Automated Paving with Electromagnetic Induction

Y. Tachibana ＆ Ｓ. Takahashi , H. Yasumatsu
NIPPO CORPORATION, Chuou-ku, Tokyo, Japan

ABSTRACT: The Electromagnetic Induction System (hereafter TEIS) is an automated machine control system for the lift height and the steering of paving machinery such as asphalt pavers. Using a set of equilibrium feeder as positioning guidance and a control sensor of a paving machine, the machine can be automatically controlled through the density of magnetic field which is induced by electrifying the equilibrium feeder.
Comparing the conventional lift height controlling method with wire rope, the advantages of TEIS are high accuracy, time shortening for preparation, cost reduction, worker’s safety and so on. Moreover, differing from automated machine control systems with the laser or the supersonic wave, it can be applied to bridge deck pavements where bridge decks will bend and its absolute height will vary during paving operation.
In the paper, we describe the details of TEIS, including the principle of the system, setting and usage, and a recent application to a bridge paving project.

KEY WORDS: Conventional construction, development, principles, electromagnetic induction, construction.

1 INTRODUCTION

The smoothness of asphalt concrete pavements in bridge section is inferior to that in earthwork sections. This is ascribable to the considerable unevenness of bridge slabs, great difficulty in correcting the unevenness through the construction of the base layer (leveling layer) and other factors.

The authors focused on the capacity of the leveling layer on the slab to improve surface smoothness, identified problems with conventional construction methods and developed and put into practical use the Electromagnetic Induction System (TEIS) to enhance safety and the finished structure and to reduce costs and efforts in the preparation phase. This paper presents the requirements, characteristics and case studies of TEIS.

2 CONVENTIONAL CONSTRUCTION METHODS AND PROBLEMS

The pavement above the slab is composed of three layers: waterproof layer, base layer and surface layer overlying the former two layers (see Figure 1). Generally because of a considerable unevenness of the slab, the base layer plays the role of a leveling layer for securing the design lift height before paving the surface layer.

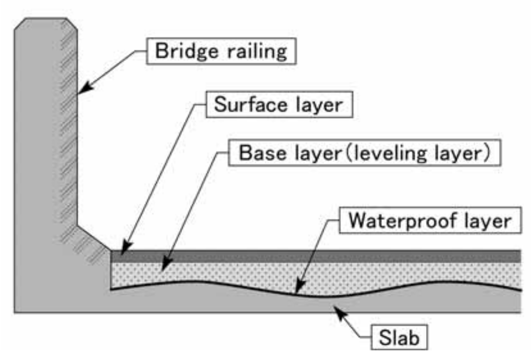


Figure 1: Structures of railing, slab, waterproof layer, base layer and surface layer

Described below are the conventional construction methods, procedures and problems. The base layer has conventionally been constructed by the following three options.

2.1 Option 1: Automatically controlling lift height by establishing a reference line

(1)Construction Method

This construction method has been most commonly used. A reference line is established on the top of the bridge railing, and the height of the pavement is automatically controlled using a contact-type lift height control system or a lift height control system with an ultrasonic sensing unit (see Photograph 1 and Figure 2).

Photograph 1: Establishing a reference line on the top of the railing, and an automatic lift height control system

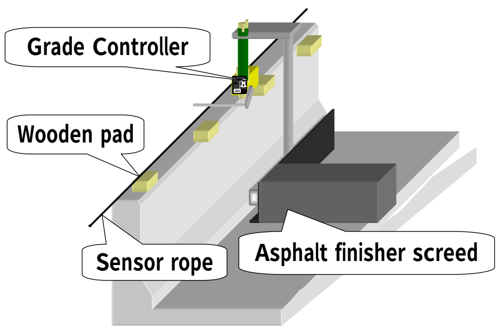


Figure 2: Reference line (sensor rope)

(i) Measure the height of the slab at each measurement point (at a standard pitch of 5 m) to establish a reference line on the top of the bridge railing
(ii) Make adjustments to achieve the reference height using wooden pads based on the collected data
(iii) Place a sensor rope on the wooden pads and tension the rope
(iv) Construct the pavement referring the sensor rope

