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INFLUENCE OF CLEARANCES ON THE QUALITY OF THE METAL CAGES WINDOWS OF TAPERED BEARINGS WITH CYLINDRICAL ROLLERS

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Abstract: *Wear of bearing cage windows is one of the primary causes of accelerated deterioration of bearing functionality. The occurrence of bearing cage wear is influenced by a multitude of factors that can vary from the manufacturing process of the cage windows to the carrying capacity and degree of bearing loading and the degree of wear of the machine tools used to obtain the sheet metal bearing cage windows. This paper highlights the main aspects, both from a theoretical point of view through finite element analysis (FEA), and from an experimental point of view through the analysis of some process parameters, which influence some quality characteristics of the bearing cages.*
Key words: *clearance, bearing cage, punching, wear, finite element analysis*

1. INTRODUCTION

Wear in bearing cages refers to the process of deterioration or degradation of the contact surfaces of bearings in a rolling system. Bearings, in general, but especially the single-row cylindrical roller bearings, are mechanical components used to reduce friction between two moving parts of a machine or equipment and to allow rotation or linear motion. Wear phenomena in bearing cages can occur for several reasons and can have various consequences, including increased friction, noise, vibrations, and eventual failure of the bearings or other components of the system [1]. Some common causes and signs of early wear in bearing cages are:

a) Wear due to friction - if bearings are not properly lubricated or subjected to excessive loads, their contact surfaces may wear prematurely due to friction. This can lead to the formation of grooves or other deformations on the cages.

b) Corrosion - exposure to moisture, chemicals, or foreign particles can cause corrosion of bearing cages, weakening their structure and reducing performance.

c) Overheating - if bearings are exposed to high temperatures or if the lubricant degrades due to extreme temperatures, the cages can undergo deformation and premature wear.

d) Bearing cage jamming - a phenomenon that often occurs due to the omission of certain machining operations, such as deburring, an operation that removes excess material from the edges of the cages after they have been perforated.

Signs of wear in bearing cages may also include abnormal noises (such as popping or squeaking), vibrations, increased friction, slow motion, which result, ultimately in bearing failure. It is important to perform maintenance and replace bearings at regular intervals to prevent major failures in the rolling system and ensure that correct and safe operation of the equipment or machine are performed.

To prevent the deterioration or degradation of bearings, it is important to have a regular maintenance plan, use appropriate lubricants, monitor operating temperatures, and replace worn bearings at appropriate intervals [2].

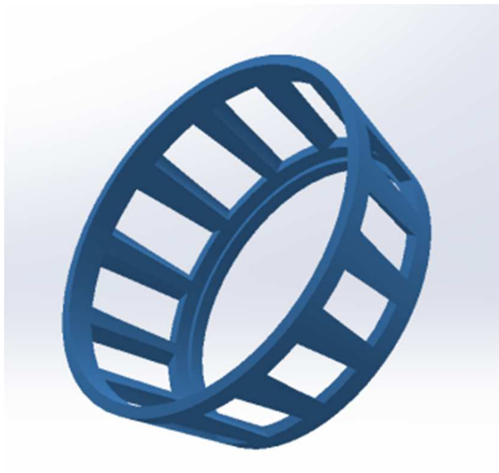


Fig.1. Steel window-type cage for a tapered bearing with rollers in a single row

The automotive manufacturing industry primarily uses single-row tapered roller bearings with steel window-type cages, as the one depicted in figure 1. These cages are typically made from low-hardness type of materials. Under these conditions, when analysing the impact of various working factors such as clearances in the active elements, material thickness, or the distance the die has to travel during the stamping process, it can be identified the quality characteristics that do not conform to international quality standards.

2. ANALYSES UPON THE PROCESS OF PUNCHING THE WINDOWS IN THE BEARING CAGES

To conduct a thorough research and to be able to accurately identify the parameters that can influence the quality of bearing cage windows, various systemic analyses were performed. The purpose of these analyses was to pinpoint the key factors affecting the quality of these crucial components of bearings. In this context, major bearing manufacturers have reached the conclusion that as the quality of the individual bearing components improves, the lifespan of the bearings can be extended, resulting in increased profitability, particularly in the case of tapered bearings with cylindrical rollers in a single row.

