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TECHNICAL REPORT

Study of two-dimensional inspection of thin sheets using Lamb wave

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Abstract: The Lamb wave inspection technique with a tire transducer has been used for the on-line defect inspection of steel sheets. However, the conventional Lamb wave inspection process has the following two problems. One is the existence of wide dead zones that appear in the near and far positions for the tire transducer. The other is misdetection due to parasitic echoes or electrical noises. Therefore, we have developed a method that could solve these problems using the two-dimensional signal characteristics. As a result, the dead zone and the misdetections can be reduced. This paper describes the measurement principle, the algorithm of the signal processing and the distinction logic. The results showed that the dead zone was reduced to 100 mm from the strip edge and the misdetection was eliminated.

Keywords: Lamb wave, Ultrasonic inspection, Tire transducer, Thin steel sheet, Two-dimensional inspection

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1. INTRODUCTION

The Lamb wave testing technique has been used for the detection of internal defects in steel strips on the production line. The basic structure of the tire transducer being used for the present inspection method of steel sheets is shown in Fig. 1(a). It is done by filling the inside of a tire with water where an oscillator was installed. The incident angle is set at the critical angle according to Snell's law. Therefore, when the sheet thickness and the kind of steel sheet change, the incident angle could change to the critical angle [1,2].

In this method, the Lamb wave propagates in the width direction of the steel strips, and an echo from a defect is detected using the tire transducer as shown in Fig. 1(b).

Figure 2 shows how to determine the defects in the sheets. The defect is distinguished by signal amplitude and position. However, the transmitting signal and edge signal appear at the same time, therefore, we must then set the inspection gate so that it rejects these noise signals. The position and the width of the inspection gate must be determined in advance by the strip width and thickness parameters from the process control computer. However, these signal positions fluctuate due to the coupling condition of the tire transducer and the steel strip on the production line. Therefore, the width of the inspection gate tends to be narrower than the most important value. As a result, the dead zone near both edges of the strip is too long for the optimum value.

Furthermore, the signal amplitude, where the signal is due to the defect, only determines the output. Therefore, misdetections due to parasitic echoes or electrical noise frequently occur in the conventional system.

We obtained the Lamb wave testing data from the pickling line of a hot strip-rolling factory, and analyzed these data to solve these problems. It was found that we processed only one-dimensional information from the received signal which was insufficient for the inspection of thin steel sheets.

We then developed a new method, which produces two-dimensional digital data from the inspection data and distinguishes the defect signals from the other signals of the two-dimensional data.

2. PRINCIPLE

We obtained the Lamb wave testing data from the pickling line of a hot strip factory, and analyzed these results to solve these problems. We then transformed these data into two-dimensional data as shown in Fig. 3. We then determined that each signal has two-dimensional signal

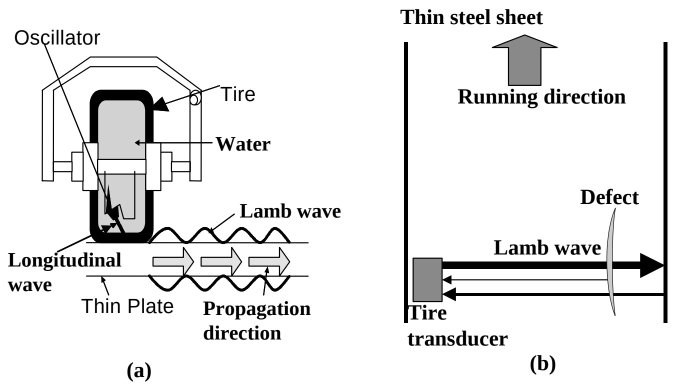

Fig. 1 Thin steel sheets inspection using Lamb wave. (a) Structure of the tire transducer. (b) Inspection method using a tire transducer on the production line.

