A Simulation Model for Estimation of Flicker Levels Induced by On-Off Switching of a Halogen Heater of a LBP Fuser

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Abstract

The present study proposes a simulation model for halogen heater to estimate flicker levels. In the present model of halogen heater, the temperature dependence of filament resistance is taken account for estimation of flicker levels and the temperature is estimated by energy balance of input and output powers. The energy balance is modeled like that an input electric power to a halogen heater filament is dissipated for rise of the filament temperature, the radiation for heating fuser and the loss. The ratio of each power dissipation is determined by the transient response measurement by using an actual halogen heater. The halogen heater model is capable of calculating a filament temperature, a filament resistance and a filament current for any input voltage pattern. Using the current value calculated, a flicker level is obtained by a calculation program developed in accordance with measuring procedure of the flickermeter which is specified by International Standard.

Flicker levels for square signals with various period and duty were calculated using the proposed model and compared with those measured by the flickermeter. A good agreement was obtained between the calculation and measurements. The present model enables flicker simulation of fuser temperature control using a halogen heater.

Introduction

A flicker is light intensity fluctuations, which is caused by voltage fluctuation in power line. The voltage fluctuation is the result of switching high power industrial appliances such as arc furnaces and welding equipment, and of domestic appliances such as refrigerators and dishwashers. The light flicker is annoying and irritating. The International Standard in Europe specifies the limitation of flicker.[1]

In these circumstances, the design of laser printers requires great attention to the flicker. Most of the laser printers use a filament-based halogen heater that fuses toner image on a paper. The temperature of the fuser is controlled by switching of the halogen heater for fixing toner image properly. The resistance of the filament is low at room temperature and the switching of a cold filament of the halogen heater causes a large current. It may cause voltage fluctuations that are originated from the interaction between the large current and the impedance of the power distribution line.

In order to reduce flicker level, a variety of control methods of halogen heater or power converters have been developed in resent years.[2,3] In the future, however, more advanced control methods to eliminate flicker will be required for using of a high power halogen heater for the quick first printing. In order to develop a flicker-free control methods of the fuser temperature, estimation of flicker levels and thermal energy radiating from filament under various condition is needed. The estimation of those values, however, is not simple for the reason that a filament resistance is a function of temperature. Reference [4] showed a model of filament resistance that is represented by an exponential function of time, while the model does not include effect of thermal energy.

In the present study, we propose a simulation model of a halogen heater of a laser printer, which allows estimation of not only flicker levels but also radiating thermal energy to develop an optimal method of fuser temperature control.

Models

The voltage fluctuations by switching of the halogen heater cause the fluctuations of luminance of illuminating equipment. The fluctuations of luminance may irritate the human. First, we describe the relationship of the voltage fluctuation and a human flicker sensation. Second, we examine the model that represents the voltage fluctuations by the switching of halogen heater.

Flickermeter Model

The block diagram of IEC flickermeter is shown Figure 1. The block 1 adapts the input voltage level to an internal reference level in order to measure independent from input carrier voltage level. The flicker is based on the 230V/60W incandescent lamp. The flickermeter includes the lamp model and human visual system in the blocks from 2 to 4. The block 4 outputs the instantaneous flicker sensation. In block 5, the instantaneous flicker sensation level is sampled for specified interval and the flicker evaluation values, such as a short-term flicker severity (*Pst*) and a long-term flicker severity, are calculated statistically using the distribution of the instantaneous flicker sensation.

In the present study, we developed the program, which simulates the flickermeter which is base on IEC standard[5] and is utilized with a heater model described later.

Halogen Heater Model

As shown in Figure 2, a power fed to a halogen heater heats a filament, and a filament emits thermal radiation. In this process, a part of the energy losses by convective or conductive heat transfer through a halogen gas, a glass bulb and so on. In the present model, we assume that the power of radiation is proportional to the forth power of filament temperature and the power loss is proportional to the temperature difference between a filament and an ambience.

