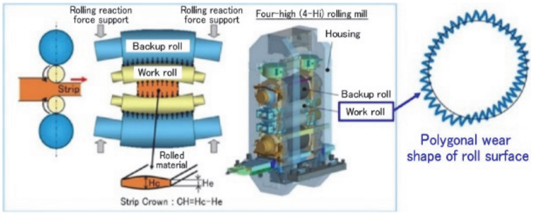
Preventing Polygonal Wear of Work Rolls: Construction of Prediction Model for Coupled Behavior of Mechanism, Vibration and Wear of Rolling Mill



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It is known that the work rolls of rolling mills are subjected to polygonal wear caused by self-excited vibration. To consider countermeasures for this phenomenon, it is necessary to identify the natural frequencies of the rolling mill and evaluate the vibrations during actual operation. Therefore, in this report, to estimate the vibration modes during operation of the rolling mill that lead to polygonal wear of the work rolls, a simulation model was developed coupling Multi-Body Dynamics with rolling theory and a wear model (1). This model is capable of simultaneously evaluating the behavior of the rolling mill during operation and the progress of wear, taking into account the dynamic model of a four-high rolling mill. This has made it possible to identify the vibration modes that cause roll wear and to consider preventive measures such as structural changes and installation of dampers and monitoring sensors.

1. Introduction

The work rolls of rolling mills are subjected to the phenomenon of polygonal wear. Similar occurrences have been observed in other rotating systems, such as railway wheels and automobile tires. Polygonal wear is generated by self-excited vibration caused by a time delay in which wear due to sliding is fed back into the contact force after one revolution. It leads to process instability. Since the occurrence of polygonal wear affects the quality of products after rolling, it is necessary to replace the rolls at timings different from regular maintenance. Because this has a significant impact on the customer's production schedule, it is necessary to identify the natural frequencies of the rolling mill that cause self-excited vibration and prevent polygonal wear.

On the other hand, a rolling mill is a complex system and possesses numerous eigenvalues. Furthermore, since a rolling mill possesses multiple natural frequencies, it is difficult to identify which frequencies are involved in polygonal wear through normal eigenmode analysis alone. To address these issues, a coupled simulation model using Multi Body Dynamics (hereinafter referred to as MBD) was developed. This model integrates the von Karman rolling model and Archard's wear law into the dynamic model of a four-high (4-Hi) rolling mill, making it possible to accurately reproduce actual machine behavior.

2. Analytical model

2.1 MBD model of four-high (4-Hi) rolling mill

Figure 1 shows the configuration of a four-high (4-Hi) rolling mill, which is the subject of this analysis. A 4-Hi rolling mill consists of four rolls, two work rolls for rolling the material and two backup rolls for supporting the rolling reaction force. It is widely used for rolling plate materials such as thick plates and hot- and cold-rolled strips. This study targeted a hot rolling mill.

A high fidelity nonlinear MBD model was created using commercial MBD software (ADAMS). **Figure 2** shows the configuration of the model. The model includes the following elements.

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- Housing: Modeled so that elastic deformation can be simulated by incorporating vibration modes.
- Rolls: Modeled as beam elements based on Timoshenko theory.
- Bearings: Modeled as nonlinear elements considering the clearance between the shaft and bearing, as well as a nonlinear stiffness curve with respect to the load.
- Contact force between rolls: Calculated using the Hertz contact model.
- Hydraulic actuator of the lifting cylinder: Modeled by considering hydraulic spring characteristics and other factors.
- Rolling model: The load acting on the roll bite (the rolls for shaping the material) during rolling is calculated based on the von Karman rolling model (2), which can derive the rolling pressure distribution and rolling load, taking the plastic deformation and friction of the material into account. Specifically, this was implemented by integrating a roll bite calculation tool developed by Mitsubishi Heavy Industries, Ltd. into this MBD model. **Figure 3** shows an illustration of the von Karman rolling model and the results of integration verification with the MBD model using simple geometry.

