Study on Shape Control and Vibration Absorber of Strip in Steel Process Line

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ABSTRACT
In a steel process line, the shape controller and vibration absorber of steel strip are important devices for improving strip quality and line speed up. Here, we report on the application of an electromagnetic method of absorbing vibrations and correcting the deformation of strips. We developed the technology that forecast an unstable phenomenon generated by using the electromagnet. This device was able to be used with stability in the steel process line, the vibration decrease and shape were corrected. The coating zinc weight was able to be made uniform in Continuous Galvanizing Line (CGL), and the improvement of the quality was brought as a result.

1. INTRODUCTION

In steel process lines, shape controlling and vibration absorbing of steel strips constitute important ways of improving line speed and quality. For example, the coated zinc weight on the strip is adjusted by a wiping nozzle. If there is cross-bowing in the width direction of the strip or vibration at the wiping nozzle position, the coating weight is not uniform and the quality of coated strip is lowered. If the vibration amplitude or cross-bowing deformation is large, the strip may make contact with the process apparatus, causing an adverse effect on the increase in line speed.

Moreover, along with the increase in the production of high- grade steel plates such as coated strips, there is also an increase in production methods in which strip contact with deflector rolls is minimized, yielding strips with fewer flows. As a result of the "roll-less" design employed for this purpose, the roll interval is extended and cross-bowing and vibration are more likely to occur in the strip.

To solve these problems, a strip shape controlling and vibration absorbing system has been developed. This system is employing the contact-free positioning and vibration control techniques which are used in the magnetic bearings(1) and magnetic levitation systems(2). This paper reports on the results that this system has been applying for the field of actual continuous galvanizing line based on the fundamenntal test(3).

2. METHOD OF STRIP SHAPE CONTROL AND VIBRATION ABSORPTION

Strips transferred in a steel process line are about 600 to 1800 mm in width and from 0.3 to 6 mm in thickness. Through annealing and galvanizing in the line, the overall line length is extended to a few kilometers. In this distance, tension is applied by bridle rolls, and the strip is supported by rolls, although the roll interval is 50m at most. A strip supported by rolls at such tension can be regarded as a string supported at both its ends, and its natural frequency is expressed in the following equation.

$$f_n = \frac{n}{2L}\sqrt{\frac{\sigma}{\rho}} \qquad n=1,2,3, \qquad (1)$$

where, L: roll span(m), σ : unit tension(N/m^2), ρ : density of strip(kg/m^3), f : natural frequency(Hz)

The purpose of control is to reduce the vibration amplitude by giving damping and stiffness to the natural frequencies.

In actual control, as shown in Figure 1(a), a set of electromagnets facing each other across a strip, and a sensor for measuring displacement of the strip is installed on one axis. Shape is controlled and vibration is suppressed by disposition of a number of axes in the strip's width direction.

The strip is likely to be deformed in a C-form, that is, the same phase at both ends and the opposite phase in the center. To keep it flat, three axes in the width direction are basically required. However, as measures against W-form deformation are more complicated in shape in the width direction, five or more axes must be arranged in the width direction.

As shown in the block diagram in Figure 1(b), a control circuit has a series circuit for PI control and phase compensation of displacement signal. This circuit gives stiffness and damping to the strip while positioning it. A contolled parameter must be determined at this time, in order to avoid static instability and spillover(hunting in higher order mode). As for static instability, we confirmed by a numerical analysis that the dynamic stability arising from control added to stiffness of the strip under tension is greater than the intrinsic unstable force of the electromagnet. As for spillover, a limit value is determined by experiment, and a constant is determined on the basis of the obtained data.