Thus, in this paper, the quality of bearing cages is assessed by measuring the burr height. This is influenced, as per the systemic analysis shown in figure 2, by a range of input parameters, with the most significant ones including clearances between active elements, material thickness, and the stamping stroke [3].

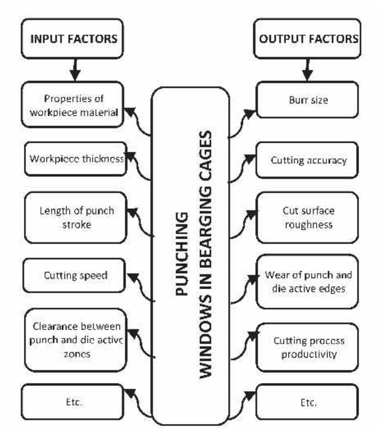


Fig.2. Graphical representation of technological factors that affect parameters in the case of bearing cages windows

The quality of a sheet metal cage, analysed in this study through the measurement of burr height, is influenced by a range of parameters and factors that can vary depending on the application, the specific material of the semi-finished product, and the quality standards. The authors performed both theoretical and experimental tests to underline this behaviour.

3. FINITE ELEMENT ANALYSIS ON TAPERED BEARING WITH CYLINDRICAL ROLLERS

The aim is to highlight possible flaws in design or to predict early wear of cage windows when functioning. Burrs can also occur due to prolonged stress induced by rollers in case of functioning because material thickness is subjected to high temperatures in case of poor lubrication or large clearances. With this in mind, assessing the stress and strain distribution produced by moving rollers upon cage windows walls can highlight weak areas that are most likely to produce burrs which can lead to early wear of moving elements of the bearing assembly.

For that matter it was chosen to apply the finite element method (FEM) by means of Ansys. A full bearing assembly was chosen with 14 rollers sitting at a defined angle inside the designated cage windows. The geometry itself has a higher degree of complexity as the rollers must be able to rotate along their own axes while in contact with the inner and outer surface channels of the parts in motion. That means that all axes must have the same direction while maintaining dimensional and geometric tolerances. The 3D geometry was modelled in Catia and exported as a Parasolid file (see figure 3).

Upon import Ansys recognizes all features from the file including the global coordinate system. It was chosen as the 100Cr6 bearing steel type of material for rollers [4]. The material was designed based on a structural steel from Ansys's library called engineering data. For all other parts it was used a regular structural steel type of material as it has similar characteristics as the ones used in industry.

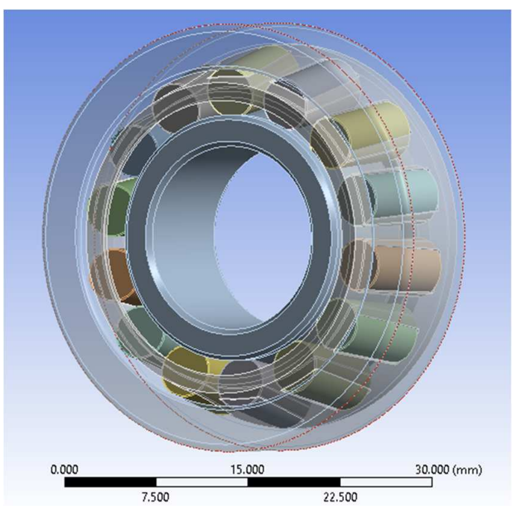
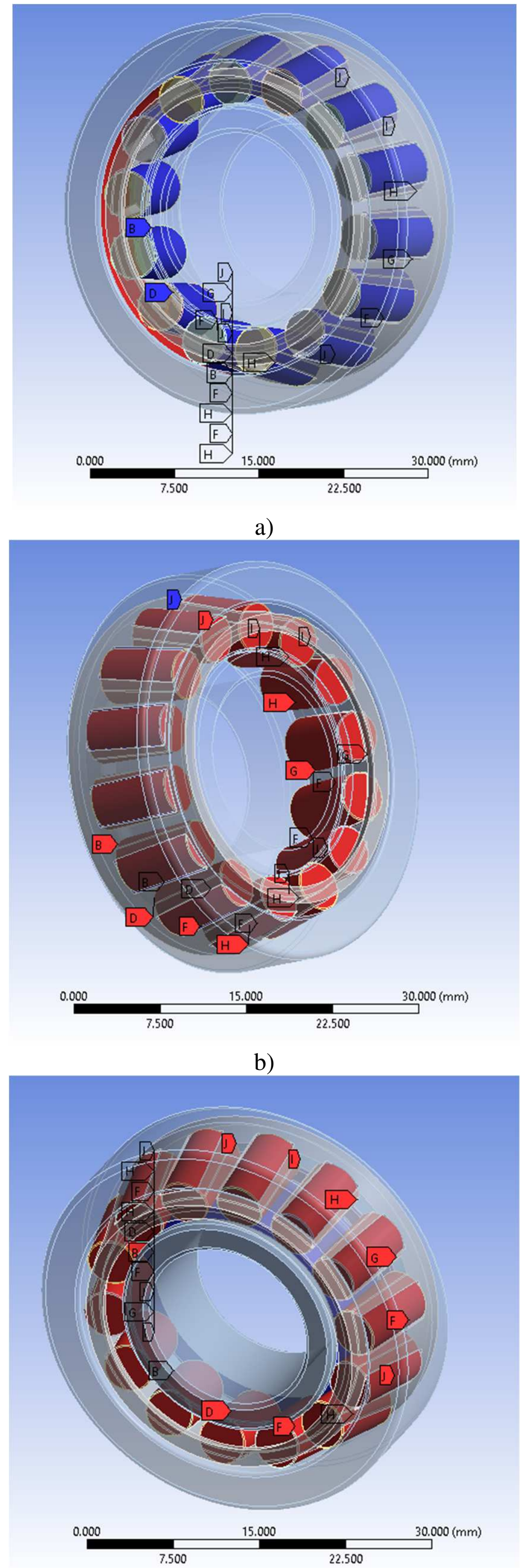


