Courses of Action to Optimize Heavy Bearings Cages

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Abstract: The global expansion in the industrial, economically and technological context determines the need to develop products, technologies, processes and methods which ensure increased performance, lower manufacturing costs and „synchronization of the main costs reported to the elementary values which correspond to utilization”. The development trend of the heavy bearing industry and the wide use of bearings determines the necessity of choosing the most appropriate material for a given application in order to meet the cumulative requirements of durability, reliability, strength, etc. Evaluation of commonly known or new materials represents a fundamental criterion, in order to choose the materials based on the cost, machinability and the technological process. In order to ensure the most effective basis for the decision, regarding the heavy bearing cage, in the first stage the functions of the product are established and in a further step a comparative analysis of the materials is made in order to establish the best materials which satisfy the product functions. The decision for selecting the most appropriate material is based largely on the overlapping of the material costs and manufacturing process during which the half-finished material becomes a finished product. The study is orientated towards a creative approach, especially towards innovation and reengineering by using specific techniques and methods applied in inventics. The main target is to find new efficient and reliable constructive and/or technological solutions which are consistent with the concept of sustainable development.

1. Introduction
The continued need for development of existing technological solutions or the need of innovation – invention regarding new higher technical solutions which are determinate by the evolution of the industrial environment at the global level. Thereby the economic efficiency of industrial companies it is an increased fact which determines also an increase of their product's efficiency. Optimization and economic efficiency of the products to ensure minimum consumption during periods of operation and post-operation require the use of specific methods for research and design. In the scientific literature it can be identified a number of methods which are centered on research and design [1] [2] which are using different approaches, techniques and methods of technical creation [3]. It is preferable that the creative work to take into consideration the relevant functions of the product studied; value engineering can be used successfully. This tool, used mainly in industry, ensures the basic functions with minimal costs without neglecting aspects of performance, quality and reliability of products [4]. For example, for the heavy bearing cages a number of key operating functions have been identified. These functions have a direct influence on the material, these being: “ensures resistance”, “ensures rigidity”, “is reliable”, “is sustainable”, “is conditioning the operating energy consumption” and “ensures less wear” [5]. It is useful to specify that the functions “is conditioning the operating energy consumption” is ensured implicitly by the reduced mass of the body which depends on the volume and density of the material used. In terms of the production, the function “it is technological” can be...
expressed by machinability of the material; for example, it can be measured by the cutting force or through another parameter, whether directly or related to the function.

Consistent with the concept of sustainable development of the products [6] is recommended to take into account the CO2 consumption and the degree of material reintegration into the economic or environment circuit. This characteristic appears indirectly from the main function “has an impact on the environment” which is corresponding to the post-use period [5].

2. Important functions and coefficients of the bearing cages

For a certain bearing, the cage selection can be done as a result of a multi-criteria analysis based on the allocation of scores to different functions of the cage. An example of such scores is given in Table 1. It is noted that most of the criteria are dependent upon the nature of the cage material: strength, stiffness, reliability / durability, density, machinability and even the degree of reintegration into the environment. At first glance, the criterion volume doesn’t appear to be dependent on the material, but it is dependent to a certain degree of the production technology, technology which it’s dependent on the nature of the material. As a result a study of different materials which could be embedded into the design of the heavy bearing cages it is useful and even necessary.

Table 1. Criteria and coefficients of importance.

| Criteria                           | Coefficients of importance |
|------------------------------------|-----------------------------|
| Resistance                        | 0.20                        |
| Rigidity                          | 0.10                        |
| Reliability / Durability          | 0.13                        |
| Ensures less wear                 | 0.10                        |
| Density                           | 0.20                        |
| Cost                              | 0.07                        |
| Machinability                     | 0.10                        |
| Degree of re-integration into the environment | 0.05 |
| CO2                               | 0.05                        |

Within the heavy bearing industry, regardless of the application in which a bearing is incorporated, the cage is mostly made of steel or non-ferrous alloys such as brass or bronze. In certain cases, plastic materials are used, usually polyamides. Plastic cages are used increasingly rare in heavy bearings, primarily due to insufficient mechanical strength. Using plastic cages in the framework of heavy bearings usually leads to a premature failure due to the deterioration of the bearing cage [7].

