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ENERGY SAVING IMPROVEMENT OF AUTOMATIC INSPECTION SYSTEM FOR COATED STEEL COILS

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Abstract. *Automatic inspection system is an important tool used in the manufacturing of steel strips. Use of automatic inspection system reduces the time required for manual inspection and allows instant reading of measured data online. A backlight light-emitting diode (LED) and charge-coupled device (CCD) camera are the main components of the strip inspection system. Use of the LED and CCD camera enhances overall accuracy efficiency, and saves energy as well. Replacing the high-frequency backlight lamp by LED provides a more uniform, stable and more saving energy without the high cost associated with the driving circuit. Using high resolution CCD cameras, the system further improves the accuracy of the inspection system up to the resolution of 0.39 mm when inspecting 1600 mm steel strips. Moreover, the proposed inspection system includes a Peltier device as an independent cooling system for CCD camera. This design reduces a significant amount of power consumption in comparison to the compressed air cooling system used originally. Finally, the proposed system integrates the backlight LED and CCD camera onto a C-type framework which provides the system with movement capability, thus decreasing maintenance issues arising from operating in the harsh environment. The proposed framework provides a safe environment for engineers to perform maintenance work without interrupting the continuous steel strip production.*
Keywords: Steel strip, Defect inspection, Backlight LED, Refrigeration chip

1. **Introduction.** The continuous iron and steel manufacturing process plays an important role in modern industry. In order to fulfill the diverse demands of various iron and steel end products, the steel slabs need to be hot rolled, cold rolled and annealed in order to produce products such as galvanized steel coils, electrogalvanized steel coils, magnetic steel coils, and tempered cold rolled steel coils, which then undergo further manufacturing steps such as plastic deformation processing. During the rolling production, complex processing procedures are prone to leave certain surface defects, such as flip, clamp marks, and engraved marks. Since the steel rolling production is a high speed process it is very difficult to detect all the defects by visual inspection. Therefore, automatic surface defects detection system is usually added in the production line to insure the quality of steel strip coils.

In [1], a system is developed in which the radial light was used over the hot rolled production line to detect surface defects. The system used temperature variance as a parameter to estimate the distribution and degree of severity of the defects. In [2,3], integrated CCD and virtual instruments were used to detect surface defects over steel plates.

In [4], mechanical vision and magnetic imaging were adopted as the detection system for inspecting surface defects over stainless steel line. The method found the defects by superimposing two captured images in order to eliminate influence of the environment, thus obtaining a more precise detection result. In [5] imaging and neuro-network algorithms were applied to enhance the accuracy of the surface defect inspection system for steel strips up to 87%. In [6] which focused on the banding curation of hot rolled strip, a high resolution scanning camera was installed over a hot rolled production line to capture the strip image. The banding curation was then calculated by estimating the distribution of radiation energy from the captured image.

Some steel plants lack width gauge for measuring the width of steel strips and instead rely on inspectors to measure the width of steel strips manually with measuring tapes. This is a time-consuming task. Therefore, researchers in [7-9] leveraged the non-contact advantage of CCD camera and used CCD camera to judge the edge of steel strips and to find the width of the steel strips. Researchers in [10-12] further combine 2 CCD cameras to capture images and to calculate the width and surface defects of steel strips. The calculated result was displayed on a graphical user interface (GUI) and was also saved in a database. Hence, on-site inspectors could know the production situation on time and provide feedbacks to engineers when severe problems happened. The data record was used as part of the quality report of the steel strip coils provided by the producers to the customers. In addition, [13,14] developed a modular and cost-effective automatic optical inspection system for hot-rolled flat steel in real time, by using two sets of line scan cameras. It was observed that the advantages of high resolution, non-contacting and good flexibility provide an opportunity for enhancing the quality controlling of hot-rolled flat steel.

