레이저 프린터 정착기의 시스템 분석 및 제어

System Identification and Control for Thermal Fuser in Electro-photographic Printer(Laser Beam Printer)

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1. Introduction

As of today, inkjet printers have been superseded by the electro-photographic printers, or laser beam printers(LBPs) so that these laser beam printers are prevalent in printer markets and easy to buy for ordinary customers with relatively lower price from several years ago. The LBP is highly attractive in that it is even faster in printing speed and cheaper in price of maintaining than inkjet printer. The main difference between the inkjet printers and LBPs is that the LBPs produce solid toner images, whereas the inkjet printers make liquid ink images. Toner is a kind of small particle which is carbon powder blended with a polymer. These substances are easily melted by heat and then perpetually fixed on the paper with an appropriate level of compression. However, the particles are so sensitive to heat that the temperature for melting them should be always uniform and steady throughout the printing operation. In fact, the sensitivity tends to be affected by not only properties of toner, but also the physical characteristics of heating rollers in the fuser. But, it is preferable to set the temperature condition for the specific toner particles than to change the physical parts of the fuser unit due in large part to cost problem. Toner properties are variable from manufacturer to manufacturer so that the target temperature for binding toner to paper depends on machines.

The fuser is composed of several important elements such as frame, heating roller, pressure roller and thermistor. The heating roller is a hollow, thin pipe and usually a heat source is installed at the center of this pipe to warm the overall surface of the pipe. The thermistor detecting temperature at the surface of the heat roller returns the information of temperature to the main controller of the machine. Halogen lamp, induction heater, ceramic heater and various types of heating materials are used as heat sources for fusers, and particularly a halogen lamp is selected as a heat source in this paper. The halogen lamp gives off heat by exerting AC to tungsten filament in the glass tube filled with halogen gas. Typically AC is connected with a power converter in a switching-mode-power-supplier (SMPS), in which a triac plays a role of a switch to control the input power. A schematic diagram of control input and temperature feedback is shown in Fig. 1.

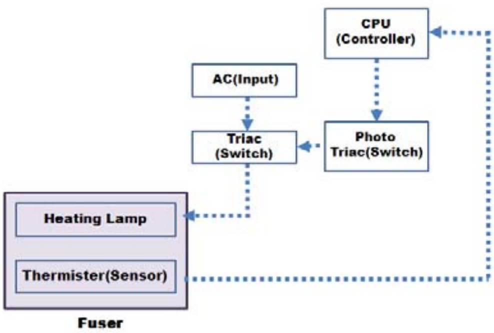

Fig. 1 Block diagram of control input and feedback of fuser in LBP

As mentioned in the foregoing, a toner for a specific machine needs an appropriate range of temperature to be melted and fixed on papers. The typical range for present toners is from around 170 degrees Celsius to 190 degrees Celsius. Of course, the exact values are dependent on their manufacturers. The amount of time to reach the specific temperature (or target temperature) is a very important feature to users of the machine. And the ability to keep uniform and steady temperature regardless of external disturbances such as variation in room temperature and temperature droop by paper passing should be secured as well. For the purpose of satisfying these needs, there have been various kinds of methodologies of ramping algorithms for toner fixing so far. Proportional control, integral control, derivative control and other methods have been applied as a ramping control of fusing temperature. But these control methods are implemented without knowing the exact information of the thermal fuser so that there have been a lot of problems both in predicting the behavior of heating pattern and in control of fusing temperature. For more exact and effective control and prediction of the fuser, it is desirable to find the dominant characteristic of the system.

In this paper, the system identification method is presented and a couple of simulation models of the fuser are proposed. These models provide suitable plants for closed loop control in the fuser heater. However, the identified models represent only an ad hoc case of a specific machine used for this paper.

