ELECTROMAGNETIC LATERAL CONTROL SYSTEM
OF FLOATING STRIP

by

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ABSTRACT

Strip floating system is effective to avoid strip wrinkles and defects caused by roll contact, and to keep high quality of steel strip in the continuous processing lines.

In development of the floating system, challenging point is its controller against lateral instability of the floating strip supported by air cushion devices. We developed the electromagnetic control system, whose response is much quicker than that of the conventional center position control (CPC) system using rollers. This paper shows validity of our new control system.

NOMENCLATURE

B : Magnetic flux density
b : Width of strip
Fe : Electromagnetic force
Fs : Lateral force of strip
I : Electric current for strip
k : Spring constant which means static characteristic of floating strip
m : Mass of strip
ds : Area, where magnetic flux acts on the strip

INTRODUCTION

A thin steel plate called 'strip' is produced in continuous processing lines. In these lines the strip is supported by rollers through a long distance at high speed. There are some problems like wrinkles or defects.

Strip floating system is effective to avoid these problems, and to keep high quality of the strip in the continuous processing lines. The difficulty to develop the system is, how to control the lateral instability of floating strip supported by air cushion devices.

This paper describes the frequency response of floating strip, and the principle of an electromagnetic control system to avoid the lateral displacement of the floating strip. We demonstrated the quick response of this system experimentally, and the effectiveness of the system was verified.

FREQUENCY RESPONSE OF FLOATING STRIP

Strip floating device supports the strip by static pressure that is generated between the strip and the nozzles as shown in Figure 1. Because of no restraint for the displacement of the strip in the lateral direction, the lateral motion of the strip is very unstable. Here, we supposed to use this system in vertical pass line that has a large strip span in particular.

About the lateral displacement of the strip, the source of side force acts on the floating strip have been studied in several papers.[1)]

Only few studies, however, have ever tried to explain the dynamic response of the strip. We measured frequency response of the floating strip through experimental apparatus as shown in Figure 2.

This includes a floating device, a programmable actuator, a road cell, two rollers, and a FFT analyzer. The programmable actuator moves the floating strip at each frequency in the lateral direction. The FFT analyzers give the frequency response of the floating strip with its position and lateral force for the strip. The strip was stainless steel with 0.37m wide and 1.0×10^{-4}m thick. Figure 3 shows the frequency response of the floating strip. Although the lateral displacement of the strip on the roller is represented by a spring-dashpot model[2)], we ignored the damping factor, because the factor was viscosity of air in this case. Frequency response of the floating strip can be explained by equation (1).

$$Fs(t) = m\frac{d^2x(t)}{dt^2} - kx(t) \tag{1}$$

where $Fs(t)$ is lateral force of strip; m is mass of strip; $x(t)$ is lateral displacement of strip; k is a spring constant, that means static characteristic of floating strip(Fs/x).

PRINCIPLE OF ELECTROMAGNETIC CONTROL SYSTEM

To eliminate the lateral displacement of the floating strip, we considered the following requirement. First, no mechanical touch for exerting lateral force is required. Second point is to get faster speed of response in lateral displacement of the strip. Since the strip supported by air, no frictional force constrains its lateral motion and gives much faster motion. Therefore it is difficult to use the conventional center position control system with rollers. In addition to these points, it is better to keep the system as compact as possible for the use in the processing lines. From these considerations, we thought electromagnetic force is suitable.

At first, the use of the Linear Induction Motor type was tested as shown in Figure 4. In this type, moving magnetic field was generated by the coils, which are faced to the strip, and electric current was induced in the strip. The lateral force was generated to the strip by combination of induced electric current and magnetic field. In case of using a thin strip, very large coils are needed to induce enough electric current to eliminate the lateral displacement of strip.

Next the use of the Direct Current type was investigated as shown in Figure 5. In this type, an electric current was not induced but turned on directly according to the thickness or electric resistance of the strip. It was possible to get enough electric current to eliminate the lateral displacement of the strip. An electromagnetic force generated in this way can be explained by Fleming's left-hand law as equation (2).

$$Fe = \frac{I}{b}\int Bds \tag{2}$$

where Fe is electromagnetic force; b is width of strip; I is electric current for strip; B is magnetic flux density on the strip; and ds is an area where magnetic flux acts on the strip.