Along with rapid improvement of electronic instruments, newer high-performance and low-cost image measuring instruments are continuously being developed. This article proposes an automatic inspection system for detecting width and defects (holes and cracks) of steel strips using a dual-camera inspecting architecture. The system utilizes advanced cameras and computational algorithms to detect the width and defects of steel strips in order to conform to a more stringent quality requirement of steel strips. Moreover, the proposed system simplifies the production and maintenance operations, reduces manpower and resource requirements, and saves energy consumed by the automatic inspection system.

2. **The Width and Defects Inspection System.** Figure 1 shows the PC-based configuration of the width and defects inspection system. The system features include human machine interface (HMI), floating and matrix computation capabilities, electromagnetic interference (EMI) free digital CCD, peripheral component interconnect (PCI) image adapter at 132 MB/s data rate, operation control and inspection GUI display, communication interface linked to plant process control computer, and peripheral alarm devices. The inspecting PC uplinks to plant process control computer and downlinks to ADAM I/O modules. There are 4 ADAM modules, including an ADAM4017 analog input module to collect the strip running speed at the entry and delivery ends of the production line, an ADAM4060 digital output module to send the signals of holes detected at both ends and cracks detected at both edges, an ADAM4050 digital input to get the strip welding cut and strip dividing cut signals, and an ADAM4024 analog output module to send the actual widths measured at entry and delivery points to the Level 1 process control computer system. In addition, there are two 50 KHz high-frequency fluorescent lamps (including ballasts), one lamp installed under the strip at entry end, and the other at delivery end. The lamp is fully sealed and covered by steel case with long slit gap to eliminate unstable edge light. Compressed air ventilates through the sealed case to cool down the lamp. A photoresistor is installed near the lamp to detect the light density

of the lamp for the stable control of light source. Above the lamp and the strip, there are 2 cameras to measure the strip width and hole defects. Dual images detection would eliminate the influence from strip vibration. As shown in Figure 1, the original system has some weaknesses, including the use of special high-voltage and high-frequency lamps, high-pressure air ventilation, medium-resolution CCD, unstable inspection and abnormal detection results, etc. Therefore, we propose in this research systematic countermeasures to eliminate the weaknesses, including backlight LED, refrigeration chips, high resolution CCD, and ease of maintenance.

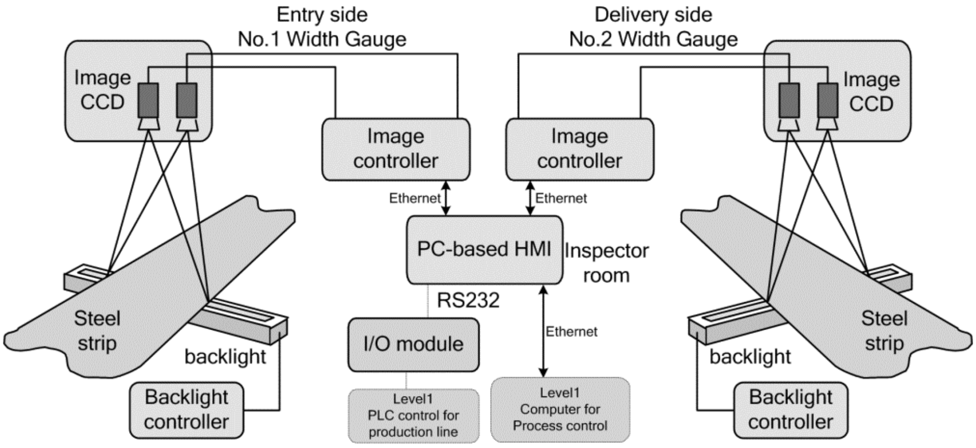

FIGURE 1. The width and holes inspection configuration diagram for the coated steel coils

