THE INFLUENCE OF TECHNOLOGICAL FACTORS UPON THE FORM ACCURANCY SURFACES OF THE COLD PLASTIC DEFORMATION BEARING RINGS

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Abstract: In this paper we present the experimental results of the influence of the technological factors (deformation force, deformation feed and the tool's rotation speed) upon the quality parameters of the surfaces processed by means of the cold plastic deformation (roughness, out-of-roundness and circularity). There were presented the matrix models and a classification of factors and their interactions after this influence.
Key words: plastic deformation, roughness, out-of-roundness, circularity, experimental design, matrix model.

1. INTRODUCTION

Surface processing by cold plastic deformation has undeniable advantages. The process is used either for smoothing and hardening surfaces, or for generating surfaces (Gavrilaş & Maier, 1987; Barnabic et.al, 2000; Lupescu, 1999; Musca & Rusu, 1993).
In SC Rulmenți SA Bârlad, processing by cold plastic deformation is used to generate rings of bearings (Pruteanu et al, 2009). To this end it uses two specialized machines: one for processing the external rings, the other for processing internal rings.
An important issue is to establish parameters so as to provide surfaces with desired quality.
A necessary step is to determine the influence of factors and interactions on quality parameters. Matrix method (Bagard & Aubry, 1992; Musca et al, 1999) provides an analysis of influence factors and their influence on quality parameters.
In the paper, quality parameters of cold plastic deformation process were considered: surface roughness, out-of-roundness and circularity.

2. EXPERIMENTAL CONDITIONS

In this experimental research we used the existing equipment of SC Rulmenți SA Bârlad, that is:
a. material: 100Cr6 – specific for bearing manufacture;
b. half-finished product: hot formed and rolled rings, with sizes corresponding to the types of bearing they are supposed to fit; in tabel 1 are given the dimensions of the rings of bearings 6207-20 and 6210-20, that were use in experiments;
c. equipment: special CRF 70 machinery IR for internal rings (figure 1);
d. tools: properly shaped mandrels and rolls, corresponding to the shapes of the types of bearing they are supposed to fit;
e. measurement and control devices:
- for roughness: Taylor Hobson Formtalysurf, series 2,
- for shape deviations: Perthometyer Marsurf CD 120.

The tools are 155 MoVCr115 steel mandrels and formation rolls, having shapes that resemble those of the track profile of the type of processed bearing.
The area that was subjected to plastic deformation was treated with a cooling-greasing fluid, that is a special plastic deformation oil called D 605, manufactured by Shell.

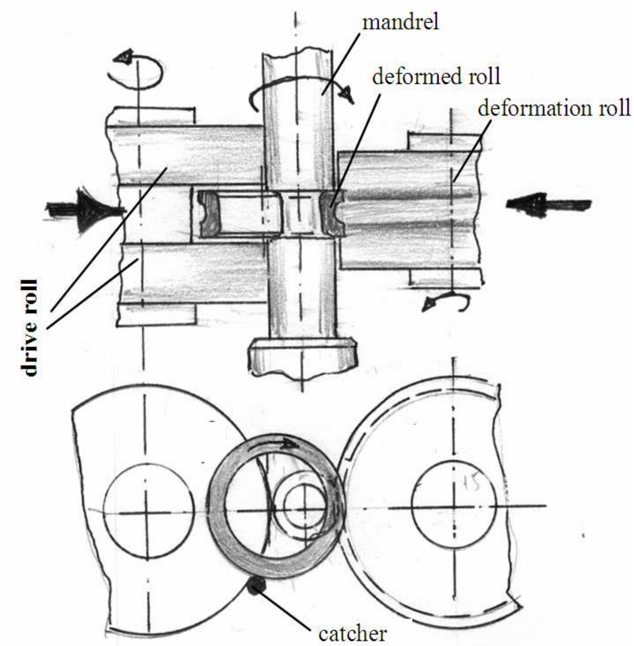
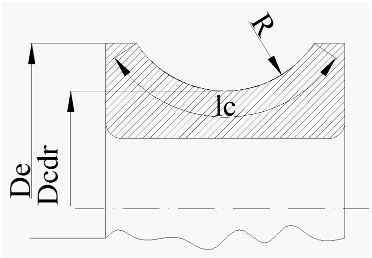