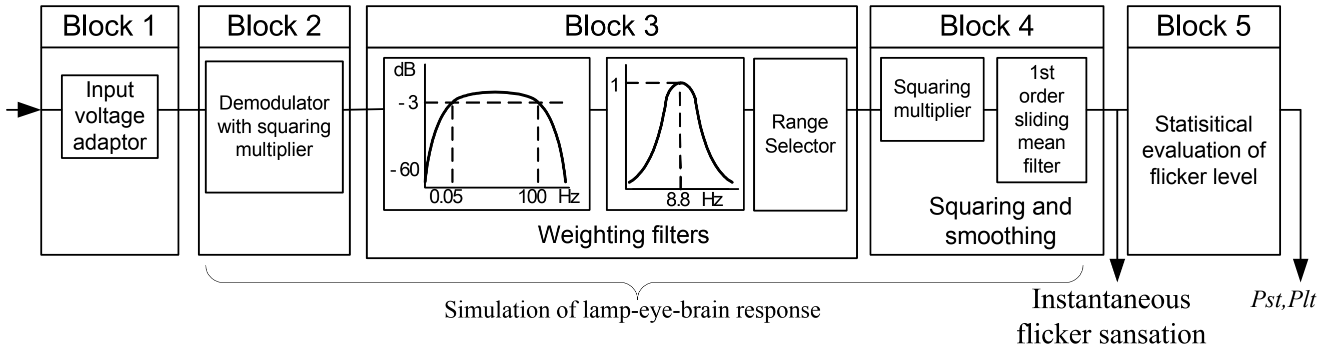

Figure 1. IEC Flickermeter diagram.

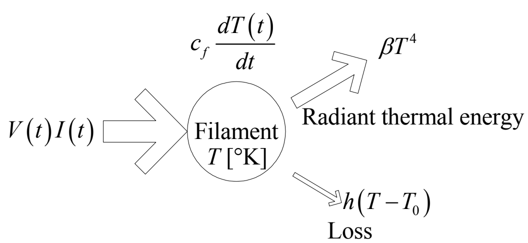

Figure 2. An energy flow model. An input electric energy to a halogen heater filament is dissipated for rise of the filament temperature, the radiation for heating fuser and the loss.

The energy balance of input and output can be expressed as,

$$V(t)I(t) = C_f \frac{dT(t)}{dt} + \beta T^4(t) + h\big(T(t) - T_0\big) \quad (1)$$

where $V(t)$ is the applying voltage to the filament, $I(t)$ is the current, $T(t)$ is the filament temperature in Kelvin, T_0 is the absolute temperature of ambience, C_f, β and h are the proportionality constants.

Using the known temperature dependence of tungsten resistivity, a filament resistance R_h is expressed as,

$$R_h = \alpha T^{1.2} \quad (2)$$

where α is a constant which is determined by the filament size.

As shown in Figure 3, the voltage $V(t)$, which is supplied from the power distribution system, can be given as,

$$V(t) = V_s(t) - R_s(t) - L_s \frac{dI(t)}{dt} \quad (3)$$

where V_s is a voltage of source (230Vrms in Europe). R_s, L_s are the impedance of a power distribution system. $I(t)$ is a current flowing a halogen heater. The relationship between the halogen heater current and the source voltage can be expressed as,

$$V_s = L_s \frac{dI(t)}{dt} + R_s I(t) + R_h(t) I(t) \quad (4)$$

where $R_h(t)$ is a filament resistance.

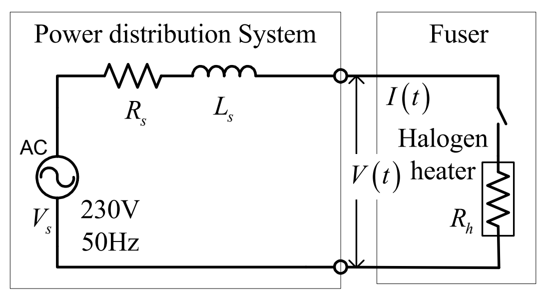

Figure 3. A schematic circuit diagram of a power distribution system and a fuser of laser printer.