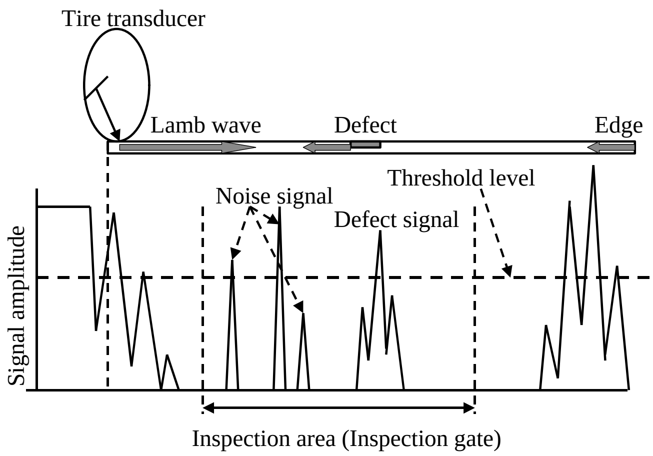

Fig. 2 Principle of Lamb wave inspection of thin steel sheet.

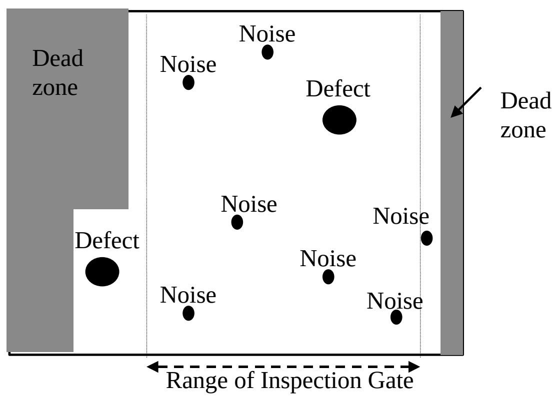

Fig. 3 Two-dimensional signal image of Lamb wave testing data.

characteristic values as shown in Table 1. The signal intensity in Table 1 was defined as the 50% signal intensity reflected from a 1 mm drilled hole. The generated ultrasonic beam had a signal duration time of 10 μs and a length in the running direction of 20 mm. In other words, the transmitting signal and the edge signal have a long duration time and strong intensity in a limited range. The electrical signal also has a short duration time at random positions.

Therefore, we devised the signal processing algorithm shown in Fig. 4 using these results. In this developed logic, the inspection data were transformed into two-dimensional data and then several features were subtracted from each signal. First, the transmitting signal, the edge signal and the electrical signal ere eliminated by judging the two-dimensional information. After that, the two dimensional data, in which the signal duration in the running direction was less than 1 m, and the signal duration in width was from 16 μs to 60 μs, was distinguished as the defect.

As a result, the new system could almost detect all the defects without any misdetections.

3. EXPERIMENTAL SETUP

The configuration of the experimental system is shown in Fig. 5. This system is attached to the conventional Lamb wave testing system. The signals obtained through the interface circuit include the received signal amplitude from the flaw detector and the position data in the running direction. The signal data are synchronously sent to the digital frame memory (1 Mbyte) in the repetition signal of the ultrasonic flaw detector and stored as two-dimensional data. The two-dimensional data in the memory is based on the width and length of the area and classified as different types of defects.

4. RESULTS AND DISCUSSION

We collected the Lamb wave inspection signal from the production line, which was located after the hot strip mill using the developed equipment. The maximum speed of this line is 150 mpm and steel strips 1.4 mm–7.0 mm in thickness, 560 mm–1,600 mm in width and over 1 km in length are produced.

We then used the logic algorithm to find a defect signal from the other signals using the characteristic two-dimensional value.

It takes about 1.1–1.5 s for the signal processing. The processing time is shorter than the data collection time, therefore, the long strip can be continuously inspected alternately using the two signal-processing boards.

To evaluate the dead-zone in both steel strip edges, we used a test coil, which contained artificial defects as shown in Fig. 6, which are 1 mm diameter drill holes. It was possible to detect a defect without using the inspection gate. The inspection results are shown in Table 2. We confirmed that the dead-zone could be reduced at the wheel-type probe side by 175 mm (Incident point of ultrasonic from 75 mm); the edge side is 100 mm from the edge.

