“FULL AUTOMATIC VERTICAL RING ROLLING MILL (VRRM) FOR ROLLING RINGS WITH PROFILED CROSS SECTION”
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Abstract
In recent years, the demands for the near-net-shaped rings, nearer to the product ring shapes, are increasing, in response to save energy and to improve cost-competitiveness.

MNM focused on the vertical ring rolling mills which are used in some of the bearing manufacturers in Japan, and had completed the fully-automated vertical ring rolling mill for rolling profiled rings. This VRRM is introduced.

1. Vertical Ring Rolling Mill
Vertical Ring Rolling Mill, or VRRM for short, being discussed here, was a machine that was developed in Japan some decades ago, and had a ring-forming roll configuration which was different from the one that is seen with the currently-conventional horizontal (radial/axial) type ring rolling mill. Fig. 1-1 shows the roll configuration of a horizontal ring rolling mill.

A horizontal ring rolling mill rolls a ring in radial direction, with a mandrel that contacts the inner diameter of the ring pressing the ring wall at a certain rolling force and speed toward the driven main roll that contacts the outer diameter of the ring. Rolling shall also be made by the driven axial rolls (motor-driven on upper axial roll only, or on both upper and lower axial rolls) in the ring height direction. Centering rolls help maintain the smooth rolling of the ring, enhancing the roundness accuracy of the ring. Mandrel and centering rolls shall make idle rotations via the ring that is being rolled.

The roll configuration of VRRM is, as shown by Fig. 1-2, made up with a pair of main rolls, one mandrel and a set of several restraining rolls. Main rolls are set to the two main axles which are inclined by $20^\circ$ - $30^\circ$ from the horizontal positions, and respectively motor-driven for rotation. It has been made possible to shift the cases that mount the main axles to the horizontal positions so that the rolling position can be adjusted. The pair of main rolls is so designed that, by the combination of their shapes, the ring’s cross section shall be formed, and that the ring’s outer diameter and widths shall be restrained. The mandrel is mounted on the lifting frame, which is hydraulically lifted up by operator-control, to press the ring in the wall direction. The mandrel shall be idle-driven via the ring being rolled. Several restraining rolls are arranged at the positions to meet
the final ring outer diameter, to secure the roundness in the final forming process of the rolling. In order to set the positions of the restraining rolls, a gauge ring to match the final shape of the product ring shall be required.

The main characteristic of the VRRM is that the main rolls are mounted at the inclined positions from the horizontal positions. Fig. 1-3 shows the relation between the main rolls and the ring as to the VRRM rolling cross section.

Fig. 1-3 Relation of rolling force

As the main rolls are mounted on the main axles which are inclined from the horizontal positions, the pressing force in Y axis direction by the mandrel, the rolling force in Z axis direction by the motor-driven main rolls, and the pressing force in X axis direction are continuously applied to the rolled ring.

The pressing force in X axis direction shall not be generated when the main axles are in the horizontal positions.

With a horizontal ring rolling mill, between the main roll and the mandrel, the ring is formed mainly in the radial direction, and the forming of the cross section is not much expected, as the continuous pressing force would not be applied in the width (or height) direction, unlike the case with the VRRM.

However, with the VRRM, the continuous pressing force in the X axis direction will lead to the advanced cross section formability, and it is believed that the rolling of the contoured cross section rings is possible. Also, as mentioned, as the several restraining rolls will work to correct the ring in the final process of rolling, the rolling with higher accuracy is possible.

2. Trend of market and needs to automatize

As the demands for forged rings with contoured cross sections for wind power, industrial machinery and construction machinery are on increase, it is desired that the technology of high-accuracy near-net shape rolling of such rings is developed. Such near-net shape rolled rings with contoured shapes would, while improving the productivity, reduce the material input weight and number of post-rolling man-hours for machining and assembly, leading to the great reduction of the costs and to the enhanced competitiveness.

Also, the effects of great improvement on the material yield and the reduction of amount of machining are believed to consequently reduce the amount of CO2 emission in rolling production process. It is hoped that this will be a technology to solve environmental issues such as global warming.

Horizontal (radial-axial type) ring rolling mills which are de facto standard of today are improving the productivity as the computer-controlled automatic operating type machines that utilize hydraulic servo control and variable motor control are becoming more common.

Horizontal ring rolling mills, however, use only one main roll, and there are many issues against improvements of forming flexibility and accuracy, requiring multi-process using plural of rolls for rolling of rings with contoured cross sections. This means that several roll-exchanges and re-heating process on the ring workpiece will be necessary.

