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HOT RING ROLLING IN BEARING PRODUCTION

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ABSTRACT

The ring rolling process is widely used to produce seamless rings with outer diameters ranging approximately from 50 millimeters all the way up to 8 meters with cold or hot workpieces. Typical products are seamless rings for ball bearings, railroad wheels and a variety of other components. The ring rolling process has the advantages of short production time, material saving, close tolerance, etc. Especially ring rolling offer great possibilities in bearing industry where many types of rings with many different sizes are produced in large series. Since the geometry of most rings is complex the process design can be very difficult.

In this paper the procedure of determining geometrical parameters of workpiece in case of radial hot ring rolling process together with forging process for annular blank producing is given. On the base of that procedure, adequate software was created too.

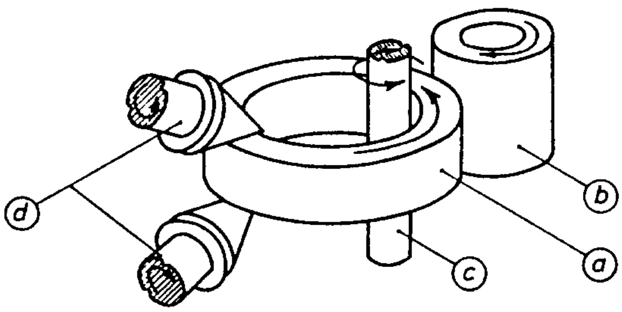
Key words: Bearings, hot ring rolling, forging

1. INTRODUCTIN

Ring rolling is a bulk metal forming process which is used in production of size and shapes different seamless rings such as rings for ball bearing, rings for railroad wheels, pipe flanges, rings for turbines, and so on. The process can be performed with cold and hot ring shaped workpiecies. Advantages of the process are uniform quality, smooth surface finish, close tolerance, short production time and relatively small material loss, especially for rings of complex profiles. The mechanics of deformation in this process are complex and generally not well understood, and there is a certain lack of information in the literature regarding relevant process parameters. In many instances, considerable experience and experimentation is required to develop a ring rolling application. Basically there are two ways of ring rolling:

- Radial ring rolling
- Radial-axial ring rolling

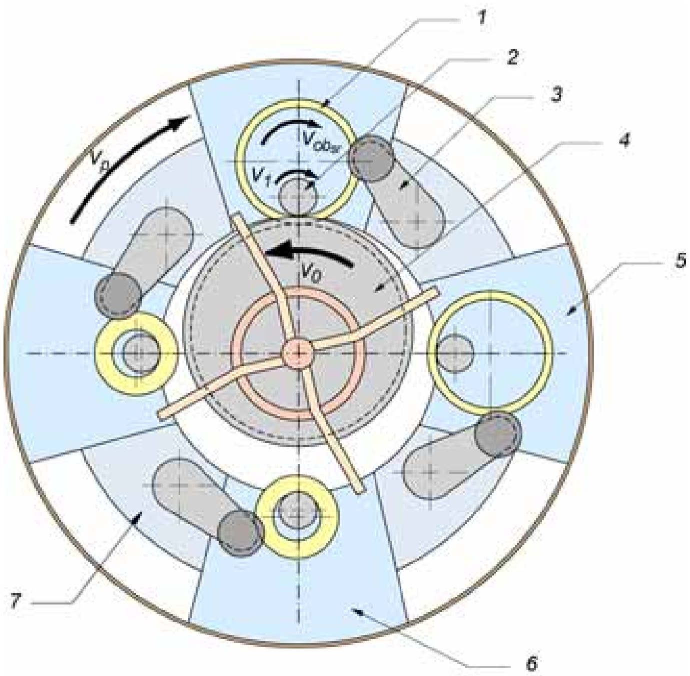
The basic principle of radial-axial ring-rolling process is shown in Figure 1. The annular workpiece is positioned between two sets of rolls: a radial set is used to reduce the radial thickness of the ring, while an axial set controls the width of the ring. During the ring rolling process, the main roll and the mandrel (pressure) roll move toward each other. The rotating main roll, supported by the friction at the roll/ring interface, forces the ring to pass through the gap. Being the gap between two rolls decreases continuously, it causes decreasing of the ring wall. As the cross-section of the ring is gradually reduced, the diameter of the ring progressively grows due to incompressibility of the material. At the same time conical-axial rolls press the ring so its width decreasing.



