e-Coil Roller Fusing System for Energy Saving and Long Life

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Abstract

An original e-Coil roller fusing system whose warm up time could be reduced below in a half compared with a conventional halogen lamp fusing system. The name of e-Coil roller is taken from which the heating coil is expanded by hydrostatic pressure onto the inner section of a heat roller. The e-coil roller fusing system was designed to have the direct heat-conductive structure without any air gap between insulation layers and the heating coil for increasing heat transfer efficiency. Also the e-Coil fusing system has excellent heat conservative capability so that on continuous printing electric power supply to fusing system is unnecessary. Since the heat source, that is the heating coil, rotates with the fusing roller, the rotating electric power supply should be maintained without any problem like spark or the increase of harmful contact resistance. For safety the robust insulation layers are prepared to sustain high withstanding voltage and surge induced by a bolt of lightning. Ni-Cr ribbon type resistive heater used as a heat source of the e-Coil roller have advantages that current is always maintained to be constant unlike the tungsten wire of halogen lamp whose in-rush current drastically increased during early time right after power-on. Major elements of SMPS are damaged that their lives are shortened. In this paper, the e-Coil roller fusing system for 22PPM MFP (Multi Functional Peripheral) is designed to satisfy the main design factors. The important performances like warm up time, power consumption on print, Flicker and additional power saving effect by slow cooling of e-Coil roller are presented and compared with results of halogen lamp fusing system.

Introduction

The Samsung SCX-6x20 MFP is designed as a true multifunctional device where all functions (copy, print, scan, fax and e-mail) are optimized for excellent performance in the office. This MFP realizes the faster warm up time from the power-on to the printable ready-state. Main characteristics of the e-Coil fusing system is that fully conductive heat transfer process makes warm-up-time short and saves electric power consumption during warming up. The other feature of the e-Coil fusing system installed in this MFP is that electric power is supplied from voltage source to the e-Coil roller through the sliding contact from a fixed carbon brush to a rotating Cu-Sn sintered electrode. Therefore the heating coil, i.e. heat source can rotate together with a fusing roller. Due to this creative configuration, the heat generation from the resistive heating coil can be effectively transferred to the surface of a fusing roller so that toner on media can be fused and adhered. In a halogen lamp, tungsten wire which has strong PTC (Positive Temperature Coefficient) property makes dangerous in-rush current right after power-on during some period. PTC is the characteristics that as temperature rises, its resistance increases. Ni-Cr heating coil of which resistance is constant to all temperature can increase the life of major elements on a SMPS (Switch Mode Power Supply) to 20% by disappearing in-rush current comparing with a halogen lamp. FEM simulation of heat transfer to minimize the temperature discrepancy acquires the optimal density distribution of heating coil along a fusing roller. The insulation layer of the e-Coil roller is strengthened to withstand unpredictable high current from power source that make circuit element breakage and accordingly image failure. The optimal thickness of the insulation layer is experimentally determined by considering the trade-off relation between warm-up-time and withstanding voltage.

Figure 1. Samsung SCX-6x20 MFP.

Conventional Halogen Lamp Fusing System

A conventional halogen lamp fusing system that has widely used as a heat source of a laser beam printer has some disadvantages as follows. First of all, since heat transfer efficiency of radiant heat from a halogen lamp is very low, the warm-up-time delay has been the main user's complaint. Tungsten wire in a halogen lamp radiates and generates heat when current is supplied to a halogen lamp as shown in Fig. 2. Light permeates transparent quartz bulb and is converted to heat energy at the black coat of the inner wall of the fusing roller and this heat melts toner and warms a media. Therefore radiant heat loss through air layer and the dependency of the emissivity (ε) of the black coat make a halogen fusing system slowest fusing system and induces large energy consumption. Also tungsten wire in a halogen lamp has the resistance difference between in the ambient temperature and in a very higher temperature (ranges from 1200 to 1400°C). Therefore right after power-on the in-rush current flows in SMPS elements like a photo triac, a fusible resistor and a diode and regularly stresses them, the life of elements can be possibly shortened. Also in-rush current gets flicker more harmful. The resistance of tungsten wire of a halogen lamp which is 8Ω in the ambient temperature increases to 80Ω after a transient period of about 300ms so that its electric power is 600watt. Figure 3 shows that in-rush current get saturated to its nominal value after 250ms.

