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Technical Report

Wall Thickness Deviation Control of Mannesmann Mandrel Mill

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Abstract

High wall thickness accuracy of seamless tube and pipe is demanded along the whole length or on the end according to the application. Meanwhile the circumferential wall thickness deviation may cause as various patterns corresponding to each process on seamless tube and pipe manufacturing. It is difficult to clarify each pattern deviation from the measured circumferential wall thickness deviation when various pattern wall thickness deviations are superposed. We developed a method analyzing the circumferential wall thickness deviation pattern by applying Fourier analysis. We also developed a method of compensating a circumferential wall thickness deviation pattern to mandrel mill. Pressing cylinders are controlled individually, an online circumferential wall thickness deviation feedback system based on a wall thickness meter is introduced, and the high wall thickness accuracy is achieved.

1. Introduction

Representative uses of seamless pipe and tube include oil country tubular goods (OCTG) for drilling oil and natural gas; line pipes for transporting oil and natural gas; mechanical pipes such as the cylinder, printing roll, and drive shaft; tubes for boilers and chemical plants; etc.

In general, those pipes and tubes are required to have a high degree of wall thickness accuracy, especially with respect to the deviation of circumferential wall thickness. For example, OCTGs must have a circumferentially uniform wall thickness so that they do not collapse even when they are subjected to high outside pressures deep under the ground or sea. The wall thickness accuracy of the pipes is also important from the standpoint of assuring precise threading at pipe joints. For line pipes, pipes having small wall-thickness deviation are demanded so that they can be precisely welded end to end on the outer and inner surfaces. With respect to mechanical pipes also, their wall thickness accuracy is important, since any pipe used as a rotating body must be free of centroid deviation and any pipe used as a cylinder, etc. is required to have a highly accurate inner diameter, as in the case of line pipes.

On the other hand, in the Mannesmann mandrel mill line, various patterns of wall thickness deviation can occur in each of the mills used in the pipe manufacturing process. They are the eccentric deviation accompanying a longitudinal twist in the piercing mill; the oval or quadrangle deviation depending on the number of rolls in the mandrel mill; and the similar triangle or hexagonal deviation in the sizing mill/stretch reducing mill. Regardless of whether the wall thickness is measured on-line using a thickness meter or the wall thickness of a test-rolled product is measured off-line, the measurement results contain different patterns of deviations that can hardly be separated from one another for identification. Therefore, author et al. developed an analytical technique to determine the mill that causes a specific pattern of wall thickness deviation and the degree of that wall thickness deviation.

In addition, for the wall thickness deviations ascribable to the mandrel mill, author et al. developed a technology to prevent the deviations by independent control of the pressing cylinders and a technology for on-line feedback of deviations utilizing wall thickness meters, thereby attaining a high degree of wall thickness accuracy.

2. Controlled Process

2.1 Seamless pipe manufacturing process[1, 2)]

In this section, we shall explain the Mannesmann mandrel mill line to which our wall thickness deviation control technology has been applied. This pipe manufacturing line is suitable for the mass production of pipes. The billet reheated in the reheating furnace is pierced through by the piercing mill, elongated to the prescribed

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wall thickness by the mandrel mill, and finished to the prescribed outside diameter by the sizing mill/stretch reducing mill (**Fig. 1**).

In the mandrel mill, the main mill for adjusting the pipe wall thickness, the mandrel bar is inserted into the hollow shell that has been pierced through. As the hollow shell passes through multiple stands, its wall thickness is reduced continuously by the caliber rolls and mandrel bar. In a 2-roll mandrel mill which uses two rolls per stand, pairs of odd- and even-numbered stands set at an angle of 90° to each other roll the hollow shell alternately (**Fig. 2**).

2.2 Causes of wall thickness deviations

The patterns of wall thickness deviations that can occur on the pipe manufacturing line shown in Fig. 1 are schematically shown in **Fig. 3**. The causes of wall thickness deviations in the mandrel mill are different from those in the sizing mill/stretch reducing mill. However, as both mills are caliber rolling mills, it has been known that in those mills, wall thickness deviations, whereby the number of thin circumferential parts becomes an integral multiple of the number of rolls per stand, can occur. On the other hand, in the piercing mill (a skew rolling mill), an eccentric wall thickness deviation can occur twisting along the length of the pipe. There are two representative causes of wall thickness deviations that reside in the finished product: uneven heating of the billet in the reheating furnace and misalignment of the mill tools. In general, the angle of twist of wall thickness deviation caused by uneven heating is smaller than that of wall thickness deviation caused by misalignment.

