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Driver roll speed influence in Ring Rolling process

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Abstract

Ring Rolling is an advanced local incremental forming technology to fabricate directly precise seamless ring-shape parts with various dimensions and materials. To produce a high-quality ring different speed laws should be defined: the speed laws of the Idle and Axial rolls must be set to control the ring cross section and the Driver roll angular velocity must be chosen to avoid too high localized deformation on the ring cross section.
Usually, in industrial environment, a constant rotation is set for the Driver roll, but this approach does not guarantee a constant ring angular velocity because of its diameter expansion. In particular, the higher is the ring diameter the lower is its angular velocity. The main risk due to this constrain is the generation of a non-uniform ring geometry. An innovative approach is to design a Driver Roll speed law to obtain a constant ring angular velocity.
In this paper a FEM approach was followed to investigate the Driver roll speed influence on the Ring Rolling process. Different Driver roll speed laws were tested starting from a model defined in an industrial plant. Results will be analyzed by a geometrical and physical point of view.

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Keywords: Ring Rolling, Driver Roll angular velocity, FEM

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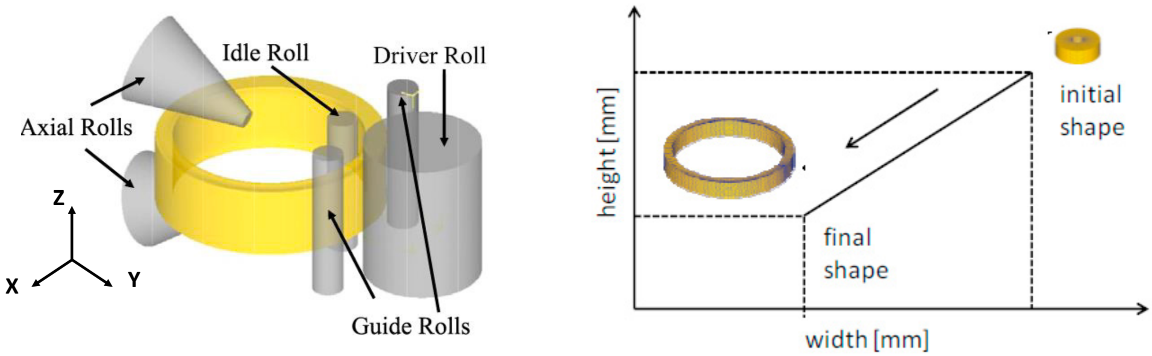
1. Introduction

In Ring Rolling process the metal is rolled between two couple of rolls [1,2]: two radial and two axial. In each couple, one roll moves toward the other one to reduce ring width and height; during the process due to the volume compensation diameter expansion occurs. This process is for the production of railway wheels, anti-friction bearings and different ring shaped workpieces for automotive, aerospace and wind industry applications. It can be both a hot or cold [3] process and different alloys as steels, light and titanium alloys can be worked [4]. The advantages of Ring Rolling process include: short production time, uniform quality, close tolerances and considerable saving in material cost. This process, compared to others as casting or plasma cutting, guarantees lower working temperatures, less required material and, consequently, a reduction in energy consumption. Moreover, the main advantage of the Ring Rolling product is given by the size and orientation of grains, especially on the worked surface which guarantee to the final product excellent mechanical properties.

Fig. 1a summarizes the Ring Rolling process: the Idle Roll forces an hollow circular preform against a Driver roll on the Y direction. At the same time, the Axial rolls apply a pressure in Z direction. A backward movement on the Y-axis is given to the Axial rolls according to the diameter expansion. Because the ring does not rotate on its own axis, two Guide rolls are designed to assure the stability of the process. Therefore, in a Ring Rolling process the following parameters must be defined:

- the Idle and Axial rolls speed laws respectively along the Y and Z directions to control the ring cross section;
- the Driver roll angular velocity, that must be set accordingly to Idle and Axial roll speed laws to avoid excessive ring deformation in the cross section;
- the Axial roll speed law along the Y direction accordingly to the ring expansion;
- the Guide rolls speed law for the stability of the process.