EXPERIMENTAL APPARATUS

Figure 6 shows the outline of the experimental apparatus to control the lateral displacement of floating strip. Table 1 shows the experimental conditions. The experimental apparatus consists of floating devices, conductor rollers, an electromagnet, a position sensor, a controller and a motor. Strip was 0.37m wide, 5×10^{-5}m and 1×10^{-4}m thick. The material was austenitec stainless steel. Strip was supported by floating devices and rollers, and was moved by a motor. During the strip was moving, the lateral displacement of the strip was captured with the position sensor and was sent to the controller. The controller gives the electric current to the strip through the conductor rollers. If the magnetic field is constant, the electromagnetic force exerts to the strip is explained by equation (3).

$$Fe = KI \tag{3}$$

Hence the amount of electric current can control the magnitude of the force to the strip. Figure 7 shows the block diagram of this apparatus. Strip time constant means, the time constant generated between control loop and the strip. It was about 40msec measured by step response.

EXPERIMENTAL RESULTS

Figure 8 shows the changes with time in lateral displacement of the floating strip and electric current for the strip with the control system. Traveling speed was 10m per minutes in this case. The strip had some displacement before the control system was turned on. The strip moved to the center position immediately as soon as the controller was turned on, although there were small overshoot. In case of strip was 5×10^{-5} m thick strip, frequency of strip motion and electric current was shorter than in case of 1×10^{-4}m thick, because of the difference of the strip mass. We can find quick convergence on both cases.

In view of response of the strip, let us then consider a changing of travelling speed of the strip. Figure 9 shows the change with time during the strip speed was increased from 10 to 40 m per minutes. It showed transient response at the point of speed shifting.

We consider two reasons for this behavior. The one reason is flutter of the strip caused by changing the speed. The fluttering of the strip changes the gap between the strip and an electromagnet. It means, the gain K (shown in Figure 7) was varied.

To get the stability of control loop while the strip is fluttering, it is needed to control the gap between the strip and the electromagnet. Figure 10 shows the Root-Locus of gain K in the control loop. This figure shows that the gain K is needed to be less than 0.008. In this experiment, the stable value of gain K was equal to 0.05m of flutter volume. A fuller study to control the flutter of the strip, is outside the scope of this paper. Though it might be possible to control the flutter of the strip by using air cushion devices which faced to the strip.

The other point is a change of the electric current condition. The electric current for strip was turned on through the conductor rollers. If the nip condition of the conductor rollers is getting worse, sometimes sparks may occur between the strip and the surfaces of rollers. It disturbs the normal electric current for the strip. Figure 11 shows the changes with time of the lateral displacement of the strip and electric current, when the sparks occurred. This figure shows that the sparks obstruct the normal control conspicuously.

To prevent the sparks, it was needed to keep a constant pressure between the strip and the rollers in whole strip width. So it kept the balance of nip pressure at both sides of rollers, and it was possible to control the lateral instability at 70m per minutes as shown in Figure 12.

CONCLUSIONS

The electromagnetic control system was developed to control the lateral instability of floating strip. We demonstrated the quick response of this system experimentally, and verified the effectiveness of the system.

The findings obtained from this study are follows:

(1) The frequency response of the floating strip is explained by spring-mass model.

(2) It is possible to control the lateral instability of the floating strip by this system.

(3) In case of the strip speed changes, it is also possible, to keep convergence with preventing the sparks and controlling the flutter of the strip.

REFERENCES

1. Ronald P. Swanson, "Air Support Conveyance of Uniform And Non-Uniform Webs ", Proceeding of the Second International Conference on Web Handling, June 1993.

2. H. Uchida and N. Suzuki, "Strip Walk Simulation for Continuous Processing Lines", Proceeding of the Second International Conference on Web Handling, June 1993.

