 years	70 %
Correction index	4.15 %
Bearing price	60,000 €
Production (manufacturing) costs	45,000 €

The above data are useful to determine the quantitative expression of the cage value and the bearing. It is worth mentioning that the price and the production cost are determined for standard requirements. Therefore the price and the manufacturing cost of the bearing may vary depending of the bearing diameter and the customer requirements, requirements that can vary significantly depending on the particular application in which the product is integrated. For example if the cage is made from brass (CuZn), its manufacturing cost reach ≈ 9,000 €, representing around 20% from the manufacturing cost of the bearing.

Using equation (1) results:

- The quantitative value of the bearing cage:

$$(\mathrm{V})_{cage} = \frac{(\mathrm{V_i})_{cage}}{(\mathrm{C_p})_{cage}} = \frac{136{,}970}{9{,}000} = 15.21 \text{ hours/€} \qquad (2)$$

- The quantitative value of the bearing:

$$(\mathrm{V})_{bearing} = \frac{(\mathrm{V_i})_{bering}}{(\mathrm{C_p})_{bering}} = \frac{136{,}970}{45{,}000} = 3.04 \text{ hours/€} \qquad (3)$$

Minimizing costs and maximizing the utilization value is a general objective typical to value engineering. Heavy bearing cost minimization requires cost reduction to one or more of its components. Reducing $(\mathrm{C_p})_{bearing}$ associated to the rings and / or rolling elements is unlikely and would require significant changes in technology.

Reducing the manufacturing cost of the bearing cage becomes the first option, even more so as its production cost is significant inwardly (in itself) and in relation to the bearing cost. According to the observation that $(\mathrm{C_p})_{cage}$ decreases the utilization value of the cage increases, see relation (2). The implicit utilization value of the bearing increases but to a much lesser extent.

In order to optimize and / or develop new constructive solutions of bearings cages a fundamental condition will be respected, namely the quality (Q) of the new constructive solutions should be at least equal to the quality provided by massive cages made from brass. Identification of the cage functions is useful and necessary, including for the qualitative evaluation of the new constructive solutions.

It should be noted that the quantitative expression of the cage value does not take into consideration the energy consumption involved in the exploitation (operating) period. They have a direct impact on the customer fact, which is a major argument, even essential, in the decision to purchase and use a particular product.

4. Bearing Cages Functions

The function represents the basic property of a product in relation with the user. The function indicates the utilization value of a component or subassembly of components, which constitute the products in its core essence [7].

In terms of utilization value, the product functions are divided into:

- Main (principal) functions – functions that contribute significantly to the primary purpose of the product both technically and in terms of the utilization value. They can be objective or subjective functions (see Table 3).
- Secondary functions - functions that work together to fulfill or supplement the main functions. These are objective functions.
- Particular Functions - when they exist or are required to be considered separately, they reflect extra core and secondary functions. These occur mainly due to the need to integrate the product into a particular application, specific and unique in some cases.

Table3. Particularities of functions

Functions	Distinguishing elements
Objective functions (O.F.)	• they have measurable technical sizes; • are perceived objectively by users.
Subjective functions (S.F.)	• technical dimensions are hardly measurable and unmeasurable; • are not perceived identical by users.

There are identified different papers and theses [9], which address to bearings functions and / or bearing components functions. A suggestive example I presented in Table 4. It may be noted that many of the functions can be associated to the components of the bearing. Functions C, E (has precision), G_C (allows lubrication), H, I, and K_E can be taken partially or completely as functions of the bearing cages.