3. The usage ratio of the material for a brass cage

Due to the anti-friction properties and good strength, durability and preservation of the rolling surface’s quality, brass is the main material used in the manufacturing of heavy bearing’s cages. Therefore it’s justified to choose a cage made of brass as reference for the current study. In Table 2 the dimensions for a heavy bearing and its massive brass cage, used in wind turbine, are given.

Table 2. Main dimensions of the bearing and its cage.

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

The blank from which the cage is manufactured, which is a ring-type and the machining allowances can be different depending on the degree of casting precision (examples can be viewed in Table 3). In the case of brass which is a deficient and relatively expensive material it’s of interest the usability of the material, defined as the ratio between the volume of the blank and the volume of the cage as a finished product. It can be distinguished between the raw blank obtained by casting and the blank which is a ring-type with rectangular section, obtained by turning, subjected to further machining in order to obtain the pockets for the rolling elements.
Depending on the machining allowance, for the cage with the dimensions given in Table 2, the volume of the raw blank obtained by casting it is shown in Table 4. Also in the same table the values for the degree of material usage are given, for the machining allowance values $t_i$ are shown in Table 3.

In order to determine the degree of material usage the next relationships (1), (2) and (3) are used.

Table 3. Machining allowances depending on the casting precision.

| Types of casting                  | Machining allowances ($t_i$) |
|-----------------------------------|------------------------------|
| High precision casting (under pressure) | 1.4 - 1.5 mm               |
| Medium precision casting          | 2 mm                        |
| Low precision casting             | 2.5 mm                      |

\[
\eta_1 = \frac{V_{\text{blank}t_i} - V_{\text{ring}}}{V_{\text{blank}t_i}}; \tag{1}
\]

\[
\eta_2 = \frac{V_{\text{blank}t_i} - V_{\text{cage}}}{V_{\text{blank}t_i}}; \tag{2}
\]

\[
\eta_3 = \frac{V_{\text{ring}} - V_{\text{cage}}}{V_{\text{ring}}}, \tag{3}
\]

where $V_{\text{blank}t_i} -$ is the total volume of the cast blank corresponding to the machining allowance $t_i$;

$\eta_1 -$ loss of material due to machining allowance $t_i$ in order to obtain the finished ring;

$\eta_2 -$ loss of materials in order to obtain the finished cage taking into account the machining allowance $t_i$ and the material milled in order to form the necessary pockets for the rollers;

$\eta_3 -$ loss of material in order to obtain the pockets for the rollers related to the cage ring without the machining allowances $t_i$.

The volume of the turned ring is $V_{\text{ring}} \approx 105110 \text{ cm}^3$ and the volume of the cage as a finished product is $V_{\text{cage}} \approx 31572 \text{ cm}^3$.

Table 4. Volume of the blank and the percentage losses of material.

| Name of the characteristics | Machining allowances | $t_1 = 1.5 \text{ mm}$ | $t_2 = 2 \text{ mm}$ | $t_3 = 2.5 \text{ mm}$ |
|-----------------------------|----------------------|------------------------|----------------------|------------------------|
| $V_{\text{blank}t_i}$      | $\approx 111248 \text{ cm}^3$ | $\approx 113323 \text{ cm}^3$ | $\approx 115412 \text{ cm}^3$ |
| $\eta_1$                   | 5.5%                 | 7.2%                   | 8.9%                 |
| $\eta_2$                   | 71.62%               | 72.13%                 | 72.64%               |
| $\eta_3$                   | 69.96%               |                        |                      |

It is necessary to specify that the design of the cage taken as a reference (see Table 2) consists of two components, namely the base body and a cover, which serves as a retention element for the rollers. In order to determine the degree of material usage the calculated volumes relate to the core body of the cage, without taking into account the volume of the retention ring. The calculation of material losses aren’t affected because the retention ring has no machining allowances and the amount of material removed during the process is significantly reduced.

It is preferred that the machining allowance to be small as possible. If the machining allowance would be zero, which is not possible, then the use of the material should be approximately 30% and the loss of material would be 70% (more precisely $\eta_3 = 69.96\%$).

From an economic perspective, as the degree of material usage is higher, with the same amount the number of machining and processing should decrease. As a result the costs of the material and processing will decrease. This provides insofar a more efficient use of the resources and manufacture time. It is therefore justified the identification and use of materials and/or processes to minimize or even eliminate machining allowance for the manufacturing of cages.
Obtaining a high degree of material usage it is however a secondary objective, this being dependent on the production technology adopted. The main priorities remain the functions of the cage, namely strength, durability and the capability to assure less wear of the rolling element.