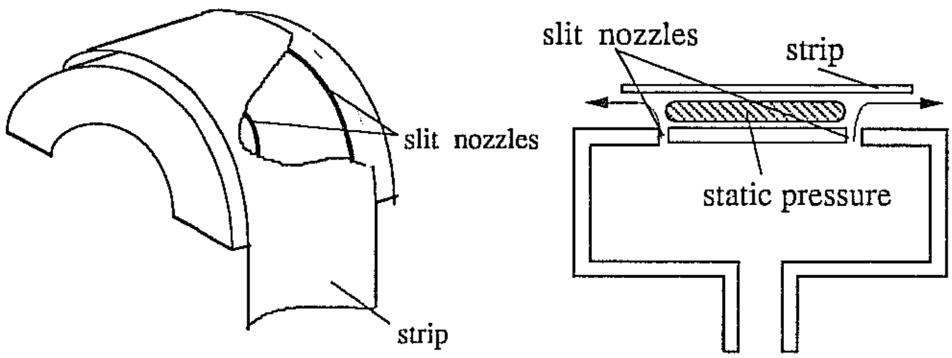


Figure 1 Outline of Floating Device

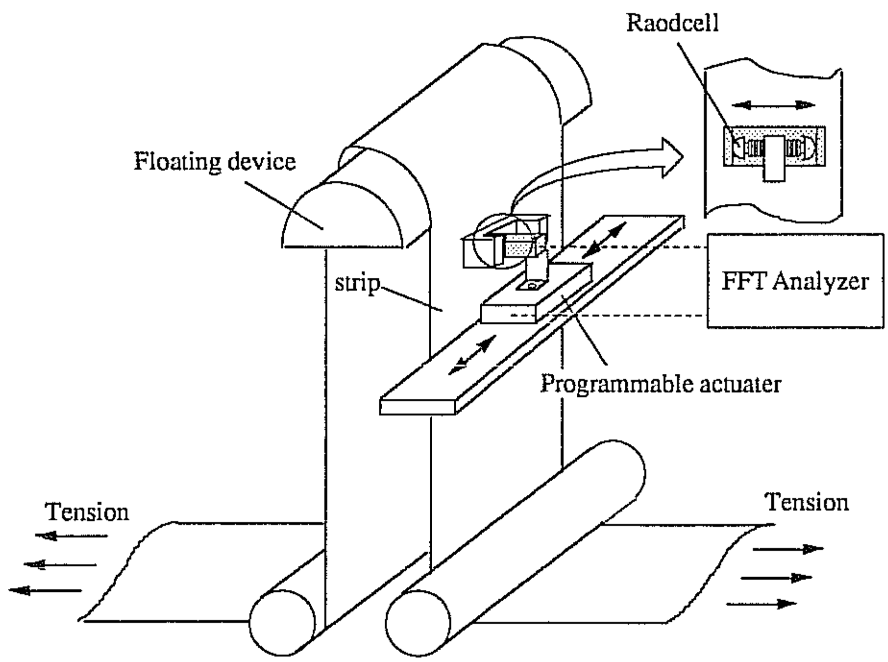


Figure 2 Outline of Experimental Apparatus to Measure Frequency Responce of Floating Strip