3. Technique to Analyze Wall Thickness Deviations by Cause[3, 4)]

3.1 Analysis of circumferential wall thickness distribution in axial section

When the different patterns of wall thickness deviations shown in Fig. 3 occur at the same time, the circumferential wall thickness distribution becomes as shown in **Fig. 4**. Therefore, it is difficult to determine the individual components of wall thickness deviation from the superposed circumferential wall thickness distribution.

Here, assuming the components of wall thickness deviation shown in Fig. 3 as functions of wall thickness distribution for circumferential angle, they approximately become sine waves having a certain frequency, as shown in **Fig. 5**. Then, by using complex Fourier analysis, the individual components of wall thickness deviation can be broken down into the base components of the Fourier analysis that are primarily independent of and orthogonal to one another,

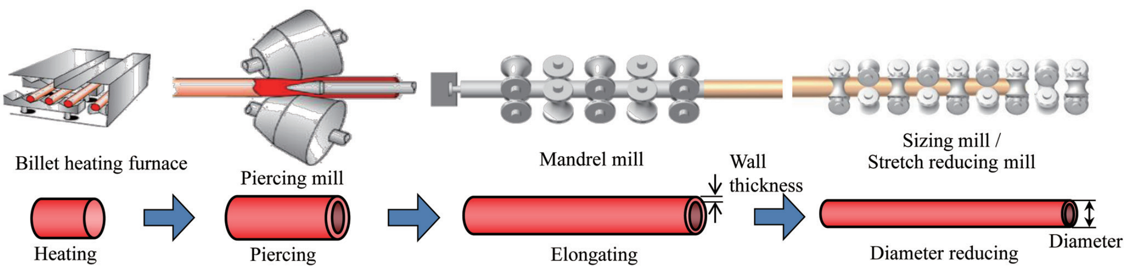

Fig. 1 Schematic of Mannesmann process

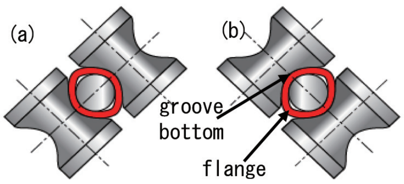

Fig. 2 Schematic of Mandrel mill along cross-section view (a) Odd numbered stand, (b) Even numbered stand

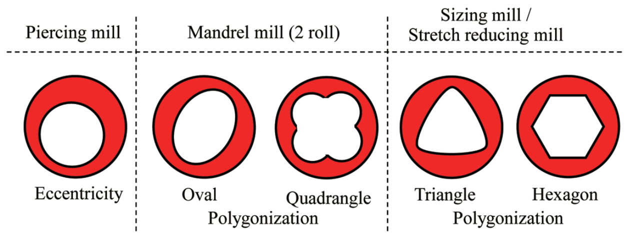

Fig. 3 Circumferential wall thickness deviation pattern on Mannesmann process (shown as emphasized)

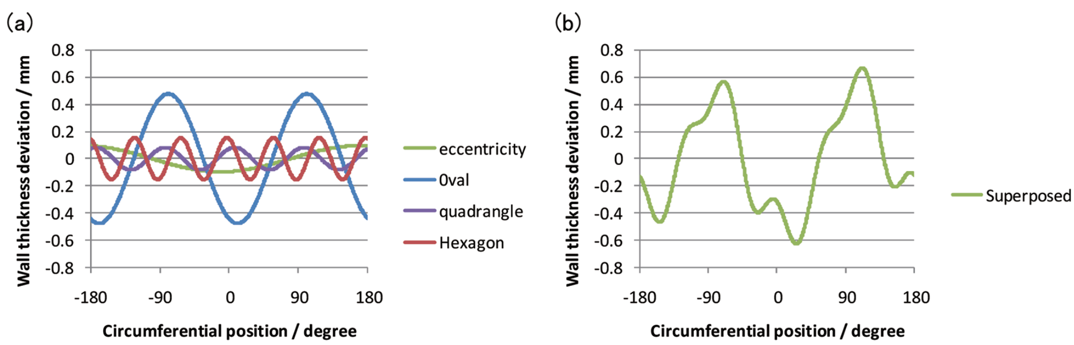

Fig. 4 Circumferential wall thickness deviation example when various patterns are superposed (a) Various patterns, (b) Superposed