a) workpiece (ring), b) main roll,
c) mandrel, d) axial rolls

Figure 1 - Scheme of radial-axial ring rolling process

The scheme of radial ring rolling process is very similar to previously described. In this case there are no axial rolls so material flows only in radial direction and initial width of the ring stays constant during the process. However, the strain degree which can be realized is much bigger than at the radial-axial process that enables production of the rings in wider dimensional spectrum. Also radial ring rolling machines have simpler construction and more economical service from radial-axial machines. Basic scheme of a four stations radial ring rolling machine including procedure of ring manufacturing is given in figure 2. At first station annular blank (1) is positioned on the fixed (mandrel) roll (2). By turning of the rotary table (7) and the driven roll (4) which are eccentricity positioned the contact between the ring and the driven roll is established i.e. process of deformation starts. At the third station deformation of the ring is finished and at the station fourth the ring is put from the rotary table of.



1 – annular blank
2 – mandrel
3 – roll for centering
4 – driven roll
5 – final station
6 – first station
7 – rotary table

Figure 2 – Scheme of the radial ring rolling machine

2. BEARING PRODUCTION

Bearing are mostly produced in large series. For a long period of time metal cutting technologies were prevailing in this field of production. Because of significant material waste, by time, this way of ring production lost position which place has been taken over by metal forming technologies. In that propose a few different procedure based on application of forging, extrusion and rolling methods have been developed. Those methods are always attractive, both for economical and ecological reasons (low material and energy consumption, higher product quality, shorter cycle time).
Optimal way of the bearing production depends on many factors. In Fig. 3 an approximate diagram with optimal ways of production, depending on rings diameter, is shown. Rings are divided into following five groups:

a) Small rings (diameter to 60mm) – cutting from tube or hot forging in closed die
b) Rings from d=50mm to 200mm – cutting or cold ring rolling
c) Rings up to 800mm – die forging or hot ring rolling
d) Rings from 100 to 7000 mm – hot ring rolling
e) Heavy rings (up to 35 000kg) – free forging

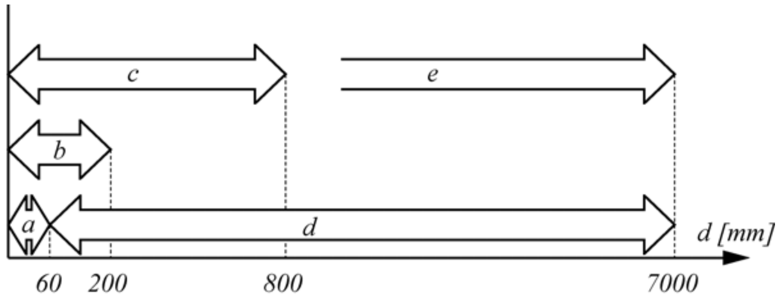


Figure 3 – Optimal way of the bearing production

In this paper short overview of the process of hot ring rolling including the process of hot forging for annular blank producing will be given as well as complete procedure for determining shape and dimensions of workpiece in case of radial rolling. On the base of that procedure a simply software for determining geometry of initial billet (bar) has been developed.

3. PROCESS STEPS OF HOT RING ROLLING PROCESS

The process for the ring production can be divided into two phases:

1. Forging of a bulk in order to get annular blank
2. Rolling of the annular blank into the finished ring

The formed part and the relevant volumetric calculation represent the starting point for developing the process plan of ring rolling. A creative process is initiated in which a wide range of boundary conditions – such as starting diameter, material, prescribed strength levels, heat treatment, number of stations, distance between stations, press force,– must be considered simultaneously.
Saws or cropping machines are used for cutting off cylindrical billets (bulks) from a bar-preferably round. Volume of cylindrical billet (figure4a) is depending on the volume of the ring (respecting all necessary operations, especially forging). Blank for ring rolling machine (figure 4b) has to be annular and these cylindrical billets are starting material for annular blank production.