2. Black box approach for identification

Before determining a suitable simulation model, it is necessary to assume the model as a LTI model. In fact, there would be slight changes in physical parameters of fusers in terms of thermal effect. However, for simplicity of modeling, the physical variation was ignored. As the signal input - *u(t)* is discrete switching in the controller, all of processes and material properties between the fuser and the controller are also involved in the *black box SISO (single-input, single-output) model* with the fuser itself. Meanwhile, in order to add flexibility in describing disturbance term - *e(t)*, the model is considered as a linear ARMAX model from the beginning,

$$A(q)y(t) = B(q)u(t) + C(q)e(t)$$

with

$$A(q) = 1 + a_1 q^{-1} + a_2 q^{-2} + \cdots + a_{na} q^{-na}$$

$$B(q) = b_1 q^{-1} + b_2 q^{-2} + \cdots + b_{nb} q^{-nb}$$

$$C(q) = 1 + c_1 q^{-1} + c_2 q^{-2} + \cdots + c_{nc} q^{-nc}$$

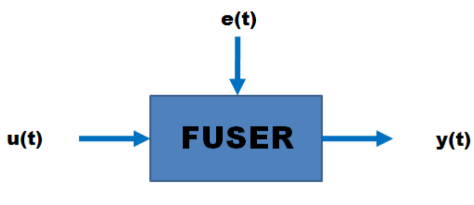

Fig. 2 Black box approach for identification

3. Experiments for identification

Modified xPC-Target in Matlab was applied for data acquisition. At first, the experiment was conducted in an open loop state. *Pseudo random binary sequence (PRBS)* was added to the system as an excitation signal and then the real time temperature was saved and imported into the host computer. As the fuser has a limitation in maximum endurable temperature (around 230 degrees Celsius), the

5th ordered PRBS period was determined as twice-repeated 63(s), or 126(s) to avoid any possible fuser burn. The maximum length PRBS referred to a choice from Davies (1970),

$$M = 2^n - 1$$

And data sampling was performed at every 0.1(s).

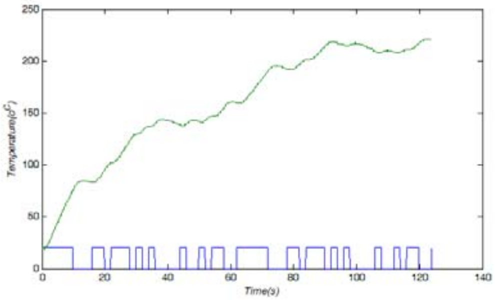

Fig. 3 Open loop experiment for identification

The overall data record was selected for estimation as well as for validation concurrently. And for simplicity of identification, an ARMAX model with *na = 2, nb = 2, nc = 2,* and *nk = 10(delay)* was suggested. Thus,

$$A(q) = 1 - 1.954q^{-1} + 0.9537q^{-2}$$

$$B(q) = 0.2355q^{-10} - 0.2053q^{-11}$$

$$C(q) = 1 - 1.233q^{-1} + 0.3014q^{-2}$$

which gives a good fit to the system(Fig. 4). Some minor disparity of output between two models especially in higher temperature section might be based on differences in unknown system gains of each models. Therefore, the simulated model represents the real fuser quite well.

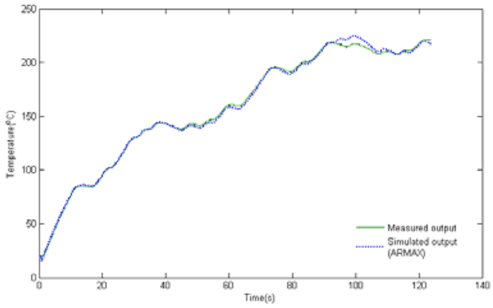

Fig. 4 Comparison of response between the simulated model and the real fuser w.r.t. PRBS

4. PID control for simulated model

As mentioned previously, this system is controlled in discrete manner. Therefore, control sequence should be a discrete form having magnitude of either one or zero. In order to discretize the controlled input value, saturation and relay blocks are inserted. Fig. 6 shows dicretization of the controlled signal from continuous values to discrete values. These nonlinear factors will be also taken into account during feedback control. For desired response of the system, several specifications such as rise time(*Tr*), settling time(*Ts*), percent overshoot and percent settling are proposed like,