This made us to turn our attention to vertical ring rolling mill which was developed in Japan and assumed to be better in forming the rings with contoured cross sections than horizontal ring rolling mills in comparison.

However, ring rolling with the then-and-now-operating vertical ring rolling mills heavily depended on the instincts and experiences of the skilled workers, and could be operated by specific users only. Our working purposes were to complete
automatization of this machine and to make it usable by wide range of users.

Fig. 2-1 shows the representative ring shapes rolled by this machine. These ring shapes are the ones that would be difficult to perform near-net shape forming in rolling with horizontal ring rolling mills.

Also, table 2-1 shows the examples of reductions in materials, machining and costs per respective ring shapes (in comparison with rectangular cross shaped rings).

<table>
<thead>
<tr>
<th>Ring shape</th>
<th>Material reduction</th>
<th>Mach-hour reduction</th>
<th>Cost reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stepped ring</td>
<td>60%</td>
<td>40%</td>
<td>30%</td>
</tr>
<tr>
<td>H/D&gt;1 ring</td>
<td>50%</td>
<td>30%</td>
<td>20%</td>
</tr>
<tr>
<td>Thin ring</td>
<td>50%</td>
<td>30%</td>
<td>20%</td>
</tr>
<tr>
<td>Contoured outer diameter ring</td>
<td>25%</td>
<td>33%</td>
<td>20%</td>
</tr>
<tr>
<td>Tapered ring</td>
<td>60%</td>
<td>40%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Fig. 2-1 Example of ring shape

Table 2-1 Example of material reduction

3. Automatization mechanism and control

For forming of rings with contoured cross sections, vertical ring rolling mill has two main rolls, one mandrel and several restraining rolls. These rolls have shapes formed on them to match the final product ring shape. This means that it would be necessary to change the rolls with the ones to meet the respective workpieces. In ring rolling, all its operations depended heavily on the skilled workers’ instincts and experiences. And, on respective units such as hydraulic unit, there were no sensors attached to pick-up such data as positions and pressures, and analysis and verification of the rolling conditions could not be made.

As such, with manual type vertical ring mills, all processes including preparations prior to rolling had to be operated manually by skilled workers, and there were such problems as the variability in rolling and the difficulty to pass the skills to the next generations. Also, as the demands for the highly accurate near-net shape rolled rings are increased, formulation of high level rolling know-how would present itself as a problem.

Based upon such issues with the manual-type vertical ring rolling mills, we had developed an automatized Vertical Ring Rolling Mill. Its mechanical construction and contents of control are described.

Table 3-1 shows the main specification of VRRM, and Fig. 3-1 shows the overall appearance of the machine.

Table 3-1 Specification of VRRM

<table>
<thead>
<tr>
<th>Forming capacity</th>
<th>Product ring weight</th>
<th>Max. 100kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product ring outer diameter</td>
<td>Min. 150mm</td>
<td>Max. 550mm</td>
</tr>
<tr>
<td>Product ring height (width)</td>
<td>Max. 250mm</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rolling force</th>
<th>Vertical</th>
<th>Max. 50Ton</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Driving force</th>
<th>Motor for right main roll</th>
<th>AC440V, 75KW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor for left main roll</td>
<td>AC440V, 75KW, Inverter</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3-1 Overview of VRRM
Table 3-2 Mechanical comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Automatic type</th>
<th>Manual type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll configuration</td>
<td>Same as manual type</td>
<td>—</td>
</tr>
<tr>
<td>Mani roll drive mechanism</td>
<td>One motor + one reducer on each main rolls (right/left)</td>
<td>One motor + one two-shaft reducer</td>
</tr>
<tr>
<td>Hydraulic unit for pressurized cylinder</td>
<td>Servo valve for flow control and proportional valve for pressure control are used.</td>
<td>Proportional valve for pressure control only.</td>
</tr>
<tr>
<td>Position sensor for pressurized cylinder</td>
<td>Applied</td>
<td>None</td>
</tr>
<tr>
<td>Restraining rolls position adjustment mechanism</td>
<td>Position adjusting mechanism by hydraulic drive</td>
<td>Adjustment by worker (no hydraulic drive)</td>
</tr>
<tr>
<td>Restraining roll position sensor</td>
<td>Applied</td>
<td>None</td>
</tr>
<tr>
<td>Main roll position adjustment mechanism</td>
<td>Position adjusting mechanism by geared motor</td>
<td>Adjustment by worker (no hydraulic drive or motor drive)</td>
</tr>
<tr>
<td>Main roll position sensor</td>
<td>Applied</td>
<td>None</td>
</tr>
<tr>
<td>Ring outer diameter measuring mechanism</td>
<td>Contact-type outer diameter measuring mechanism by hydraulic drive</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 3-3 Control comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Automatic type</th>
<th>Manual type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respective roll position setting</td>
<td>Automatic adjustment by computing the input values</td>
<td>Manual adjustment by worker using gauge ring</td>
</tr>
<tr>
<td>Measurement of ring outer diameter</td>
<td>Real-time measuring of outer diameter, it is possible to use for automatic control</td>
<td>Judgment to tell if the ring had reached the finish diameter or not is difficult to make. (Dependent on the worker’s skill)</td>
</tr>
<tr>
<td>Pressurized cylinder control</td>
<td>Control of feedback speed and position by using serve valve</td>
<td>Manual operation by worker</td>
</tr>
<tr>
<td>Rolling setting</td>
<td>Automatic rolling setting or rolling setting by data input are possible</td>
<td>Dependent on the operator’s skill each time</td>
</tr>
<tr>
<td>Rolling setting saving function</td>
<td>Saving of rolling setting is possible</td>
<td>Repeatability is erratic</td>
</tr>
<tr>
<td>Data sampling function</td>
<td>Condition monitor and trend graphs are used</td>
<td>Data sampling not possible</td>
</tr>
<tr>
<td>Main roll motor rpm control</td>
<td>Rpm of one of the main rolls variable and controlled</td>
<td>Right/left main rolls rotate uniformly</td>
</tr>
</tbody>
</table>

