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Method to Monitor and Control Heater Bulb Filament Temperature to Stabilize Operation and Extend bulb Life in Printing Applications

Abstract:

This disclosure relates to the use of heater bulbs in printing applications but can also be applied to other applications of heater bulbs in many other industries. Halogen and incandescent light bulbs are often used in radiant heater and drying applications in the printing process. Some of the more common uses in the printing industry are for fixing of inks to printing substrates, drying of inks and coatings, and heating surfaces of moving parts. The bulbs used in these applications are often expensive, and it is beneficial to maximize their life to reduce the operating cost of the printing press.

It is very common to use some form of active control to adjust the power to the bulb heaters to allow for closed loop control of the surface that is being heated. Many existing bulb controllers already monitor the voltage and current to calculate bulb power, then control for constant power. This disclosure takes this further by using the voltage and current data to calculate the bulbs resistance, then the temperature of the filament can be derived using the resistance Vs temperature curves for the filament material (typically a tungsten alloy). The derived temperature data can then be used as an input to the bulb control algorithms to maximize the bulb life, monitor for cooling and environmental changes, and/or to stabilize the bulbs radiated spectrum.

Details:

Some of the possible applications for use of the filament resistance & derived temperature measurement method described are:

1. Use the measured resistance/temperature as an input to the controller to set temperature limit values that keep the bulb temperature within the acceptable range to maximize the halogen bulbs life. Some of the reasons why it is desirable to operate in this range are:
   - If Halogen bulbs are run **above** their designed temperature range, it will significantly shorten their life due to filament evaporation, failure of the quartz housing/envelope, or failure of the end seal.
   - If halogen bulbs are run **below** their designed temperature range, it will also significantly shorten their life due to the “Halogen Cycle” stopping, which will also result in increased filament evaporation.
     - When the Halogen cycle is properly working evaporated tungsten is re-deposits back onto the filament. This can more than double the useful life of the bulb.
   - If operated outside the designed temperature range for a sufficient time, evaporated tungsten can condense on the quartz envelope causing discoloration. This will result in rapid bulb failure as the radiated energy is absorbed by the discoloration, which will result in the envelope melting or fracturing.

2. Use resistance/temperature as an input to the control algorithm to achieve “constant temperature” operation of the bulb.
   - Operating a bulb in a constant-temperature mode will assure long life, AND that the bulb’s radiated spectrum is held constant. The radiated spectrum from a bulb is directly correlated to its filament temperature. That is why it is very common to talk about a bulb’s spectrum in terms of

the bulbs Kelvin temperature. Graphs of light bulb spectrum Vs filament temperature are widely available in textbooks and on the internet for reference.

3. If groups of bulbs are being used in the system, the resistance measurements from the individual bulbs can be used as feedback to help control the temperature of each bulb individually.
    - During development of this idea, a 6-bulb system was found to have the center bulbs running hotter than the outside bulbs. The resistance calculations detected this, and it was then possible to adjust the individual bulb powers to maintain all bulbs at the same temperature. This prevented the center bulbs from prematurely failing, which had been observed to occur prior to implementing the filament temperature control described.
4. The bulb resistance can also be used as a "sensor" since any change in filament temperature would be due to a change in the local environment. This can be useful since it is often difficult to include temperature sensors in the harsh environment in the area around the heater bulbs. Some of the possible changes that can cause bulb temperature to change are:
    - Surface emissivity changes of the target surface being heated that would cause a change in the amount of reflected energy back to the bulb. In a printing application the target surface is usually moving, and the surface can change characteristics depending on the current print job.
    - Changes in the speed or material that is passing under the bulbs.
    - Airflow has changed. When cooling air fails or is degraded the resulting temperature rise of the bulb can be detected in real time. The controller can then decrease power to maintain the bulb in the "safe zone", or it can take other protective actions to protect the press.
    - Note: when used as a sensor, the response speed is limited by the thermal mass of the bulb.
5. Perform bulb resistance checks at a known and repeatable condition in the application, then track this over time to monitor filament "evaporation".
    - As a bulb ages the filament slowly evaporates and the resistance will increase. This can be used to anticipate end-of-life for the bulb.

These bulb heaters are often used in radiant heater and drying applications. Some examples of their uses in printing processes are:

- To heat/melt the printing material (ink) prior to application onto the printing substrate to enhance adhesion of the printed material to the substrate.
- To heat/melt the printing material after application to the substrate to improve adhesion.
- To dry coatings and/or priming materials in pre and/or post printing processes.