Tr = 37(s) / Ts = 40(s) / %overshoot = 20 / %settling = 1

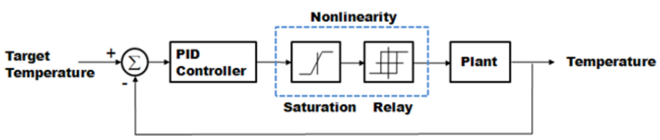

Fig. 5 Control of fuser system

Consequently, *Kp(P-gain)=1.0, Ki(I-gain)=*9.6×10^{-5} and *Kd(D-gain)=1.0* are determined by iteration and responses between a new PID control and a current P control are compared in Fig. 7. In terms of the new PID control algorithm, the number of times of control chopping is conspicuously reduced and the overshoot is decreased as well. Typically frequent chopping makes bad flicker effect and an abnormal offset image is caused by excessive overshoot relating to toner's sensitivity to heat.

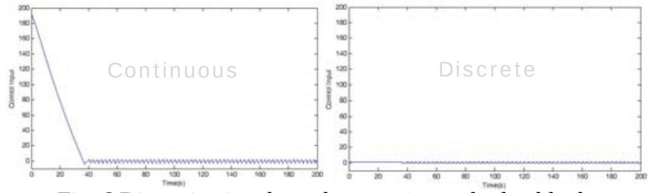

Fig. 6 Discretization through saturation and relay blocks

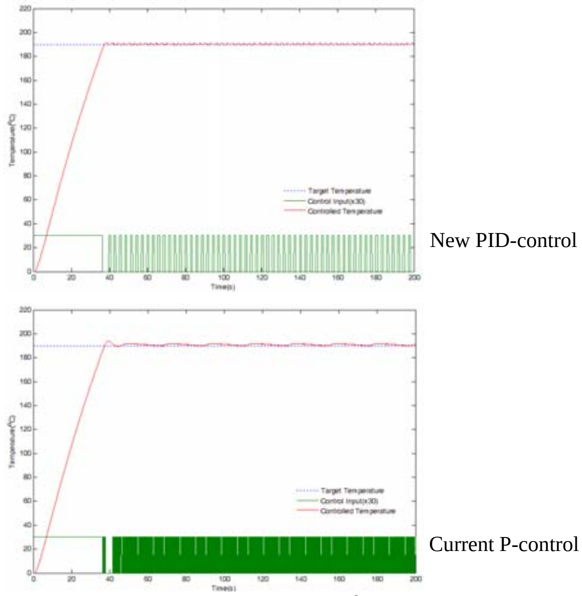

Fig. 7 Comparison of responses

5. Conclusion

Through the identification of the fuser, more efficient controller was found. This result will conduce to resolve other fuser-related problems such as bad flicker and image offset caused by excessive overshoot in temperature. And it will be possible to predict and control the behavior of the fuser to avoid abnormal cases during operation.

6. References

1. L. Ljung, *System Identification – Theory for the User(2nd ed)*, Prentice Hall(NJ), 1999
2. L. Ljung, *System Identification Toolbox 7 – User's Guide*, The MathWorks Inc.(MA), 2007
3. Davies, W. D. T., *System Identification for Self-Adaptive Control*. Wiley Interscience(NY), 1970
4. Marta Barenthin, *On Input Design in System Identification for Control*. Licentiate Thesis at Stockholm University : p33-p47, 2006
5. B. Mark Hirst & Herbert L. Hess, *Low-Flicker Universal Power Converter for Filament-Based Heating Processes*. IEEE Transaction on Industrial Applications, Vol. 34, No. 6, Nov/Dec, 1998
6. Botao Miao, Regan Zane & Dragan Maksimovic, *System Identification of Power Converters with Digital Control through Cross-Correlation Methods*. IEEE Transaction on Power Electronics, Vol. 20, No. 5, Sep, 2005
7. Gene F. Franklin, J. David Powell & Abbas Emami-Naeini, *Feedback Control of Dynamic Systems(5th ed)*, Prentice Hall(NJ), 2006