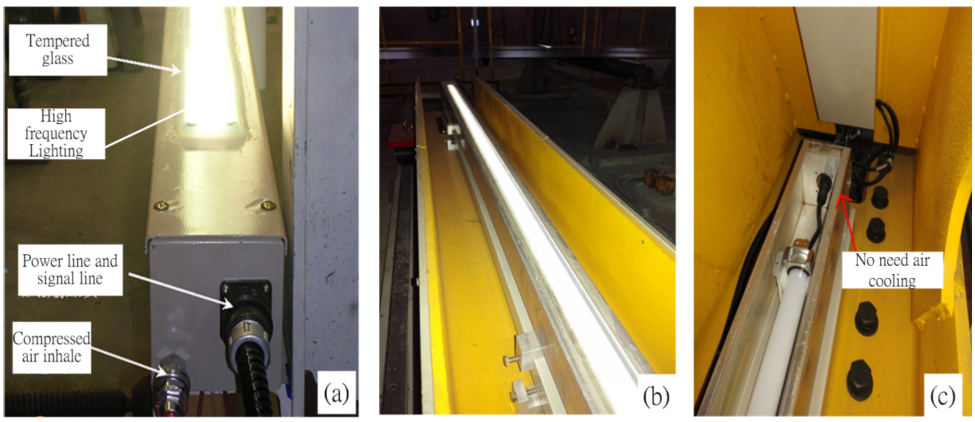

FIGURE 2. (a) High frequency lamp, (b) LED lamp, (c) LED lamp without air cooling

3. **Backlight Source Improvement.** The high-voltage and high-frequency fluorescent lamp has a very high working temperature. Thus, compressed air ventilation is needed for cooling to decrease the temperature down to 50 degrees Celsius. Under this condition, the normal lifespan of the lamp is around 2 years. Without compressed air cooling, the lifespan would be much shorter. In order to save energy and to have a more stable light source, we propose in this research to replace the original F96/T12 high-frequency fluorescent lamp with an LED lamp. The working temperature of an LED lamp is around 40 degrees Celsius without the compressed air ventilation. The lifespan of an LED lamp is around 100 thousand working hours, resulting in reduced maintenance requirement. An LED lamp also consumes much less power than high-frequency lamp. Figure 2(b) shows the LED backlight module. Figure 2(c) shows the inside view of the LED case without compressed air ventilation. The performance differences of the images captured under backlight of

high-frequency lamp and LED were shown in Figure 3. The brightness of images captured using the original lamp was insufficient at both sides. However, images captured using an LED lamp has satisfactory results with more uniform brightness. During the strip inspection process, there are many uncertain conditions, e.g., strip vibration, dust and fog, unstable backlight and non-uniform brightness. These uncertainties may cause the inspection system to error and allow unqualified steel strip coils to be released for sale. On-site experiments proved that use of LED backlight would reduce the uncertainties and could help avoid customer compensation claims.