Table 3-2 shows the comparison as to the main mechanical constructions between VRRM and the manual-type vertical ring rolling mill. Although VRRM’s fundamental mechanical construction is similar to that of the manual-type vertical ring rolling mill, for the purpose of automatization, such changes as the devices other than the pressurized cylinder can shift their positions by using hydraulic or geared motors, and added various sensors have been made.

One of the foremost mechanical difference from the manual-type vertical ring rolling mill is that the ring outer diameter measuring feature had been added. This feature was achieve with one of the several restraining rolls function as the ring outer diameter measuring roll, which will be in constant contact with the ring diameter during ring rolling, unlike the other restraining rolls, and will measure the ring outer diameter. Upon reaching the ring’s final outer diameter position, this roll will automatically be fixed, and will function in the same way as the other restraining rolls will do.

Table 3-3 shows the comparison between VRRM and the manual-type vertical ring rolling mill as to the control automatization, and the details of respective items are explained.

Setting of respective roll positions had used gauge ring each time the rolls were changed, requiring the manpower and worker’s skills in the past. It had been so made that the target positions are automatically computed from the input data such as the roll diameters, and that the rolls would move to the respective positions in automatic preparation mode.

Contact-type ring outer diameter measuring mechanism enables real-time measuring of the ring outer diameter which is used for the control of automatic rolling.
Servo valve is used for pressurized cylinder control, enabling highly accurate control of feedback position and speed.

Ring rolling, in the past, had been manually made, dependent on the skills of the workers, and the repeatability of the ring rolling had been erratic, product varying per individual workers, even if the rings to be rolled were the same. VRRM has been so made that the setting of various rolling patterns either automatically or by data inputting is easy, and that the rolling setting data saved as per the item number can be repeated. In other words, VRRM can make automatic rolling with high repeatability can be made independent of workers’ skills.

![Fig. 3-2 Rolling condition on monitor](image)

![Fig. 3-3 Trend graph](image)

Also, position sensor, pressure sensor and motor ammeter are mounted on respective part of the mill, to display condition monitoring screen (Fig. 3-2) and trend graph (Fig. 3-3), leading to easier investigation of causes of rolling failures and to reduction of troubleshooting time.

The trend graph can be used, not only for failure diagnosis, for the collecting of the detailed rolling data per rolling. This will help in the quantitative analysis and verification of various rolling data, and the formulation of the rolling know-how.

Vertical ring rolling mill can roll asymmetrical ring shapes, as well as symmetrical ring shapes. However, there is an issue that the circumferential velocity difference will be generated between the right/left asymmetricity points. VRRM had dealt with the rolling defects from this circumferential velocity difference issue, by using rpm-variable control driving motor for one of the two main rolls.

4. Optimization of blank shape and ring rolling conditions

Fig. 4-1 shows the manufacturing sequence of contoured cross section ring using VRRM.