Fig. 1. Working diagram for CRF 70 IR machinery (Pruteanu et al, 2009)

3. EXPERIMENTAL RESULTS

Analysis of factors influence the process of cold rolling circular inner ring of bearing was performed using matrix method on a 2^4 factorial experiment.

Table 1. Dimensions of rings

Ring and dimensions	Diagram
6207 – 20 De=46,95 mm D_{cdr}=42,60mm R = 5,61 mm l_c = 10,20 mm	
6210 – 20 De=62,35 mm D_{cdr}=57,50mm R = 6,24 mm l_c = 11,40 mm	

De – external diameter of the half-finished product, mm; D_{cdr} - diameter of the running track, mm; R- radius of the running track, mm; lc – length of the contact arch, mm.

Input factors of cold plastic deformation process were bearing size (type), M, deformation force, F, deformation feed, A, and the speed of rotation of the drive wheel, v. For each input factor was established two values:
- the bearing size, M: 6205-20 and 6308-20;
- the deformation force, F: 5019 and 7529 daN;
- the deformation feed, A: 22.5 and 30 mm/min;
- speed of rotation, v: 106.5 and 118 rpm.

The roughness, Ra, the out-of-roundness, Ov, and the deviation from circularity, Cir, values for the two levels of input factors are presented in table 2.

The matrix mathematical model of the roughness is:

$$\begin{aligned} Ra = {} & 0.37875 + [0.095 \quad -0.095]\cdot[M] + [-0.05625 \quad 0.05625]\cdot[F] + [0.005 \quad -0.005]\cdot[A] + \\ & + [-0.04125 \quad 0.04125]\cdot[v] + {}^t[M]\cdot\begin{bmatrix} 0.0075 & -0.0075 \\ -0.0075 & 0.0075 \end{bmatrix}\cdot[F] + {}^t[M]\cdot\begin{bmatrix} -0.00375 & 0.00375 \\ 0.00375 & -0.00375 \end{bmatrix}\cdot[A] + \\ & + {}^t[M]\cdot\begin{bmatrix} 5.55\cdot10^{-17} & -5.55\cdot10^{-17} \\ -5.55\cdot10^{-17} & 5.55\cdot10^{-17} \end{bmatrix}\cdot[v] + {}^t[F]\cdot\begin{bmatrix} 0.0025 & -0.0025 \\ -0.0025 & 0.0025 \end{bmatrix}\cdot[A] + \\ & + {}^t[F]\cdot\begin{bmatrix} -0.00375 & 0.00375 \\ 0.00375 & -0.00375 \end{bmatrix}\cdot[v] + {}^t[A]\cdot\begin{bmatrix} -0.0025 & 0.0025 \\ 0.0025 & -0.0025 \end{bmatrix}\cdot[v] \end{aligned} \quad (1)$$

Tabel 2. The roughness, out-of-roundness, and deviation from circularity values of factorial experiment

No.	Ring bearing	Deformation force, F [daN]	Feed, A [mm/min]	Speed of rotation, v [rpm]	Roughness, Ra [μm]	Out-of-roundness Ov [mm]	Circularity Cir [μm]
1	6207-20	5019	22.5	106.5	0.39	0.4	201.5
2				118.0	0.45	0.1	92.65
3			30	106.5	0.44	0.1	64.55
4				118.0	0.35	0.11	52.1
5		7529	22.5	106.5	0.39	0.14	74.2
6				118.0	0.41	0.32	164.15
7			30	106.5	0.38	0.16	93.65
8				118.0	0.43	0.12	71.75
9	6210-20	5019	22.5	106.5	0.48	0.35	428.1
10				118.0	0.27	0.07	63.2
11			30	106.5	0.4	0.3	197.35
12				118.0	0.62	0.5	324.72
13		7529	22.5	106.5	0.23	0.08	67.65
14				118.0	0.4	0.16	183.85
15			30	106.5	0.25	0.18	138.5
16				118.0	0.53	0.1	65.72

The average effects of the factors and their interactions on the roughness are represented in figures 2 and 3.