3. APPLYING FOR REAL FIELD PROCESS LINE

3.1 Apparatus for real line

An apparatus configuration of 6 axes control for CGL is shown in Figure 2. Using a Digital Signal Processor(DSP) in the control unit, a function of an

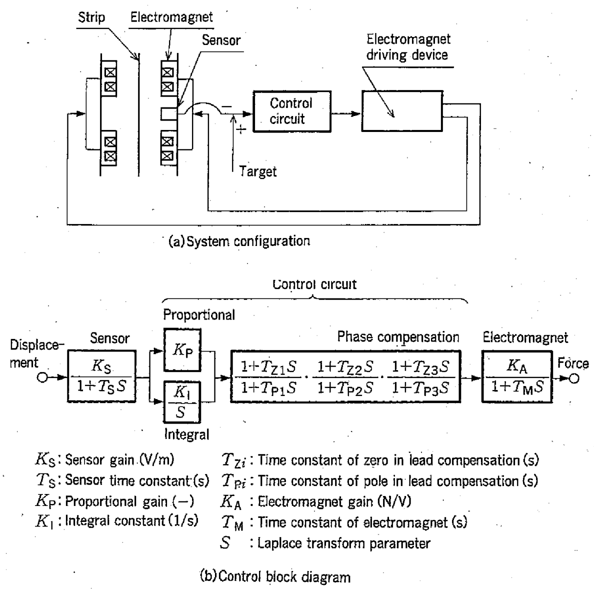


FIGURE 1: System and transfer characteristics

automatic level of compesation could be assigned for opimum control constants, depending on line conditions such as strip width, thickness and tension. An electromagnet driver independently drives six axes by PWM control. The disposition of electromagnets and sensor comprises upper and lower electromagnets for each axis, with a sensor disposed between them. The temperature of the steel strip becomes about 450℃ in the CGL. Because the steel strip temperature is high, the attractive force of the electromagnet decreases. Then, the attractive force of the steel strip at high temperatures is measured, and the result is shown in Figure 3 (thickness : 0.8mm, distance of electromagnet and steel strip : 15mm). The attractive force decreases rapidly from about 600℃ as shown in Figure 3, and the attractive force becomes 0 by curie point of 800℃. Figure 4 shows relationship between attractive force and coil current at each strip temperature. The magnetic flux density is saturated in the section of the steel board when the current of the coil is increased because the steel board is thin, and the attractive force also shows the saturation tendency. In a thin strip of 0.58 to 0.98 mm, a magnetic force of 100 N/axis or more is presented. And now, much stronger electromagnet is developed for thicker strip.