4. Multi-criteria analysis for choosing the material of the cage

Depending on a particular application, the materials used must fulfill a plurality of functions and a wide range of properties. Selecting the most appropriate material for the heavy bearing cage can be also done based on a multi-criteria analysis. A significant number of materials [8] [9] which can be used to manufacture heavy bearings cages determines the need to select those materials which have similar characteristics or superior to commonly used materials. For the current paper the said materials which have been selected are specified in Table 5, where M1 - Brass (CuZnPb); M2 - Hardened and tempered steel; M3 - Aluminium; M4 - Duralumin; M5 - Hard plastic (thickness 70 mm); M6 – High-Density Polyethylene; M7 - Polypropylene; M8 - Polytetrafluoroethylene; M9 - Polyamide 6.6.

| Properties / Characteristics | M. U. | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 |
|------------------------------|-------|----|----|----|----|----|----|----|----|----|
| Tensile strength, $R_m$ [N/mm$^2$] | 200…300 | 980 | 70 | 270 | 65…100 | 1…16 | 17…40 | 17…28 | 70 |
| Tensile yield stress, $R_{p02}$ [N/mm$^2$] | 290 | 1030 | 60 | 200 | 1 | - | - | - | - |
| Relative elongation, $E_r$ [%] | 14..20 | 9 | 6 | 5 | 1 | 12 | 10 | 250 | 6 |
| Young's modulus, $E$ [N/mm$^2$] | 10.5 | 21 | 7 | 7.1 | 0.6…1 | 1.2…1.4 | 5…19 | 35…62 | 32 |
| Hardness, [HB] | 60 | 64...66 | 200 | 50 | 35 | 55 °Shore | 95 °Shore | 65 °Shore | 15 |
|密度, $\rho$ [g/cm$^3$] | 8.65 | 7.8 | 2.8 | 2.8 | 1.4 | 0.9 | 0.9 | 2.1 | 1.13 |
| Maximum working temperature [°C] | 350 | 630 | 250 | 300 | 150 | 70...120 | 110 | 300 | 150 |
| Cost [10] [11] [€/kg] | 4.22 | 0.49 | 1.44 | 1.44 | 5.5 – 6.66 | 0.67 | 0.67 | 17 - 22 | 1.18 |
| Machinability | VG | VG | G | G | G | G | G | G | G |
| Degree of re-integration into the environment | VG | VG | VG | VG | W | G | G | G | G |
| CO$_2$ | Great | Great | Great | Great | Medium | Medium | Medium | Medium | Medium |

Table 5. Properties / Characteristics of materials.

M2 material is part of the steel category used in bearings (e.g. RUL1, RUL1V, RUL2, RUL2V and RUL3V), regulated by STAS 1456/1 and STAS 11250 [9].

Various functions of the cage correspond to one or more properties of the material used. Table 6 shows the main characteristics considered in the multi-criteria analysis developed by the author.

| Function | Material properties / characteristics of the multi-criteria analysis |
|----------|---------------------------------------------------------------|
| Resistance | Tensile strength, $R_m$ |
| Rigidity | Young's modulus, $E$ |
| Reliability / Durability | Young's modulus, $E$ |
| Ensures less wear | Hardness; Maximum working temperature |
| Density / Volume | Density, $\rho$ |
| Cost | Machinability |
| Degree of re-integration into the environment | CO$_2$ |
In Table 7 a single set of results are presented from the multi-criteria analysis, scores and weights for all nine materials selected are given. In Figures 1 and 2 the results of the multi-criteria analysis are presented as charts, but downwards and highlighting the most recommended materials. Multi-criteria analysis was repeated several times, allocating different weights and scores in order to identify the materials which are kept into the top of different iterations.