An analysis of Figure 2 shows that surfaces roughness improves as the bearing size are increased and as the deformation force and the speed of rotation are decreased.

To test the significance of the model, we apply Snedecor test, which consists in the comparison of the variation factor or interaction with the residual variation of the matrix model, based on test Fisher.

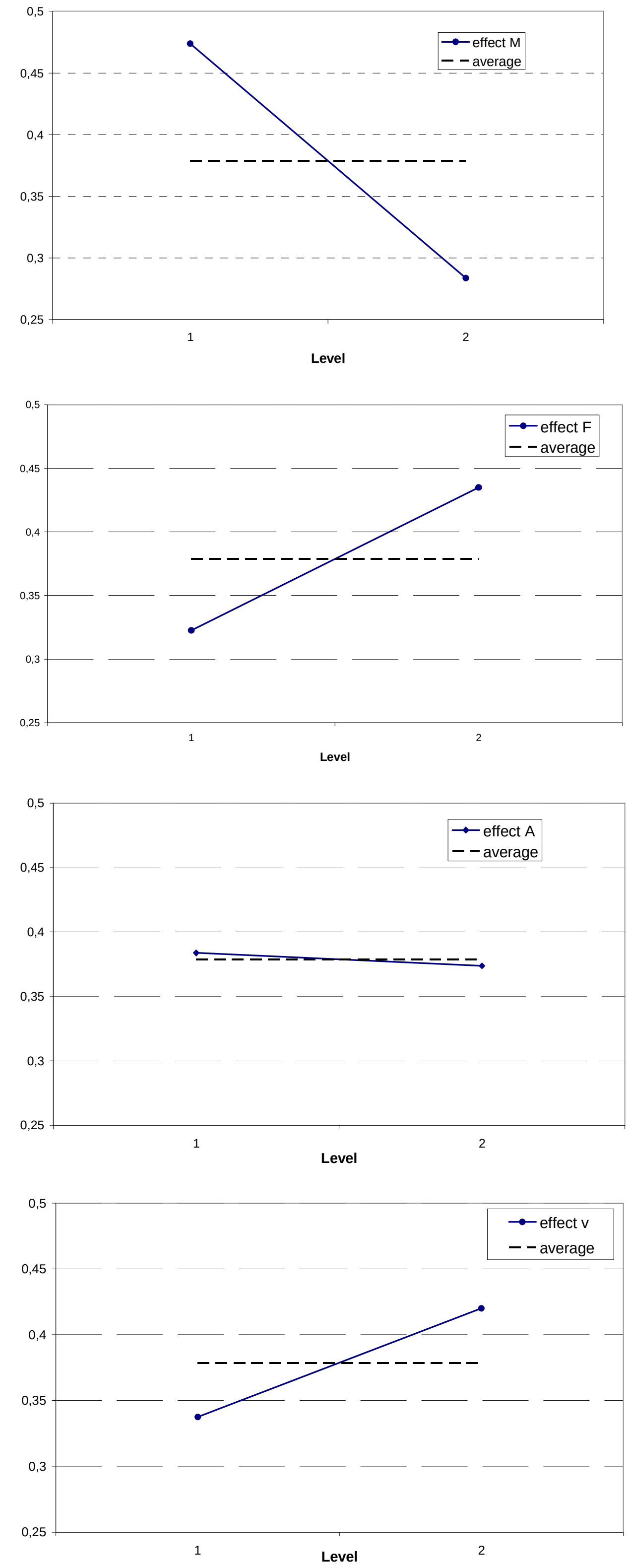


Fig. 2. The effects of the independent factors on roughness: M - the bearing size; F – the deformation force; A – deformation feed; v – the speed of rotation.