The present model expressed by Equations (1)-(4) is made up by the blocks of Simulink (The MathWorks, inc.), which has a switching pattern of halogen heater as input and current I, voltage V, filament temperature T, filament resistance R_h, instantaneous flicker sensation P.U. and short-term flicker severity Pst as output.

Identification of Halogen Heater Model

The model described above has unknown coefficients of α, C_h, β and h. When we simulate the behavior of real halogen heater, we need the values of these coefficients.

We identified a halogen heater of rated power of 844W. The coefficient α in Equation (2) was calculated using the resistance of the halogen heater at room temperature measured by a circuit tester. The each value of C_h, β and h in Equation (1) were identified as follows. The voltage of 230V(50Hz) is applied to the halogen heater filament of room temperature at the voltage zero crossing point, and the transient waveform of the current is measured. Then, C_h, β and h are obtained by fitting the calculated curve using the present model to the measured current waveform data as shown in Figure 4. In this fitting, the least-squares method is used and a set of coefficients C_h, β, h that minimize the difference between the model data and measured data is searched by an optimization command of MATLAB (The MathWorks, inc.). A set of coefficients values of the Equation (1) is not unique in general and depends on the initial values and constraints. In Equation (1), the coefficient C_f of the first term in right side represents a thermal capacitance and the second term and third term in the right side represent radiation power and power loss, respectively. The initial value of β and h were set up in such a way that the values of second term and third term of Equation (1) were 99% and 1% of the rated power at the expected filament temperature of 2400°K, respectively. The coefficient C_f was set up to be 0.1 as initial value at a rough estimate of filament thermal capacitance and was searched under the constraint of $C_f > 0$.

As a result of searching, $\alpha = 5.18 \times 10^{-3}$, $C_f = 0.165$, $\beta = 2.54\times10^{-11}$ and $h = 3.73\times10^{-3}$ were obtained.

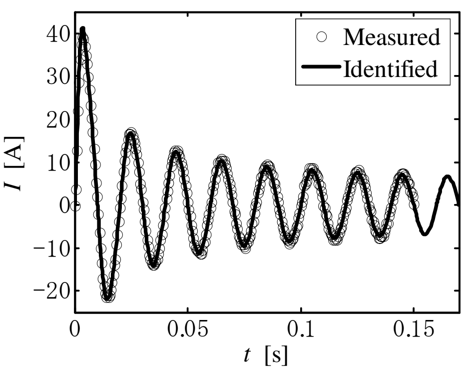

Figure 4. Measured current data after application of voltage and calculated current waveform using coefficients identified by measured data.

Results and Discussion

Figure 5 shows the responses calculated by the model with identified coefficients at an arbitrary switching pattern of the halogen heater. The behaviors of all variables including current (I), filament temperature (T), filament resistance(R) and radiating power (P) are reasonable. It should be noted here that the identification of the values of coefficients with physical constraints determines values with physical meaning such as thermal capacitance.

Figure 6 shows the comparison of the calculated and measured short-term flicker severities (Pst) as a function of period. The on-off duty ratio is 12.5%. As a whole, a good agreement between the calculated curve and measured curve was obtained, although the calculated values themselves were a little higher than the measured values. The difference between the calculated and measured value at the period of around 10^{-1} second is larger than other periods. Similar results were obtained for other heaters and other duty ratios. It seem that the reason is that the signal utilized for the identification did not include a filament state of switching at period of around 10^{-1}. The identification utilizing input pattern including variety of states of filament increases accuracy of Pst value itself.

Nonetheless, it appears that the present model and the method of identification have practical and sufficient accuracy for qualitative examination of on-off pattern for the fuser temperature control.