The steps to determine the filament temperature are:

1. Use the bulb measured applied voltage and current data to calculate the resistance of the bulb using Ohms Law (R=V/I). R_filament=Vrms applied / Irms measured) This calculation can be done as part of the control loop for the bulb controller to track the resistance in "real time" while the bulb is in operation. Many bulb PWM controllers already include voltage and current monitoring so they can operate the bulb in a Constant Power mode, so calculating the resistance is a simple division.
2. Use the known resistance Vs temperature data for the filament material (usually a Tungsten alloy) to convert the calculated filament resistance into temperature.
    Figure 1 below shows the ratio change of a Tungsten wire as temperature is increased from room temperature. This graph shows that resistance will increase by about 10x to 20x as the temperature rises from room temperature to normal operation temperatures for incandescent bulbs. This change is large enough to allow temperature calculations with good resolution with easily implementable voltage and current measurement techniques. The resistance data is shown here in ratio form since

the room temperature resistance will be different for different bulb designs, but the ratio of a given bulb's resistance as temperature is changed will follow this graph.

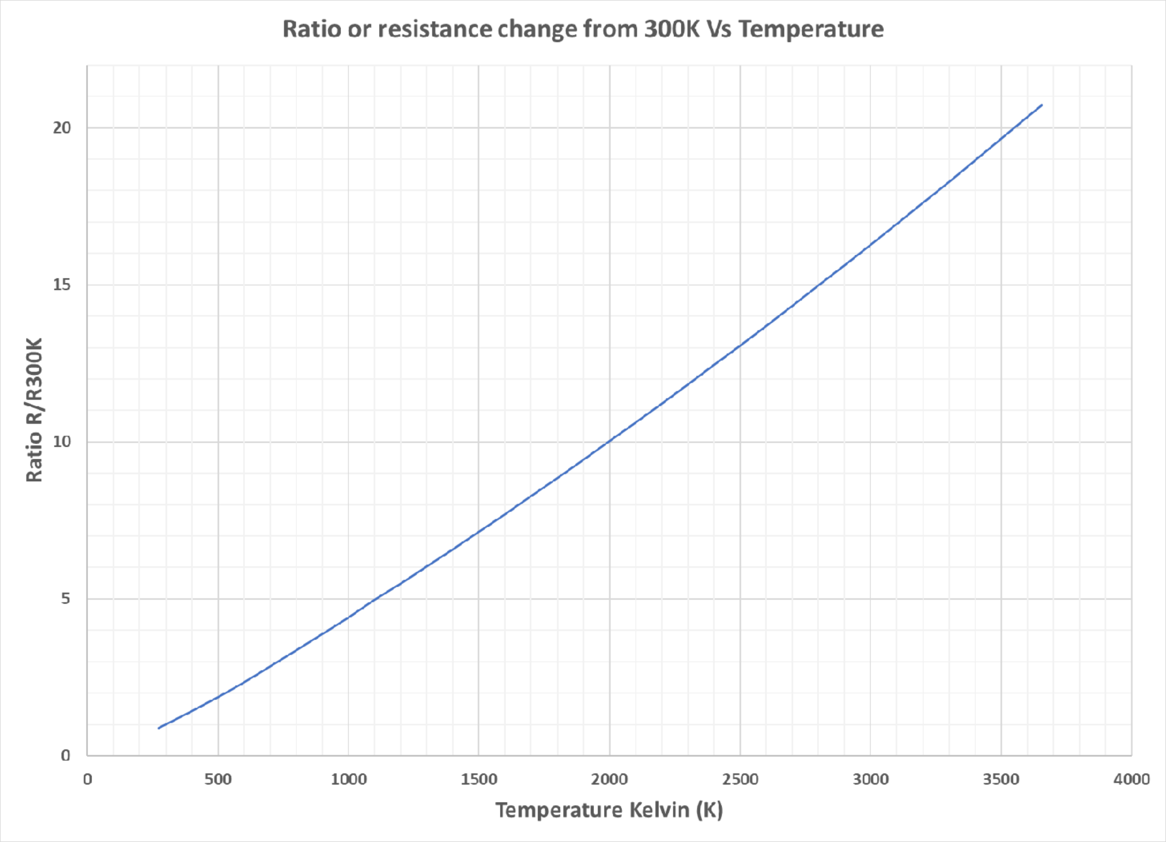

Figure 1

- A rough approximation of temperature can be found from the filament resistance curve using a simple linear approximation. A much more accurate value can be determined using a 2nd order curve fit equation. Equations and coefficients are readily available in textbooks and on the internet.

- Note that bulb filaments are typically a tungsten alloy formed with small additions of other materials to optimize the durability of the filament. These additional materials will change the resistance to temperature curves of Tungsten found in textbooks a small amount. For the most accurate temperature data, the actual filament resistance vs temperature curves for the bulb should be used. If these curves are not available, the resistance of a bulb can be measured while it is in an oven and the temperature is slowly ramped up to generate at least a portion of the curve, then the 2nd order curve fit coefficients can be adjusted to match the bulb data.