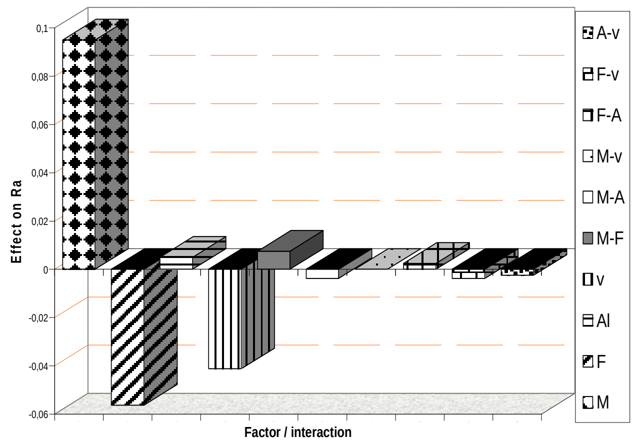


Fig. 3. The average effects of the independent parameters and their interactions on the roughness

Table 3 show the significance of the independent parameters and their interactions.

Table 3. The significance of the independent parameters and their interactions

No	Factor/ Interaction	Variance of factor/ interaction	Residual variance, V_r	Experi-mental criterion Fisher,	Tabelar Fisher criterion, F_T	Signi-ficance
1	M	0.1444	0.000115	1255.65	6.61	YES
2	F	0.050625		440.217		YES
3	A	0.0004		3.47826		NO
4	v	0.027225		236.739		YES
5	M-F	0.0009		7.82609		YES
6	M-A	0.000225		1.95652		NO
7	M-v	2.465E-32		2.1E-28		NO
8	F-A	1.0E-04		0.86957		NO
9	F-v	0.000225		1.95652		NO
10	A-v	0.0001		0.86957		NO

The influence of the deformation feed on the roughness is insignificant. In descending order, the semnificative factors are: the bearing size, the deformation force and the speed of rotation. Only interaction the bearing size with the deformation force on roughness is significant.

After eliminating insignificant factors and interactions from relationship 1, the matrix mathematical model is present in the relationship 2.

$$Ra = 0.37875 + [0.095 \quad -0.095]\cdot[M] + [-0.05625 \quad 0.05625]\cdot[F] + [-0.04125 \quad 0.04125]\cdot[v] +$$

$$+ {}^{t}[M]\cdot\begin{bmatrix} 0.0075 & -0.0075 \\ -0.0075 & 0.0075 \end{bmatrix}\cdot[F] \qquad (2)$$

The matrix mathematical model of the out-of-roundness is:

$$
\begin{aligned}
Ov = {} & 0.1994 + [-0.0181 \quad 0.0181]\cdot[M] + [0.04188 \quad -0.04188]\cdot[F] + [0.00313 \quad -0.00313]\cdot[A] + \\
& + [0.01438 \quad -0.01438]\cdot[v] + {}^{t}[M]\cdot\begin{bmatrix} -0.0456 & 0.0456 \\ 0.0456 & -0.0456 \end{bmatrix}\cdot[F] + {}^{t}[M]\cdot\begin{bmatrix} 0.0556 & -0.0556 \\ -0.0556 & 0.0556 \end{bmatrix}\cdot[A] + \\
& + {}^{t}[M]\cdot\begin{bmatrix} 0.0556 & -0.0556 \\ -0.0556 & 0.0556 \end{bmatrix}\cdot[v] + {}^{t}[F]\cdot\begin{bmatrix} -0.01438 & 0.01438 \\ 0.01438 & -0.01438 \end{bmatrix}\cdot[A] + \\
& + {}^{t}[F]\cdot\begin{bmatrix} 0.03188 & -0.03188 \\ -0.03188 & 0.03188 \end{bmatrix}\cdot[v] + {}^{t}[A]\cdot\begin{bmatrix} 0.0256 & -0.0256 \\ -0.0256 & 0.0256 \end{bmatrix}\cdot[v]
\end{aligned}
\qquad (3)
$$

The average effects of the factors and their interactions on the out-of-roundness are represented in figures 4 and 5.