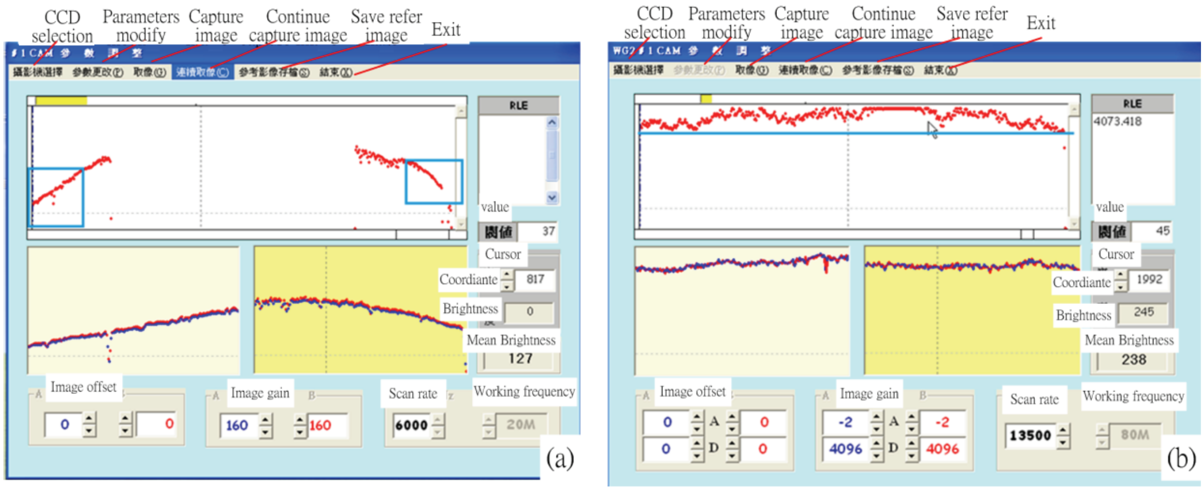

Figure 3. Lamp lighting image in software: (a) by high frequency operation lamp, (b) by LED lamp

4. **Image Processing and Refrigeration Chip.** The resolution of camera used in the automatic inspection system would affect the width and defect (holes) inspection results. Hence, the original Basler L101-02K CCD was replaced by the newer DASLA S3-20-04K40 CCD. The resolution was upgraded from 2048 pixels to 4096 pixels. Since the newer camera is manufactured by the same company, there is no compatibility problem. For 1600 mm steel strip, the original camera provides 0.78125 mm/pixel (1600 mm divided by 2048 pixels) resolution, and the newer camera provides a resolution down to 0.390125 mm/pixel (1600 mm divided by 4096 pixels). Hole inspection precision is increased from 1.6 mm to 0.8 mm. In addition, the newer DASLA S3-20-04K40 raises the scanning rate up to 13500 per second. This rate is 2 times higher than that of original Basler L101-02K, which means the measuring speed is also doubled.

In addition, as the case that CCD is sealed and high temperature associated with the production environment often causes the CCD to shutdown, compressed air was needed to cool the CCD outer case. However, periodic maintenance of the air compressor system may affect the CCD and cause unstable detection. Therefore, in this research, a Peltier device is used to cool the CCD. Meanwhile, the integration of advanced image capturing adapter and the inspection system could improve measuring speed, precision, and stability. The basic principle of a Peltier device is that it consists of a diode with ceramic substrate on two sides. When DC flows through the diode, one side becomes hot, and the other side becomes cold. For practical application, ventilation fans and plate-fin heat exchangers should be added on both sides to achieve ideal cooling effect. The specification of the proposed Peltier device TEC1-127040-40 is as follows. (1) I_{max}(A): 8 A, VMax(V): 15.5 V, (2) Assembly pressure: 85 N/cm^2, (3) Max. Draw OcmaxW: 77 W, (4) Temperature Deviation $\triangle$Tmax (Qc $=$ 0): over 60°C, (5) Working Condition: $-55 \sim 83$°C, (6) Package: silicon rubber sealed, (7) Dimension: L $\times$ W $\times$ H $=$ 40 (mm) $\times$ 40 (mm) $\times$ 4.8 (mm), (8) Element: 127 couples. Figure 4 shows the CCD camera cooling design before and after the proposed improvement.

There is usually a leakage associated with the air compressor equipment. 5% $\sim$ 10% is an acceptable range for the leakage. For instance, the leakage of a one-fourth inches pipe is about 2.8 M^3/min. Assume that it works for 8000 hours per year, and the calculated total wastage is up to 200 thousands NT$ (based on 2 NT$ per KWH and 61% bleeding coefficient). This wastage is equal to the one-year electric cost of one hundred and fifty 60 W lightbulbs. On the other hand, if two 77 W Peltier devices with 90% efficiency are utilized as the cooler instead of the air compressor system, it would cost just 8.21 NT$ for 24 hours ($2 \times 0.077 \times 2 \times 24 \div 0.9 = 8.21$), which is less than 3000 NT$ per year. Two small fans are used to ventilate the air near the inner and outer heat exchangers of the Peltier devices as shown in Figure 4(b).