![Fig. 4-1 Manufacturing sequence](image)

The manufacturing sequence is basically similar to one that uses horizontal type ring rolling mill for final forming of the contoured cross section rings.

Even in the case that a vertical ring rolling mill is used for final forming, pre-rolling will be required in most cases. Pre-rolling machine can either be horizontal or vertical. The number of pre-rolling processes in the vertical ring rolling mill forming, however, can be less than that in the horizontal ring rolling mill forming, and basically, only one pre-rolling will complete the process. The “blank” shape that was formed in this pre-rolling process would greatly affect the shape-forming and accuracy in the
final forming by VRRM, and it is important to optimize the blank shape.

In the present-day manufacturing process of contoured cross section rings, repeated tests of pre-rolling and final rolling shall be made to determine the optimum roll shapes and blank shapes. Such a series of test-modify-test process needs a lot of time, efforts and costs.

So, in addition to the automatization of vertical ring rolling mill, formulation of a new know-how to optimize the blank shape is required.

Concurrently with the completion of the full-automatic Vertical Ring Rolling Mill, the high-level rolling know-hows, including the optimization of the blank shapes and the ring rolling conditions, have been made, based on the analytical simulation technology on the deformation of contoured cross sectioned rings (Fig. 4-2), and on the results of the simulations. This formulation of rolling know-how by simulations made it possible to reduce the number of test rollings, and reduction of costs for roll repairs, materials, and labor are expected.

The design shape of the final ring was, as shown by Fig. 5-1, contoured on the outer diameter and straight on the inner diameter; a drum-shaped ring, with larger outer diameter $\phi$ 429mm, smaller outer diameter $\phi$ 383mm, inner diameter $\phi$ 316mm, width 220mm and weight around 90kg. This is a shape that a horizontal ring rolling mill would have great difficulty in forming the flange on the large outer diameter.

5. Results of test rolling

Examples of the rolling of contoured cross section ring by VRRM are introduced.

This blank was formed by a horizontal ring rolling mill as the pre-rolling machine.

Fig. 5-3 is showing the rolled ring shape after final rolling by a vertical ring rolling mill. As the forming of the flange on the large outer diameter in the blank forming was insufficient, there was a significant underfill on the flange of the final rolled ring. This indicates that the blank forming by pre-rolling machine would greatly affects the ring
final forming.

Fig. 5-3 Rolled ring 1

◎ Ring rolling from blank type 2

Fig. 5-4 is showing the blank shape type 2. Type 2 blank shape was an optimized one, with simulation analysis based on the results of ring rolling from type 1. The blank forming was made, same as type 1, by a horizontal ring rolling mill.

Fig. 5-4 Blank 2

Fig. 5-5 Result of simulation

Fig. 5-5 is showing the final ring shape from the simulation analysis. This shape generally matches with the final ring design shape. Accordingly, ring rolling of type 2 blank by VRRM was made with the rolling conditions based on the simulation analysis.

Fig. 5-6 is showing the rolled ring shape after final rolling by VRRM.

Fig. 5-6 Rolled ring 2

Fig. 5-7 Achieved accuracy

Fig. 5-7 is showing the measured dimensions (large outer diameter, width, inner diameter) after rolling
and the difference from the final ring design dimensions.

When the final VRRM-formed dimensions and shape are compared with the final ring design, the accuracy is generally within 0.5 mm on the large outer diameter and on the width, and the “R” on the outer diameter nearly matches in shape. It is believed that the differences on the inner diameter are the excess blank material volume that flowed to the side of the inner diameter, as the automatic rolling control is made on the outer diameter side.

Blank weight control is a major issue in the production.

Fig. 5-8 is showing the ring outer diameter growth from the simulation analysis, the actual ring outer diameter growth on VRRM, and rolling force. Although there are some differences, the graph curves of the ring outer diameter growths and the rolling force are generally identical.

![Fig. 5-8 Comparison of rolling data](image)

From these results of rolling, it has been verified that the contoured cross section rolled rings, which had been difficult to do the near-net shape forming with a horizontal ring rolling mill, can be formed on a full-automatic Vertical Ring Rolling Mill.

Also, the effectiveness of the formulation of the rolling know-how, including the optimization of the blank shape and rolling conditions using the simulation analysis, concurrently made along with the VRRM automatization, had been verified.

6. Conclusion

Automation of the machine and the establishment of the new rolling know-how had helped in completion of a machine that would help users in the improvement of the workability, productivity and quality.

Further improvements to provide the machine with advanced functions and the rolling know-hows will be made, and a better equipment will be provided with our confidence.