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GRAPHICAL RECONSTRUCTION AND FEM ANALYSIS METHOD FOR SMALL DIMENSIONAL FUNCTIONAL PARTS

Abstract: *The paper describes in which way an efficient and conclusive analysis procedure could be successfully applied for parts with functional role for small dimensional bearings. The main issue was to establish to what extent, applying the procedure for small functional parts scanning, could be used without measuring errors caused by deformation in case of contact principle. Considering the contact principle scanning may be due to the fact that metallic surfaces (in case of bearings) invoke high brightness in case on non contact scanning method, using LASER beam principle. The proposed solution proved to be reliable for such of small dimension components with functional role, to find which scanning principle would be more appropriate in terms of dimensional inspection.*

Key words: *FEM, ANSYS, small dimension bearings, forces, deformation, scanning.*

1. ROLE SMALL DIMENSION FUNCTIONAL COMPONENTS

It is known that high precision micro-system are more and more used for micro-robots with industrial, medical or food applications. All of these robotic micro-systems include several precision joints, having in their composition micro-elements bearing type. For instance, a proper and safe functioning of the joints depends strictly by the micro-bearings functioning of the ordering systems. This can be ensured only respecting the condition the bearing components to correspond dimensional standpoint. For this reason, dimensional inspection and scanning the micro-bearings components (like inner rings, outer ring, rollers) is an indispensable operation to ensure the high quality in their functioning [1], [2].

2. FEM METHOD USING FOR PARTS ANALYSIS BEHAVIOR – APPLIED METHOD

To determine the parts behaviour in case of static or dynamic forces means a study with applications in a lot of domains, interest being the aspects on deformation. More exactly, the main issue is to determine what is the deformation of the probe for a certain load (previously determined) applying static or dynamic forces. In this way, generally, the known information refers to the constraints and loading forces, while the parameter to determine is the part deformation. It can be considered that the probe is entrained in rotation during scanning process (Figure 1).

In the particularly case, referring to the bearings components (inner or outer rings), it can be considered that in case of measuring inspection or scanning the fixing supports are disposed at an angle of 120°, radial direction, measured from the centre of mass (Figure 1). As a result, the reaction forces (N) are disposed also equiangular (at 120°), radial direction.

It can be considered that the applied force (F_s) is given by the measuring force of scanning device's rod probes during process. This can be considered the worst case, when the loads are distributed equidistant and equiangular, in case of annular components, in this case the deformation (f) being the largest (Figure 1) [1], [2].

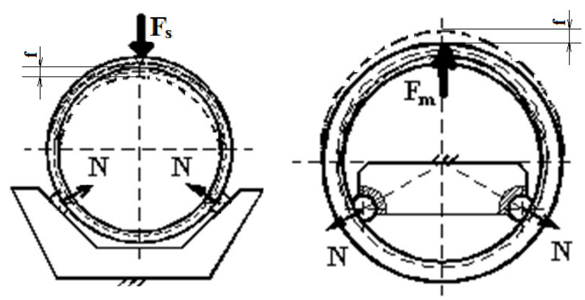

Fig. 1 Example of loads and constraints disposing in case of inner and outer bearing rings

The research was focused on annular parts composing micro-bearings, different types of annular components providing from radial bearing being studied. The main issue was to determine the total deformation of the annular components if these would be subjected to scanning process, contact principle. For this reason, graphical reconstruction and Finite Element Modelling (FEM) proved to be a good solution for conclusive results. This paper presents two examples (the most representative) regarding the studied method and its results. These consist in two categories of radial bearings, the first one, radial ball bearings and the second, radial cylindrical roller bearings.

It was taken into account the static and dynamic loads, meaning the forces given by the measuring or scanning devices. More exactly, the research aim was to establish dimensional range limit of the bearing rings for which the contact principle scanning procedure could be applied without perturbing the process accuracy [3], [4]. Thus means that in case of exceeding rings deformation values, their scanning and dimensional inspection is affected. In this situation is more appropriate to use the non contact principle for scanning.

The proposed method was the Finite Element Modelling (FEM), using *ANSYS* as software environment [5]. For this reason, the research invoked the following steps: graphic 3D reconstruction of the studied bearing rings, 3D models meshing into finite elements, applying the forces and constraints and software running to determine the results on deformation (Figure 3). For the 3D model obtaining it was used *Pro Engineer Wildfire* software environment, meaning, first of all drawing an outline sketch in a predefined plane. Next, the 3D model generating has been done through the contour outline revolution around an axis of symmetry (Figures 2 and 3).