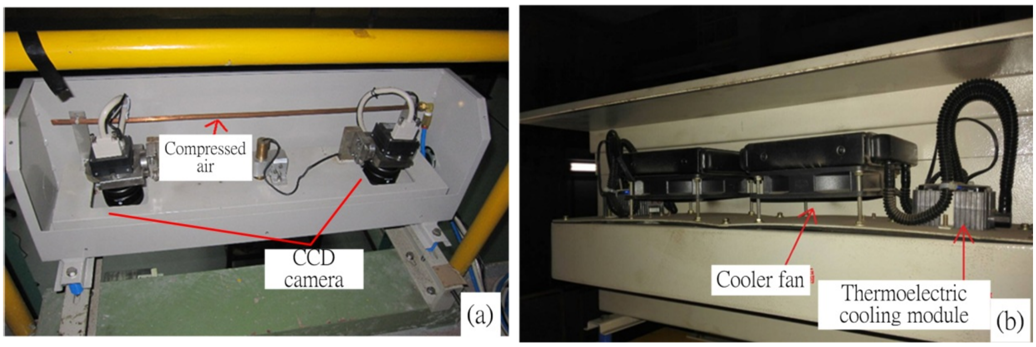

Figure 4. CCD camera cooling: (a) compressed air cooling system, (b) refrigeration chip module

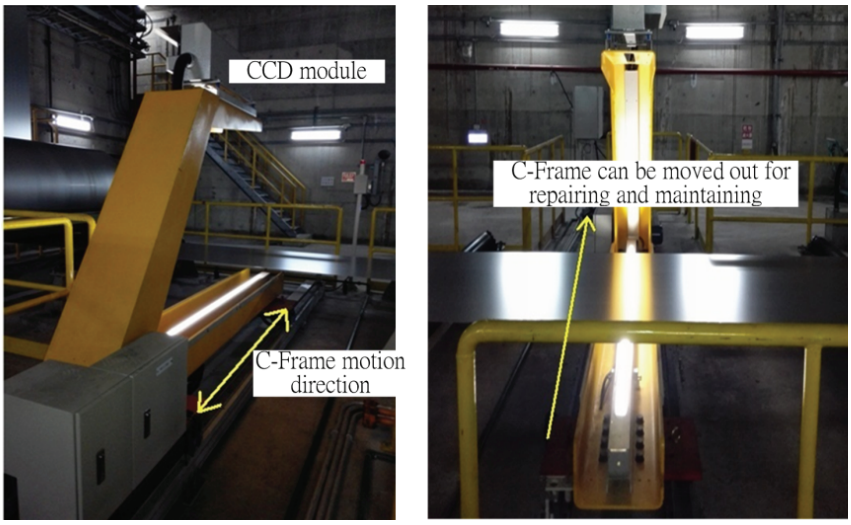

Figure 5. The proposed C-frame maintenance module

5. **C-Frame Maintenance Module.** Original inspection system is installed on a fixed bridge over the production line. It is impossible to replace the camera or make the necessary calibration during continuous production. To ease the maintenance work, the camera and the bridge were combined into a C-frame as shown in Figure 5. During continuous production, if maintenance required, it is easy to move the camera mounted on the C-frame out of the production environment, thus ensuring ease of maintenance and human safety.

6. **Conclusions.** Under increasingly stringent quality control and automatic inspection requirements for steel strip production process, the automatic width and defects inspection system proposed is able to reduce the amount of manual inspection needed and to enhance the efficiency, stability, precision, and performance of the automatic inspection system. This paper presents several new designs to improve the existing inspection system: (1) new backlight LED to smooth the lighting brightness, improve lighting stability, and to save more energy; (2) new high resolution CCD to double the inspection precision and measuring speed; (3) new Peltier device for CCD camera cooling; (4) integration of backlight LED and CCD cameras as a C-type framework to ease the maintenance works during continuous steel strip production. Future works proposed on the automatic inspection system include: (1) to replace the CCD cameras with 8 K resolution cameras in order to double current precision; (2) to decrease the strip vibration and fog factors in order to decrease the inspection error; (3) to stabilize the temperature of the CCD cameras in order to reduce the variance of width measurements.

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