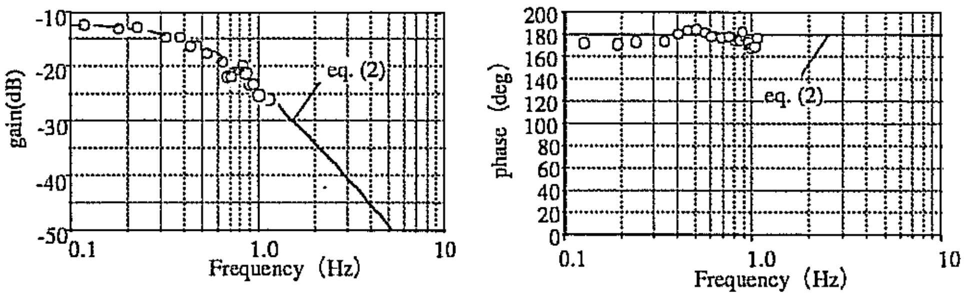


Figure 3 Frequency Responce of Floating Strip

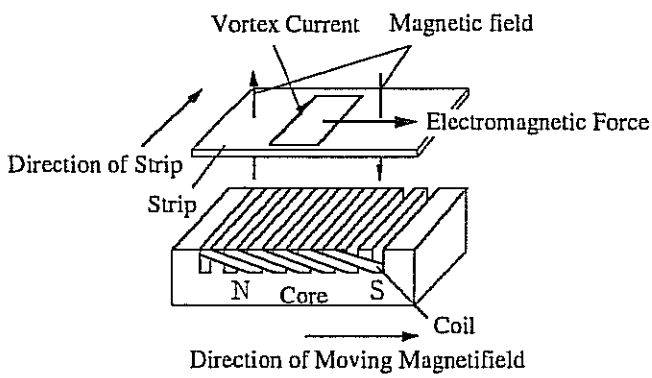


Figure 4 Principle of Linear Induction Motor - Type

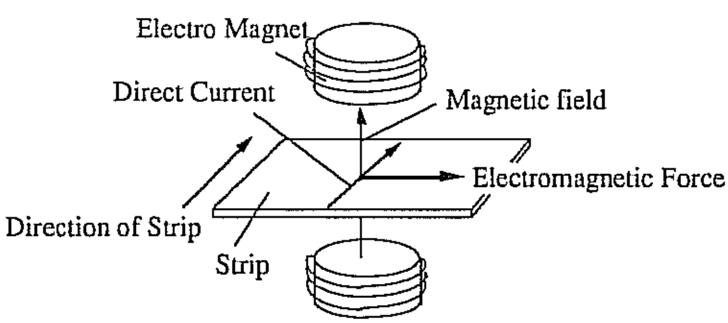


Figure 5 Principle of Direct Current - Type

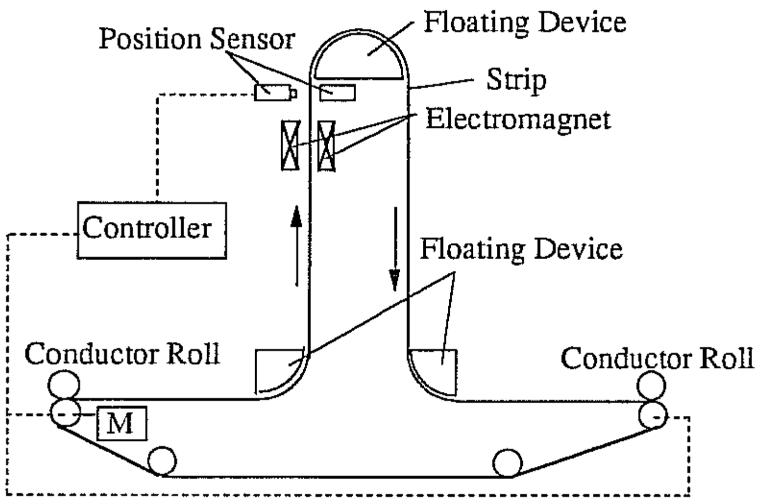


Figure 6 Outline of Experimantal Apparatus
to Control the Latarel Instability of Floating Strip

Table 1 Experimantal Condition

Tension for Strip	9.8×10^{5}N/m
Line Speed	0～70mpm
Floating Height of Strip	Ave. 5×10^{-4}m
Magnetic flux density	0.3T
Nip Pressure for Strip	3000N/m