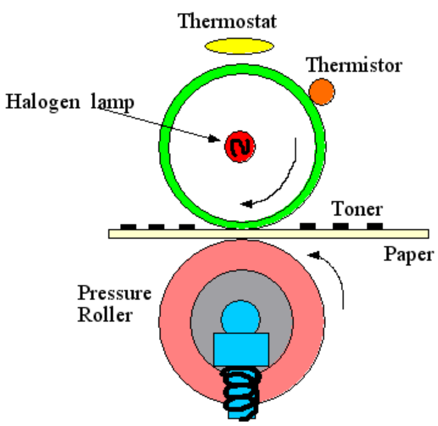

Figure 2. Schematic diagram of the conventional lamp system.

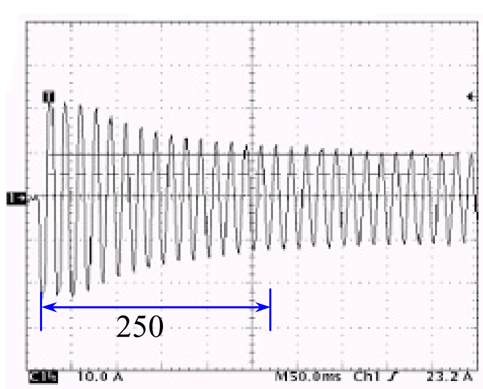

Figure 3. In-rush current occurred by halogen lamp.

e-Coil Roller Fusing System

For eliminating the referred problems of a halogen lamp fusing system, the e-Coil roller fusing system that uses Ni-Cr resistive heating coil is developed. In the e-Coil system, warm-up-time and power consumption during warming up are shortened respectively to 47% and 51% comparing with a halogen lamp fusing system. Also Ni-Cr heating coil has no PTC feature so that in-rush current doesn't generate in what case. Heat transfer mechanism of the e-Coil roller is perfect conduction process which heat generated from Ni-Cr heating coil is transferred through insulation layers to the releasing surface of a fusing roller. In the e-Coil fusing system, the heat transfer efficiency can be increased by the perfect consolidation between multi-layers which are composed of a fusing roller, outer insulation layer, heating coil, inner insulation layer and an expansion pipe, inwardly. Eventually plastic deformation of an inner expansion pipe by hydrostatic pressure increases heat transfer by diminishing air gap between layers. If heat generated from a heating coil is not effectively transferred to the neighboring material that temperature of a heating coil is highly increased, a heating coil would be abruptly broken to the end. Therefore the perfect consolidation by expansion is very important to increase the life of a heating coil and decrease warm-up-time.

In the e-Coil roller immediately after manufacturing the expansion pipe that pushes the insulation mica sheet and a heating coil to the inner surface of the fusing roller didn't be rotated by 12Nm of torque. The torque transmission capability of the e-Coil roller after 100k prints isn't under 10Nm so that this expansion has enough combining force.

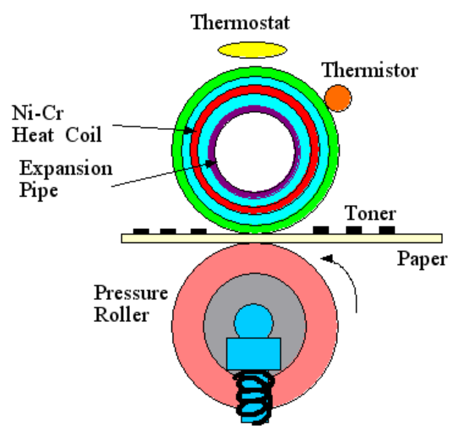

Figure 4. Schematic diagram of the e-Coil system.