Table4. Functions of a tapered roller bearing [9]

Function	Denomination	Type	Observations
A	Supports the shaft	O.F. (primary)	
B	Takes over radial and / or axial forces	O.F. (primary)	
C	Ensures the reduction of friction	O.F. (primary)	
D	Allows determined working speeds	O.F. (primary)	
E	Assures precision at assembly	O.F. (primary)	
F	Allows (regular) bearing clearance adjustment	O.F. (auxiliary)	
GC	Requires and allows lubrication	O.F. (auxiliary)	Helps to achieve function C
H	It has durability	O.F. (primary)	
I	It is reliable	O.F. (primary)	
JH	Allows maintenance and repair	O.F. (auxiliary)	Helps to achieve function H
KE	It is interchangeable	O.F. (auxiliary)	Helps to achieve function E

For the cage, integrated part into the heavy bearings the following functions can be highlighted:

- Main (principal) exploitation functions:

Function A - Ensures the equidistance between rolling elements (O.F.)
Function B - Provides resistance (O.F.)
Function C - Provides rigidity (O.F.)
Function D - It's reliable (O.F.)
Function E - It has durability (O.F.)
Function F - It has precision (O.F.)
Function G - Restricts the exploitation energy consumption (O.F.)
Function H - Provides lubrication (O.F.)
Function I - Ensures the wear reduction (O.F.)

- Secondary exploitation functions:

Function K - Ensures undertaken of forces (O.F.)
Function L - Assures only the useful mobility of rollers / balls (O.F.)
Function M - It is interchangeable (O.F.)

- Main (principal) function of manufacturing:

Function N - It is technological (O.F.)
Function O - Implies a specific degree of technological complexity (O.F.)

- Main (principal) post-operation function:

Function Q - It has reusable material (O.F.)
Function R - It has impact on the environment (S.F.)
Function S - Requires post operating power consumption (O.F.)

Function A – Ensures the equidistance between rolling elements. It is the main function of the cage and reflects its vital (key) role. This function is materialized by the slots provided for the rolling elements (Fig. 4). If the cage would be removed from the bearing assembly, it is unavoidable the occurrence of uneven movements of the rolling elements, which implicitly leads to loss of equidistance between them and even their accumulation in certain areas of the bearing (Fig. 5).Because of this reason the cage is a component that has a decisive impact on the functioning and on the life of the bearing. Until now there has been not found or developed a constructive solution of a bearing that does not require the cage. It requires the optimization of its functions so as to ensure the fulfillment of the core function for a longer period of time. This can be ensured from the design phase through increased performance and by reducing the manufacturing, operation and post-operation energy consumption.

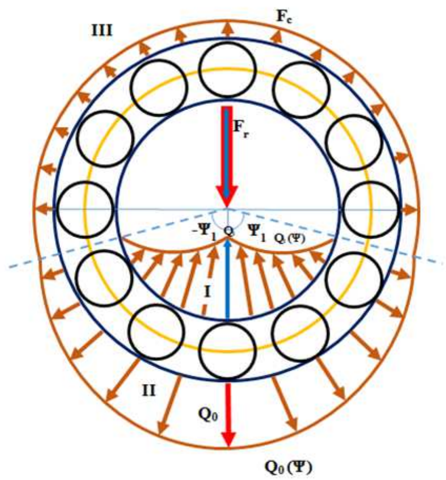

Fig. 4. Distribution of rolling elements for a bearing with a cage

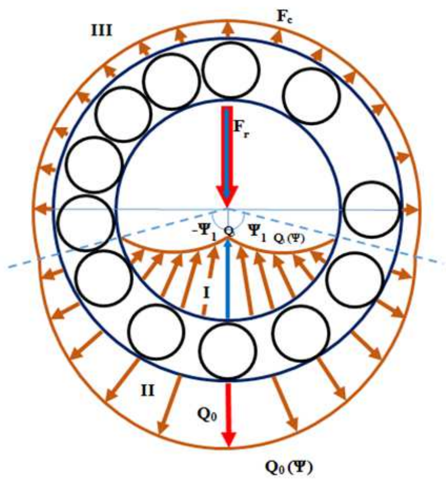

Fig. 5. Distribution of rolling elements in the absence of the cage (possible case)

Function B – Provides resistance. It is a complementary function for function A. The cage is subjected by the rolling elements at certain impacts (crush forces), tensions and compressive forces, unevenly and in different areas. These solicitations are in the vast majority of cases influenced and amplified by thermal phenomena, sliding or dragging effects, by the degree of components wear, etc.