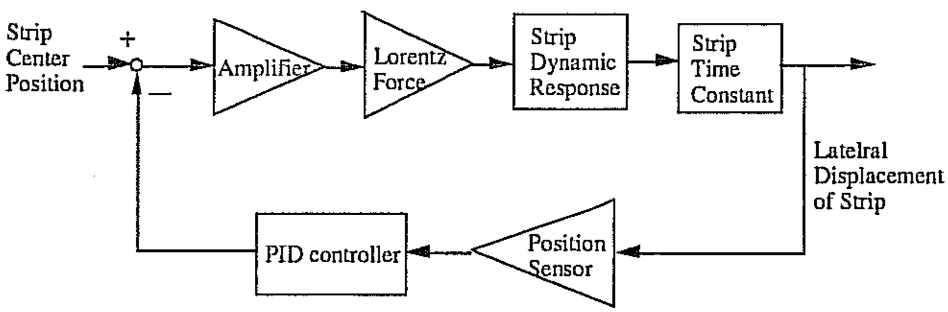
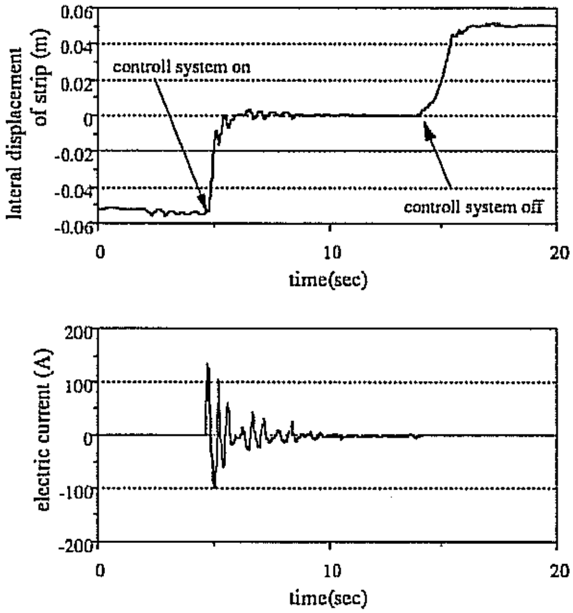
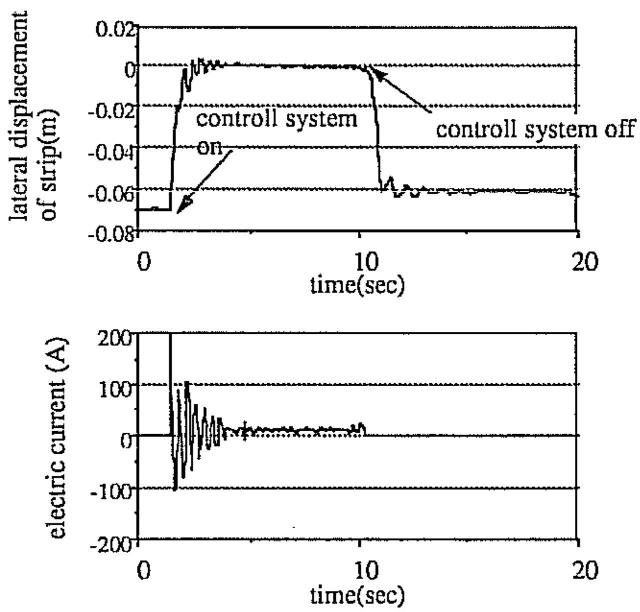


Figure 7 Block Diagram of Experimental Apparatus



(a)Strip thickness : 1×10^{-4}m



(b)Strip thickness : 5×10^{-5}m

Figure 8 Changes with time in lateral displacement of floating strip

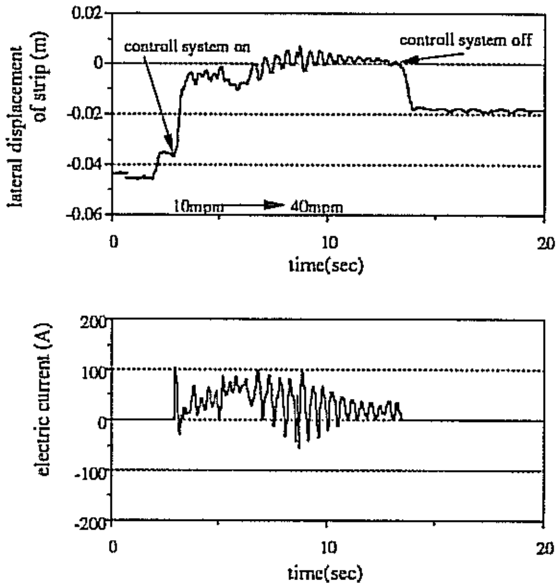


Figure 9 Changes with times of lateral displacement and electric current (Effect of the sparks)