Fig.3. Graphical representation of the 3D model of a tapered bearing with rollers

It was chosen the static structural module of Ansys for the finite element analyses. After the 3D model was imported it shows the same global coordinate system for the entire assembly exactly as it was designed.

The connections branch allows the user to define contacts and joints for a complete simulation of the bearing assembly in function.



c)

Fig.4. Graphical representations of contacts:

a) Between rollers and outer ring,
b) Between rollers and cage windows,
c) Between rollers and inner ring

For us to be able to highlight the stress distribution when the bearing functions it was considered a friction coefficient of 0.15 for static conditions with lubricant [5].

Contacts were divided in three categories: rollers in contact with the outer ring (see figure 4a), rollers in contact with cage windows (see figure 4b) and rollers in contact with the inner ring (see figure 4c). The behaviour when in contact was set to asymmetric with a trim tolerance of 0.12 mm and software controlled trim contact.

The formulation used in computations is augmented Lagrange and the other option are controlled by software. Stiffness is updated by each iteration and the interface treatment was set to adjust to touch at all time.

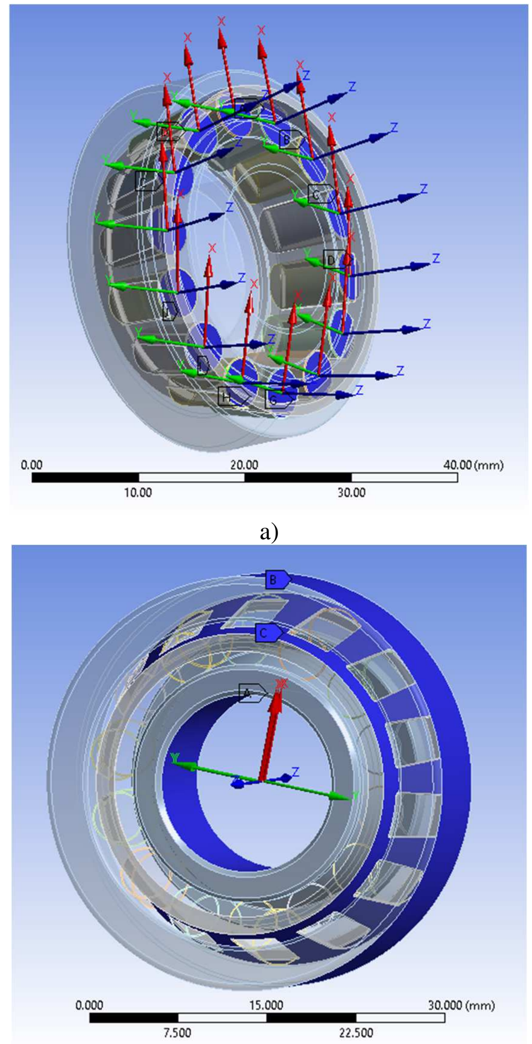
For movement purposes it was chosen to define two sets of joints: planar for all rollers (see figure 5a) and joints for each one of the remaining parts. The inner surface of the inner ring was assigned a revolute type of joint with no body-to-body interaction (see figure 5b). The outer surface of the cage received the same type of joint (see figure 5b) but the outer surface of the outer ring was grounded and allowed no movement (see figure 5b).

