Temperature Automation for a Propellant Mixer

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This past year has been spent analyzing and installing an automatic temperature controller on a propellant mixer. Ultimately, the entire mixing process will come under automation. Automation is not only important for producing a uniform product, but it will be necessary for envisioned space-based propellant production.

The propellant mixer was obtained from the Jet Propulsion Laboratories. It was installed on campus for the purpose of studying and improving the mixing process. In its installed configuration, the mixer was not automated. Control of mixing time, speed, and temperature profile was provided by the operator. Each of these factors is important in providing a reliable and predictable product. Since precise adherence to the temperature profile is very difficult to sustain manually, this was the first component to be automated.

Figure 1.15 illustrates the water circulation system for the installed system. It was a closed system in which water could be drawn from one of two hot water tanks that were set at 140°F and 160°F. The water was circulated around the system by means of a pump. The storage tank provided for fluctuations in the flow. The actual mixing bowl is surrounded by a jacket through which the water flows. By operating valves at the outlet of the hot water tanks, the operator is able to vary the water temperature in the jacket and thus influence the temperature of the components in the mixing bowl. The temperature profile desired during the mixing process is one in which the components are held at 160°F (for the first 35 minutes) and then at 140°F (for an additional 165 minutes). The manual operation involved simply drawing water from the 160°F tank for the first 35 minutes and then drawing water from the 140°F tank for the remaining time. However, this procedure did not provide an accurate profile, as illustrated in Figure 1.16. This figure illustrates (for the first 65 minutes) the desired temperture profile, the water temperature in the jacket, and the temperature at the inside of the jacket in contact with the materials being mixed. This latter temperature (jacket temperature) is taken to be representative of the temperature of the components.

In order to improve the jacket temperature profile, as well as to automate the process, a control system (Figure 1.17) was designed and implemented. The system uses the same water circulation system as before, except now water is drawn from the two tanks by means of a control valve. Rather than having the tanks at the two set-point

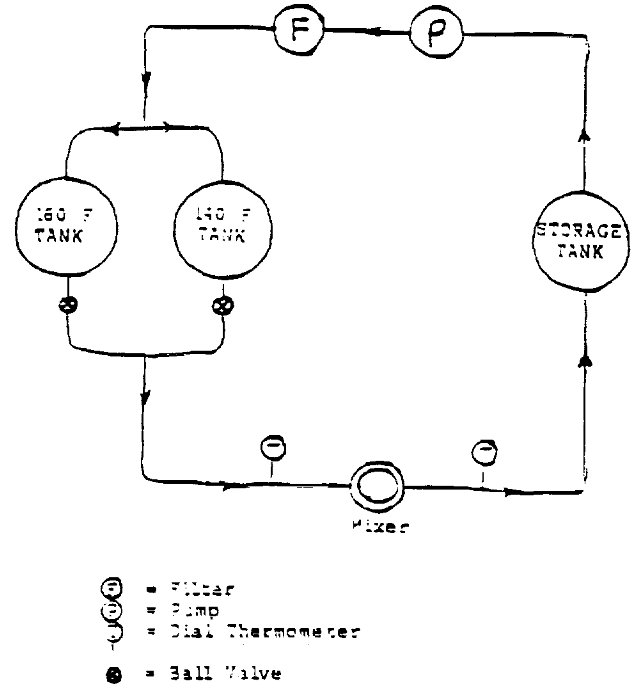

Figure 1.15 Original water circulation system.