The main solicitation which causes the deterioration or destruction of cages, are crushing (squeezing) and tension forces.

This leads to the identification of two sub-functions, hierarchical to the function B, namely:

- **Function B_1** – Providing resistance to crushing forces;
- **Function B_2** – Providing resistance to tensile forces.

In Fig. 6 and 7 are represented graphically the crushing, tension and compressive solicitations to which the cage is subjected during the operating time, solicitations caused mainly due to the differences of the rolling elements diameters. The elastic and thermal deformations of the rings and rolling elements also contribute to the mentioned solicitations of the cage. Two rollers / balls, not necessarily closer one to another, come into contact with the cage in points 2 causing either crush and tensile solicitations or crush and compressive solicitations. In various areas of the cage occur simultaneously two types of effects crushing-stretching and crushing-compression. The main effects which lead to the damage or destruction of the cage are the crushing and stretching solicitations.

The function "Provides resistance" is fulfilled through the material from which the cage it is manufactured. The materials most commonly used for the bearing cages are: steel (HRC = 60-64), brass, bronze and various plastics and / or composite materials. They provide different resistances to the solicitations to which cages are subject. Increase resistance for a cage can be achieved initially by identifying existing or new materials with superior mechanical characteristics to brass, but with hardness less than the hardness of the rolling elements to avoid the phenomenon of wear. Ideally identified materials should possess anti-friction properties similar to brass or better.

Increase resistance for a cage can be ensured not only by changing the material, but also mainly throu the design of new constructive solutions with higher quality.

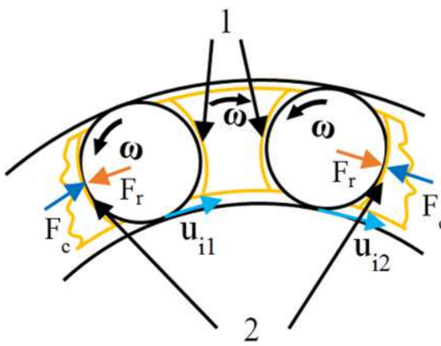

Fig. 6. Graphical representation of the crushing-stretching forces applied on cages

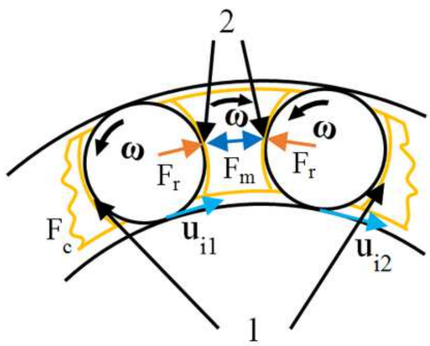

Fig. 7. Graphical representation of the crushing-compression forces applied on cages

Function C - Provides rigidity. Function C is directly complementary to the function "Provides resistance" which represents the ability / attributes of the material from which the bearing cage it is made to prevent deformation under the forces exerted on it through the rolling elements. It is known [10] that between 50% and 95% of the total deformations of certain components of an assembly are represented by contact deformations (elastic deformations, elasto-plastic and contact).

Cage stiffness is directly influenced by the material used, determinant is the longitudinal elasticity module of the material. For example, the steel provides increased rigidity in relation to brass, and brass in relation with a variety of plastic materials. In certain situations constructive solution can lead to the increase or decrease of stiffness. For example, a one-piece cage made of brass or bronze will provide a higher rigidity compared with a modular cage [11].

Function D – It's reliable. Cage reliability is its ability to perform its functions over a period under certain specified conditions, without malfunction [12]. Cage reliability is influenced by many factors, among which we can mention the design conditions, the material used, execution technology and the operating conditions, these latter having a significant contribution and an impact on the reliability [4].

To ensure a greater reliability for cages it should be taken into considered the following functions B (resistance), C (stiffness), F (precision) and H (lubrication). If these functions are fulfilled and optimized by default this determines an increase in reliability.