This setup allows a complete revolution of moving parts of the assembly by applying to the inner ring related joint a rotation along the Z axis in time-steps.

Analyses settings include four time-steps spanning one second each. The auto time-stepping option was set to on in combination with the possibility to carry results over each time step. Minimum time step was set to 0.01 sec and the maximum at 0.1 sec.

Large deflection was on as it may capture cracks or large deformations. After multiple trial & errors it was set a stabilization method in form of constant energy. Other program-controlled options were left default. The solver type was set to direct as iterative did not offer satisfactory results.

Mesh wise it was applied a patch conforming method for all bodies which uses tetrahedrons for its elements. This forces the nodes to align to each other and thus achieve a continuity for the parts in contact. Dependent on the geometry it was set a 1.7 mm element size for the inner and outer rings as well as for the cage.



a)

b)

Fig.5. Graphical representations of joints:
a) Applied to rollers,
b) Applied to the inner and outer rings and cage

The inner face of the outer ring and the outer face of the inner ring have 0.777 mm element size. Each face of each cage window received the same value as well as the outer surfaces in contact of each roller. This produces a mesh with 135030 nodes and 76638 elements (see figure 6). This combination of mesh methods and user defined element sizes allows capturing stress distribution on each part.

Solution requires results for stress and strain distribution. Depending on the results one could properly identify areas that are subjected to higher values as an indicator of possible lack of lubrication due to complex geometry that imposes liquid to travel between angled moving parts. Also, one could asses if clearance values are right for this type of bearings with rollers depending also on the most stressed highlighted areas.

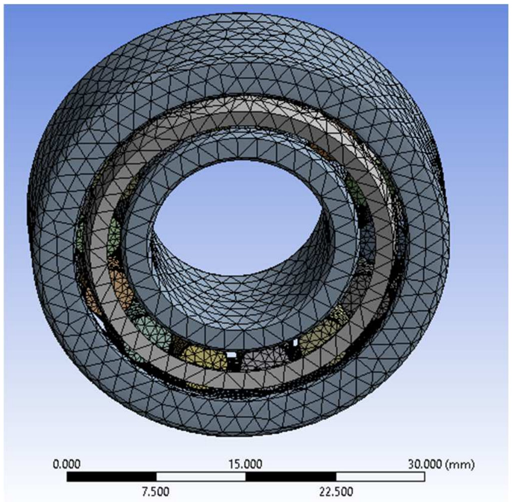


Fig.6 Graphical representation of the meshed bearing assembly

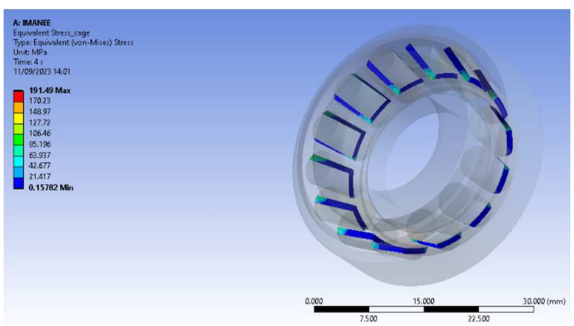


Fig.7. Graphical representation of stress distribution on cage windows

Equivalent stress is evaluated according to von-Mises criterion, and it peaks at 191.49 MPa for each cage window lateral faces (see figure 7). The distribution shows that in function, each roller tries to overcome physical boundaries and imposes additional stress which can later transform in premature wear. That is why clearances must be as minimum as possible to prevent vibratory phenomena. This has a significant influence on the lifecycle of analysed geometry as it can lead to burr occurrences in the most stressed areas.