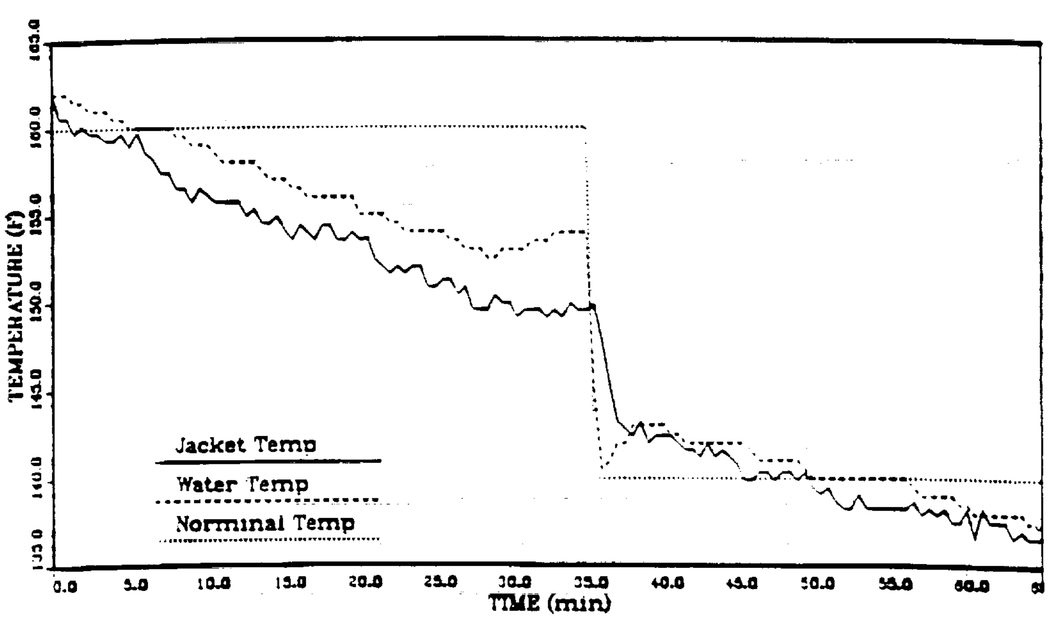

Figure 1.16 Temperature profile for the manual control system.

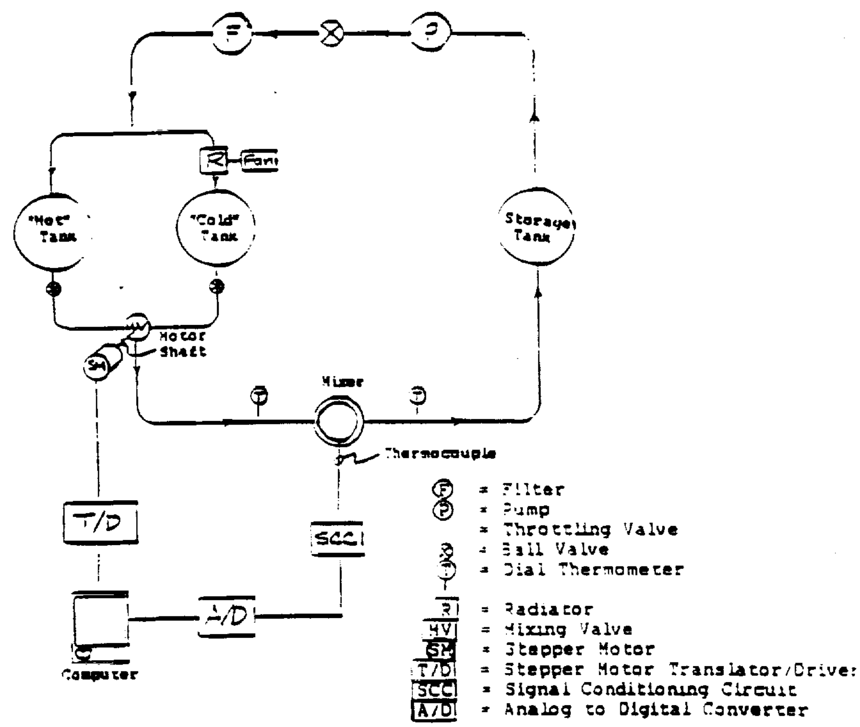

Figure 1.17 Automatic control system.

temperatures, one tank (hot tank) is set for a temperature greater than 160°F and the other tank is turned off (cold tank). The control valve that regulates the amount of water drawn from each tank is set using a stepper motor according to a control algorithm. Temperature measurements are made using a thermocouple, which scans the inside jacket temperature. An 8-bit A/D converter is used in conjunction with an Apple computer to implement the control algorithm. The control algorithm uses open-loop command feed-forward in conjunction with closed-loop error feed-back.

