Design and Fabrication of Profiled Ring

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ABSTRACT

Bearing outer rings are aimed to be produced by profiled ring rolling instead of turning. Bearing rings produced by profiled ring rolling as a cold metal forming operation, is anticipated to have longer fatigue life. Material hardness, resistance to dynamic loading and surface quality are good advantages for cold formed products. These advantages shall lead to longer life for bearings. Application of cold roll forming to the final shaped product includes studies such as creation of simplified simulation models, making three dimensional simulations and experiments to verify the results. A detail of the bearing ring is a challenging process to be directly filled by workpiece during rolling. Therefore, a special shaped perform is needed for each final product. This perform shape is to be manufactured by turning by shape and dimensions acquired from trials made with simulation models. Production of full profiled bearing rings will be an original

production method. A significant advantage of parts produced by this metal rolling process is that the forming of the material will impart the ring with a grain orientation that gives it enhanced strength relative to most applications
Keywords: Finite Element Method, Profiled Ring Rolling, Bearing, Metal Forming

1. INTRODUCTION

Ring rolling is a particular category of metal rolling, in which a ring of smaller diameter is rolled into a precise ring of larger diameter and a reduced cross section.

This is accomplished by the use of two rollers; one driven and one idle, acting on either side of the ring's cross section. Edging rollers are typically used during industrial metal rolling manufacture, to ensure that the part will maintain a constant width throughout the forming operation. The work will essentially retain the same volume; therefore the geometric reduction in thickness will be compensated for entirely by an increase in the ring's diameter. Rings manufactured by ring rolling are seamless. This forming process can be used to manufacture not only flat rings, but rings of differently shaped cross sections as well, producing very precise parts with little waste of material.

Ring rolling is a specialized type of metal forming operation, which reduces the thickness (cross section) and enlarges the diameter (circumference) of the work piece by a squeezing action as it passes between two rotating rolls. The ring rolling process is widely used to produce seamless rings with outer diameters ranging from 100 millimeters all the way up to 8 meters with cold or hot work pieces. These rings are commonly used as flanges, pipe flanges, ring gears, structural rings, gas-turbine rings etc. Titanium and super alloy rings are used as housing parts for jet engines in the aerospace industry. Advantages of the process include the attainment of uniform quality, smooth surface finish, close tolerance, short production time and relatively small material loss, especially for rings of complex profiles. There are, however, certain disadvantages in this process compared to the forging process. For example, ring rolling is poor in adequate filling the roll cavities, especially when they are too deep. This is due to the fact that during the ring rolling process the reduction in the cross-section of the ring tends to enlarge the diameter of the ring, instead of forcing the material to fill the roll cavities.

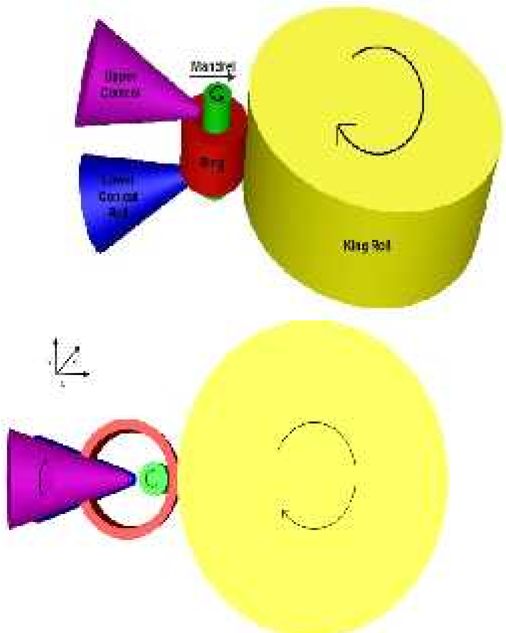

Figure: 1. (a) 3-D View of Ring Rolling Process, (b) Schematic View of Ring Rolling Process

1.1. General Overview of Rolling Mills

Most technically used basic metals (iron, aluminium, magnesium, titanium) and most alloying elements (silicon, manganese, chromium, nickel, molybdenum, tungsten …) are found in nature in a chemical stable form as ore (oxides or other chemical compounds, only carbon is found in a pure state as coal or as carbon hydrides). Only precious metals such as gold are found in nature as pure metal.