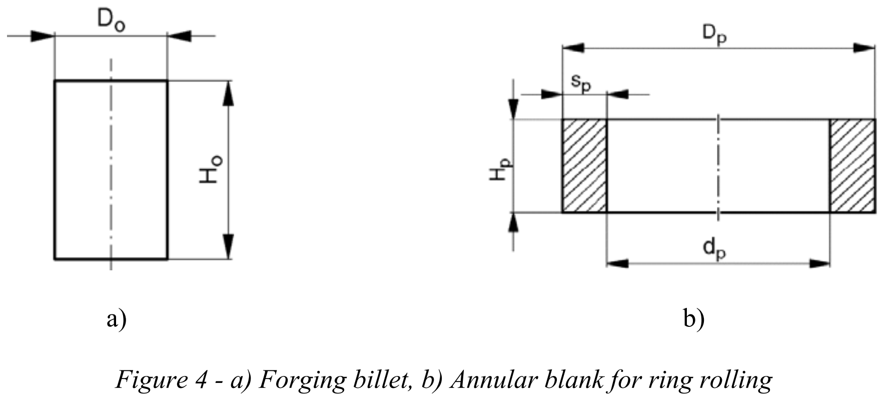


Figure 4 - a) Forging billet, b) Annular blank for ring rolling

Production of annular blanks consists of three stages: free upsetting, backward extrusion (piercing in the die) and piercing (figure 5). Cylindrical billets are heated before forging in rotary hearth furnaces or induction heaters. After forging, annular blanks are transported to the ring-rolling machine.

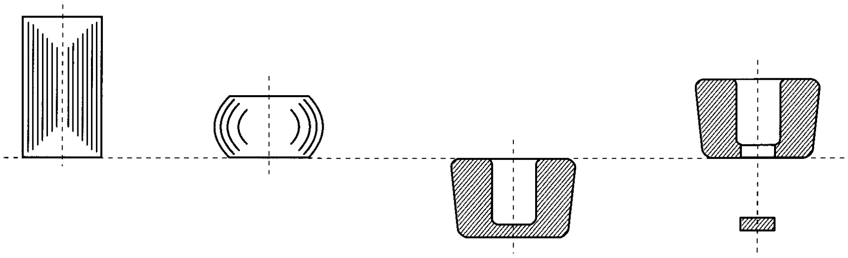


Figure 5 - Forging operations: upsetting-piercing in the die-piercing

Profile (cross-section) of annular blank for most rings is rectangular. For rings with more complex profile annular blank can be with different cross-section which should be technologically compatible with final ring shape.

4. DESIGN OF WORKPIECE IN RING ROLLING

One of the most important things in developing bearing ring rolling process is to design initial billet. Failure in perform design may lead to surface defects, under-filling in the cross-section and immature tool fracture. Starting with the geometry of the formed ring, development work proceeds to determine the volume and the geometry of workpiece from previous stages, working backwards towards the starting billet. In practice, the volume is calculated by dividing the overall part geometry into simple volumetric elements, whose calculated individual volumes are added to obtain the total part volume. The calculation must take into account slug and shearing scrap which allows for material overflow during the forming process as well as large machining allowances especially in case of hot forging.
In extension, the procedure of determining geometry of the initial billets will be given for case of radial rolling of the ring with rectangular cross-section.

4.1 Shape and dimension of the ring after rolling

Outset for determining shapes and dimensions of annular blank is a draw of assembly ready ring (figure 6) and its final dimensions (D, d, H). First step in this procedure is to describe a rectangle around the cross-section of the ring adding machining allowances ($\Delta D/2$, $\Delta d/2$, $\Delta H/2$), as it shown in Figure 7. Such obtained dimensions (D_k, $d_{k,}$ $H_{k)}$ are dimensions of the ring after rolling. The average values of the machining allowances as well as tolerances in case of hot forging and radial ring rolling are given in Table 1.