Table 1. Specification of the e-Coil Roller Fusing System

Fusing Roller	AL 5052 Outer diameter Ø26.3 Thickness t1.0
MICA sheet	Thickness t0.15 × 3 layers
Heating Coil	Ni-Cr Resistive Coil
Expansion Pipe	AL 3003 Outer diameter Ø22.1 Thickness t0.3

Superiority in Energy Saving

The advantage of the fusing system having fast warm-up-time is that total energy consumption can be reduced because preheating isn't required for stand-by mode. In a conventional halogen lamp fusing system of 900watt, the rising time spends about 40 seconds from ambient temperature to the toner fusing temperature of 190°C. After performing printing job, stand-by mode in which temperature of a fusing roller is maintained to about 150°C during 5 minutes is preparing for next printing commands. However the e-Coil roller in same electric power only requires 20 seconds to the toner fusing temperature so that electric power consumption during stand-by mode is not needed maintaining to constant temperature. Comparing with a halogen lamp fusing system having energy consumption pattern like figure 5, the e-Coil roller fusing system having energy consumption pattern like figure 6 is more advantageous. SCX-6x20 MFP adapting the e-coil roller cuts the power consumption during stand-by mode by 30watt.

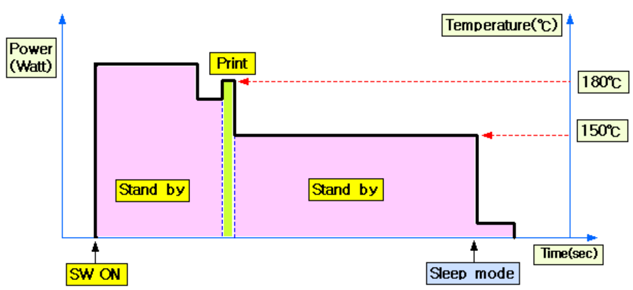

Figure 5. Energy consumption in the halogen lamp system.

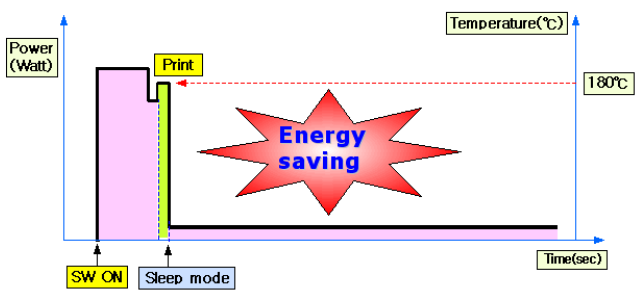

Figure 6. Energy consumption in the e-Coil system.

Heat source : Resistive Heating Coil

The wide and thin ribbon type heating coils with a large aspect ratio are applied to the e-Coil roller so that heat transfer is very quickly performed to the neighboring materials and physical damage of the insulation mica sheet can be minimized. Since the electric power and the resistance of the e-Coil roller is set to 900watt and 54Ω for 220V, width and thickness of the heating coil are determined to 2.0mm and 0.1mm respectively. In 110V the resistance of the e-Coil roller is set to 13.5Ω, width and thickness are determined to 1.0mm and 0.09mm respectively.

AC Connections

Both end parts of the e-coil roller are composed as Figure 7. At most outer of the e-Coil roller an aluminum pipe with teflon coat is located and a Ni-Cr heating coil are covered with insulation mica sheets. At most inner the expansion pipe is located to minimize air gap between a heating coil and insulation sheets. The terminal plate that is made of phosphor bronze connects electrically a heating coil and a Cu-Sn electrode. Terminal plate and Ni-Cr coil are laser-welded in two points to reduce the possibility occurring spark at a point of contact at which its tensile strength is increased over 100N.