Then, to import the 3D model in *ANSYS,* a specific operation was necessary, to save the model as IGES format, in *Pro Engineering* environment, to be compatible for *ANSYS* environment [6].

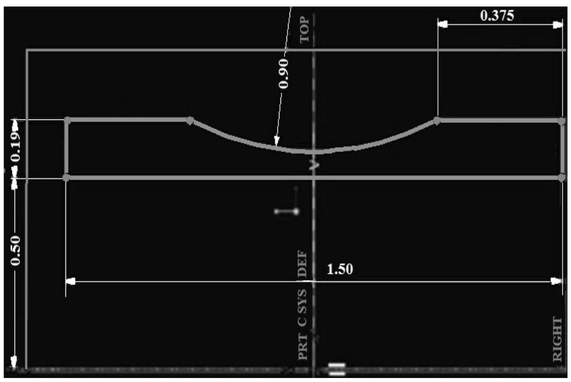

Fig. 2 Example of 2D model reconstruction for a radial ball bearing inner ring, small dimension

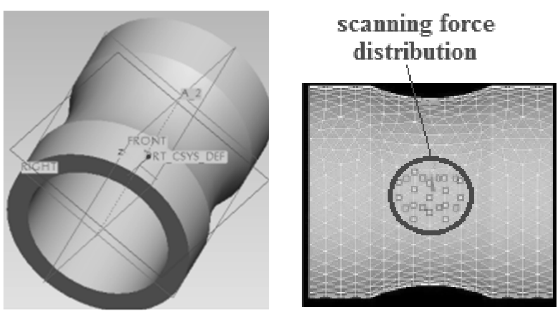

Fig. 3 Example of 3D model reconstruction, meshing and loads distribution for a radial ball bearing inner ring, small dimension

Once imported the IGES model into ANSYS, all necessary conditions were established for the simulation of the behaviour of the ensemble scanning device – inner ring. For this, several hypotheses have been taken into account:

- it was considered that the scanning force is applied for a finite circular surface, its projection intersecting the rotation axis; the radius of the surface must not exceed 50% of the raceway's width (being considered the worst case to be studied);
- in case of radial ball bearings inner and outer rings, the supports have been considered to be spherical, supposing that the reaction distribution is given by a circular surface;
- for radial cylindrical roller bearings, the contact with the supports being linear, it was considered that the surface of constraints given by the reaction forces is rectangular;
- determining of the rings deformation was made according to the scanning force direction, for which the deformation amplitude being maximum (most relevant);

For each studied inner or outer ring, it proceeded to several determinations, meaning gradual scanning forces (the most common real situations): The paper presents four examples referring to the applied forces: F_s = 1.5N; F_s = 2N (as static loads) F_d = 2.5N; F_d = 2.8N (as dynamic loads). The aspect referring to static or dynamic load means the scanning force depending by the entraining of the probe during process [6], [7], [8].

The dimensional values of the studied types of rings are presented in tables 1 ÷ 4:

Table 1

The dimensions in case of outer rings providing from radial ball bearings

Geometrical dimensions [mm]	**Tolerance range imposed for scanning accuracy [mm]**
ϕ_{ext} = 2; ϕ_{int} = 1,7; B = 1,5; b = 0,87; h = 0,06; H = 1	0,005
ϕ_{ext} = 4,2; ϕ_{int} = 3,4; B = 2,3; b = 1,25; h = 0,08; H = 1,5 b = 1,25; h = 0,08; H = 1,5	0,006
ϕ_{ext} = 5,2; ϕ_{int} = 4; B = 2,6; b = 1,4 h = 0,12; H = 1,75	0,0065
ϕ_{ext} = 6,2; ϕ_{int} = 4,5; B = 3,2; b = 1,7 h = 0,17; H = 2,1	0,007
ϕ_{ext} = 8,5; ϕ_{int} = 5,2; B = 3,2; b = 1,7 h = 0,33; H = 2,1	0,008

Table 2

The dimensions in case of inner rings providing from radial ball bearings [mm]

Geometrical dimensions [mm]	**Tolerance range imposed for scanning accuracy [mm]**
ϕ_{ext} = 1,3; ϕ_{int} = 1; B = 1,5; b = 0,87; h = 0,06	0,005
ϕ_{ext} = 2,7; ϕ_{int} = 2; B = 2,3; b = 1,3; h = 0,14	0,005
ϕ_{ext} = 3,4; ϕ_{int} = 2,3; B = 2,6; b = 1,5; h = 0,2	0,006
ϕ_{ext} = 4; ϕ_{int} = 2,6; B = 3,2; b = 1,9; h = 0,3	0,006
ϕ_{ext} = 5,5; ϕ_{int} = 3; B = 3,2; b = 1,8; h = 0,5	0,007