(2) Problems

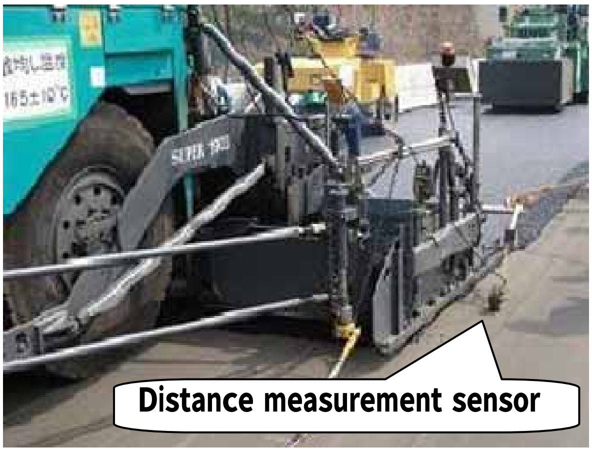
(i) Preparations require much time and manpower.
(ii) The sensor rope is generally tensioned at 500 to 600 N. The cutting of the rope may involve risks.
(iii) The bridge slab may deflect under the loads of pavement equipment and dump trucks, causing the sensor rope indicating the reference line to be separated from the adjustment pads. Then, the reference height may be wrong.
(iv) A noise insulation wall, fence or supports thereof installed on the top of the railing, if any, may prevent the establishment of the reference line. Developing special jigs according to the shape of the railing is necessary (see Photograph 2).

Photograph 2: Structure and jig on the railing

2.2 Option 2: Automatically controlling pavement thickness by using Pave-Set

(1)Construction Method

The thickness of the pavement is automatically controlled to obtain the designated lift height of the finished pavement. The system continuously controls pivot cylinders so that the design pavement thickness may be achieved at all the measurement points by inputting the pavement thickness data obtained at the measurement points into a computer (see Photograph 3).



Photograph 3: Use of Pave-Set

(i) Measure the height at measurement points on the slab (at a longitudinal pitch of 5 m)
(ii) Input the reference height of finished pavement to a computer based on the measurements
(iii) Construct the pavement based on the input data

(2) Problems

(i) Preparations require much time and manpower.
(ii) Asphalt emulsion adheres to the distance measurement sensor, and designated accuracy can hardly been obtained (see Photograph 3).
(iii) Handling the system requires high skills.

2.3 Option 3: Manually controlling pavement thickness

(1)Construction Method

The designated pavement thickness by the measurement of bridge slab height is marked on the bridge slab, and pavement thickness is manually controlled.

(i) Measure the height at each measurement point on the slab (at a longitudinal pitch of 5 m)
(ii) Mark the pavement thickness on the slab and construct the pavement manually to provide the designated thickness.

(2) Problems

(i) Preparations require much time and manpower.
(ii) The skills of the operator greatly affect the finished structure.

3 REQUIREMENTS FOR DEVELOPING TEIS

The requirements for the system to be developed for automatically controlling the leveling layer on the slab were the simplicity of the device, usability to non-expert operators and high-level safety.

Methods were examined that involved the use of laser beam or GPS (Global Positioning System) among the latest technologies. Both, however, required the specification of a fixed design height (reference height) and could not provide for deflection, one of the properties of bridge structures. Then, the wall surface of the railing that was expected to behave in synchronization with deflection was used as conventionally practiced. A schematic drawing of TEIS is given in Figure 3.

