Color-Fusing Technology Using Induction Heating

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Abstract

A unique color-fusing technology using induction heating has been developed, which has adopted in a newly released one-pass color laser printer. The color-fusing unit consists of a thin fusing belt made of heat-resistant resin containing metal, a heating roller with low thermal capacity, a fusing roller, and a pressure roller to compress the fusing roller with the fusing belt in between. An induction heater is disposed along and adjacent to the outer periphery of the fusing belt and heating roller. The newly developed fusing belt has a low thermal capacity, with a thickness of only several hundred micrometers, and has a structure that self-heats at high efficiency since eddy currents are generated in the heating portion by electromagnetic induction. The alternating magnetic field generated by the induction heater efficiently heats both the fusing belt and heating roller. This design shortens the warm-up time of the fusing unit from cold start to only 20 seconds. This color laser printer eliminates the need to preheat the fusing unit during stand-by time by employing the induction heating technique and achieves energy saving of 90% or more compared with conventional printers.

Introduction

The WORKiO KX-CL500/KX-CL510 series color laser printers featuring our tandem printing system was released in early 2003. This series realized the fastest printing speed in the same class due to the utilization of our original IH (induction heating) fusing technology and also featured compactness and light weight. In the KX-CL500/KX-CL510 series, the printing rate is 17 ppm for color and 21 ppm for black printing, respectively, and the IH fusing technology is optimized to achieve stable and high fusing quality.

The main feature of the IH color-fusing unit installed in the printer is a configuration that an induction heater is located at the external periphery of a fusing belt. In addition, the fusing belt is made of heat-resistant resin base including metal.

Due to this creative configuration, the heat generation by electromagnetic induction gives high efficiency and that enables the fusing belt to be directly and rapidly heated. Even when cold starting, the printer finishes warming-up in slightly 20 seconds.

In a color laser printer with this IH fusing unit, therefore, preheating of the fuser can be eliminated and the overall power consumption is suppressed to 9 watts at its power-save mode. This represents drastic energy saving compared with conventional printers.

Figure 1. Panasonic WORK KX-CL500/ KX-CL510

The Technical Challenges of Color Fusers

A conventional laser printer employs a heat roller fusing system. A halogen lamp is installed inside a heating roller and warms the roller by radiant heat. For color printing, in particular, both the heating roller and pressure roller need to have a large diameter to secure a wide nip area and ensure stable fusing quality. In addition, the heating roller is designed to become concave in the nip area to enable easy separation of the printed paper at the exit of the area. This design, however, gives a high thermal capacity to the heating roller since the roller is covered by a thick rubber layer with low heat conductivity.

This causes a problem: it takes a long time for the heating roller to reach the predetermined control temperature. To solve this problem, in conventional models the heating roller is preheated during the waiting time to shorten the warm-up time. However, preheating in this way wastes a considerable amount of power.

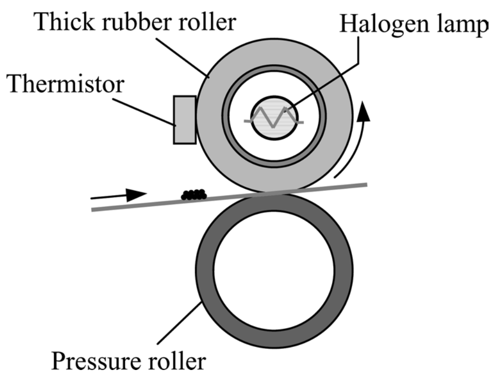

Figure 2. Schematic of conventional heat roller fusing

IH Color Fuser

To solve these technical challenges, an IH color-fusing unit with short warm-up time has been developed: that is, the device warms up very rapidly without the need for pre-heating during the waiting time. The configuration of our newly developed IH color-fusing unit is shown in Fig. 3. The device consists of a thin belt made of heat-resistant resin including metal, a heating roller with low thermal capacity, a fusing roller made of foamed material, and a pressure roller which applies pressure to the fusing roller through the fusing belt. An induction heater is disposed along and adjacent to the external periphery of the fusing belt and the heating roller. The advantage of this fusing unit is that the toner fusing portion and belt heating portion are completely separated functionally from each other. This configuration enables the reduction of the thermal capacity of the heating roller by the use of a thin metal roller with high heat conductivity. In addition, a temperature-detecting thermistor can be located inside the fusing belt, preventing wear to the belt surface. Tables 1 and 2 show an outline of the construction of the IH color fuser and its operational specifications, respectively.