Table 3

The dimensions in case of outer rings providing from radial cylindrical roller bearings

Geometrical dimensions [mm]	**Tolerance range imposed for scanning accuracy [mm]**
ϕ_{ext} = 5,2; ϕ_{int} = 4; B = 2,6; b = 1,75; H = 0,6; h = 0,4	0,006
ϕ_{ext} = 6,2; ϕ_{int} = 4,5; B = 3,2; b = 2,1; H = 0,85; h = 0,57	0,007
ϕ_{ext} = 8,5; ϕ_{int} = 5,2; B = 3,2; b = 2,1; H = 1,65; h = 1,1	0,008

Table 4

The dimensions in case of inner rings providing from radial cylindrical roller bearings

Geometrical dimensions [mm]	**Tolerance range imposed for scanning accuracy [mm]**
$\phi_{ext} = 3,4$; $\phi_{int} = 2,3$; B = 2,6; b = 1,75; h = 0,18	0,0055
$\phi_{ext} = 4$; $\phi_{int} = 2,6$; B = 3,2; b = 2,1, h = 0,23	0,006
$\phi_{ext} = 5,5$; $\phi_{int} = 3$; B = 3,2; b = 2,1; h = 0,42	0,0065

For FEM analysing via ANSYS environment, the following steps were necessary:

- establishing the type of finite elements composing the meshed 3D model;
- establishing the material properties from which the ring is made: material structure, Poisson coefficient (ν), elasticity module on longitudinal direction (E); in case of bearing rings the material is isotropic (E = 2,1 10^{-5} MPa and $\nu = 0,3$);
- creating the meshing elements volumes; these were arbitrary chosen, the 3D model meshing in finite elements being in this case the most efficient;
- placing the loads and constraints applying to the model for as accurate simulation of the small dimensions bearing components behaviour.

On the contact modeling it was taken into account the imposed values of deformation tolerances on which it has been determined the maximum admissible deformation value (δ_{adm}) (equation 1) [9]:

$$\delta_{adm} = (10 \div 20\%) * T \qquad (1)$$

where *T* represents the imposed value of the manufacturing tolerance for the studied bearing components. In figure 4 is presented an example of FEM analysis in case of a bearing component for a static load of 1,5 N.

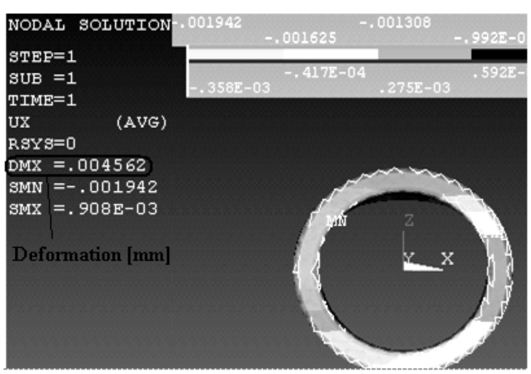

Fig. 4 Example of FEM analysis results displaying, in case of an inner ring providing from a radial ball, bearing, with the dimensions specified in table 1

4. RESULTS

Due to the successive simulations using FEM method, for studied bearings parts and considered scanning forces (static and dynamic loads), there were obtained the results referring to the behaviour of each type of part. In case of the two described examples in the paper, the results can be observed in the tables below:

Table 5

FEM results in terms of deformation in case of inner rings providing from a radial ball bearing [mm]

Geometric dimensions	**Scanning force [N]**	**Determined deformation**	**Maximum admissible deformation**
$\phi_{ext} = 1,3$; $\phi_{int} = 1$; B = 1,5; b = 0,87; h = 0,06	1,5	0,0046	0,0006
	2	0,0061	
	2,5	0,0076	
	2,8	0,0086	
$\phi_{ext} = 2,7$; $\phi_{int} = 2$; B = 2,3; b = 1,3; h = 0,14	1,5	0,0041	0,0006
	2	0,0054	
	2,5	0,0068	
	2,8	0,0076	
$\phi_{ext} = 3,4$; $\phi_{int} = 2,3$; B = 2,6; b = 1,5; h = 0,2	1,5	0,0014	0,00075
	2	0,0019	
	2,5	0,0023	
	2,8	0,0026	
$\phi_{ext} = 4$; $\phi_{int} = 2,6$; B = 3,2; b = 1,9; h = 0,3	1,5	0,72	0,00075
	2	0,97	
	2,5	1,21	
	2,8	1,35	
$\phi_{ext} = 5,5$; $\phi_{int} = 3$; B = 3,2; b = 1,8; h = 0,5	1,5	0,0002	0,00085
	2	0,00025	
	2,5	0,0003	
	2,8	0,0004	