Table 7. Results of the multi-criteria analysis.

| Nr.  | Criteria               | Weighted score 1 | Weighted score 2 | Weighted score 3 | Weighted score 4 | Weighted score 5 | Weighted score 6 | Weighted score 7 | Weighted score 8 | Weighted score 9 | Total score/Weighted value |
|------|------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|--------------------------|
| 1    | Resistance             | 3.66             | 3.5              | 3.51             | 3.35             | 3.32             | 3.1              | 2.91             | 2.86             | 2.72             | 1.09 94 140 76 34 29 273 26 1.86 18 112 26 2.94 28 1.31 76 3.35 |
| 2    | Rigidity               | 3.1              | 2.8              | 2.7              | 2.5              | 2.4              | 2.2              | 2.1              | 2.0              | 1.9              | 1.0                   |
| 3    | Reliability / Durability | 3.5              | 3.4              | 2.4              | 3.0              | 3.1              | 3.0              | 2.9              | 2.8              | 2.7              | 1.5                   |
| 4    | Stress/heat wear       | 3.8              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 1.5                   |
| 5    | Density                | 3.6              | 3.6              | 3.6              | 3.6              | 3.6              | 3.6              | 3.6              | 3.6              | 3.6              | 1.5                   |
| 6    | Cost                   | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 1.5                   |
| 7    | Machinability          | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 3.7              | 1.5                   |
| 8    | Duralumin the manufacuring technology for a cage | 3.1              | 3.1              | 3.1              | 3.1              | 3.1              | 3.1              | 3.1              | 3.1              | 3.1              | 1.5                   |
| 9    | Disposal of the technogy into the environment | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 3.5              | 1.5                   |

Figure 1. Ordering of materials selected according to weighted score.

Figure 2. Ordering of materials selected according to unweighted score.

According to the unweighted scores obtained, brass, steel and polyamide P66 occupies the top three places; duralumin is placed on the fourth place. The other materials, except aluminum, are placed at a short distance. According to the weighted scores first places are occupied by brass, hard plastics and steel, while aluminum, polypropylene and polyethylene are occupying disqualifying places. Apart from brass and steel the next materials are noted for further studies: hard plastics, duralumin, polyamide (Polyamide 6.6) and polytetrafluoroethylene. It is necessary to point out that by opting for duralumin the manufacturing technology for a cage does not change. According to the multi-criteria analysis in the case of the presented iteration it can be observed that the materials presented may partially or totally fulfill the requirements.

The approach for optimization of a heavy bearing cage like the type taken as a reference may be summarized only to the change of material, opting for a cheaper one – the effect is to reduce costs, opting for a less dense material – determines the reduction of energy used, or for a material that has a higher degree of machinability. The multi-criteria analysis performed provides solutions for each of these lines of action.
Also it is possible to opt for a combination of materials, course of action which involves primarily a design / redesign effort to identify proper solutions. This is the recommended direction; investing in knowledge it is a sustainable investment and always gives results.

5. Conclusions
A heavy bearing cage satisfies several functions with different coefficients of importance. The current study accomplished by the author aims primarily to obtain higher resistance, to keep or increasing the sustainability of the cage and usage of a material that are cheaper and have low density.

Mainly the material of the cage determines the manufacturing technology. If the manufacturing process involves splintering, then it is necessary to take into account the degree of material usability, especially if the material it is relatively expensive.

Depending on a particular application, the material(s) used must fulfill a plurality of functions and a wide range of properties. Selecting the most appropriate material(s) for the heavy bearing cage can be also done based on a multi-criteria analysis. The current study carried out by the author takes into consideration four metallic materials, four plastic materials and a plastic composite material (hard plastics). From the materials selected the steel, brass, duralumin and hard plastics ensures superior mechanical strength. The same materials also ensure the best reliability and durability properties. Good protection against wear of the rolling surfaces presents brass but also polytetrafluoroethylene, Polyamide (Polyamide 6.6), duralumin and hard plastics, with the exception of steel. Higher costs, but acceptable, has duralumin and polyamide (Polyamide 6.6).

A keen interest it is granted to the material density. Based on this aspect the kinetic energy of the bearing depends, and implicitly the operation energy. Polyamides and hard plastics have low densities, but also polytetrafluoroethylene. Accepted density has also duralumin.

Multi-criteria analysis was repeated several times, allocating different weights and scores in order to identify the materials which are kept into the top of different iterations.

The decision for selecting the most appropriate material is based largely on the overlapping of the material costs and manufacturing process during which the half-finished material becomes a finished product.

The study is orientated towards a creative approach, especially towards innovation and reengineering by using specific techniques and methods applied in inventics. The main target is to find new efficient and reliable constructive and/or technological solutions, consistent with the concept of sustainable development.

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