Table 1. Specification of IH Color Fuser

Member	Diameter [mm]	Thickness [mm]	material
Heating roller	Φ20	0.4	iron
Fusing roller	Φ30	2.0	Silicone sponge
Pressure roller	Φ30	5.0	Silicone rubber
Fusing belt	Φ45	0.26	PTFE+silicone+PI

Table 2. Performance of IH Color Fuser

Process speed	125 [mm/s] (black) 100 [mm/s] (color)
Input power	900 [W] or less
Warm-up time	20 [s] or less

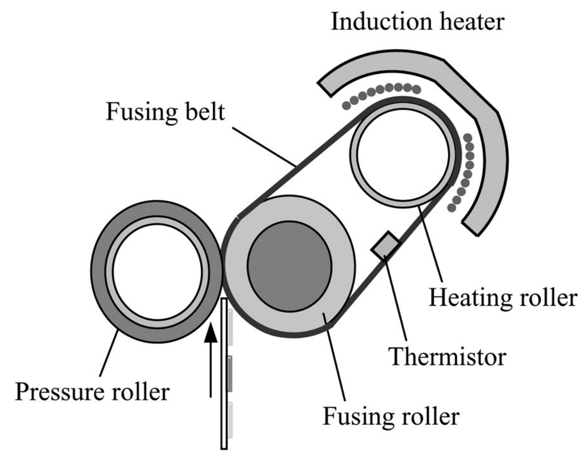

Figure 3. Construction of IH color fuser

Figure 4 shows the transformed state of the roller at the fusing nip portion. The structure is designed such that the fusing roller is softer than the pressure roller, and thus the pressure roller creates a moving depression in the fusing roller through the fusing belt. Owing to this depressed portion, the paper is pulled off the belt when leaving the nip portion. This leads to easy detach of the paper.

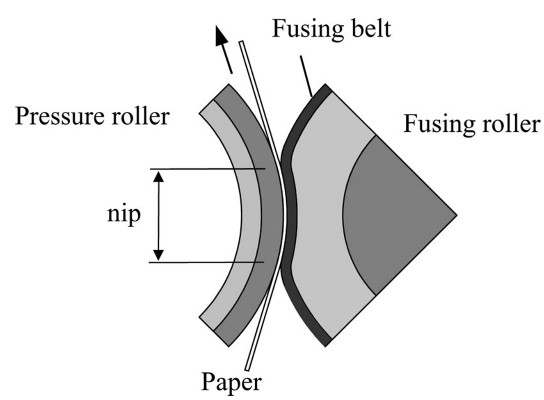

Figure 4. Profile of roller deformation at nip region

Heat Generation by Induction Heating

The heating principle of the IH fusing unit is described referring to Fig. 5. High frequency alternating current supplied to the IH coil produces an alternating magnetic field, which creates eddy currents in the heating portion of the fusing belt and heating roller. Due to Joule heat caused by these eddy currents, both the fusing belt and fusing roller self-heats. Figure 6 shows a simulation result of the electromagnetic field near the IH coil. This illustrates that the magnetic field induced by the IH coil is concentrated on the heating roller and the magnetic field generated at the back of the IH coil is absorbed by the ferrite cores.

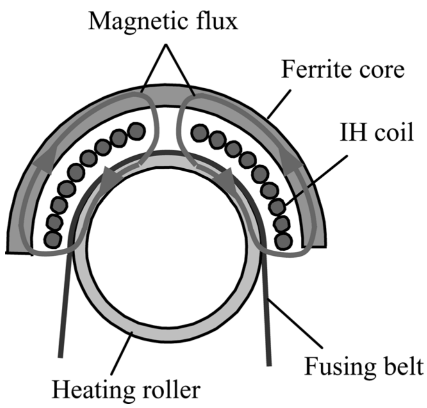

Figure 5. Principle of heat generation by induction heating

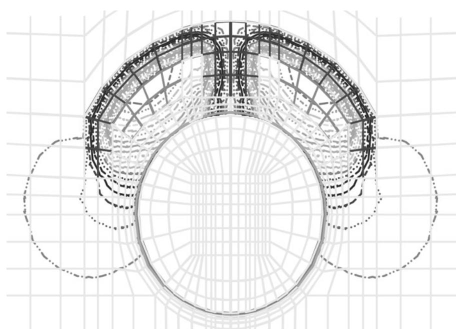

Figure 6. Simulated magnetic field

IH Coil Unit

The IH coil unit is an important factor in the design, since the electromagnetic field induced by the IH coil is greatly influenced by the coil and cores arrangements. Figure 7 shows how the magnetic characteristics change depending on the coil and cores arrangements. Compared with when the coil is wound around the ferrite cores in an overlapping manner (a), when wound along the outer periphery of the roller (b), the load resistance for the same inductance is nearly tripled. This indicates that the arrangement (b) generates greater magnetic binding strength and magnetic energy is being converted into Joule heat at higher efficiency.