Equivalent elastic strain registers a maximum of 0.012327 mm/mm (see figure 8). The same areas are subjected to strain distribution which confirms the fact that when in function, without proper lubrication premature wear may occur. As expected, the geometry of a tapered bearing with rollers is an intricate one because the lubricant has to reach all four walls of each cage window even at if they are angled. That means that, when in function, the rotational movement tends to push the fluid towards upper edges leaving exposed the lower ones. This phenomenon can be fought by means of high-density fluids and proper clearances values.

The analysed geometry contains no clearances as it needs all components to be in permanent contact with each other for the simulation to work. For that matter this case study is an ideal one which helps in identifying areas most subjected to stress and strain. However, values are to be treated with care since the presence of lubrication and clearances could not be simulated.

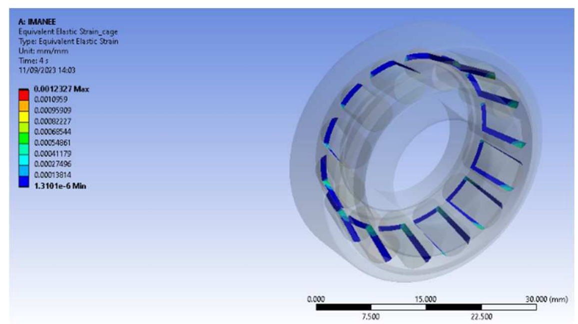


Fig.8. Graphical representation of strain distribution on cage windows

The authors acknowledge that further refinement may be needed and recommend the use of results for documentation purposes.

4. EXPERIMENTAL RESEARCH

The experimental research presented in this paper is being focused on the input parameters mentioned earlier, which, after interpreting the experimental results, were found to have the most significant influence on burr height. Thus, the research was carried out on semi-finished products made of DD13 steel (1.0335, EN 10111) in accordance with the current standards.

The experiments were performed on a hydraulic pressing machine of the LVD 600 type, equipped with a die for punching windows in bearing cages [6]. The measurements of the burr height parameter were obtained using a

Conturograf MarSurf XC equipment. A print screen of the software used for retrieving results in presented in figure 9.

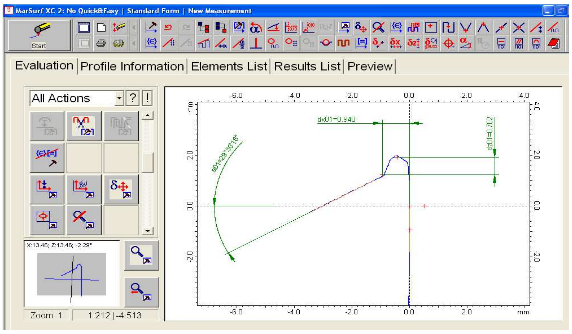


Fig.9. The graphic representation and geometric shape of the burr height when measured with Conturograf MarSurf XC equipment

It was developed an experimental Taguchi plan in order to evaluate values for the blank thickness clearances between the stamp's active components which has resulted in graphical representations.

Each experiment was performed twice. For blank thickness, there were taken into account three values as follows: t1=3.5 mm, t2=4 mm and t3=5 mm. The windows were punched at an optimum value of the stamping force, generally used for processing the considered sheet metal cage windows.

The distances for the actual stampings are c1=5.5 mm, c2=6.5 mm and c3=7.5 mm. As one could see in Table 1, the clearance values vary between 0.51 mm and 0.58 mm.

Table 1.

Experimental results for the burr height measured after the cage window stamping process with the clearance between the active elements between the two values.