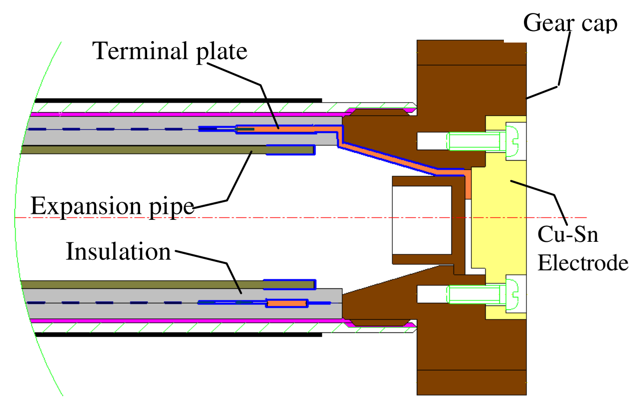

Figure 7. End section of the e-Coil roller.

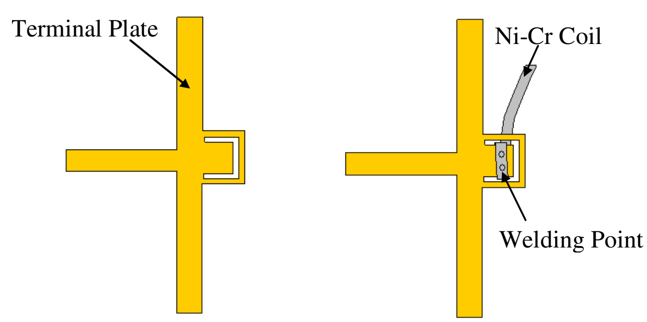

Figure 8. Terminal plate and Joint method.

Insulation Layers

Though mica sheet is thin, it has sufficiently superior insulation property. Because mica sheet have enough flexibility to wind to a roll and have cost competitiveness to mass production, it is regarded as the optimal solution to the e-Coil roller. The withstanding voltage of one mica sheet of 0.15mm ranges from 2kVac to 3kVac, which is made by blending mica powder with silicon adhesive for high temperature. In general electric insulation material is hard to efficiently transfer heat so that heat conductivity of mica sheet is about 3~4W/mK which is much smaller than that of metal like aluminum and copper. Insulation layers are designed to sustain withstanding voltage of 6kVac when the leakage current is maintained under 10mA for one minute. These insulation layers are specially prepared to satisfy PL

(Product Liability) rules for an electric shock and a fire. The edge burr of terminal plate that can be induced to crack to insulation sheet is strictly removed so that it is manufactured by etching method. This micro crack in the mica sheet could result in the breakage of insulation. Figure 9 shows relation between warm-up-time and withstanding voltage according to the thickness of mica sheet in the e-Coil roller of SCX-6x20 MFP.

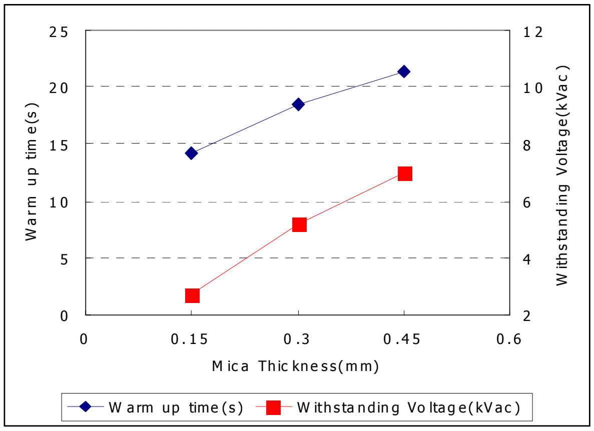

Figure 9. Withstanding voltage and warm-up-time according to thickness of mica sheets.