Table 3 shows a summary of the specifications of the IH coil unit. General-purpose litz wire, which is reasonably priced and easy terminal preparation, is used for the IH coil. The heat loss of the coil is about 5%. In addition, by optimizing both inductance and resistance, the coil is designed such that the current is limited to 50 A or less, even at peak value, and the heat loss and noise at IGBT are suppressed.

In the arrangement (b), the sum of energy loss of the coil and control circuit loss is about 10%, meaning that the heat generation efficiency is over 90%.

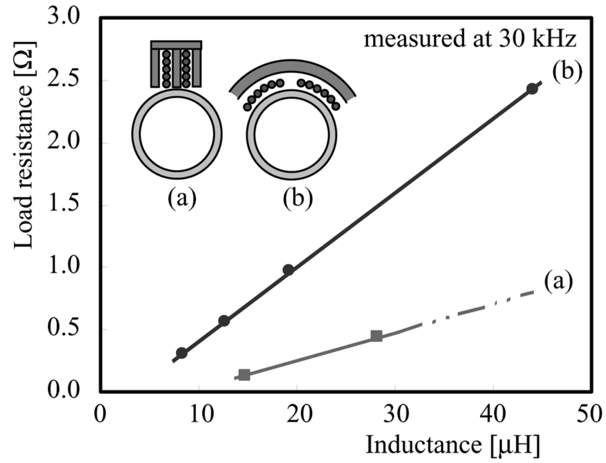

Figure 7. Comparison of coil and cores arrangements

Table 3. Specification of IH Coil Unit

Grade of heat resistance	H[180°C]
Diameter of a wire	0.19 [mm]
Number of strands	40
Operating frequency	20 ~ 50 [kHz]
Coil currency	50 [A] or less
Coil inductance	45 [mH at 20 kHz]
Load resistance	1.45 [Ω at 20 kHz]

Fusing Belt

The fusing belt is made by covering PI (polyimide) heat-resistant resin base with a silicone rubber layer and PTFE surface-releasing layer. The structure of the fusing belt is shown in Fig. 8. A resin-based belt is more resistant than a metal-based belt to repeating fatigue at the nip portion and mechanical load in the thrust direction generating during rotation. This mechanical resistance of resin-based belt, therefore, makes the life of the belt long. The newly developed fusing belt is made of PI heat-resistant resin base containing metal. As a result, the belt self-heats by electromagnetic induction, and a high-speed thermal response is obtained due to efficient heat conduction to the belt surface. Table 4 shows the results of a comparison experiment on the warming characteristics of the metal-contained belt. The added metallic material shortens the warm-up time from 22 seconds to 18 seconds.

Table 4. Comparison of Base Layer Material

Base layer material	PI	PI+metal
Heat generation efficiency [%]	84	90
Warm-up time [s]	22	18

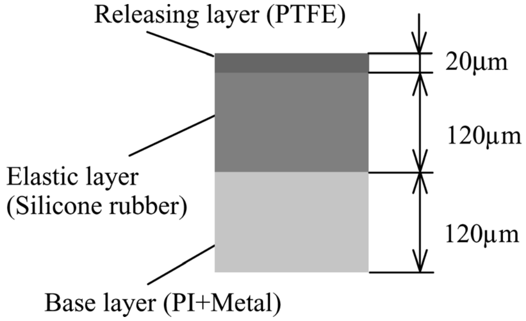

Figure 8. Layer construction of fusing belt

Features of Outer-IH vs. Inner-IH

As shown in Fig. 3, the newly developed IH coil unit has an outside heating structure where the IH coil is located along the outer periphery of the heating roller. Figure 9 also shows another type,[1-3] with an inside heating structure in which the IH coil is disposed along the inner surface of the heating roller.

