SOFTWARE-BASED ENERGY MANAGEMENT SYSTEM FOR AN INFRARED DRYER

M Adonis and MTE Kahn
Cape Peninsula University of Technology, South Africa

ABSTRACT

A software program was developed which is capable of controlling a hybrid convective-infrared dryer that had previously been designed and developed using sixteen ceramic far-infrared heaters. The dryer was developed for the drying of fruit and only the infrared heaters are subjected to temperature control. The control mechanism uses sixteen buck converters to attain individual control of each infrared heater. The software program in LabView was designed which would be able to regulate the buck converters. The fully automated and user-friendly software program is capable of developing and maintaining a temperature profile.

1. INTRODUCTION

The drying of fruit is done to remove water for two reasons: to inhibit (or prevent) micro-organisms and hence preserve the fruit and to reduce the weight and bulk of fruit for cheaper transport and storage. Many different drying methods exist in the food industry. Some of these include: vacuum drying, freeze drying, solar drying, contact and air drying. For food and agricultural products, the drying should preserve the taste, colour and quality in the finished product.

The modeling of the drying dynamics for various foodstuff and agricultural products is available in the literature. Some of these mathematical models incorporate the following: heat and mass transfer in grain drying [2], hot air drying of sweet potato slices [3], fluid bed drying of tea [4], ear corn drying [5]. Further mathematical models describing various aspects of drying of porous solids have been the topic of research for several years. Some of these encompass the following: model of drying of hygroscopic media [6], convective drying of wet porous material [7] and the prediction of drying rates for foods [8], heat and moisture transfer in dehydrated food [9].

2. HEATER POWER CONTROL

The method of controlling the power output of each individual heater is through the use of a buck converter. There are sixteen buck converters used to effectively manage the temperature regulation of each of the sixteen infrared ceramic heaters.

Figure 1 illustrates the circuit diagram of the buck converter used. The feedback loop further incorporates a data acquisition facility that provides the interface between the hardware and the software program. The input to the buck converter is a 400Vdc bus. The switching action of the insulated gate bipolar transistor (IGBT) establishes the output voltage across each heater load. The data-acquisition module which acts as the interfaces between the hardware control circuitry and the software control program is used to drive the IGBT. In order to drive the IGBT, the drive pulses provided to the switch need to have with a pulse-width modulated (PWM) characterisation.

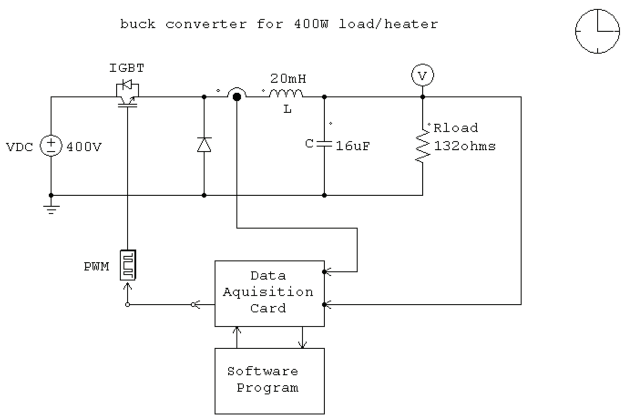

Figure 1: Power control loop

The duty cycle (D) of the PWM signal is derived from the following relation,

$$D = \frac{V_{OUT}}{V_{IN}} \qquad (1)$$

Equation 1 describes the ratio of the output voltage with regards to the input voltage. The PWM nature of this signal provided for the switch, the IGBT, is determined by the software program developed in LabView. The software program is fully automated and user configurable so that it is able to allow the user maximum functionality for the temperature control of each individual heater. The LabView program is further elaborated upon in the next section.

3. SOFTWARE PROGRAM ASPECTS

3.1 ASPECTS

The purpose of the software program is to enable the user the functionality of deriving a range of temperatures from the infrared grid of heaters. These ranges of temperatures derived are necessary for the complete processing of the material being dried. A temperature profile is a set of temperatures arrived at in various stages of material processing which each have a predetermined processing time. Figure 2 illustrates an example of a typical temperature profile for the soldering of surface-mount components onto a printed circuit board (PCB).