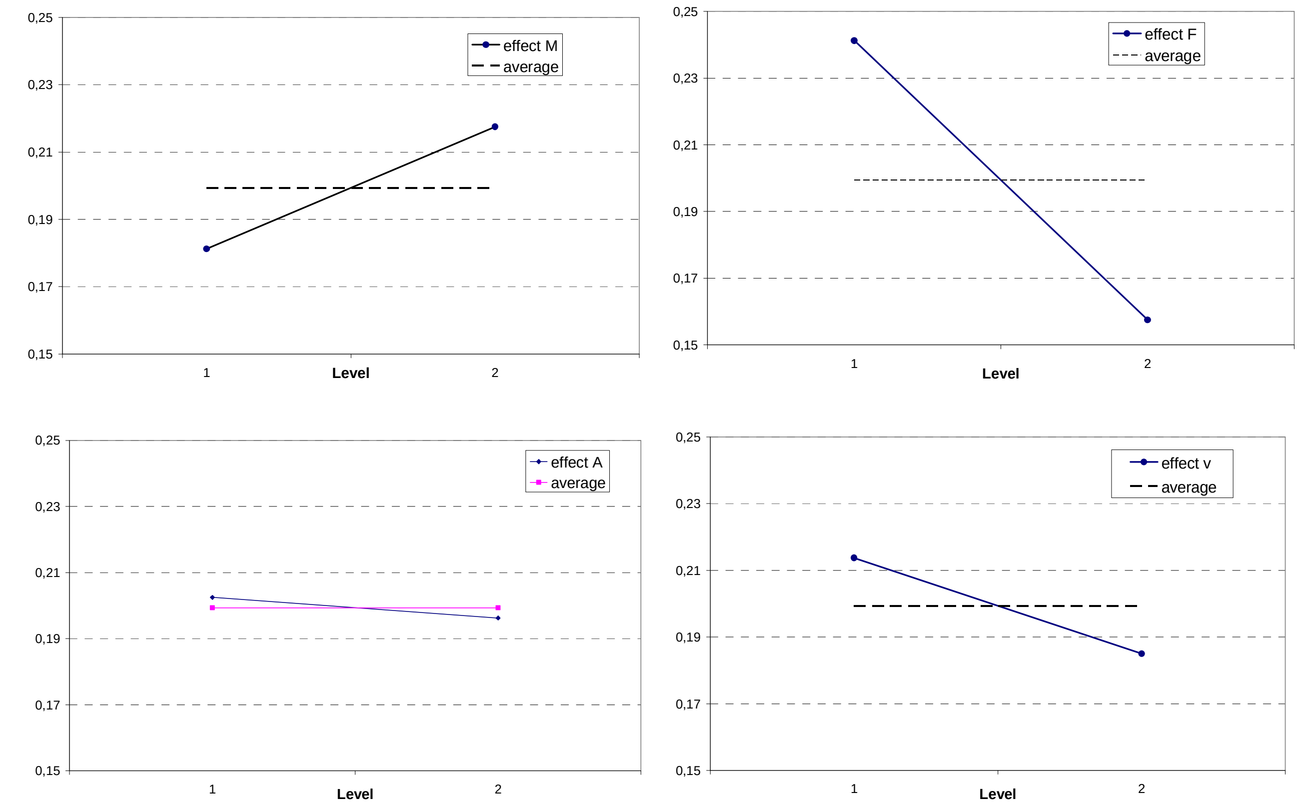


Fig. 4. The effects of the independent factors on out-of-roundness: M - the bearing size; F – the deformation force; A – deformation feed; v – the speed of rotation.