The displacement of each roll can be set independently from the others. For this reason, in industrial practice the milling curve is introduced as a function of the instantaneous ring height (H) and width (W) (Fig. 1b).



a) b)
Fig. 1.a) Ring Rolling scheme; b) Milling curve for a Ring Rolling process

The milling curve definition is fundamental to guarantee a correct ring production [5-8]: by imposing an optimized curve it is possible to reduce rolls load [9] and production times while ensuring a correct ring geometry avoiding the fishtail defect [10].

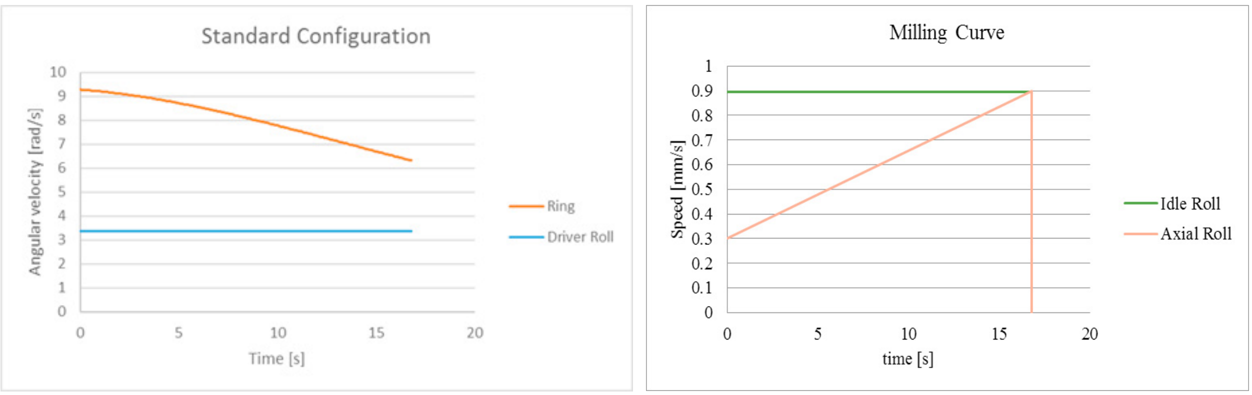
Usually the studies focused on Ring Rolling, consider constant Driver Roll's angular speed (namely Standard Configuration). This means that the angular velocity of the ring decreases as a function of the growth of the external diameter; this can lead to general deformation problems such as fishtail, local deformations of the ring that produce errors on the external diameter (D_{ext}), height (H) and width (W). In literature, there are limited works about the influence of the Driver Roll on the process [11]. In the present work, a FEM approach has been used in order to investigate the influence of different non-constant Driver Roll rotation laws. The aim was to verify if a constant ring rotation (namely New Configuration) can generate benefits in terms of the geometry of the ring and forces acting on the milling plant.

2 Numerical set up

For this work Deform 3D FEM software was used. First, a simulation of a Ring Rolling Standard Configuration was performed. The main characteristics of the ring and the rolls are summarized in Table 1. The simulation is limited to model half ring considering the symmetry on the XY plane; the rolls were considered as rigid bodies and tetrahedral mesh was used with 10680 elements for the preform. A friction factor of 0.7 was imposed between the rolls and the preform and no heat exchange was set. This simulation imposes a constant Driver Roll angular velocity ($\omega 1$), that leads to a decreasing angular velocity of the ring ($\omega 2$), as shown in Fig. 2a. Fig. 2b shows the milling curve for this process. In particular, the Idle and Axial rolls speed laws are defined.

Table 1: Ring and rolls dimensions and characteristics

	H[mm]	W[mm]	D_{ext} [mm]
Preform	75	69	258
Finished ring	56	50	373
Material			AISI 1045
Workpiece Temperature			1150 ° C
Milling time			16.8 sec
Idle Roll Diameter [mm]			110
Driving Roll Diameter [mm]			700
Driving Roll angular velocity [rad/sec]			3.35
Axial Roll Height [mm]			400
Axial Roll taper angle [°]			15.7



a) b)