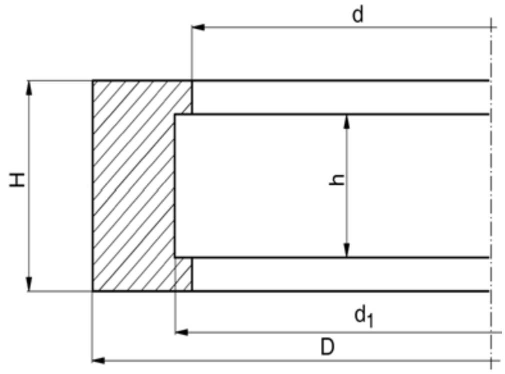


Figure 6 - Dimension of the final ring

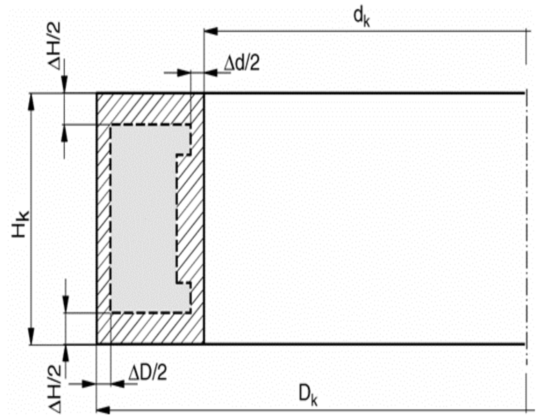


Figure 7 - Dimensions of the ring after rolling

Table 1 - Average values of machining allowances and tolerances in case of radial ring rolling

Ring diameter [mm]: - outer **D** - inner **d**	Machining allowances [mm]			Tolerances [mm]		
	Outer diameter Δ**D**	Inner diameter Δ**d**	Width Δ**H** (Δ**h**)	Outer diameter T_D	Inner diameter T_d	Width T_H ($-T_h$)
to 80	2.5	2.5	3.0	+1.0	-1.5	+1.5
80 ÷120	3.0	3.0	3.5	+1.5	-2.5	+1.5
120 ÷160	3.5	3.5	3.5	+1.5	-2.5	+1.5
160 ÷ 200	4.0	4.0	4.0	+2.0	-3.0	+2.0
200 ÷ 250	4.5	4.5	4.5	+2.0	-3.5	+2.5
250 ÷ 300	5.0	5.0	5.0	+2.5	-4.5	+3.0
300 ÷ 450	6.0	6.0	6.0	+3.5	-7.5	+4.0

Dimensions of ring after rolling are:

- Outer diameter:

$$D_k = D + \Delta D \tag{1}$$

- Inner diameter:

$$d_k = d - \Delta d \tag{2}$$

- Width:

$$H_k = H + \Delta H \tag{3}$$

4.2 Dimension of the annular blank

Dimensions of the annular blank are determined by the dimensions of ring after rolling, and the value of the limit strain degree expressed by the coefficient of reduction (Kv). This coefficient is defined by the ratio of the ring cross section areas before and after rolling:

$$K_v = \frac{A_p}{A_k} = \frac{D_{k\,sr}}{D_{p\,sr}} \tag{4}$$

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where are:

- D_{ksr} - mean diameter of final ring
- D_{psr} - mean diameter of annular blank

From (4) mean radius of annular blank is:

$$D_{p\,sr} = \frac{D_{k\,sr}}{K_v} \tag{5}$$

In Table 2 recommended values for the coefficient of reduction are given. In practice, higher values from those given in table 2 can be used, but it depends on type of rolling machine and its condition.

Table 2 - Recommended values for coefficient of cross-section reduction K_v

$\mathbf{K_v}$	Usage
1.25 ÷1.30	– cylindrical rings to ϕ 100 mm
1.34 ÷1.50	– cylindrical rings over ϕ 100 mm
1.20÷ 1.25	– rings with conical inner channel
1.25 ÷1.30	– rings with spherical inner channel

From volume constancy and equation (5), the inner diameter of the annular blank can be obtained as:

$$\mathrm{d_p} = \frac{D_k + d_k}{2K_v} - \frac{K_v\left(D_k - d_k\right)}{2} \tag{6}$$

Such obtained inner diameter of the annular blank must be compared with minimal value which is defined by mandrel diameter (D_m) and eventually corrected. The minimal value of the inner diameter of annular blank is:

$$\mathrm{d}_{p\,\min} = (1.05 \div 1.15)D_m \tag{7}$$

Outer diameter of annular blank is

$$D_p = \sqrt{D_k^2 - d_k^2 + d_p^2} \tag{8}$$

As it said before, the width of the ring in case of radial rolling is non-changeable, so annular blank is the same width as the ring after rolling.

$$H_p = H_k \tag{9}$$

4.3 Shape and dimension of the billet

When designing a billet for forging process, there are two scopes of consideration:

a) geometrical aspects of the finished ring and
b) the limitations of the individual processing operations utilized in the total process sequence.