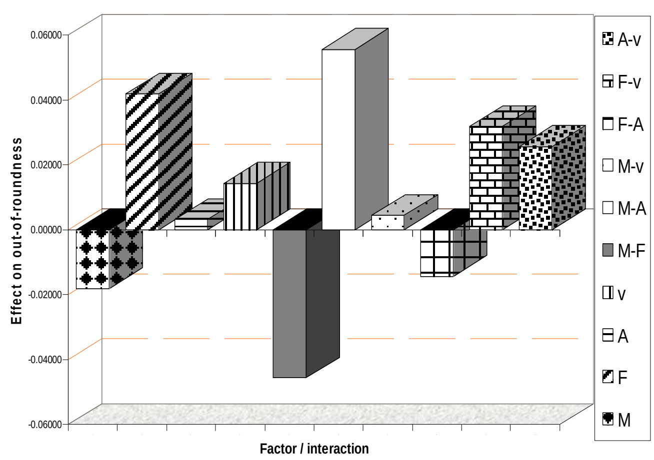


Fig. 5. The average effects of the independent parameters and their interactions on the out-of-roundness

An analysis of Figure 4 shows that surfaces out-of-roundness improves as the bearing size are decreased and as the deformation force, the deformation feed and the speed of rotation are increased.

Table 4 show the significance of the independent parameters and their interactions.

In descending order, the semnificative factors are: the deformation force and the bearing size. The most significant interactions are those between the bearing size with deformation feed and deformation force.

After eliminating insignificant factors and interactions from relationship 3, the matrix mathematical model is present in the relationship 4. The matrix mathematical model of the deviation from circularity is give by relationship 5.

The average effects of the factors and their interactions on the deviation from circularity are represented in figures 6 and 7.

$$Ov = 0.1994 + \begin{bmatrix}-0.0181 & 0.0181\end{bmatrix}\cdot[M] + \begin{bmatrix}0.04188 & -0.04188\end{bmatrix}\cdot[F] + {}^{t}[M]\cdot\begin{bmatrix}-0.0456 & 0.0456\\ 0.0456 & -0.0456\end{bmatrix}\cdot[F] +$$

$$+{}^{t}[M]\cdot\begin{bmatrix}0.0556 & -0.0556\\ -0.0556 & 0.0556\end{bmatrix}\cdot[A] + {}^{t}[F]\cdot\begin{bmatrix}0.03188 & -0.03188\\ -0.03188 & 0.03188\end{bmatrix}\cdot[v] + {}^{t}[A]\cdot\begin{bmatrix}0.0256 & -0.0256\\ -0.0256 & 0.0256\end{bmatrix}\cdot[v] \quad (4)$$

$$Cir = 142.728 + \begin{bmatrix}-40.909 & 40.909\end{bmatrix}\cdot[M] + \begin{bmatrix}35.294 & -35.294\end{bmatrix}\cdot[F] + \begin{bmatrix}16.685 & -16.685\end{bmatrix}\cdot[A] +$$

$$+\begin{bmatrix}15.46 & -15.46\end{bmatrix}\cdot[v] + {}^{t}[M]\cdot\begin{bmatrix}-34.413 & 34.413\\ 34.413 & -34.413\end{bmatrix}\cdot[F] + {}^{t}[M]\cdot\begin{bmatrix}14.62 & -14.62\\ -14.62 & 14.62\end{bmatrix}\cdot[A] + \quad (5)$$

$$+{}^{t}[M]\cdot\begin{bmatrix}-8.804 & 8.804\\ 8.804 & -8.804\end{bmatrix}\cdot[v] + {}^{t}[F]\cdot\begin{bmatrix}1.656 & -1.656\\ -1.656 & 1.656\end{bmatrix}\cdot[A] +$$

$$+{}^{t}[F]\cdot\begin{bmatrix}29.394 & -29.394\\ -29.394 & 29.394\end{bmatrix}\cdot[v] + {}^{t}[A]\cdot\begin{bmatrix}17.99 & -17.99\\ -17.99 & 17.99\end{bmatrix}\cdot[v]$$