No. of Crit.	j [mm]	t1 c1	t1 c2	t1 c3	t2 c1	t2 c2	t2 c3	t3 c1	t3 c2	t3 c3
		Burr height [mm]								
1	0,51	0,69	0,62	0,53	0,77	0,76	0,66	0,83	0,78	0,73
2	0,53	0,67	0,63	0,56	0,81	0,66	0,78	0,91	0,88	0,79
3	0,54	0,72	0,68	0,57	0,97	0,89	0,84	1,01	0,96	0,86
4	0,55	0,74	0,72	0,64	0,99	0,91	0,87	1,02	0,96	0,88
5	0,56	0,79	0,77	0,67	1,02	0,94	0,89	1,02	1,00	0,91
6	0,57	0,84	0,82	0,76	1,03	0,97	0,91	1,05	1,02	0,93
7	0,58	0,93	0,8	0,84	1,06	1,02	0,94	1,06	1,02	0,96

After all stamping experiments were performed, measurements of the burr's height for the windows of all obtained cages had been carried out and then the related data was centralized for future analyses concerning the influence of input parameters upon quality. The values presented in Table 1 were processed in Microsoft Excel environment. The correspondence between burr's height and the clearances between active elements is graphically presented in figures 10, 11 and 12. These show a direct interdependence for the above-mentioned type of correspondence similar to other found in scientific literature [7].

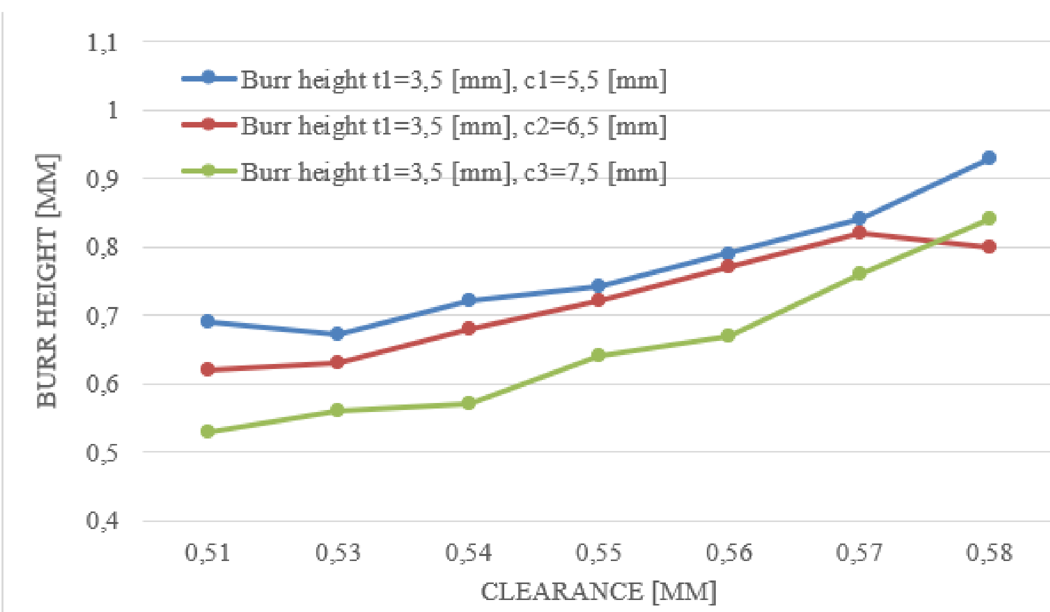


Fig.10. Burr's height dependence on clearance in the stamping process of 3.5 mm thick cages

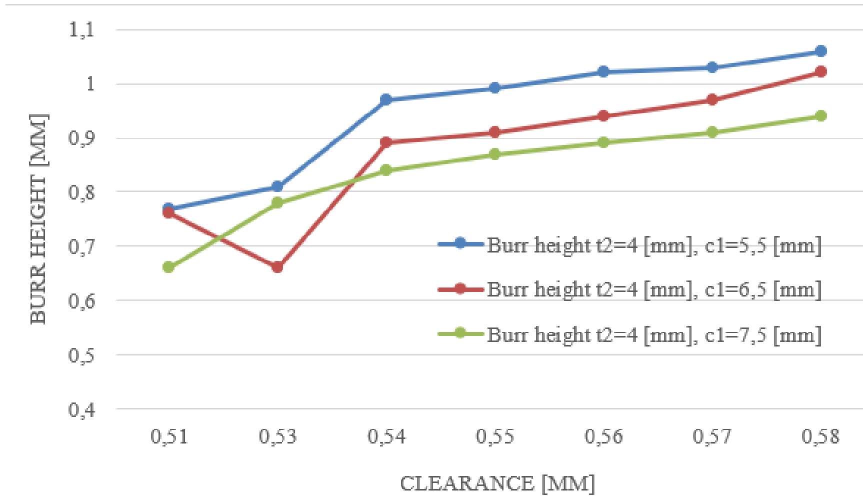


Fig.11. Burr's height dependence on clearance in the stamping process of 4 mm thick cages