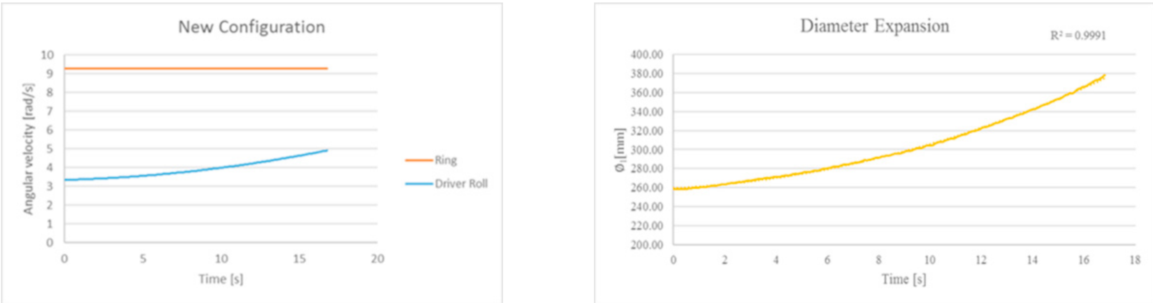
Fig. 2. a) Angular velocities for Standard Configuration; b) Diameter expansion.

Since the peripheral velocity at the contact point between the Driver Roll and the ring is the same, Equation 1 has been used for calculating the Driver roll law guarantying a constant ring angular velocity.

$$\emptyset 1 \cdot \omega 1 = \emptyset 2 \cdot \omega 2 \quad (1)$$

Being: $\emptyset 1$=External diameter of the ring;
$\emptyset 2$=Diameter of the Driver roll;
$\omega 1$=Angular velocity of the ring;
$\omega 2$=Angular velocity of the Driver roll.

Where the external ring diameter was evaluated based on the constant volume constrain coupled with the milling curve equation (fig. 3.b)



a) b)
Fig. 3. a) Angular velocities for New Configuration; b) Diameter expansion of the ring

As it can be seen in Figure 3.a, the New Configuration assures a constant angular velocity of the ring equal to 9.27 Rad/s. In order to investigate the effect of the ring rotational speed, a total of 5 different simulations have been set considering two models with lower $\omega 1$ (2.77 and 6.91 Rad/s namely Test A and B) and two models with higher (13.83 and 27.64 Rad/s namely Test C and D). By using Equation 2 the $\omega 2$ expressions have been derived as reported in Table 2.

Table 2: Details of the simulations performed

Test	Driver Roll Angular Velocity Rad/s $\omega 2$	Ring Angular Velocity Rad/s $\omega 1$
Standard Configuration	3.35	$\frac{2391.9}{0.3285t^2 + 1.6768t + 258}$
New Configuration	$0.0042t^2 + 0.0217t + 3.3496$	9.27
Test A	$0.0012t^2 + 0.0064t + 0.9998$	2.77
Test B	$0.0031t^2 + 0.0162t + 2.4968$	6.91
Test C	$0.0063t^2 + 0.0324t + 4.9973$	13.83
Test D	$0.0127t^2 + 0.0649t + 9.9875$	27.64

For evaluating the rings quality, often geometrical comparisons between the external diameters, heights and widths were performed. The fishtail defect, defined as the difference between the maximum and minimum ring height in correspondence of the Idle and Driver rolls was measured too. The physical parameters were analyzed taking into account the maximum Idle, Axial loads and the Driver Roll torque and the power reached during the deformation. The Idle and Axial energy required to carry out the process were also considered.

3 Finite Element results

All the FEM investigated parameters were analized in order to identify the optimal speed law in terms of both the final geometry of the ring and the production forces. In particular, Table 3 shows the geometry of the ring obtained at the end of each Test, while Table 4 reports the phisical parameters. Since the FEM software considers a constant volume of the ring, the external diameter is always (except for Test A in which the resulting ring has a non homogeneus geometry) bigger than the one obtained in the industrial process. This can be explained considering the material lost during the actual process due to oxidation of the external surface of the ring. For this reason, the quality of the final geometry of the ring was considered in terms of the dispersion of the geometrical parameters H and W (σ_H and σ_W). The related fishtail defect was analized too.