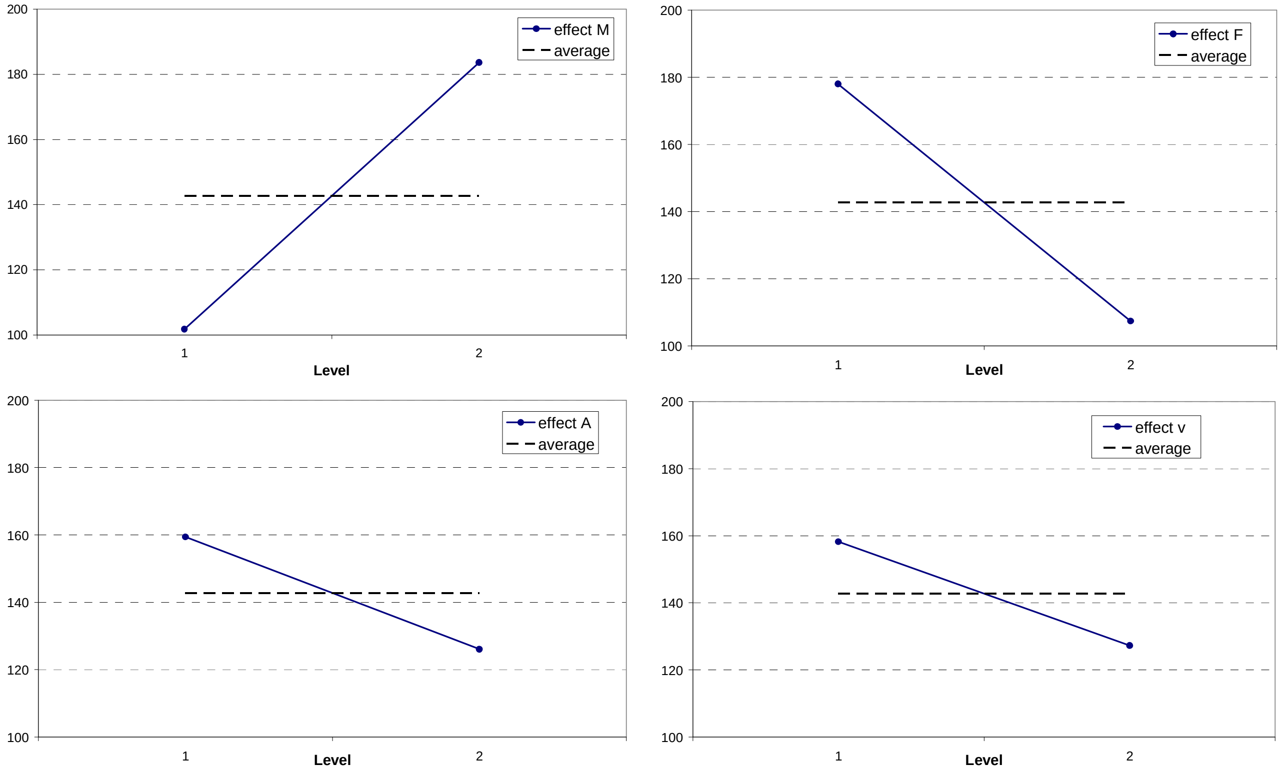


Fig. 6. The effects of the independent factors on deviation from circularity: M - the bearing size; F – the deformation force; A – deformation feed; v – the speed of rotation.

An analysis of Figure 6 shows that deviation from circularity improves as the bearing size are decreased and as the deformation force, the deformation feed and the speed of rotation are increased.
In descending order, the semnificative factors are: the bearing size and the deformation force. The most significant interactions are those between the bearing size with deformation feed and deformation force.
After eliminating insignificant factors and interactions from relationship 3, the matrix mathematical model is present in the relationship 6.
Table 5 show the significance of the independent parameters and their interactions.