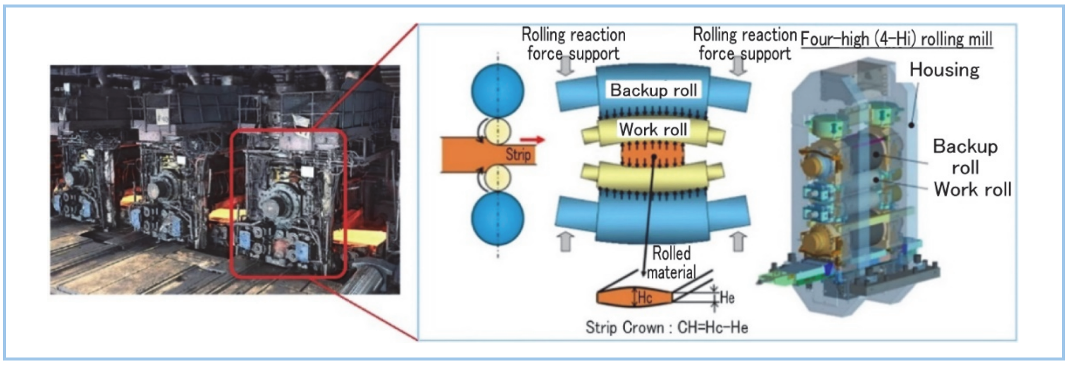


Figure 1 Configuration of four-high (4-Hi) rolling mill

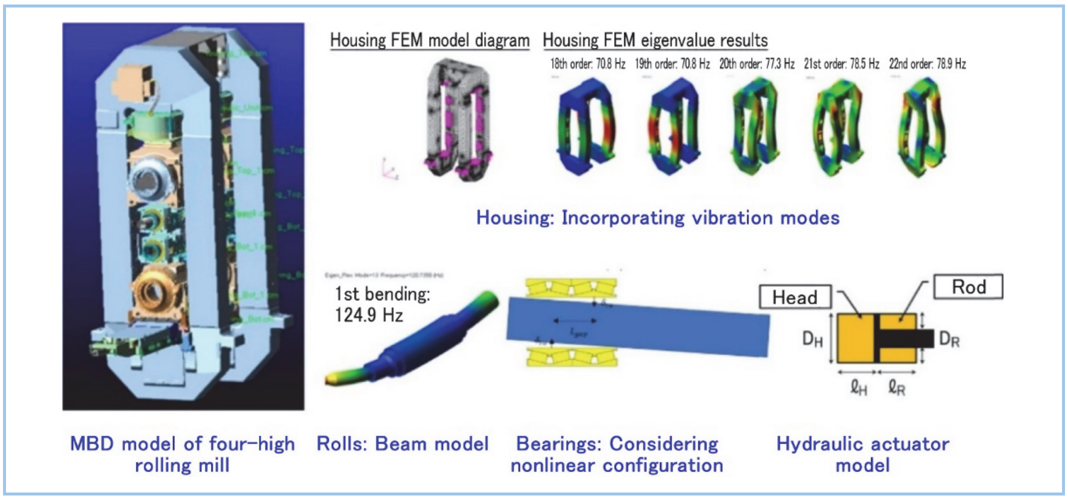


Figure 2 MBD model configuration

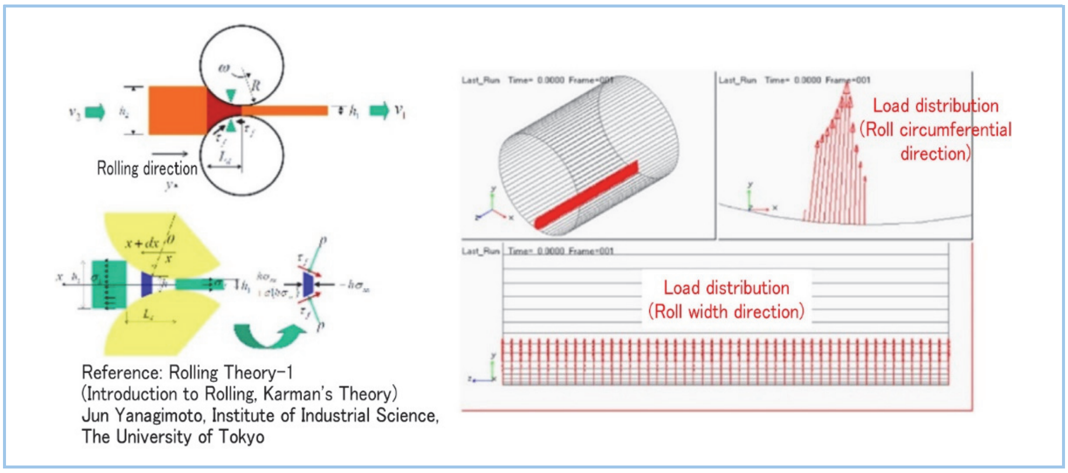
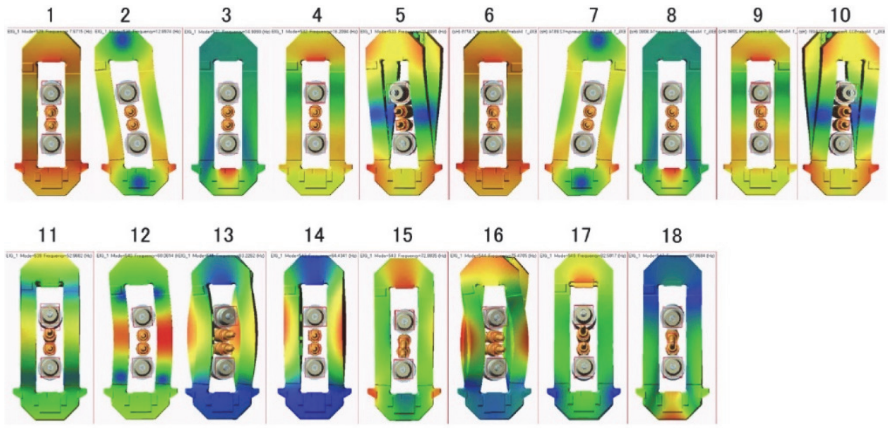