Table 6

FEM results in terms of deformation in case of inner rings providing from a cylindrical roller bearing [mm]

Geometric dimensions [mm]	**Scanning force [N]**	**Determined deformation [mm]**	**Maximum admissible deformation**
$\phi_{ext} = 3,4$; $\phi_{int} = 2,3$; B = 2,6; b = 1,75; h = 0,18	1,5	0,00065	0,00067
	2	0,0009	
	2,5	0,0011	
	2,8	0,0012	
$\phi_{ext} = 4$; $\phi_{int} = 2,6$; B = 3,2; b = 2,1; h = 0,23	1,5	0,0004	0,00075
	2	0,0005	
	2,5	0,0007	
	2,8	0,00075	
$\phi_{ext} = 5,5$; $\phi_{int} = 3$; B = 3,2; b = 2,1; h = 0,42	1,5	0,00015	0,0008
	2	0,0002	
	2,5	0,00025	
	2,8	0,0003	

Table 7

FEM results in terms of deformation in case of outer rings providing from a radial ball bearing [mm]

Geometric dimensions [mm]	**Scanning force [N]**	**Determined deformation [mm]**	**Maximum admissible deformation**
$\phi_{ext} = 2$; $\phi_{int} = 1,7$; B = 1,5; b = 0,87; h = 0,06; H = 1	1,5	0,0006	0,0006
	2	0,00079	
	2,5	0,00099	
	2,8	0,0011	
$\phi_{ext} = 4,2$; $\phi_{int} = 3,4$;	1,5	0,0023	0,00075
	2	0,0031	
	2,5	0,00385	

Geometric dimensions [mm]	Scanning force [N]	Determined deformation [mm]	Maximum admissible deformation
B = 2,3; b = 1,25; h = 0,08; H =1,5	2,8	0,0043	
ϕ_{ext} = 5,2; ϕ_{int} = 4; B = 2,6; b = 1,4; h = 0,12; H = 1,75	1,5	0,0013	0,0008
	2	0,0017	
	2,5	0,00215	
	2,8	0,0024	
ϕ_{ext} = 6,2; ϕ_{int} = 4,5; B = 3,2; b = 1,7 h = 0,17; H = 2,1	1,5	0,0008	0,00085
	2	0,001	
	2,5	0,0013	
	2,8	0,0015	
ϕ_{ext} = 8,5; ϕ_{int} = 5,2; B = 3,2; b = 1,7; h = 0,33; H = 2,1	1,5	0,0003	0,001
	2	0,00035	
	2,5	0,0004	
	2,8	0,0005	

Table 8

FEM results in terms of deformation in case of outer rings providing from a cylindrical roller bearing [mm]

Geometric dimensions [mm]	Scanning force [N]	Determined deformation [mm]	Maximum admissible deformation
ϕ_{ext} = 5,2; ϕ_{int} = 4; B = 2,6; b = 1,75; H = 0,6; h = 0,4	1,5	0,00012	0,00075
	2	0,00015	
	2,5	0,00019	
	2,8	0,0022	
ϕ_{ext} = 6,2; ϕ_{int} = 4,5; B = 3,2; b = 2,1; H = 0,85; h = 0,57	1,5	0,00065	0,00085
	2	0,0009	
	2,5	0,0011	
	2,8	0,0012	
ϕ_{ext} = 8,5; ϕ_{int} = 5,2; B = 3,2; b = 2,1; H = 1,65; h = 1,1	1,5	0,0002	0,001
	2	0,0003	
	2,5	0,0004	
	2,8	0,0004	

Due to the results it was demonstrated that only the larger dimensional range would lend for contact principle scanning. Thus is recommended that such of small dimension bearings to be measured or scanned using the non contact principle, like LASER emission. In this case problems like surfaces brightness could be partially solved due to more CCD for several digital images (grey level) for LASER radiation interference compensation [10], [11].

5. CONCLUSION

The obtained results using graphical 3D model reconstruction and FEM method proved to led (in an efficient way) to very conclusive information about the required scanning principle for small bearings. Moreover, the applied FEM method may be used also for other small dimension components (e.g. for mini-robotics, mini – electronics etc.).

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