To acquire technically useful metals and their alloys ore has to be reduced (and alloyed) and primarily shaped by casting or sintering. These processes are suitable only for achieving an almost finished shape for "small" compact parts. For other products the primarily shaped metal needs secondary forming: forging and in case one dimension of the product is very much bigger than the others, then the secondary forming is done in a rolling machine, a rolling mill with cylindrical tools, the rolls.

While casting and forging are old technologies going back more than 3 000 years, rolling assumed major importance in the industrialized world during the 19th century. Initially steel was the only product to be rolled to profiles (rails, beams, channels, rounds) but since about 1930 flat products (sheet and strip) have become increasingly dominant. Profiles and flats are hot rolled (the latter to a minimum size). Thin flat products are finished by cold rolling for various reasons, e.g. to achieve a better shape and profile, because of mechanical properties, surface conditions, etc.

1.2. Historical Development of Rolling Mills

Leonardo da Vinci invented the first rolling mill but a few centuries passed before rolling mills became important for the steel industry in the 19th century. Initially more long products than sheet were rolled; today the opposite is true.

Mass production of flat products, "hot strip mills", were developed in America in the first half of the 20th century and became widespread throughout the world after the Second World War. To produce flat steel more efficiently and economically some major developments dramatically changed the manufacturing technology. The goal was and continues to be the reduction of energy, man power, financial investment, etc., thereby lowering production costs but at the same time increasing yield (relation of weight of good finished strip to weight of material before rolling) and strip quality.

2. HISTORICAL DEVELOPMENT OF MATERIALS USED IN ROLLING MILLS

In the 19th century basically unalloyed grey iron - modified only by various carbon equivalents and different cooling rates (grey iron chill moulds, or sand moulds) - and forged steel was used for rolls.

The cast iron grades varied from "mild - hard", to "half - hard", to "clear chill", where the barrel showed a white iron layer (free of graphite) and grey iron core and necks due to reduced cooling rate; this type of roll was used for flat rolling without any roll cooling in "sheet mills", as long "sheet - mills" existed (end of 20th century). Later on cast steel rolls were developed with carbon content up to 2.4 %, with and without graphite, and are still produced today.

Around 1930 "Indefinite Chill Double Poured (ICDP)" rolls were invented for hot rolling, especially for work rolls in finishing mills of hot strip mills, which were also used for many other applications such as roughing stands of hot strip mills and work rolls in plate mills. This grade was to become the world standard for many years with very limited variations. Until today no other material could replace this grade for some applications. In the late 1990s finally ICDP enhanced with carbide improved roll performance and started a new phase for this old grade, still successfully in use today in work rolls for early finishing stands of finishing hot strip mills (replacing high chromium iron and HSS - see further down) and for plate mills.

2.1. Metal Forming Processes According To Operating Temperature

- COLD FORMING $T < 0.3*T_m$
- WARM FORMING $0.3*T_m < T < 0.5*T_m$
- HOT FORMING $0.5*T_m < T < 0.75*T_m$

Cold Forming, is a metal deformation process performed at room temperature namely below the melting and recrystallization temperature. Advantages are dimensional accuracy, better surface finish, high strength and hardness of the finished part. Whereas; there is need for higher forces and power in addition sometimes annealing before process.

3. RING ROLLING DEFINITION AS A METAL FORMING PROCESS

Ring rolling is a metal forming process that is being used for ring shaped industrial parts' production. Rolling processes generally involve area of the cross-section decrease while the total length of the product increases. Flat rolling processes need subsequent operations to obtain desired cross-sections after rolling process. In ring rolling process, as similar to the native rolling process, there is cross-section shrinkage and also increase in length resulting diameter enlargement in a ring.