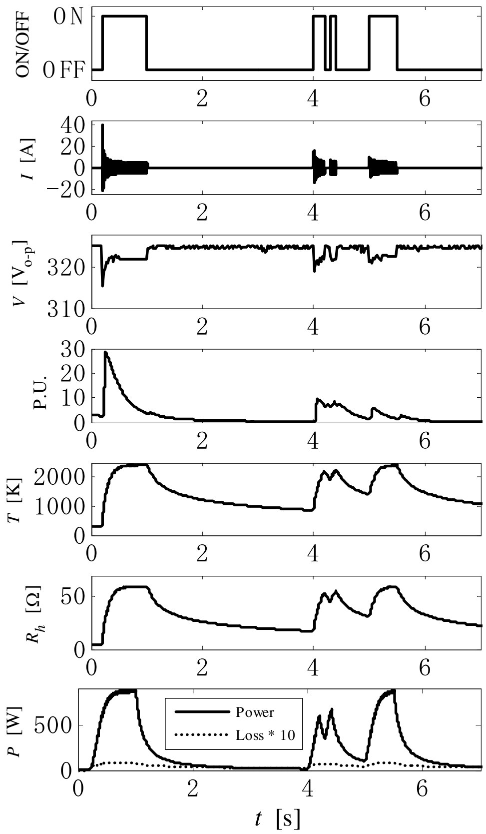

Figure 5. Changes of variables calculated by the model with identified parameter at an arbitrary switching pattern.

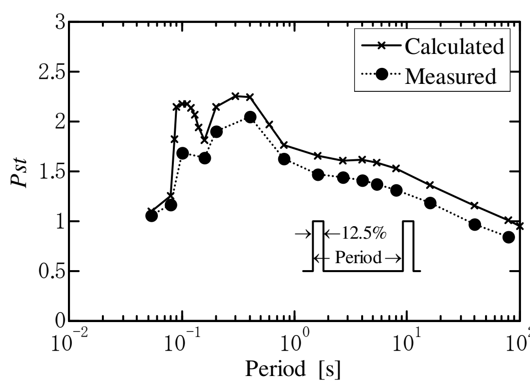

Figure 6. Comparison of the calculated and measured Pst as a function of period.

There are two peaks in *Pst*-period curve in Figure 6. Human eye is most sensitive to a flicker of 8.8Hz and the flickermeter is designed to be most sensitive at 8.8Hz as shown at block3 in Figure 1. It appears that the left peak in Figure 6 is the result of characteristics of human eye.

In order to find a cause of the right peak in Figure6, voltage fluctuations were calculated as a function of period. Figure7 shows the voltage fluctuations at the duty of 12.5%. The voltage fluctuation increases with an increase in period in the range of 10^{-1} to 10^{1}. The increase of the period makes cooling time of filament long. The low resistance of cold filament causes large current and increases voltage fluctuation. The increase of flicker level associated with an increase of voltage fluctuation brings about the right peak.

Thus, by using the model proposed in this paper, we can obtain not only flicker level but also radiating power of halogen heater at any switching pattern.

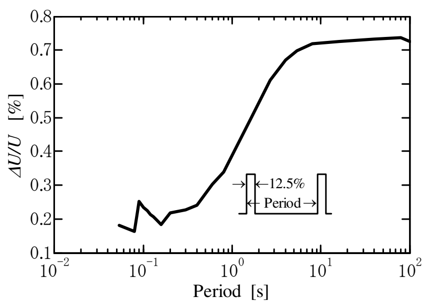

Figure 7. Calculated voltage fluctuation as a function of period.

Conclusion

In the present work, a new halogen heater model has been developed. This model makes the estimation of the flicker and the thermal energy possible.

Although the improvement of identification signal is needed to obtain precise flicker value, this model will allow to develop optimal methods of fuser temperature control with consideration of the flicker by simulation.

References

1. IEC Standard 61000-3-3.
2. B.M.Hirst, H.L.Hess, IEEE Trans. Ind Appl., 30 6, (1998) pg.1284.
3. S. Sakata, T.Mtsudaira, R.Okutomi, Konica Technical Report 11(1998) pg.95-98 (in Japanese).
4. USP 5789723
5. IEC Standard 61000-4-15

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Author Biography

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