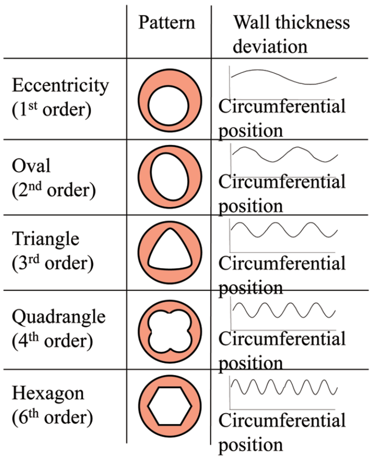

Fig. 5 Relation between circumferential wall thickness deviation pattern and basis function of Fourier analysis

as shown in Equations (1) and (2), respectively.

$$f(\theta) = \sum_k G_k \, \mathrm{e}^{ik\theta} \tag{1}$$

$$G_k = \frac{1}{2\pi}\int_{-\pi}^{\pi} f(\theta)\, \mathrm{e}^{-ik\theta}\, \mathrm{d}\theta \tag{2}$$

In Equations (1) and (2), $f(\theta)$ denotes circumferential wall thickness distribution; θ denotes the circumferential angle; and G_k denotes the component of the k-th ordered wall thickness deviation. Specifically, the amount and direction of each of the components of wall thickness deviation shown in Fig. 3 can be obtained using Equations (3) and (4) using complex Fourier analysis of the wall thickness distribution.

$$g_k = 4\,\|G_k\| \tag{3}$$

$$a_k = \frac{1}{k}\angle G_k \tag{4}$$

where g_k denotes the amount of k-th ordered wall thickness deviation and a_k denotes the angle of direction of thick-walled part of the k-th ordered wall thickness deviation.

When the circumferential wall thickness distribution cannot be measured continuously, it can be obtained by using Equation (5) rather than Equation (2), using discrete Fourier analysis.

$$G_k = \frac{1}{N}\sum_{i=1}^{N} f(i)\, \mathrm{e}^{-ik\frac{2\pi(i-1)}{N}} \tag{5}$$

If the amount and direction of wall thickness deviation occurring in each of the processes can be analyzed as described above, it is possible to prevent the wall thickness deviation by adjusting the equipment parameters in such a way that the wall thickness deviations occurring in the processes are offset.

3.2 Analysis of twisting component of eccentric wall thickness deviation

For the eccentric wall thickness deviation, it is necessary to not only apply an analytical technique for the axial section but also classify angles of longitudinal twist by cause.

For eccentric wall thickness deviations caused by various factors, the position of the center of the pipe inside the diameter of the section at a longitudinal distance x on a complex plane can be expressed by the following Equation (6) using the base function $\mathrm{e}^{i\omega_i x}$ of complex Fourier analysis.

$$-r_i \mathrm{e}^{i(\omega_i x+\delta_i)} = \left(-r_i e^{i\delta_i}\right)\mathrm{e}^{i\omega_i x} \tag{6}$$

where r_i denotes the amount of eccentric wall thickness deviation caused by various factors: $\omega_i x+\delta_i$, the angle of direction of thick-walled part of eccentric wall thickness deviation; ω_i the angle of twist; and δ_i the initial twist.

Specifically, by complex Fourier analysis as the function of longitudinal distance x of the position of pipe inside diameter of the section at x (Equation (7)) using the analysis results of eccentric wall thickness deviations obtained by Equations (1)–(5), it is possible to classify longitudinal twists by cause.

$$-\frac{g_1(x)}{2}\,\mathrm{e}^{ia_1(x)} \tag{7}$$

Thus, author et al. developed an analytical technique to determine the process in which a specific wall thickness deviation has occurred and the degree of the wall thickness deviation.

4. Wall Thickness Control Technology for Mandrel Mill[3, 5)]

4.1 Independent control of pressing cylinders

Author et al. developed technology for preventing second-ordered wall thickness deviations determined by complex Fourier analysis by independently controlling the mandrel mill pressing cylinders (**Fig. 6**).