The advantage of an outside heating structure over an inside heating structure is that the temperature rise of the coil due to radiant heat from the heating roller is smaller and the coil can be cooled more easily. A general-purpose grade coil, which is reasonably priced and high produceability, can therefore be employed.

In addition, maintenance cost is minimized because the fusing unit can be replaced, leaving the IH coil unit in the printer body. On the other hand, the outside heating type has a larger volume than the inside type, since the IH coil unit is placed outside.

In addition, magnetic flux generated by the coil must be blocked so as not to leak outside, since the IH coil is not wrapped by the metal roller.

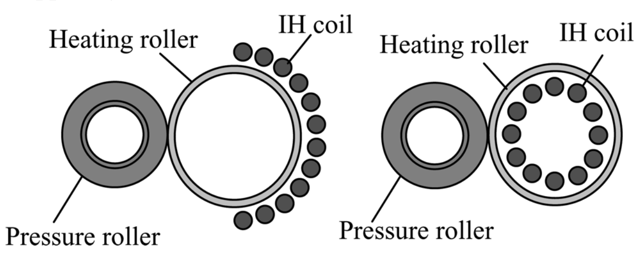

Figure 9. Outer-IH vs. Inner-IH

Table 5. Outer-IH vs. Inner-IH

Items	Outer – IH	Inner – IH
Coil temperature	<150°C (heating roller at 170°C)	>200°C (heating roller at 170°C)
Fuser maintenance	Replaced without IH coil unit	Replaced with IH coil unit
Volume	Bulky	Compact
EMC	Outer shield member required	Absorbed by heating roller

IH Control Technologies

EMC Control

Because the IH coil of the newly developed IH color fuser was not wrapped by a metal roller, a configuration for blocking magnetic flux leakage was devised. Figure 10 shows the magnetic shield configuration. Nonmagnetic metal plates with looped shape are arranged outside the coil. Since the eddy currents generated when leaked flux passes through the shield plate induce magnetic fields in the opposite direction of the coil-generated field, the leaked flux is canceled. Thereby, flux leakage was reduced by 20 dB or more at the fundamental frequency compared with the version without a magnetic shield.

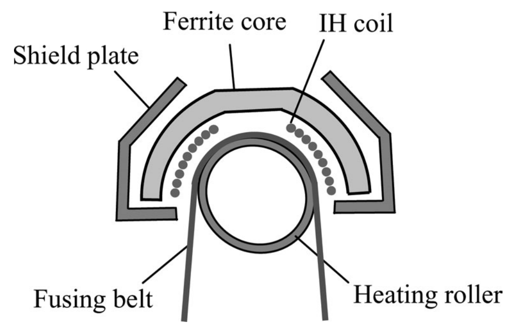

Figure 10. Construction of EMC control

Magnetic Flux Control

In the IH color-fusing unit, several ferromagnetic ferrite cores are placed on the reverse side of the IH coil to efficiently heat the fusing belt and heating roller. Figure 11 is a simulation result of magnetic flux density distribution of the fusing belt. It is seen that the flux concentration around the ferrite cores generates non-uniformity in the flux distribution. Under these conditions, as shown in Fig. 12, temperature non-uniformity occurs in the rotation direction to the fusing belt. Figure 12 shows the surface temperature of the belt just after warming-up, as measured by an infrared thermometer, and the temperature distribution along the axis.