Rotating Electric Power Supplying Elements

The carbon brush and Cu-Sn electrode which supply electric power to the e-Coil roller in Figure 10 are manufactured by sintering fine powders under 10 µm so that they have sufficient self-lubricating property. The end shape of the carbon brush with a large round can be self-adjusted to maintain optimal contact with Cu-Sn electrode and make stable application of high current. Not only the carbon brush made of copper and carbon but also Cu-Sn electrode made of copper and tin are apt to oxidize with oxygen from air. This thin oxidized film increases contact resistance and result in locally heating at the contact point by the bottleneck of current. A small amount of silver powder to the carbon brush prevents this thin oxidization from growing. Accordingly contact resistance can be lowered than 10%. The allowable current capacity of the material of the carbon brush is 25A/cm^2. The size of the carbon brush is determined by considering its current level of electric circuit. For 900watt of the e-Coil roller, the current in 220V is 4.5A and the current in 110V is 9.0A. Therefore the diameter of the carbon brush are determined to be Ø7.5 and lead wires are determined to be a bundle of 256 in which allowable currents are 14A. This allowable current level of the carbon brush is 55% higher than 9A in 110V and local heating by current bottleneck is prevented. These carbon brush and Cu-Sn electrode for rotating power supply can be used without any spark and arc under phase angle changing AC current of 50~60Hz. After 100k prints mass change of the carbon brush is only 2% when the carbon brush presses Cu-Sn electrode with 2.7N.

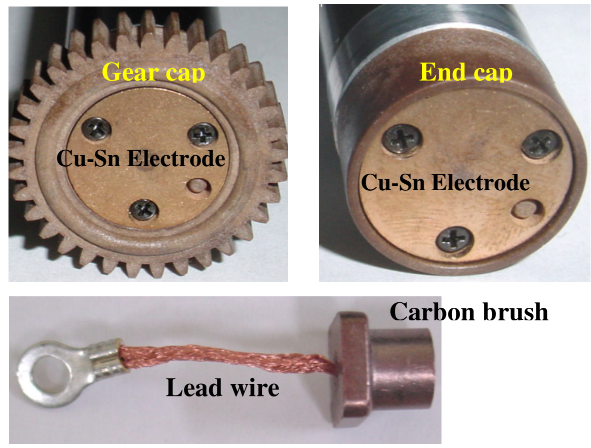

Figure 10. Cu-Sn electrodes and a carbon brush.

Heat Transfer Mechanism

When AC power is supplied to Ni-Cr coil of the e-Coil roller of 900watt, the temperature of Ni-Cr coil goes up from 25°C to 190°C like Fig. 11 at 7 seconds. However heat conductivity of the insulation mica sheet is very low, ranges from 4 to 6W/mK, so that the surface temperature of the e-Coil roller goes up to 190°C at 23 seconds. When the surface temperature of the e-coil roller rises to 190°C, the temperature of Ni-Cr heating coil rises by 390°C. After transient period the temperature of Ni-Cr heating coil will become low at 240°C and will maintain this temperature during continuous printing. Table 2 shows temperature distributions of each component of the e-Coil roller. Transient temperatures of each component represent when temperature of Ni-Cr heating coil is 390°C as maximum. Steady state temperatures of end cap and gear cap are fully saturated values after printing during 2 hours.

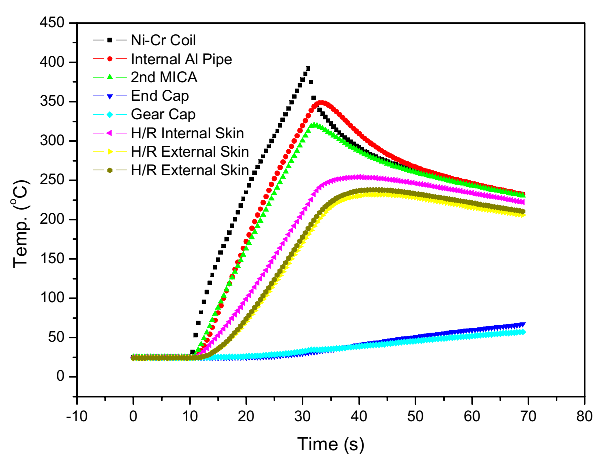

Figure 11. Temperature rising comparisons among each parts.