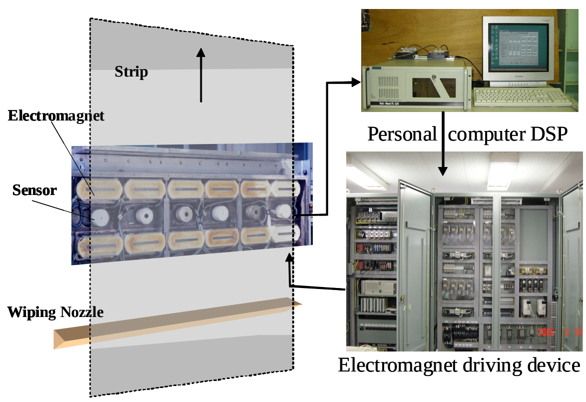


FIGURE 2: Device for CGL

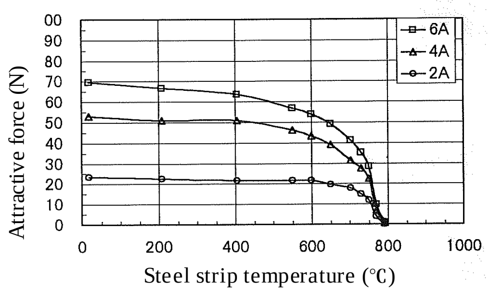


FIGURE 3: Electromagnet attractive force temperature parameter

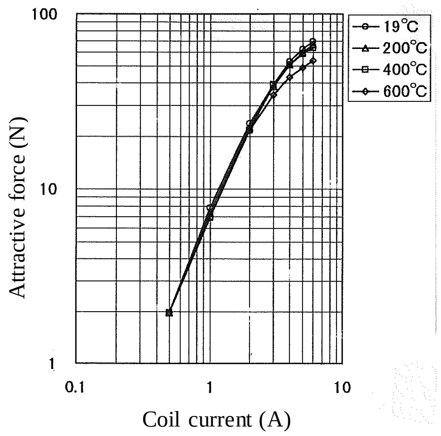


FIGURE 4: Electromagnet attractive force coil current parameter

3.2 Real process line

This device was installed in several real CGL. Figure 5 shows an establishment position of this device in a continuous galvanizing line. A strip passes a pot full of fusion zinc, the zinc thickness on a strip is equalized by a wiping nozzle, and the strip enter a cooling section after having carried out the alloys more. When a strip is cross-bowing and vibrates much at a position of a wiping nozzle, it is impossible to keep the zinc thickness uniformity. It is a purpose to reduce the cross-bowing and the vibration of a strip in a wiping position. Thus, it is more effective to install this device near a wiping nozzle as much as possible, and actually it installs in about 400 mm from a wiping nozzle. In addition, the distance from bottom roll to top roll is 15 – 50 m, and this device is located in bottom roll neighborhood.

3.3 Control lability and stability

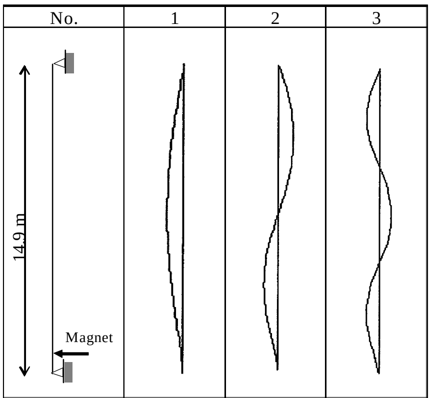
In order to control the shape and vibration of strip stably, the vibration of strip is analyzed and the parameter of control is set. Figure 6 shows the one example. This is the natural frequency analysis result when this device is installed in the vicinity of the bottom roll. Then, the distance between sink roll and top roll is 15 m. This shows a result to the third natural frequency.

And, there is the phenomenon that is two following instability problem in the positioning technology by electromagnetic force [1].

(1)As the gain of control is smaller, the first mode becomes static unstable.

(2)As the gain of control is larger, the higher mode becomes dynamic unstable, which is called as spill-over problem.

As an example of static instablity is shown in Figure 7. When this device was applied to CGL, this data was generated.This cause is that the absolute value of passive negative stiffness produced by electromagnets is larger than the sum value of positive stiffness produced by the tension of strip and the active control of this device. And the proportinal gain is set in order to secure the positive of stiffness as a system.



No.	1	2	3
Frequency (Hz)	1.28	2.74	4.51
Mass(kg)	56.2	56.5	56.4
Damping (%)	1.20	1.24	1.17

FIGURE 6: Modal analysis results

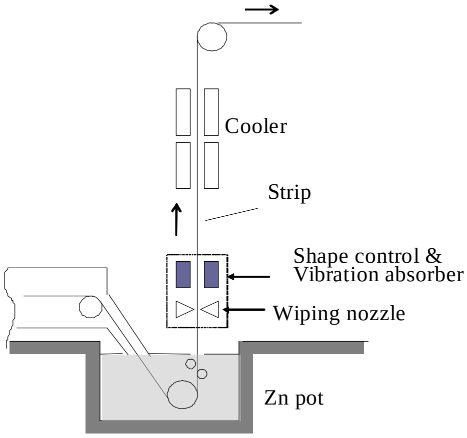


FIGURE 5: Device arrangement in CGL

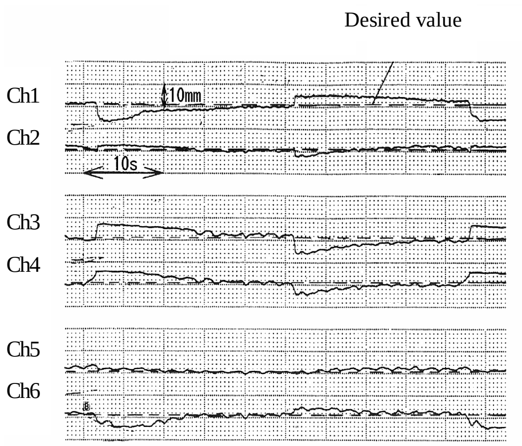
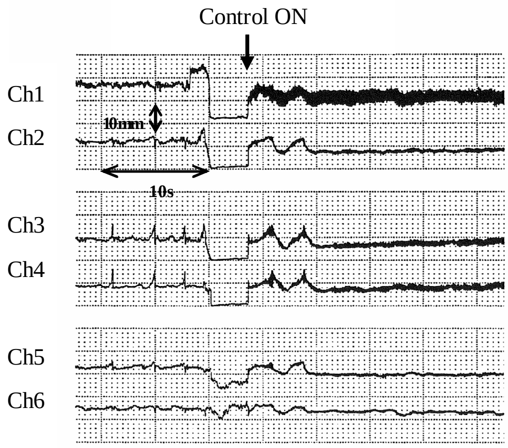
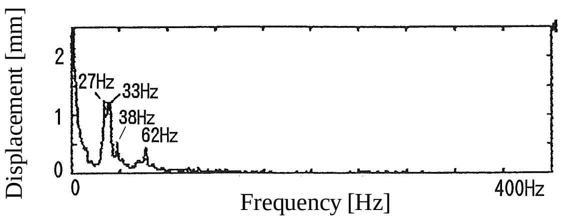