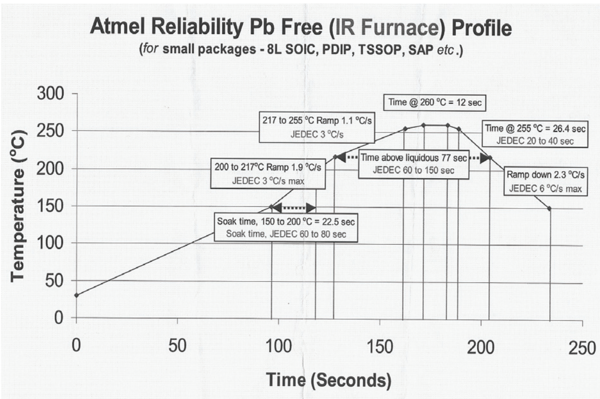

Figure 2: A typical temperature profile

The software program needs to accurately follow a temperature profile as indicated in Figure 2. This program requires the user to select predetermined values of temperature and processing times. These predetermined values can either be arrived at experimentally or by consulting with industry professionals. The program then executes and determines the required PWM signal that is needed to attain the requisite heater temperature.

3.2 FUNCTION LOOPS

There are three function loops that form the basis of the software program. It will enable the user to set the system up and leave the rest to the program. This gives any user the time to do other important things while running an experiment.

3.3 PRESET SELECTION

This loop enables the user to set the system up for any desired temperature profile, just by selection of parameters. In other words the user can choose the starting temperature the heater should ramp to before it starts controlling the temperature at that point. Figure 3 illustrates this concept, showing four of the sixteen heaters and their temperature set points. The dwelling period at that point is also selectable before the program steps the temperature up or down to level two, level three, level four and so on. The system will allow for selecting up to ten level options. After the last level selected by the user, the system will ramp the temperature down to 0 degrees Celsius. And stop the running of the program.

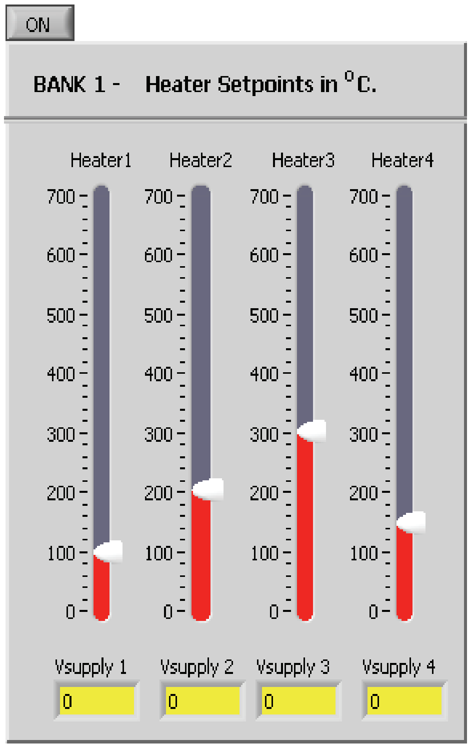

Figure 3: Heater temperature set points

3.4 PULSE WIDTH MODULATION (PWM) OUTPUT

This loop sets the temperature for all the levels within a profile. The PWM output code is a controllable variable in the program that allow for the heater temperature to be controlled. This code has been developed and tested with the buck converter and is illustrated in figure 4 below. With this feature the program allows the user to select the frequency of the PWM signal between 0 and 40 kilo Hertz (kHz) and the input DC voltage is also user adjustable.

3.5 FEEDBACK CONTROL

This function loop adjusts the PWM output signal according to a logical calculation that compares the feedback temperature status of the heaters to their set-points and responds subsequently. It is the most critical part loop within the program, because it can alter the expected results of the experiment drastically if the program does not control the heater temperatures accurately and fast enough.

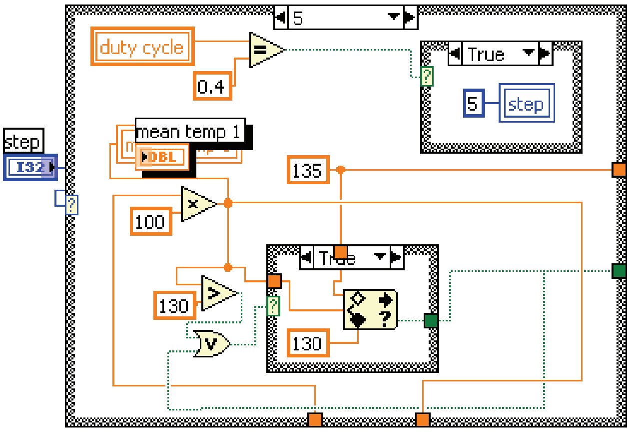

Figure 4: Routine to set the PWM

3.6 TEMPERATURE MEASUREMENT AND DISPLAY LOOP

The heater voltages that is fed back into the program will be converted into temperatures and displayed on the front panel of the program. The plan is to take temperature measurements of a heater using an accurate temperature thermometer whilst increasing the voltage supply to the heater linearly between 0 and 220Vdc. The results are then tabled and used in the program and an equation will be derived from this information in order to calculate the temperature for each heater at a certain voltage. This feature is intended to be done using the buck converter and subsequently operate the buck converter satisfactory. The plan is now to take linear temperature measurements by manually adjusting the supply voltage to the heater so that it can be used for calculating the temperatures using the program.