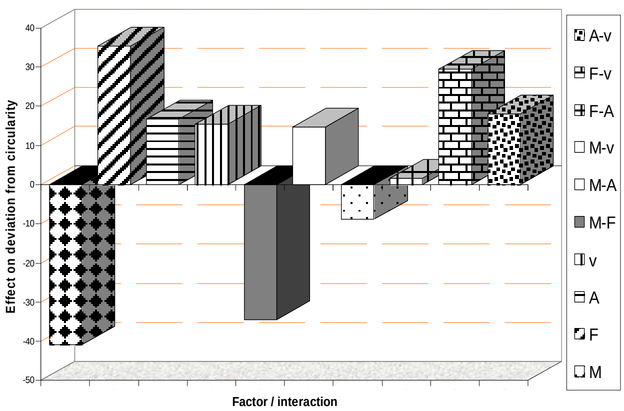


Fig. 7. The average effects of the independent parameters and their interactions on the deviation from circularity

Table 4. The significance of the independent parameters and their interactions

No	Factor/ Interaction	Variance of factor/ interaction	Residual variance, V_r	Experi-mental criterion Fisher,	Tabelar Fisher criterion, F_T	Signi-ficance
1	M	0.005256	0.0007329	7.172	6.61	YES
2	F	0.028056		38.282		YES
3	A	0.000156		0.213		NO
4	v	0.003306		4.511		NO
5	M-F	0.033306		45.446		YES
6	M-A	0.049506		67.551		YES
7	M-v	0.000306		0.418		NO
8	F-A	0.003306		4.511		NO
9	F-v	0.016256		22.181		YES
10	A-v	0.010506		14.336		YES

Table 5. The significance of the independent parameters and their interactions

No	Factor/ Interaction	Variance of factor/ interaction	Residual variance, V_r	Experi-mental criterion Fisher,	Tabelar Fisher criterion, F_T	Signi-ficance
1	M	26776.41	2719.55	9.8459	6.61	YES
2	F	19930.38		7.3286		YES
3	A	4454.23		1.6379		NO
4	v	3824.19		1.4062		NO
5	M-F	18947.52		6.9672		YES
6	M-A	3420.50		1.2577		YES
7	M-v	1240.10		0.4560		NO
8	F-A	43.89		0.0161		NO
9	F-v	13823.88		5.0831		YES
10	A-v	5178.24		1.9041		YES

$$Cir = 142.728 + [-40.909 \quad 40.909] \cdot [M] + [35.294 \quad -35.294] \cdot [F] + {}^{t}[M] \cdot \begin{bmatrix} -34.413 & 34.413 \\ 34.413 & -34.413 \end{bmatrix} \cdot [F] \qquad (6)$$

5. CONCLUSIONS

The results of experimental research upon cold plastic deformation bearing rings indicate follows:

- the surfaces roughness improves as the bearing size are increased and as the deformation force and the speed of rotation are decreased;
- in descending order, the semnificative factors on the surface roughness are: the bearing size, the deformation force and the speed of rotation; the influence of the deformation feed on the roughness is insignificant; only interaction the bearing size with the deformation force on roughness is significant;
- the surfaces out-of-roundness improves as the bearing size are decreased and as the deformation force, the deformation feed and the speed of rotation are increased;
- in descending order, the semnificative factors on the surfaces out-of-roundness are: the deformation force and the bearing size; the most significant interactions are those between the bearing size with deformation feed and deformation force;
- the deviation from circularity improves as the bearing size are decreased and as the deformation force, the deformation feed and the speed of rotation are increased;
- in descending order, the semnificative factors on the deviation from circularity are: the bearing size and the deformation force; the most significant interactions are those between the bearing size with deformation feed and deformation force.

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