As blank material, there is a ring; that normally has a constant cross-section around whole circumference. This cross section is also generally symmetric about the axial central plane. For specific final shapes forming cases, this initial cross-section might have special edge profile. In Figure 2, representation of blank ring and rolled workpiece is given. In ring rolling process, a ring blank is squeezed between two cylinders, one or two of which are rotated at the same time. A smaller cylinder is placed inside the workpiece ring. That means the diameter of the small cylinder should be smaller than the hole diameter of the initial blank ring. Another large diameter cylinder is placed at the axes of the blank ring and smaller diameter cylinders are in parallel while positioned at the same line. These two smaller and large diameter cylinder shaped tools used in the process are called as mandrel and form, respectively. Rolling relatively light pieces requires one large cylinder is rotated and the other is rotated by the effect of the workpiece. Whereas, larger diameter and heavier workpieces require both cylinders are rotated at the same time. Figure * dictates the rolling process with roll tools' movements.

Figure 2 Final ring workpiece (right) rolled from the blank ring (left)

3.1. Aim and Scope of the Study

Work in this research aims to apply profiled ring rolling in the production of bearing rings. Application of profiled ring rolling comprises near net shape forming. Therefore, forming tolerances are required to be compatible with machining (turning) process tolerances. This issue requires the blank material tolerances to be tighter than the final requirements. Conventional production of bearing rings include flat ring rolling and then turning of the details that include bearing raceway and seal groove. Raceway and seal groove with all the surfaces turned during the process cuts off 60% of the material. This huge amount of material loss should be somehow eliminated. Therefore, main investigation results should look for both improvement in quality and reduction in cost.

4. LITERATURE SURVEY

4.1. General Information on Profiled Ring Rolling

This chapter gives information about ring rolling for both modeling and application areas. Investigation subjects can be listed as; products manufactured by ring rolling, tools used, manufacturing technology by ring rolling, imperfection occurring, modeling techniques, possible results obtained from models, process design and parameter definitions.

Ring rolling technology was invented in Britain for producing railway wheels. Later, seamless ring producers applied the process to more kinds of products such as bearing rings.

Technique in the process is squeezing the ring in radial direction by decreasing gap between roll shaping tools as seen in Figure 5. Other selective tools are guide rolls and axial rolls. Guide rolls control the circularity and axial rolls control the ring height during the rolling process.

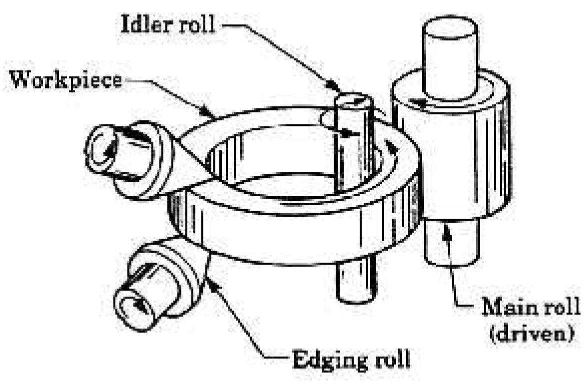

Figure 5 Schematic of a radial-axial ring rolling mill

Authors mention about their research to verify comparison of product fatigue life between metal formed and machined bearing rings. They claim that bearing service life is improved by a factor of two in profiled ring rolled part. They state the reason as streamline layout differences in the final product. During turning the raceway, streamlines are being cut where in opposition to that profiled ring rolling helps to make streamlines positioned along the edge of the raceway resulting in anti-corrosion effect and fatigue life improvement with the aid of contact fatigue strength increase.

5. PROBLEM DESCRIPTION

This chapter gives information about general metal forming processes and the specific cold ring roll forming process, process parameters, tools used in the process and ring rolling applied product types with examples. Deformation characteristics such as shape of the deformation zone and affecting parameters are defined. General information about the ring rolling equipment's is also provided.

5.1. Process Parameters

Characteristic parameters in ring rolling process are listed below;

1. Profile of the form roll and mandrel
2. Rolling ratio
3. Rotation speed of the ring
4. Feed rate of the form roll
5. Material flow (shape of deformation zone)
6. Rolling force and torque
7. Pressure distribution between workpiece and tools.
8. Lubrication and friction between contacting surfaces.