Dimensions of the billet depend on the volume of the ring to bi rolled i.e. annular blank, the mandrel diameter and the width of the ring. According to the process steps and the procedure given in Fig. 5, the volume of the billet can be calculated as:

$$V_o = \kappa\left(V_k + V_{pl}\right) \tag{10}$$

where are:

κ - coefficient of volume increasing due to scaling (table 3)

V_k - volume of the annular blank

V_{pl} - volume of the slug

The ring volume is**:**

$$V_k = \frac{\pi}{4}\left(D_k^2 - d_k^2\right)H_k \tag{11}$$

while the slug volume is:

$$V_{pl} = \frac{d_p^2 \pi}{4} h_{pl} \tag{12}$$

The slug thickness (h_{pl}) may be calculated using next empirical expression:

$$h_{pl} = 0.1 d_{kov} + 2 \; [mm] \tag{13}$$

The position of the slug depends on the high/inner diameter ratio (H_{kov} /d_{kov}) and there are two possibilities:

- for: $\frac{H_{kov}}{d_{kov}} = 0.667...2.0$ - the slug is at the bottom of workpiece
- for: $\frac{H_{kov}}{d_{kov}} = 2.0...4.0$ - the slug is at the middle of workpiece

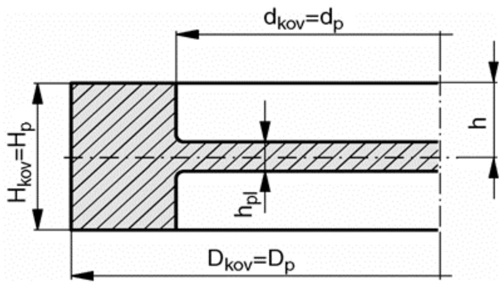

Figure 8: Dimensions of workpiece after piercing in the die

Depending on outer/inner diameter ratio, cavity in workpiece can be obtained on two ways:

- for: $\frac{D_{kov}}{d_{kov}} \geq 3$ - free piercing
- for: $\frac{D_{kov}}{d_{kov}} < 3$ - piercing in the die

Under unfavorable conditions, scale may constitute up to 3% of the workpiece weight. In the table 3 corrective factors due to scale forming are given

Table 3 - Coefficient of volume increasing κ [2]

κ	**Way of heating**
1.007	induction heaters
1.0015	rotary heart furnaces

Also, when the billet dimensions are calculating the limit high/diameter ratio (C_H) must be respected, so the expression for the billet diameter has the next form:

$$D_o = \sqrt[3]{\frac{4V_o}{\pi C_H}} \tag{14}$$

The limit ratio (C_H) is in the range:

$$\frac{H_o}{D_o} = C_H = 0.8...2.5 \tag{15}$$

Middle and higher values of C_H are recommended. It means that billet will be thinner and higher which reduce material losses and cutting time in case of using a saw machine. Obtained diameter should be modified to the value which corresponds to the standard diameter of bar, or to the diameter that can be finding in the stocks. After that, the height of the billet is:

$$H_0 = \frac{4V_0}{D_0^2 \pi}$$

5. SOFTWARE

On the base of the above shown procedure software for automatic determining workpiece geometry and choosing initial bar has been developed. This software is used both for billet and annular blank dimensioning. In this version the software is applied only for radial ring rolling process of the ring with rectangular cross section. Also the software enables the calculation of load in stages of the forging process. The software is created by Access (part of Microsoft Office 2000 program package) and it is tabular based computation program. After running, starting window appears (figure 9) and it is needed to enter data about final ring dimension as well as to choose the type of the forging press. After that the software automatically do all necessary calculations of all process steps and obtained values are successively displayed in the next program windows (figure 10 and 11).