Function E - It has durability. The current function "It has durability" can be regarded as an implicit function of the function "It's reliable". The durability of the cage is expressed in operating hours until the first sign of the cage material fatigue. A proper sizing of the cage ensures fulfillment of the functions durability and reliability. It should be mentioned that durability and reliability have a direct impact on the user.

Function F - It has precision. It is a basic function, of significant importance because it has a direct influence on the functioning of the bearing and thus the phenomena that occur during its operation. Cage accuracy is influenced by several factors, the most important ones are the production equipment (the machine), working devices used, materials, cutting tools, measuring equipment etc.

A high accuracy leads to high costs. It requires a good relationship between the cage accuracy and cage cost. It is very important to respect the required accuracy because it is imperative to ensure interchangeability [13].

Function G – Restricts the exploitation energy consumption. Revolving kinetic energy consumed during operation of the system in which it is integrated is directly influenced by, among other things, by the density of the materials components. The basic materials used for the manufacturing of cages are brass (8.4 – 8.75 g/cm^3), bronze (7.6 – 8.8 g/cm^3), steel (7.7 – 7.85 g/cm^3) and plastics such as polyamide (1.13 – 1.41 g/cm^3). Using low density material helps to reduce energy consumption needed in exploitation and this can contribute to the decrease of friction between the cage and the rolling elements. Using materials with low density has a direct impact on the strength of the cage, mostly on the downside.

Replacing current materials with materials that have low density represents a possible solution and direction of research. It is preferred that such materials to ensure at least the comparable strength and quality of brass or bronze.

Function H – Provides lubrication. From the constructive point of view bearing cages are designed so as to provide lubrication during the operation of the rolling elements. To ensure optimum lubrication it must be taken into consideration the lubricant viscosity and the operating temperature, which affects directly the behavior of the lubricant (viscosity) [14].

Embedding new constructive elements in the cage design to facilitate lubrication [15] is a solution that can help increase bearing performance over its lifetime, which is worthy to be taken into consideration in the redesigning phases of the cages. Related it is recommended that the new solutions should exclude the possibility of lubricant contamination with foreign particles.

Function I – Ensures the wear reduction. The cage has the role to ensure the maintenance of the rolling elements qualities. The function is fulfilled if the cage material hardness is smaller than that of the rolling elements and it has anti-friction properties. In the case of the bearing cages it is accepted deliberately the wear of cage instead of the wear of the rolling elements.

3. Conclusions

Value engineering is an instrument that ensures the development and optimization of existing and new products functions. Value engineering is an instrument extensively used in industry to optimize and improve products according to customer requirements.

Determination of the overall quantitative value and the value of the product components provides valuable information regarding the importance of each function cost.

Form the functions identified for the bearing cage, the basic / main function is to ensure the equidistance of rolling elements, function which ensures a uniform distribution of the load on the bearing and provides avoidance of sliding friction effects. In addition to the basic function were identified a number of principal functions which have an important impact at the development of new constructive solutions. Main functions which are recommended to be taken into account especially are "Provides resistance", "Provides rigidity", "It has precision", "It has durability", "Restricts the exploitation energy consumption", and "Provides lubrication".

Most of the functions are interconnected so that when the resistance of the cage is optimized through redesigning or replacement of the material it is likely to affect negatively or positively other functions of cage.

Strength, stiffness and accuracy are functions that can be influenced by the composition of the material or materials used in the constructive structure of cage, by the design and manufacturing tolerances.

The design and the material used have a direct impact on the operating energy consumption. In order to diminish these consumptions it is advisable to use materials with low density or to use supple construction solutions.

Another factor that has a significant influence on the functioning / operation of the bearing is lubrication. In order to ensure optimum lubrication during exploitation of the bearing it is recommended to develop or integrate into the cage structure special / dedicated systems.

Based on the current value engineering analysis it turns out that the vast majority of functions can be influenced by the replacement of the cage material, fact that imposes the necessity to accomplish a comparative analysis of possible materials. It should be also noted that the possibility of constructive optimization by redesigning the different solutions of cages is not excluded.

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