Table 2. Temperatures at Each Point of the e-Coil Roller

State	Transient	Steady state
Ni-Cr Coil	390°C	241°C
Expansion Pipe	334°C	230°C
2nd Mica sheet	308°C	227°C
End Cap	34°C	140°C
Gear Cap	34°C	123°C
Inner Surface of the Heat Roller	216°C	200°C
Outer Surface of the Heat Roller	184°C	185°C

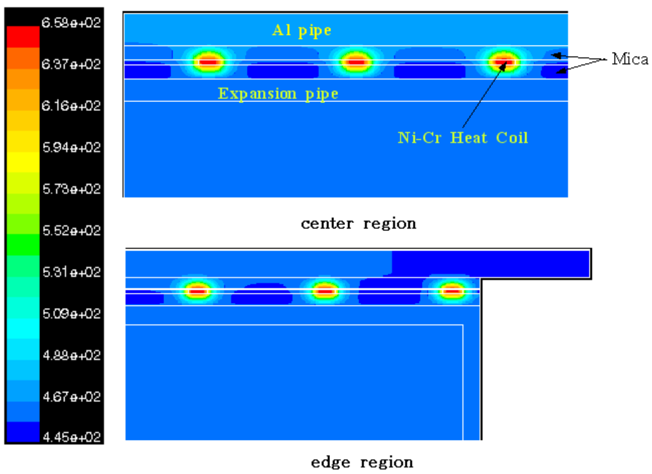

Figure 12. Temperature gradient around the heating coil.

Determination of the Winding Density of the Heating Coil

When the interval among each turn of the heating coil is equal, temperature deviation is occurred by heat irregularity that is induced by flowing out through both ends of the e-Coil roller. The FEM simulation of heat transfer determines the optimal density distribution and the interval of the heating coil. Figure 11 shows that temperature distributions of the e-Coil roller around a heating coil in transient period.[1,2] All components like a fusing roller, insulation mica sheet, a heating coil and an expansion pipe are modeled as 2-dimensional axisymmetric elements. The uniformity of the surface temperature of the e-Coil roller, in which the variation of temperature is less than 5°C, obtained when the interval among the heating coil at central region is set to 3.5 mm and the interval among the heating coil at both 20% end region over total length is set to 2.0 mm. In transient period when the temperature of the heating coil rises to 385°C, the surface temperature of the e-Coil roller rises to 190°C. We can know that this calculated result is very similar to the experimental result.

Conclusion

The newly developed e-Coil roller fusing system which uses heat energy generated from Ni-Cr heating coil as heat source is composed of the carbon brush and Cu-Sn electrode as the rotating power supplying elements and mica sheet layers as insulator and a thin aluminum pipe for expansion. In the e-Coil roller fusing system, warm-up-time and electric power consumption during warming up are shortened respectively to 47% and 51% comparing with a halogen lamp fusing system. Insulation mica layers can sustain withstanding voltage of 6kVac from the abnormal electric surge. In this development, the following original technologies have been developed.

1) The optimal heat transfer layer design for fast heat conduction through squeezing air by expansion,
2) In rush current-free Ni-Cr resistive heating coil as heat source for toner fusing, and
3) Rotating electric power supplying elements without any spark and arc.

References

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2. F. P. Incropera, David P. DeWitt, Fundamentals of Heat and Mass Transfer, 5th edition, John Wiley & Sons, Inc., 2002, pg. 204.

Biography

Durk-hyun Cho received his Ph.D. in Mechanical Engineering from the Korea Advanced Institute of Science and Technology, Korea, in 2000 majoring in mechanical design with new materials. Since 2000 he has worked in the Digital Printing Division at Samsung Electronics in Suwon, Korea. His work has primarily focused on the development of the new instant-fusing technology, including induction heating and insulation materials.