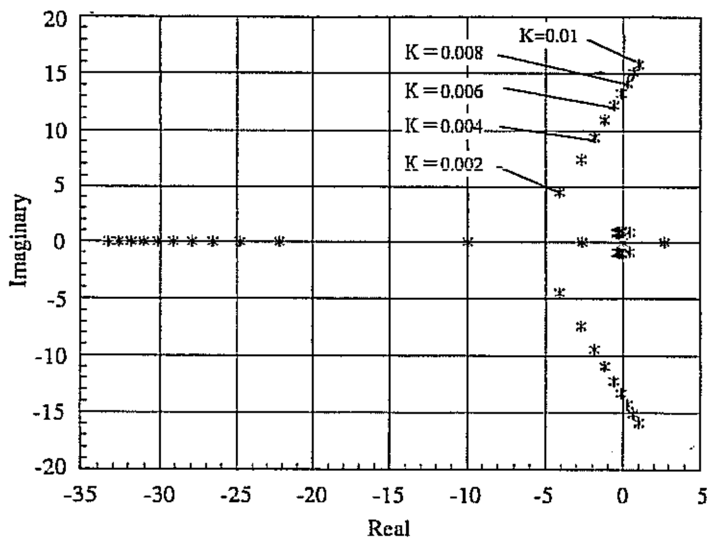


Figure 10 Root Locus of control loop

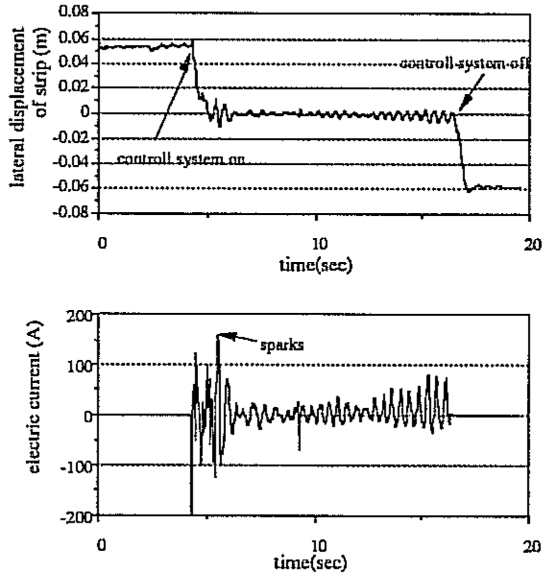


Figure 11 Changes with time of lateral displacement and electric current when the sparks occured

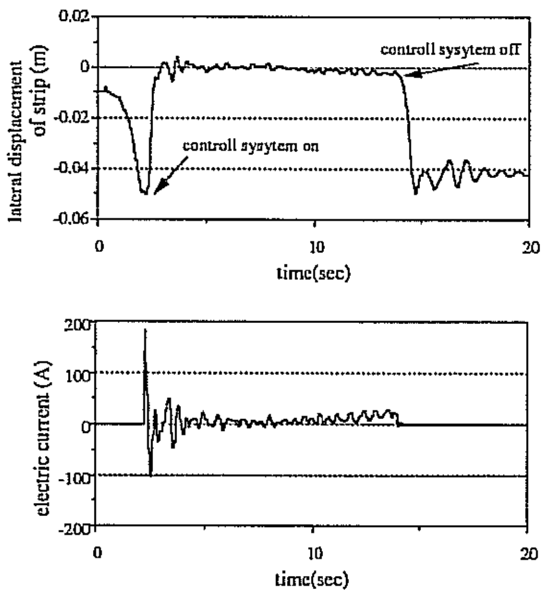


Figure 12 Changes with time of lateral displacement and electric current (Line speed : 70mpm)

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Electromagnetic Lateral Control System of Floating Strip
6/20/95 Session 4 2:00 - 2:25 p.m.

Question - How do you avoid that strain under non-flat conditions with the magnets. There is an interaction between magnet and metal, steel strips. How can you avoid such a strip? It's not drawn against the magnet. Not under flat conditions.

Answer - You mean if it is touched to the magnet?

Question - It is a nonmagnetic, nonferrous material?

Answer - Yes., it is not magnetic.

Question - What about any current effect if the strength is passing at a high speed. Any current is generated. Has this any effect in mechanical resistance to the strand?

Answer - (Trouble understanding translation) Sorry.

Question - How much power did you have to put in the strip? How much voltage was required to put 100 amperes through the strip? How many volts did it require?

Answer - Electrical power? You mean the ..? of the electric current?

Comment - No, the volt amperes. What is the resistance of the strip?

Answer - The resistance of the strip? How do you say? Energy in the system? I see. About 30 or 40 kilowatts.

Question - How wide of a metal strip have you evaluated and been successful with?

Answer - 0.35 meters.

Question - Have you done any other widths?

Answer - Of course, I tried other widths.

Question - What limitations have you found in width?

Answer - No, sorry. The experiment used 0.45 meters.

Thank you.