FIGURE 7: Static instability phenomena



(a) Displacement



(b) Spectrum (Ch3)

FIGURE 8: High-frequency instability phenomena

And, an example of spill-over phenomenon shows Figure 8. When control is on, the strip vibrates in a high frequency and the state becomes uncontrollable. Frequency of this vibration is about 27 Hz and this frequency is a minimum natural frequency which is out of phase compensation range. Under these data, the control parameters are set to be able to secure the stability of this system. Above mentioned, the control parameters are automaticaly set for the change of kindness of the strip and operation conditions and the stability of a system is guaranteed logically and experimentaly.

If this device is installed in the center between top and sink roll, the reduction of strip vibration is most effective. However, actually this device is installed in the vicinity of a sink roll for roll spans more than 15 m like Figure 6. An analysis result in this state is shown in Figure 9, which is the compliance at this device position when the strip is excited at the center between two rolls. Resonaces, which have not almost damping ratio are to have about 1 % damping ratio by control, the vibration is able to reduce to 10 – 20 % of original at resonance frequency and there is reduction effect of vibration even at else frequency area. For example, at 2 Hz it is estimated to have about 50 % vibration reduce

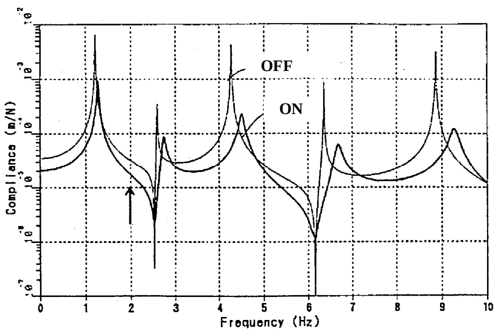


FIGURE 9: Frequency response analysis results

effect, and it is seen that the vibration of 2 Hz examined in a real line, reduced the same order in Figure 11 shown later. It is thought that there are a few effect to reduce vibration of a strip in the whole line, but this device is expected to have an enough effect to absorb the local vibration of its neighborhood.

A control object is not to avoid the resonance with the exciting forces, and to be natural frequencies higher as possible, to be resonance magnification lower as possible. At the case of broad band exciting force like a white noise or a 1/f fluctuation, the vibration of strip is able to be reduced certainly. But, at the case of line spectrum exciting force, the case that vibration does not become small comes out, but order of amplitude is same as original.

4. RESULTS IN REAL FIELD LINE

This device ia installed in a position shown in Figure 5 of continuous galvanizing line and the test that controls shape of strip at a wiping nozzle and reduces vibration is examined. The effect of this device is shown below at two case of strip size

4.1 Thickness of strip: 0.5 mm, Width:1230 mm

The shape control result at the opened state of upper support roll, is shown in Figure 10. In the control off state, a atate of cross-bowing deformation of 6 mm_{p-p} at a position of this device and 4.4 mm_{p-p} at a positon of a wiping nozzle is set up on the strip. And, in order to make a strip shape flat at a position of wiping nozzle, the object of control at a position of this device is set to be cross- bowing deformation 2 mm_{p-p} in the opposite side. By this operation, cross-bowing deformation at a positon of a wiping nozzle ia able to be kept within 0.5 mm_{p-p} and a difference of the amount of zinc coating on the front and back of strip decreases from more than 50 g/m^2 to less than 20 g/m^2.