Figure 3 Overview of von Karman rolling model and results of integration into MBD model

2.2 Natural frequency analysis

Natural frequency analysis under rolling conditions was conducted using the model constructed in Section 2.1 to narrow down the target modes for vibration suppression measures. However, because the target rolling mill is a complex system and has numerous eigenvalues, it was difficult to narrow down the modes that cause polygonal wear through this analysis alone. As an example, the natural vibration modes below 100 Hz are shown in **Figure 4**.



No	Hz
1	8.0
2	12.9
3	14.9
4	16.2
5	20.9
6	26.4
7	27.0
8	41.7
9	42.9
10	47.9
11	53.0
12	60.1
13	63.2
14	64.5
15	72.9
16	75.5
17	82.6
18	97.0

Example of eigenmode analysis during rolling (Coupling of MBD model and von Karman rolling model)

Figure 4 Natural frequency analysis results of rolling mill

2.3 Coupled dynamic simulation

Regarding the relationship between the polygonal wear shape and the natural frequency, the following points are known from literature and past findings.

(1) When there is no pressure fluctuation relative to the roll bite, wear is uniform and circular.

(2) When dynamic pressure fluctuations occur due to the vertical vibration of the rolls, polygonal wear is generated, and the number of sides of the polygon depends on the ratio of the vibration frequency to the rotational frequency. The growth conditions for polygonal wear are approximately expressed by the following equation.

$fr \times N \approx fn$

(fr: roll rotational speed, N: number of sides of the polygon, fn: natural frequency)

For this reason, a coupled analysis model capable of predicting the polygonal wear shape was constructed by coupling the model developed in Section 2.1 with Archard's wear law [(3)], and an analysis was conducted to narrow down the target vibration modes from the polygonal wear shape.

3. Analysis results and discussion

3.1 Dynamic wear simulation results

An unsteady rolling analysis was conducted using the coupled MBD model, with the work rolls rotating at a constant speed of 1.5 Hz. As a result, the polygonal wear increased over time and saturated as the roll shape approached a polygon with 40 sides. At this time, it was observed that the work rolls vibrated horizontally while the backup rolls vibrated vertically. The results are shown in **Figure 5**.