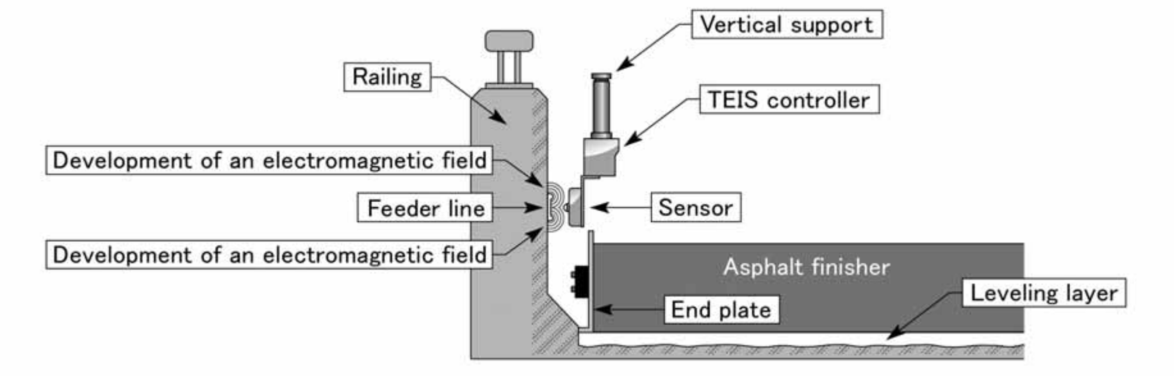


Figure3: Schematic drawing of TEIS

4 Outline of TEIS

The system automatically controls lift height. A weak electric current is fed by an inductive wave transmitter to a reference electric wire installed along the side of the railing (equilibrium feeder line that is referred to as feeder line below). The electromagnetic field that develops owing to the weak electric current running in the feeder line is detected by the sensor. Based on the result of detection, the leveling arm of the asphalt finisher is controlled (see Figure 3).

4.1 Principles of TEIS

The principles of TEIS are described below.

(1) Feeding a 2 kHz-frequency electric current from the transmitter to the feeder line produces electromagnetic fields around the feeder line.
(2) The phase of frequency is zero and no electromagnetic field develops at the point of contact (along the center line) between the top and bottom electromagnetic fields.
(3) Detecting the electromagnetic field using two coils built into the receiver in the sensor produces a potential.
(4) The potential detected using a coil becomes highest at the peak of the electromagnetic field.
(5) Each coil is located opposite the center of the feeder line where the potentials are identical to each other.
(6) If the potentials are not identical to each other, each coil moves so that the potentials may become identical to each other.

Based on the above principles, the pivot cylinders are controlled so that the center of the automatic controller (center of each coil) may be aligned along the center line between the two wires of the feeder line (see Figure 4).