Table 1 Characteristic values of two-dimensional Lamb wave inspection signals.

The kind of the signal	Signal intensity	Signal duration in running direction (in length)	Signal duration in width direction (in time)	Signal position
Defect signal	Under 100%	20–250 mm	16–60 ìs	Unknown
Transmitting signal	Over 100%	Over 1 m	60–120 ìs	Known approximately
Edge signal	Over 50%	Over 1 m	60–120 ìs	Known approximately
Electrical noise signal	Under 100%	Under 5 mm	Under 8 ìs	Random position
Residual signal in the probe	Over 50%	15 mm–1 m	Under 16 ìs	Known approximately

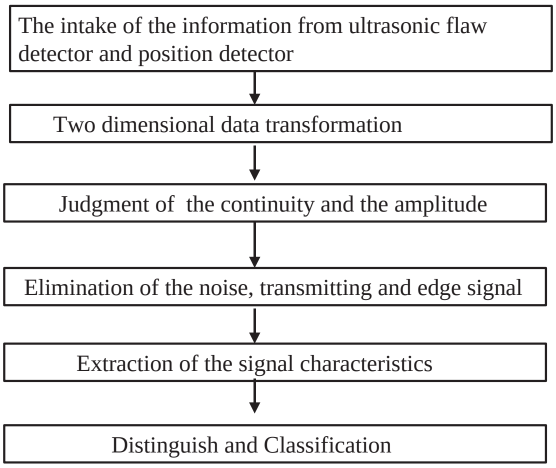

Fig. 4 Signal processing flow.

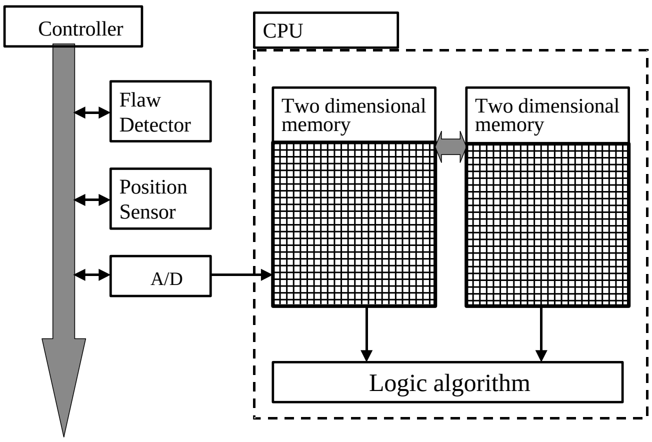

Fig. 5 Experimental setup.

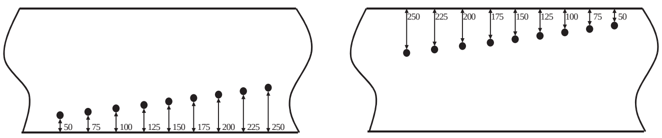

Fig. 6 Test sheet with 1 mm holes drilled through the sheet.

Table 2 Test results.

Item	Method	Commercial method (a)	New method (b)
Dead zone	Tire side	300–400 mm	125 mm(min)
	Edge side	250–350 mm	75 mm(min)
Electrical noise		Detection at all inspection area	No-detection
Sensitivity		(a) > (b)	

5. CONCLUSIONS

It could reduce the dead zone of the Lamb wave testing and false readings due to parasitic echoes. We described the configuration of this system along with its algorithm of the signal processing and distinction procedure. We showed some typical two-dimensional data, which was determined by the developed system on a production line.

In the new method, the defect signal was distinguished from the transmitted echoes, edge echoes and noise signals using the two dimensional signal characteristics, such as the continuity and observed position of these signals in the strips. Also, a digital signal processing technique was used for the real-time estimation of the signal characteristics.

We showed that this new method effectively reduced the dead zone in the line Lamb wave testing by using a test coil which included drilled holes as artificial defects. The dead zone can be reduced to less than 100 mm at the opposite side of the probe and 175 mm at the probe side. We confirmed that the parasitic echoes and the electrical noise signal do not cause any false readings by this new method.

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