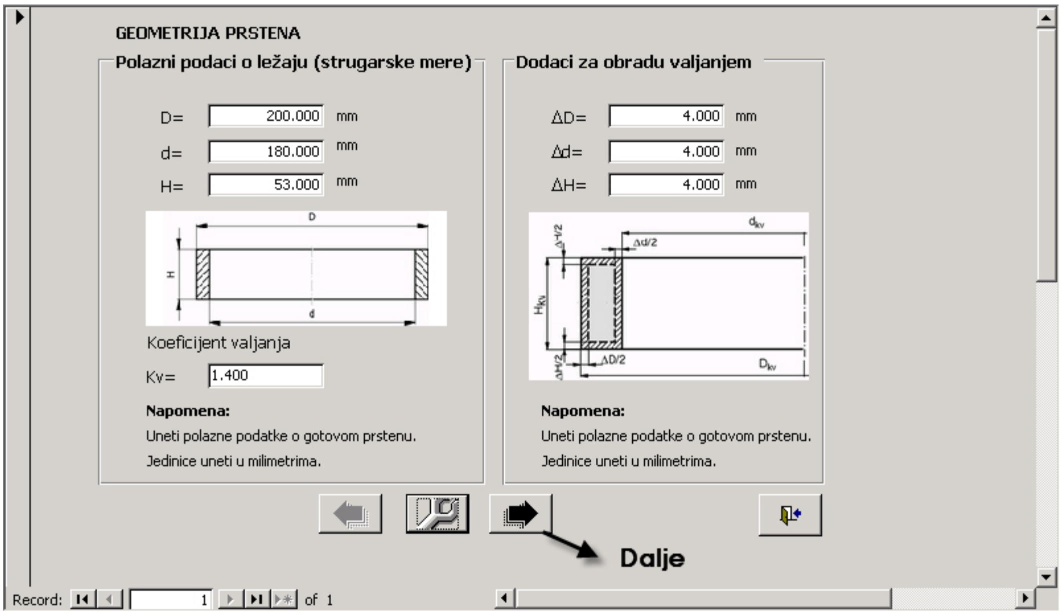

Figure 9 - Starting windows for entering data of final ring dimension

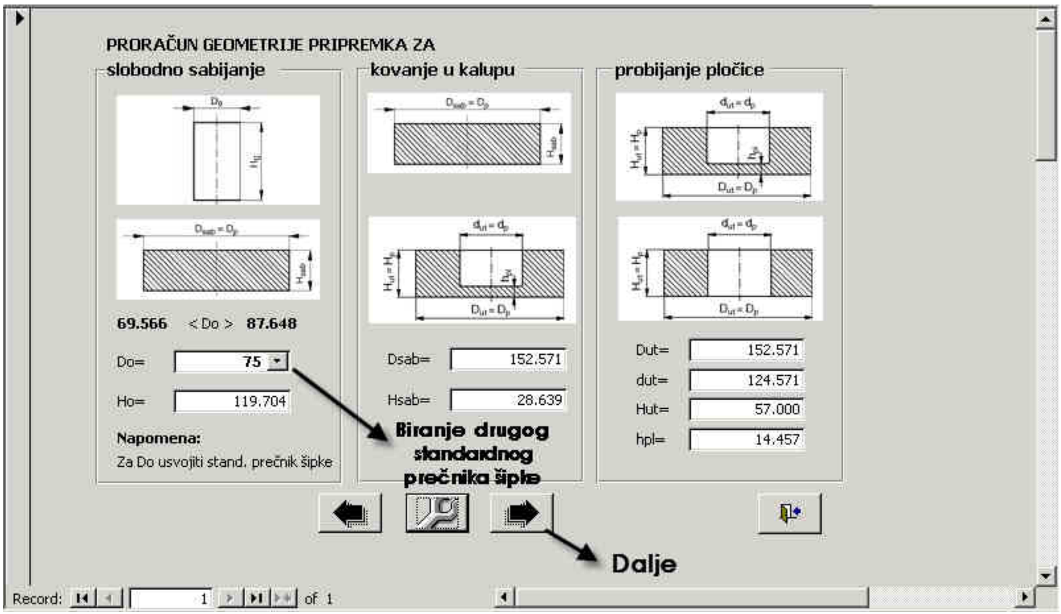

Figure 10 – View of the display with calculated workpiece geometry of forging process steps