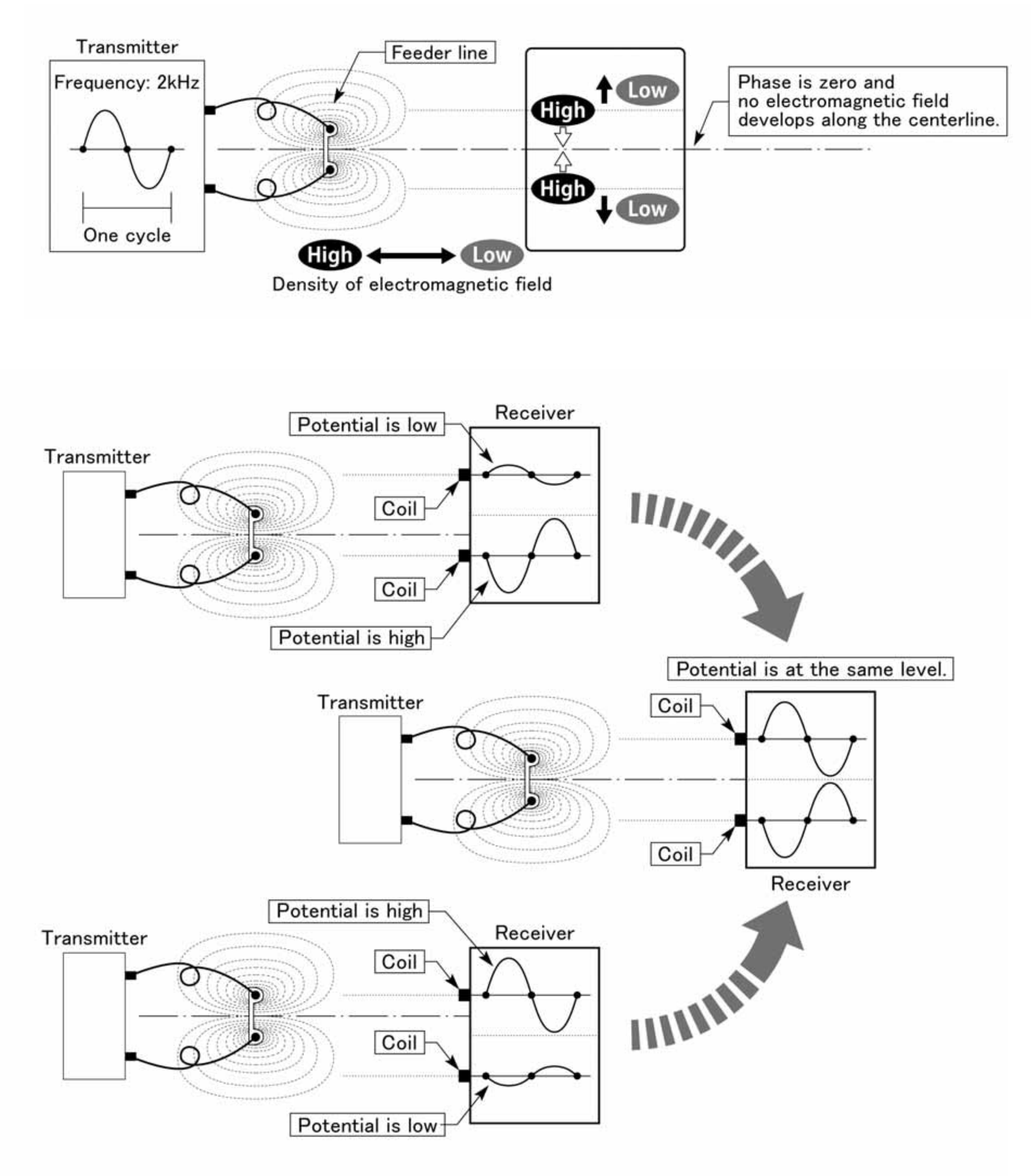


Figure 4: Principles of TEIS

4.2 Automatically Emergency Shutdown System

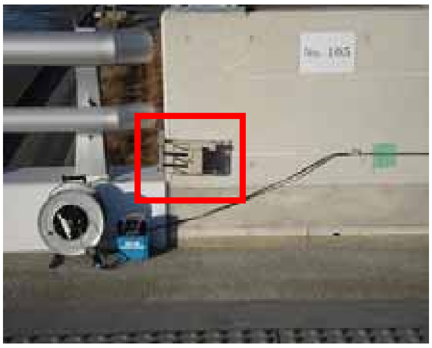
The automatic lift height control system is designed to discontinue the control function in case of deviation from the center line between the two wires of the feeder line by 20 mm or more in the vertical direction (in case of detection of an anomaly).

5 CASE STUDY OF TEIS

A case study is given below of the construction of an asphalt pavement on a bridge slab using TEIS.

5.1 Installation of a Feeder Line

(1) Place a mark on the wall surface of a designated bridge railing to indicate the reference height
(2) Set on the bridge railing the equipment for tensioning the feeder line (see Photographs 4 and 5)
The equipment enables
(i) Tensioning at a given force using a spring,
(ii) Arbitrary installation of tensioning equipment regardless of the shape or thickness of the railing, and
(3) Install the feeder line at the marked point
(4) Tension the feeder line at approximately 200 N using the tensioning equipment
(5) Attach the tensioned feeder line with packing tape in a simple manner



Photograph 4: Horizontally installed

Photograph 5: Vertically installed

5.2 Installation of controller

(1) A sensor for detecting electromagnetic fields and a control box for automatically controlling screed height are set in the asphalt finisher (see Photograph 6).

Photograph 6: Automatic control box (left) and sensor (right)

5.3 Result Obtained by Applying TEIS

The results obtained by applying TEIS are described below.

(1) Safety improvement
The feeder line is tensioned at approximately 200 N while the sensor rope is tensioned at 500 to 600 N. Tensioning therefore never causes the cutting of the wires, contributing to greater safety.
(2) Moderation of installation conditions
The feeder line is installed not on the top but on the side wall of the railing. Sound insulation walls, fences or other structures would not affect the application of TEIS.
(3) Improvement of general-purpose applicability
What is required is simply installing a feeder line on the wall surface of the railing. No special jigs are required and the system is applicable to any type of wall surface.
(4) Ease of installation
A simple device is used that requires no high skills or expertise. Ordinary workers can easily install the system.
(5) Enhancement of finished structures
The feeder line is attached to the wall surface of the railing. The deflection of the bridge has no effects on the reference lift height. Smoothness increased by 13points above conventional system (see Figure 5 and Table 1).