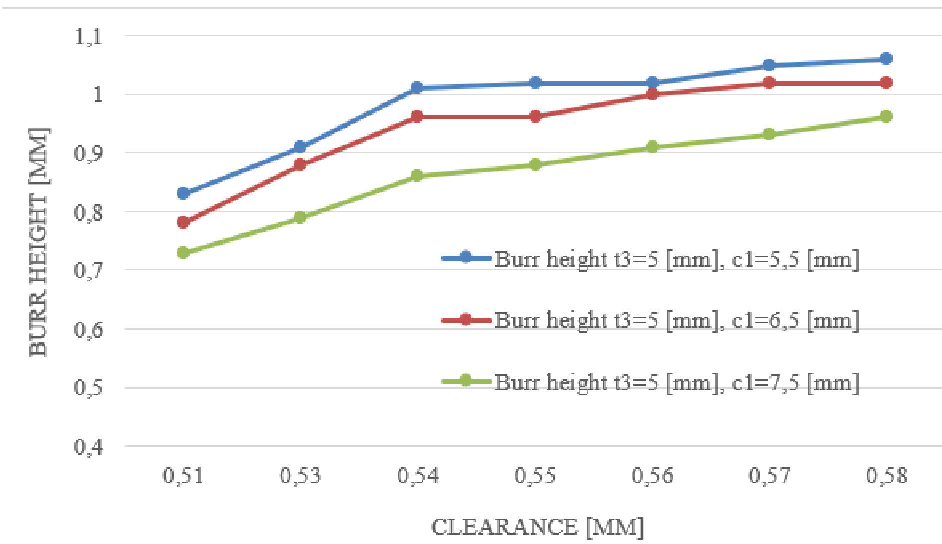


Fig.12. Burr's height dependence on clearance in the stamping process of 5 mm thick cages

5. CONCLUSIONS

Analysing the obtained experimental results and the graphical representations from the three graphical representations, it is clear that an increase in the clearance between the active components leads to an increase in burr height, thus indicating a decrease in quality. The only exception is observed in figure 11, where, for a clearance of 0.53 mm and a stamping stroke of 6.5 mm with a blank thickness of 4 mm, the burr height suddenly drops to 0.66 mm. The reduction in burr height for this combination of values may be attributed to the influence of disruptive factors that were not considered or measurement errors.

Finite element analysis showed a similar correspondence by highlighting the areas that are most affected by stress and strain phenomena showing that if not proper lubricated or if clearance values to high this could result in the formation of burrs which may lead to early wear and even failure. By observing the results obtained by means of finite element analyses one could propose the right type of lubricant and even modify the geometry of cage windows in such a way that it would minimize the effects observed when functioning.

By analysing results both type of results, theoretical and experimental, it can be observed that the clearance between active components is one of the most important input characteristics in the process and can significantly impact the quality of bearing cages. Furthermore, it can be concluded that besides a lower quality of bearing cages, a higher burr height can also lead to premature wear of the cutting-punching elements in the design of the die that produces windows in the bearing cages of single-row tapered roller bearings.

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Influența jocului dintre elementele active asupra calitătății ferestrelor coliviei de la rulmenții conici cu role cilindrice

Uzura accelerată a ferestrelor coliviilor de rulmenți este o cauză principală a deteriorării accelerate a funcționalității rulmenților. Apariția uzurii coliviilor de rulmenți este influențată de o multitudine de factori care pot fi legați de procesul de fabricație al ferestrelor coliviei, de capacitatea de transport și de gradul de încărcare a rulmentului dar și de gradul de uzură al mașinilor-unelte cu care sunt realizate ferestrele coliviilor de rulment din tablă. Această lucrare evidențiază principalele aspecte, atât din punct de vedere teoretic prin intermediul analizelor cu elemente finite (*eng*. FEA), cât și din punct de vedere experimental prin analiza unor parametri de proces, care au influența asupra unor caracteristici de calitate a coliviilor de rulmenti.

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