In the case of the second-ordered wall thickness deviation whereby the roll groove bottom of each stand becomes a thick- or thin-walled part, it can be prevented by increasing the reduction of the rolling stand where the roll groove bottom becomes a thick-walled part in Fig. 6 and by decreasing the reduction of the rolling stand where the roll groove bottom becomes a thin-walled part. Even when the thick-walled part is positioned outside the roll groove bottom, the wall thickness deviation can be prevented by independently controlling the pressing cylinders shown in Fig. 6.[5)]

4.2 On-line feedback control of wall thickness deviation

Author et al. developed technology for feedback control of wall thickness deviation measured on-line by hot wall thickness meters installed on the downstream side of the mandrel mill (Fig. 1) or on the downstream side of the sizing mill/stretch reducing mill when it is coupled with the mandrel mill (**Fig. 7**).

Multiple circumferential points are measured by the hot wall thickness meters, and the measurement results are subjected to Fourier analysis to determine the amount and direction of the second-ordered wall thickness deviation first. The trend of the second-ordered wall thickness deviation for individual pipe-rolling conditions is learned. Then, during the next pipe-rolling operation, the results of the learning are fed back to the mandrel mill and the pressing cyl-

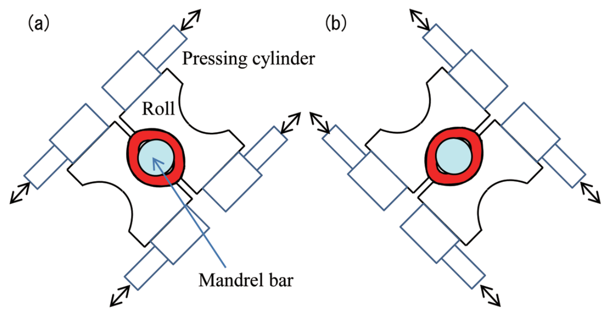

Fig. 6 Compensating 2nd ordered circumferential wall thickness deviation with pressing cylinders of mandrel mill individually controlled (a) Odd numbered stand, (b) Even numbered stand

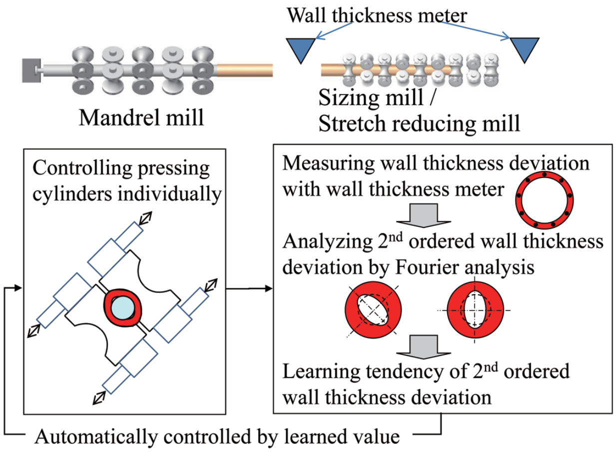

Fig. 7 Feedback control system of circumferential wall thickness deviation on mandrel mill

inders are properly controlled independently, thus reducing wall thickness deviations automatically.

The developed technology has made it possible to reduce second-ordered wall thickness deviations to approximately 0.1 mm or less (**Fig. 8**). Thus, a high degree of wall thickness accuracy has been attained.

5. Conclusion

Seamless pipe and tube are required to have a high degree of wall thickness accuracy. On the other hand, various patterns of wall thickness deviations can occur in the individual pipe manufacturing

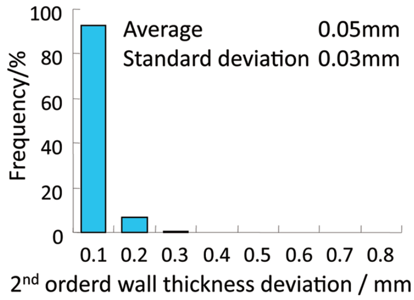

Fig. 8 Result of feedback control system of circumferential wall thickness deviation

processes. We developed new technology for determining the patterns of deviations by complex Fourier analysis.

In addition, for wall thickness deviations that can occur in the mandrel mill, we developed new technology for preventing them through independent control of the pressing cylinders. Furthermore, we applied on-line wall thickness deviation feedback control technology using a wall thickness meter to attain a high degree of wall thickness accuracy.

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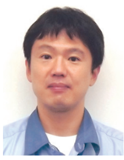

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