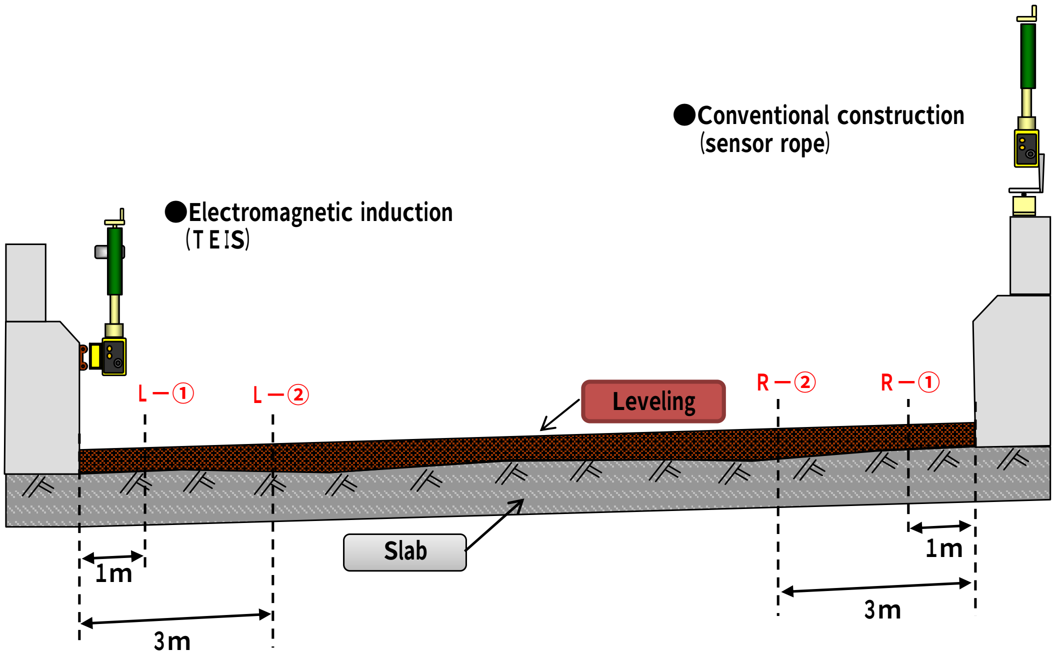


Figure 5: Measurement point on the levering layer on a bridge slab

Table 1: List of smoothness measurements on the leveling layer on a bridge slab

System	Measurement point		Slab	Leveling layer	Ratio of smoothness improvement
Electromagnetic induction (TEIS)	L	①	σ =4.43	σ =1.82	60%
		②	σ =4.49	σ =1.79	
Conventional construction (sensor rope)	R	①	σ =4.53	σ =2.41	47%
		②	σ =4.00	σ =2.09	

(6) Greater economy

TEIS reduces the equipment installation cost to 40% of that incurred when a conventional system is used (see Table 2).

Table 2: Cost comparison between TEIS and conventional method

System	Item	Quantity	Unit	Unit price (yen)	Amount (yen)	Total amount (yen)	Ratio
Electromagnetic induction (TEIS)	Use of equipment	1	Sets	1,400	1,400	57,400	40
	Ordinary worker	4	Persons	14,000	56,000		
Conventional construction (sensor rope)	Use of equipment	1	Sets	5,040	5,040	145,040	100
	Ordinary worker	10	Persons	14,000	140,000		

Note: Comparison in installation cost per 500m

6 CLOSING REMARK

TEIS described in this paper automatically controls lift height on the side of the railing where a feeder line can be installed. On the other side where no feeder lines can be installed because of a wide construction width, the pavement is constructed by a conventional method using a sensor rope or Pave-Set, or manually. In the future, efforts will be made to reduce costs and efforts and improve the finished structure through innovation.