3.7 PROGRAM FRONT PANEL

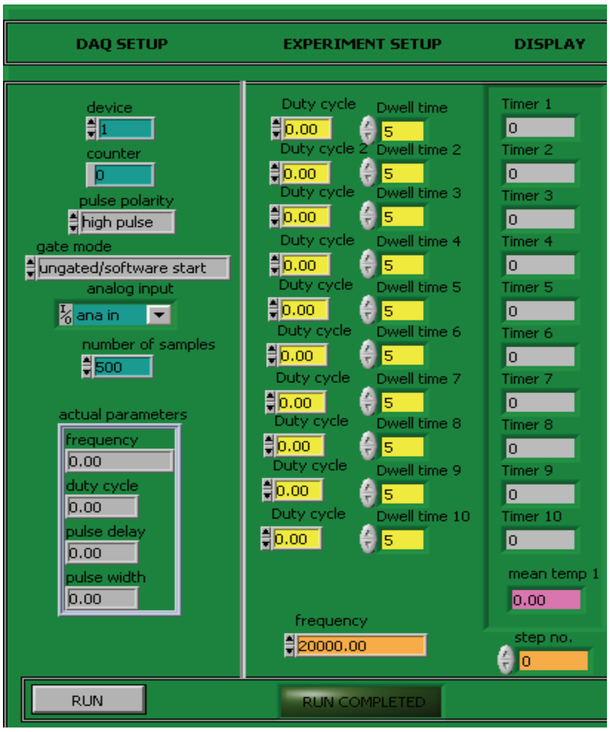

Figure 5: LabView front panel

Figure 5 shows a section of the LabView front panel from which the user is able to configure the operation of the temperature regulation process. The user is able to select and configure the type of data-acquisition device to be used in the process. The frequency of the PWM signal is also configured here. This feature enables the use of many different types of IGBT's to be used in the operation of the circuit. The optimum ranges of frequencies for many IGBT switches do differ. This feature enables the program to be portable from one system to another.

The user also has the option to manually select the duty cycles for each of the PWM signals for the individual switches in the buck converters. The required processing times for each buck operated infrared heater is also user configurable. These times are entered in the time required in second's units.

After all these program parameters have been selected, the user is ready to begin the program execution. This is achieved by selecting the RUN command. The user is able to view the time remaining in each of the sections of the program that execute the temperature profile. The program then executes and upon completion the RUN icon is disabled and the RUN COMPLETED icon is then highlighted.

4. CASE STUDY

Tests were performed on the buck converters using the software program developed. The buck converters are interfaced to the LabView program through a data acquisition module (DaQ) that outputs the train of pulses required to drive the buck converters. These buck converters determine the set point voltage for each infrared heater connected. Embedded thermocouples in each of the heaters are also interfaced to the DaQ module and used for temperature measurement and control purposes.
Table 1 below summarises the set points provided and the results obtained from these tests. The thermocouple temperature measured in these tests were compared to temperature measurements obtained from an infrared pyrometer which results in the average temperature values indicated in table 1.

Table 1: Duty cycle vs. temperature tests

Duty cycle (%)	Switching frequency (Hz)	Heater temperature (°C)
40	20k	400
50	20k	520
60	20k	640

A duty cycle greater than 60% is not desired since at this point the system represents the maximum heater voltage possible before potential damage to the ceramic heater could result. The heaters are rated at 240V.

5. CONCLUSION

The paper summarises the design, development and implementation of a software program for the temperature regulation of an infrared dryer. The program developed in LabView is user configurable and is able to control the temperature output of sixteen individual infrared heaters that comprise the dryer. The software program interfaces the hardware system of the power control circuit and data acquisition module to the power control switch, the IGBT. The PWM signal derived from the software program is used to control the IGBT switch.

6. ACKOWLEDGEMENTS

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7. REFERENCES

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8. AUTHORS

Principal Author: Marco Adonis holds an MTech degree in Electrical Engineering from Cape Peninsula University of Technology. At present he is a lecturer at Cape Peninsula University of Technology and completing his DTech degree. He also supervises a number of BTech students.

Co-author: MTE Khan is a Professor of Electrical Engineering at Cape Peninsula University of Technology. He is a lecturer and supervisor of DTech, MTech and BTech projects and is head of the Centre for Distributed Power Electronic Systems.

Address: Cape Peninsula University of Technology, PO Box 1906, Bellville, 7535

Presenter: Marco Adonis presents the paper.