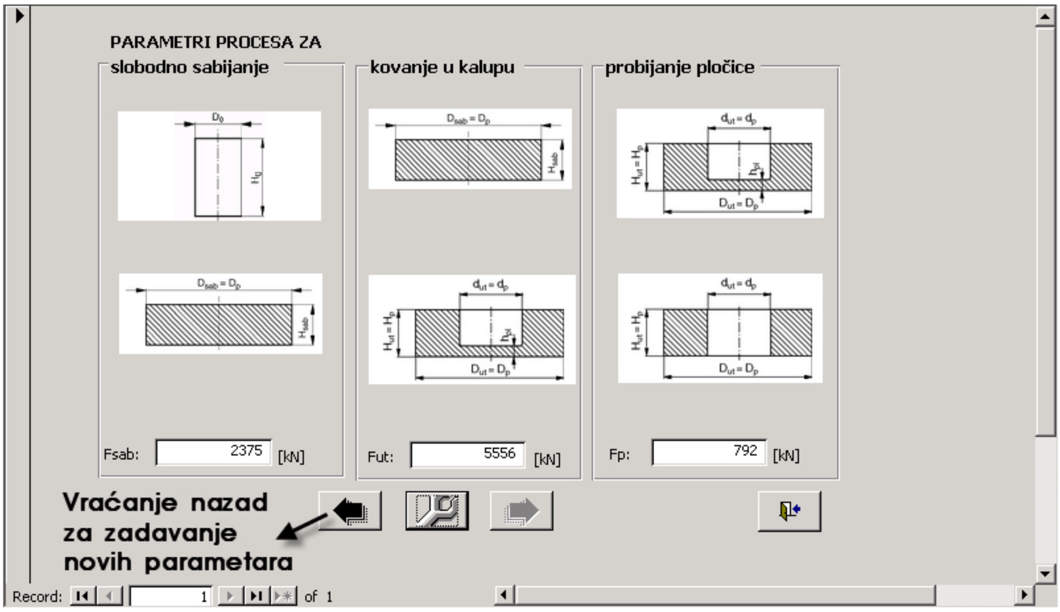

Figure 11 – View of the display with calculated load of forging process steps

6. CONCLUSION

Due to the technical and economical advantages manufactory of bearing rings is based mainly on metal forming technologies. Main advantages of the ring rolling process are:

1. The process is highly material efficient. The perform typically utilizes up to 95% of the starting billet.
2. Better physical properties of workpiece. It is attained by mechanical fibering and hardening due to the plastic deformation.
3. The process is continuous and most suitable for mass production.
4. Tooling cost is low, set-up time is fast, rolled sections require little or no machining

There are different possibilities to design the process of bearing ring production (technologies, production steps, needed equipment). In this paper designing of hot ring rolling process including forging process for annular blank producing was given. Expressions for determining workpice geometry in each process steps was defined and appropriate software for automatic calculation of the initial bar was created.

ACKNOWLEDGEMENT

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[7] Prospectus for HATEBUR, SMS and WAGNER DORTMUND equipment

TOPLO VALJANJE U PROIZVODNJI PRSTENOVA KOTRJAJNIH LEŽAJEVA

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REZIME

U radu se razmatra metodologija određivanja oblika i dimenzija pripremnog materijala u procesu proizvodnje toplovaljanih prstenova za kotrljajne ležaje. Proizvodni proces odnosi se na varijantu izrade prstena radijalnim valjanjem uz prethodno kovanje koje se koristi za izradu prstenastog pripremka. U prvom delu rada definisan je postupak određivanja dimenzija pripremka u zavisnosti od određenih tehnoloških uslova, dok je u nastavku razrađen računarski program za brzo i efikasno određivanje dimenzija pripremka, odnosno, izbor poalzne šipke za njegovu izradu. Program je podešen za jednostavnu primenu u praksi, omogućuje variranje polaznih dimenzija i prilagođavanje odgovarajućim standardnim merama. Na taj način se može značajno unaprediti postupak definisanja optimalnih količina pripremnog materijala u skladištu proizvodnog sistema. Potreba za optimizacijom polaznog materijala naročito je izražena u industriji kotrljajnih ležaja, gde se radi sa veoma velikim brojem standardnih prstenova različitih veličina i oblika.