Table 3: Geometrical results

Test	D_{ext} [mm]	H [mm]	σ_H	W[mm]	σ_W	Fishtail [mm]
Test A	347.86	28.66	1.014	55.20	1.396	1.88
Test B	377.51	27.89	0.519	54.38	0.462	0.99
Test C	380.94	27.54	0.234	54.04	0.149	0.55
Test D	383.66	27.40	0.127	53.88	0.051	0.43
Standard Configuration	378.01	27.86	0.483	54.475	0.631	0.86
New Configuration	378.01	27.65	0.301	54.14	0.181	0.56

Table 4: Physical results

Test	Idle_F_{MAX} [N]	Idle_Energy [J]	Axial_ F_{MAX} [N]	Axial_Energy [J]	Torque [N*mm]	Power [W]
Test A	1.00E+05	7.75E+05	2.09E+05	1.52E+06	1.26E+07	1.68E+07
Test B	8.73E+04	7.27E+05	1.97E+05	1.38E+06	9.19E+06	2.96E+07
Test C	7.63E+04	6.18E+05	1.57E+05	1.37E+06	4.98E+06	3.56E+07
Test D	7.40E+04	4.96E+05	1.70E+05	1.32E+06	3.92E+06	4.97E+07
Standard Configuration	8.93E+04	6.91E+05	1.88E+05	1.46E+06	8.09E+06	2.71E+07
New Configuration	8.76E+04	6.29E+05	1.81E+05	1.37E+06	7.35E+06	2.98E+07

Results show that the New Configuration produces a ring with better geometry compared to the Standard Configuration. In particular, the dispersion of the height (σ_H) and the width (σ_W) of the ring is reduced. Tests A and B produce a geometry of the ring characterized by higher dispersion of the data compared to the New Configuration suggesting that an angular velocity of the ring lower than 7 Rad/s is not enough for a correct ring milling. On the other hand, Tests C and D result in a lower standard deviation values of both height and width of the ring compared to the other Tests. In particular Test D is the best configuration assuming the more homogenous ring. Concerning the physical parameters, comparing Standard and New Configurations, it is evident that the maximum forces and energies on the Idle Roll, Axial Roll and on the Torque of the Driver Roll decrease in comparison with the Standard Configuration. Considering the others Tests, it is possible to see how increasing the angular velocity of the Driver Roll leads to a reduction of the forces and energies acting on the rolls, although there is an increasing in the power spent by the Driver Roll. Figure 6 reports the comparison between the fishtail defect for the Standard Configuration and Test D. It is possible to verify that Test D results in a reduction of the defect of 50%

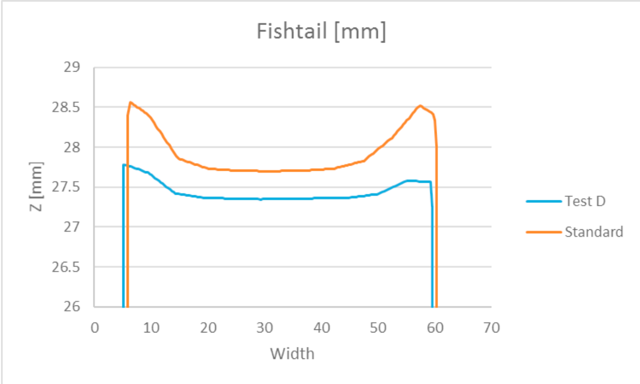


Fig.4. Fishtail defect in Test D and Standard Configuration

4 Conclusions

The aim of this work was to investigate the influence of different non-constant Driver Roll rotation laws on the Ring Rolling process. In a Standard Configuration of the process, the angular velocity of the Driver Roll is set as constant causing the decrease of the angular velocity of the ring. This effect leads to the generation of local geometrical defects as the fishtail artifact and a high deviation of the heights and the widths of the produced rings.

To overcome this limitation, a finite element model has been used to verify if a constant angular velocity of the ring can generate benefits in terms of final geometry of the ring and forces generated on the milling plant. Five different rotational speeds have been considered to analyze their effect on the produced ring. The results showed that the New Configuration is able to reduce both the deviation of the geometrical data (σ_H and σ_W) and the fishtail defect (reduction of 35 %) compared to the Standard Configuration. Moreover, an angular velocity of the ring lower than 7 Rad/s is not enough for a correct ring milling. On the other hand, an angular velocity of the Driver Roll of 10 Rad/s can lead to a more homogenous geometry of the ring and a reduction of the forces and energies acting on the rolls. In conclusion, the proposed finite element model can be used to identify the optimal configuration of a Ring Rolling process that ensures low deviations of the geometrical parameters with an optimization of the forces acting on the milling plant with 2 variable Driver roll angular speeds.

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