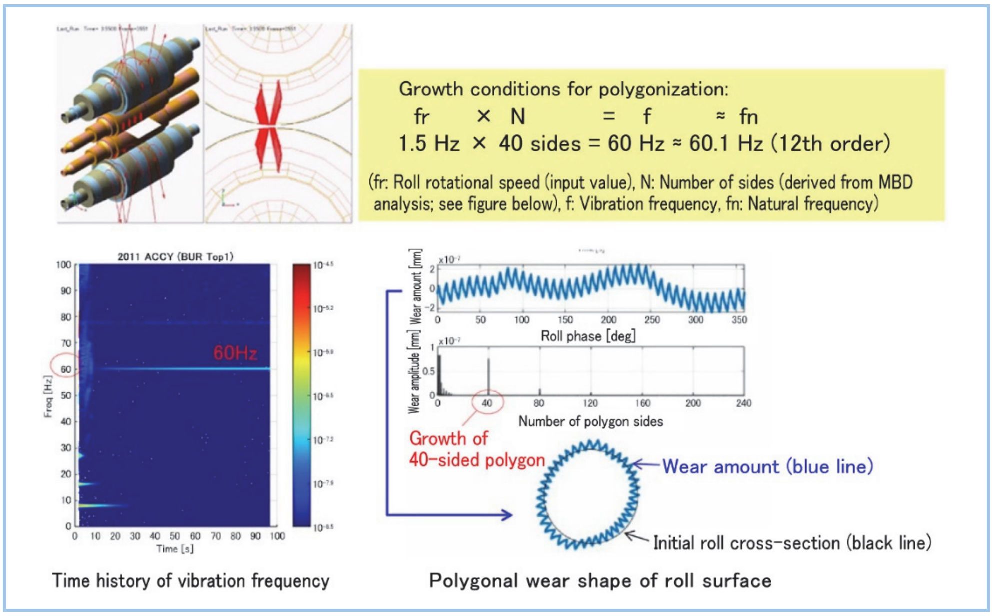


Figure 5 Results of unsteady rolling analysis using MBD rolling mill model

3.2 Mode identification

The following equation is obtained by applying the results from Section 3.1 to the growth conditions for polygonal wear shown in Section 2.3 yields.

fr (1.5 Hz) × N (40 sides) ≈ 60 Hz

By examining the operating mode shape closest to this frequency, it was predicted that the 12th-order mode at approximately 60.1 Hz is the cause of polygonization. The identified natural vibration mode is shown in **Figure 6**. Since this 12th-order assembly mode includes the overall bending mode of the housing in the steel plate rolling direction, vertical load fluctuations and horizontal vibrations occur between the work rolls. These fluctuations cause slipping, which is considered to lead to the occurrence of polygonal wear.

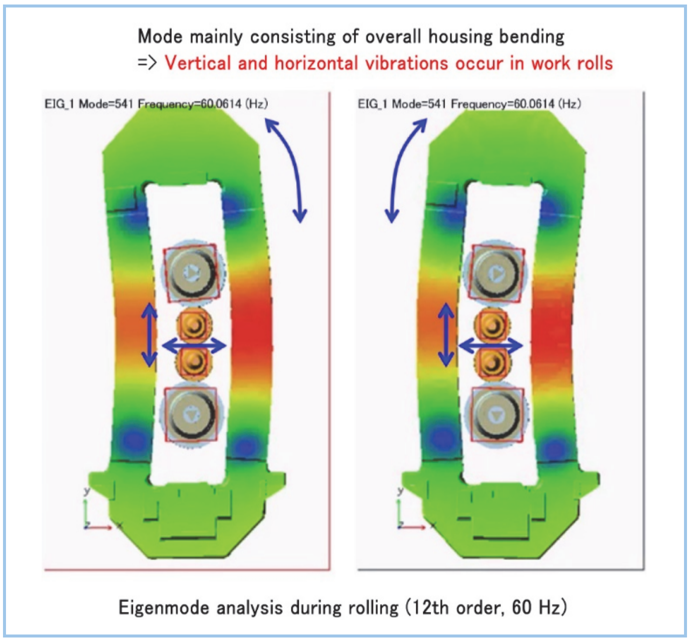


Figure 6 Identification of natural mode causing polygonal wear

3.3 Derivation of countermeasures

Identifying the cause mode through the studies conducted so far clarifies the locations and frequency bands where vibrations are significant. Therefore, it is possible to appropriately take preventive measures, such as structural changes, installation of dampers, or placement of monitoring sensors.

4. Conclusion

Regarding polygonal wear of rolling mill rolls, a sophisticated MBD analysis model has been constructed by coupling the roll specifications (dimensions, shape, mass, and stiffness) and the support mechanism structure's stiffness and vibration characteristics with the von Karman rolling model and Archard's wear law. Through simulations using the constructed model, polygonization was reproduced, and the vibration modes causing polygonization were identified. Consequently, the prospect of devising anti-vibration measures for polygonization has been obtained.

In the future, validation of simulation results and improvement of prediction accuracy are expected to be possible through the measurement of vibration behavior in actual machines and the correlation of the MBD analysis model based on those results. By improving simulation prediction accuracy, it will be possible to consider specific anti-vibration measures (such as investigating damping mechanisms and determining locations for implementing countermeasures); furthermore, by applying the model to other machine types and new designs, it will be possible to propose monitoring systems that enable high-quality product design and the detection of maintenance timing to prevent failures before they occur.

References

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