And, when the object of control at a position of this device is set to be flat as a strip shape, cross-bowing deformation 1.1 mm^{p-p} at a position of wiping nozzle is stayed. Then, it is confirmed that to control cross-bowing deformation in the opposite side is much effective.

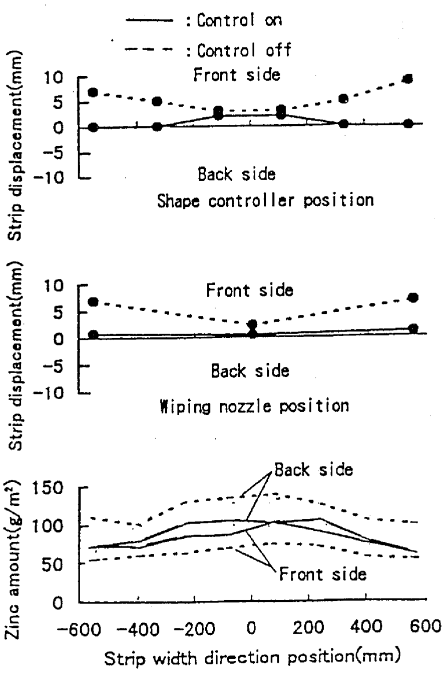


FIGURE 10: Effect(1) of application test in CGL

4.2 Thickness of strip: 0.8 mm, Width:1700 mm

The shape control result at the closed state of upper support roll, is shown in Figure 11(a). In the controll off state, the strip was transported by inclining in the width direction, and a state of displacement of 3.5 mm between the two edges is set up. At this time, fluctuations in the amount of zinc coating on the strip were about 20 g/m^2 in the width direction. By its shape control, the shape in the width direction is made flat, and the strip is then moved pararell from the back side to the front side. By this operation, the displacemennt of the strip in the width direction is able to be kept within 1 mm, and fluctuations in the amount of zinc coating on the strip in the width direction are halved to 10 g/m^2. In addition, the galvanizing amount is equalized on the front and back sides.

Vibration absorbing results are shown in Figure 11(b). It refers to the vibration near the strip edge, and the amplitude corresponds to the control on and off state in Figure 11(a). Above mentioned, the effect is considered to be small for the absorption of vibration on the long span, as the mode of natural frequency is small at a position of this device.

5. CONCLUSIONS

A device for controlling the strip shape and absorbing vibration was developed, its performance was tested in a real continuous galvanizing line, and the following results were obtained.

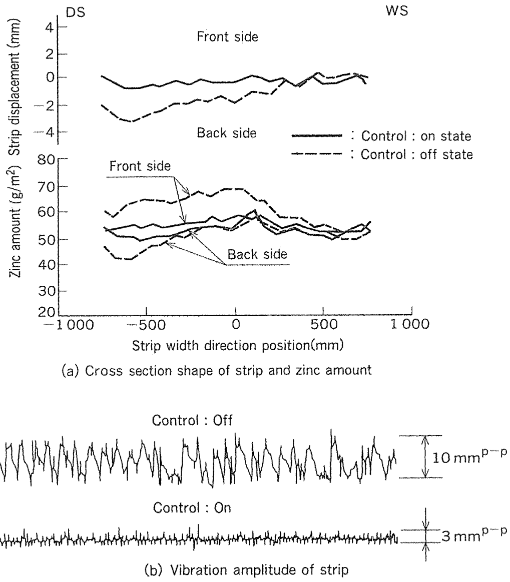


FIGURE 11: Effect(2) of application test in CGL

(1) By its shape control, the strip shape at a position of wiping nozzle is able to be made flat, and even when the strip inclines in the width direction, the value is able to be within 1 mm$_{p-p}$. As a result, fluctuations in the amount of zinc coating on the strip are reduced by half and the galvanizing amount is able to be equalized on the front and back sides.

(2) The vibration absorbing effect was also recognized, as the vibration of 6 to 18 mm$_{p-p}$ was reduced to about 3 mm$_{p-p}$.

After having done the above-mentioned examination at the real continuous galvanizing line, this devices are installed in several production lines and are contributing the production of high quality strips now.

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