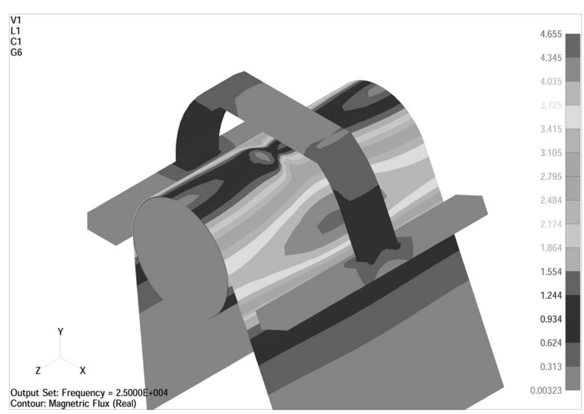

Figure 11. Simulated magnetic flux distribution

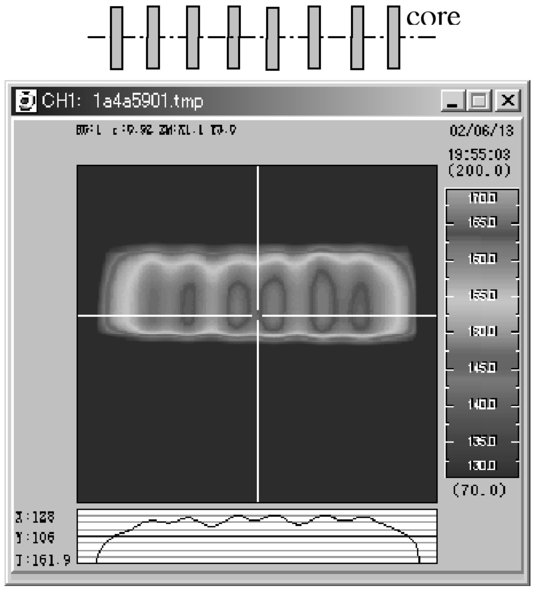

Figure 12. Temperature distribution in case of rectangular arrangement

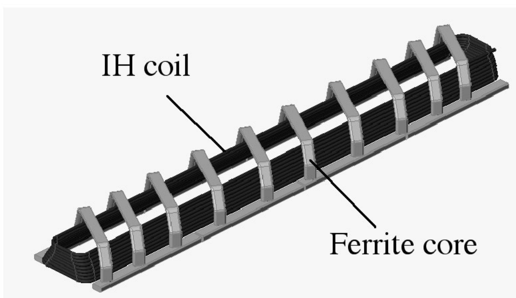

Figure 13. Construction of ferrite core

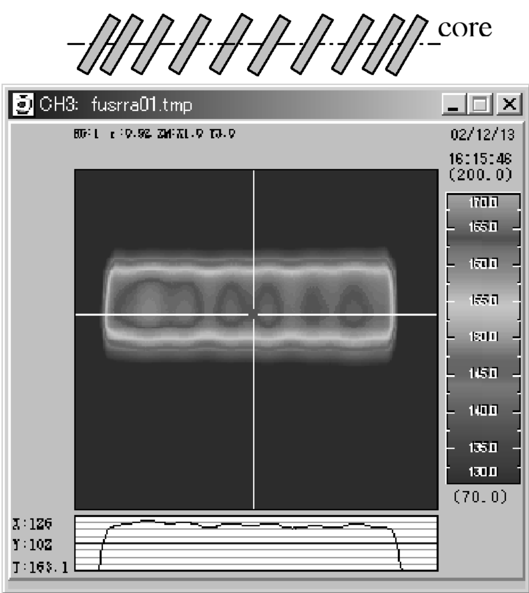

Figure 14. Temperature distribution with slant arrangement

As a countermeasure to this temperature non-uniformity, the ferrite cores in the coil reverse side were arranged with slant to the roller axis as shown in Fig. 13. To prevent temperature drop at both ends of the fusing belt due to heat radiation from the belt and heat loss from the ends, the cores are arranged densely around both ends, and the reverse-side ferrite cores are connected by the cores on each side. As a result, flux from the coil is almost evenly distributed along the roller axis, making the temperature of the belt surface uniform. Figure 14 shows the surface temperature of the belt just after warming-up, measured by an infrared thermometer, and temperature distribution along the axis when the cores are slant to the roller axis. The surface temperature non-uniformity was improved by about 15 degrees centigrade compared with the previous arrangement of cores.

Conclusion

In the IH color-fusing unit, the induction heater is placed along the outside periphery of the fusing belt and heating roller. This newly developed fusing belt, which has a low thermal capacity and contains metal, efficiently self-heats by the eddy currents generated in the heating portion by electromagnetic induction. Warm-up time from cold starting of the unit has been reduced to only 20 seconds. The color laser printer in which this IH fusing unit is installed achieves more than 90% energy saving compared with conventional machines. In this development, the following original technologies have been developed.

1) The generation of heat in the belt itself by mixing metal into the base resin material,
2) Suppression of the magnetic flux leakage from the IH coil effectively, and
3) Making the magnetic flux uniform distribution by the proper arrangement of ferrite cores.

References

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Biography

Masahiro Samei obtained his B.E. and M.E. degrees in Mechanical Engineering from Kyushu University, and his Doctorate in Engineering from Kyushu Institute of Design. He joined Kyushu Matsushita Electric Co., Ltd. (now Panasonic communications Co., Ltd.) in 1989, where he has been working on the study of the heat transfer in toner fusing process and the improvement of fuser performance by induction heating technique since ever.