Filament temperature can then be used as an input into the bulb controller to implement algorithms to maximize bulb life and/or detect system changes. Some possible examples are:

1. For controllers that operate in a controlled PWM or Constant Power mode:
    a. New algorithms can set upper/lower temperature limits and change the controller's behavior if it is detected that the bulbs temperature has crossed one of the limit lines. Note that the control algorithms do not need to perform the full calculation to derive temperature for each sample. For example, when implementing high and low temperature limits, the calculations can be performed once to determine the associated high and low resistances. From then on,

the controller need only perform the much faster resistance calculations to detect violation of the limits.

- When the controller is holding PWM or Power constant, any bulb temperature change will be due to changes in environmental conditions. This means the calculated temperature can be used to detect such things as:
    1. Changes in the emissivity of the target material that would change the amount of reflected heat that goes back to the bulb.
    2. Change or loss of cooling air/water to the bulb housing.

b. To provide feedback to keep the bulb within its optimal temperature range.

c. Control for bulb "constant temperature" operation. This will maximize bulb life AND keep the bulbs radiation energy and spectrum more consistent. Radiation spectrum is directly correlated to the filament temperature as shown below. So, holding the temperature constant will also hold the radiated spectrum constant.
  - Note that when operating in constant-temperature mode, the temperature-to-resistance calculation need only be performed once to determine the resistance for the target temperature, then the controller just runs in a constant-resistance mode to simplify the calculations needed within the control loop. This allows the control loop to operate at a faster rate.

d. Tracking the filament resistance over time can provide an indication of the status of the bulb. The bulbs filament resistance typically rises over the life of the bulb due to "filament evaporation".
  - i. For this to be accurate, the bulb resistance must be sampled when the bulb is in a similar environmental condition each time. For example, we might take this measurement as we perform the first Get Ready each morning.

Example of a specific problem that was solved:
IR heating bulbs were used to construct a test fixture that allowed post-print heating of printed sheets. This fixture was made to develop and test models of ink/paper heat absorption, and to experiment with improvement of fixing of inks to paper. The test fixture consisted of a paper feeder, adjustable speed paper transport path, an IR heater module, an AC forward phase controlled PWM dimmer circuit, and several non-contact IR thermometers to monitor before and after paper temperatures.

The IR heater module used contained 6, 1,000-Watt heater bulbs inside a module that contained a back reflector that had a water-cooled jacket. The module also had variable air flow across the bulbs for additional cooling. Each bulb had its own PWM control and voltage and current monitor circuits.

Early in development several failures occurred where the very expensive heater bulbs overheated and melted sections of their quartz housings. Cooling water and air flow were verified to be within the manufactures required values and the bulbs were replaced, but the system again experienced a second failure.

To investigate and prevent further failures, we developed the described idea to be able to monitor all the bulb filament temperatures while in operation. Using this method, we found that the bulbs temperature increased during times when there was no paper under the heater assembly. It was theorized that when no paper was present to absorb the radiated energy, a significant amount was reflected back from the metal back plate and caused a large increase in the bulb's temperature.

With the new monitoring method, it was possible to:

- Monitor each bulbs filament temperature while they were in operation.
- Verify that the bulb temperatures increased when no paper was under the IR module.
- Characterize the bulb temperatures vs their placement in the group of 6.

The new monitoring/control method was then used to adjust the power to each bulb to keep all bulbs at equal temperatures. The controller was also programmed with temperature limits that would immediately initiate protection procedures if violated.

To establish a rough upper temperature limit, a bulb was operated at its rated full voltage while keeping it horizontal in free air far from any other objects. The applied voltage and current were measured, and a filament resistance of 55 Ohms was calculated using R=V/I. We then programmed this into our controller as an absolute upper limit. Any reading above this value caused the controller to decrease the bulbs power.

After implementation of these protection algorithms no further bulb failures occurred.

Tests were then run operating the bulbs in constant resistance/temperature mode and in constant power mode with temperature limits to observe the impact on paper temperatures while in operation.

Problems Solved and advantages observed:

1. Bulb life is extended.
2. Able to detect and respond to environmental changes that would have otherwise caused premature bulb failure.
3. Can be used to control for constant bulb filament temperature, which will result in longer bulb life and have a more consistent radiation spectrum for the bulb.
4. Able to see the bulb temperatures changing in real time as paper sheets were feed through the system.
5. Able to monitor and control the individual bulb temperatures in a group of bulbs.
6. Small changes in resistance over time were also observed and it was theorized that it would be possible to monitor this over long periods of time as a method of monitor bulb aging. This could then be used as an indicator that bulbs were reaching “end of life”.

Prior Solution Disadvantages:

1. Could not detect environment changes or respond to them to keep bulbs within their optimal temperature ranges. This resulted in premature bulb failures.
2. Individual bulb temperatures could not be easily obtained.
3. The temperature of the bulb group was only indirectly measurable using thermocouples mounted in the housing.

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