6. NUMERICAL MODELING OF RING ROLLING PROCESS

6.1. Force equilibrium: The sum of forces exerted by all members that meet at a joint balance the external force applied to that joint.

$$\begin{bmatrix} f_{x1} \\ f_{y1} \\ f_{x2} \\ f_{y2} \\ f_{x3} \\ f_{y3} \end{bmatrix} = \begin{bmatrix} K_{x1x1} & K_{x1y1} & K_{x1x2} & K_{x1y2} & K_{x1x3} & K_{x1y3} \\ K_{y1x1} & K_{y1y1} & K_{y1x2} & K_{y1y2} & K_{y1x3} & K_{y1y3} \\ K_{x2x1} & K_{x2y1} & K_{x2x2} & K_{x2y2} & K_{x2x3} & K_{x2y3} \\ K_{y2x1} & K_{y2y1} & K_{y2x2} & K_{y2y2} & K_{y2x3} & K_{y2y3} \\ K_{x3x1} & K_{x3y1} & K_{x3x2} & K_{x3y2} & K_{x3x3} & K_{x3y3} \\ K_{y3x1} & K_{y3y1} & K_{y3x2} & K_{y3y2} & K_{y3x3} & K_{y3y3} \end{bmatrix} \begin{bmatrix} u_{x1} \\ u_{y1} \\ u_{x2} \\ u_{y2} \\ u_{x3} \\ u_{y3} \end{bmatrix}$$

F=K x U

K is defined as stiffness of the system, U is defined as displacement at nodal points that occurs due to applied force and F is defined as applied force on the system.

6.2. Metal forming and finite element analysis

1. Material flow during embodiment of the part.
2. Stress and strain values in the deforming material.
3. Forming force variations of the tools with respect to movements and process time.
4. Frictional forces over the tool surfaces.
5. Normal stresses (pressures) affecting on the tools giving clues about tool life.

6.3. Axisymmetric Finite Element Model of Ring Rolling

Profiled ring rolling process parameters

Volume Constancy Model:

$$\pi(R^2 - r^2) = Constant$$

$$(R + r)(R - r) - R_0^2 - r_0^2$$

$$R \quad r - h$$

$$R + r \quad \frac{R_0^2 - r_0^2}{h}$$

$$r - R \quad h \rightarrow R + R - \frac{R_0^2 - r_0^2}{h} + h - D$$

$$R \quad r + h \rightarrow r + r \quad \frac{R_0^2 - r_0^2}{h} \quad h \quad d$$

$$R = h + r$$

Note:

D: Ring outer diameter [mm]
d: Ring inner diameter [mm]
R: Half of the outer diameter of the ring [mm]
r: Half of the inner diameter of the ring [mm]
h: Ring thickness along the cross-section [mm]

6.4. Mathematical Modeling Steps for Axisymmetric Analysis

1. Values of inner and outer diameters calculated from volume constancy model based on flat ring rolling.
2. Determination of the shift amount at outer surface contact between form and ring work piece.
3. Modify ring thickness values (increase) and accordingly calculate ring inner/outer diameter values based on h.
4. Change ring outer diameters by recalculating with instantenous values of ring inner diameter and thickness.

DISCUSSION AND CONCLUSIONS

Metal forming process is nonlinear due to its nature. It has large displacements. It has nonlinear stress-strain relationship due to plasticity with elastic effects. It has changing contact conditions due to tool-work piece interfaces. Cold metal forming gives us a benefit in terms of static and dynamic strength increase. Therefore, crack forming is impeded.

Results of this research study can be listed as following;

Physical Property	Value
Blank Ring Inner Radius (r)	21.8 mm
Blank Ring Outer Radius (R)	29.68 mm
Blank Ring Thickness	7.88 mm
Formed Ring Thickness	4.36 mm
Mandrel Outer Radius	15.75 mm
Mandrel Center Coordinate	6.05 mm
Form Outer Radius	87.50 mm
Form Center Coordinate	122.18 mm
Form Roll Rotation Speed	13.3 rad/sec
Process Rolling Time	**~6 seconds**

1. Costly and time consuming trial and error process could be accomplished by simulation studies in computer with a faster succesion.
2. All dimensions and tolerances will be obtained by cold ring roll forming

instead of manufacturing by ongoing machining (turning) process.

3. Material saving and increased turnout will be obtained.
4. New technology about simulation of cold metal forming will be produced.
5. Working life of the produced bearing shall improve by the effect of ring rolling process.

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