Figure 1.18 illustrates the desired temperature profile, as well as the actual temperature profile of the jacket obtained under this control system for the first 65 minutes. Compared with Figure 1.16, this represents a considerable improvement. Two factors prevented even better results. First, the 8-bit A/D converter limited the resolution of the temperature readings to 0.4°F. This is about the extent of the chatter about the nominal profile. Second, there is very little temperature control available at the hot end. The highest temperature that the hot water tank can be set to is 170°F. This is very close to the higher command temperature. As water is circulated through the system, the heat loss is greater than the heating element in the hot water tank can

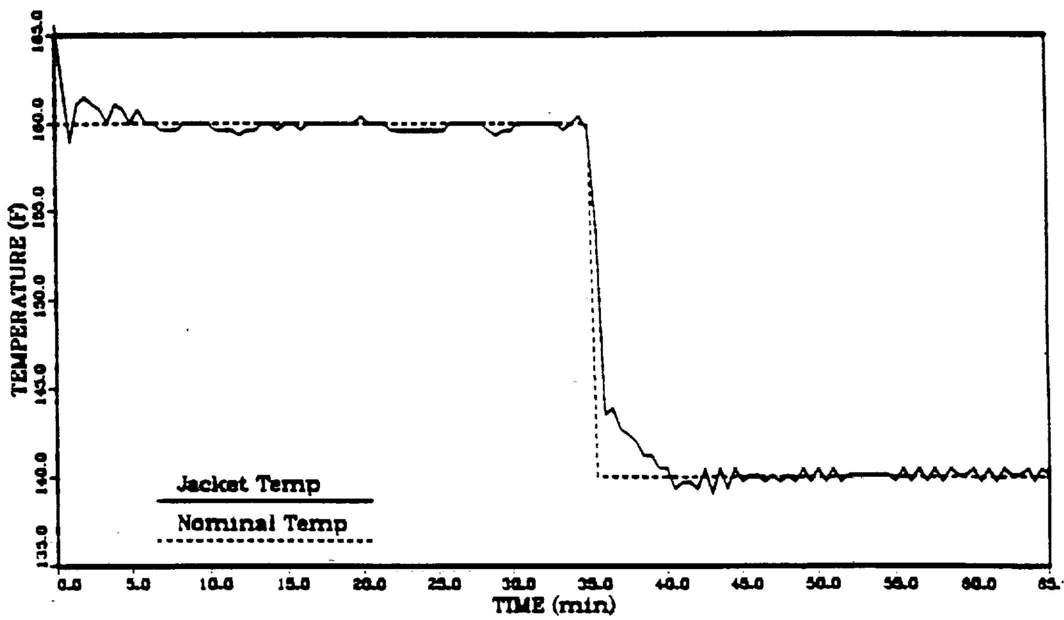

Figure 1.18 Temperature profile using automatic control.

replace, hence, the system is started hot (165°F) to give enough reserve to last the first 35 minutes. At the jump point in command temperature, the temperature of the cold water tank is not known with sufficient accuracy to allow for a proper setting of the control valve. This accounts for the discrepancy in jacket temperature for about the first 5 minutes after the jump. This problem can be eliminated by installing a thermocouple in the tanks so that these temperatures can be used in the control algorithm.

This first design was implemented with minimal change to the existing system and with some older equipment (Apple computer, A/D converter) in order to demonstrate the feasibility of the procedure. Our intent now is to replace this older equipment and to modify the water circulation system. With these changes, it should be possible to precisely maintain any desired temperature profile. The new design will also consider minimizing the energy required to heat the water.

A complete description of this project is contained in a Master's report submitted by R. G. Wilson to the Department of Aerospace and Mechanical Engineering, dated November 20, 1989.