DETERMINING TEMPERATURE CONTROL OF WASH WATER IN A LAUNDRY ENVIRONMENT

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Fisher and Paykel (F&P) are developing a new model of washing machine. One of its key features will be that it uses less water. It is important to regulate the operating temperature of washing machines since if they operate hotter than the user-selected temperature there is a risk of damage to clothes and if they operate below the user-selected temperature there is a risk of incompletely dissolved detergent being sprayed onto clothes, which is also undesirable. F&P seek to improve their temperature regulation strategies from the current state-of-the-art. Further, since the new machine will have a smaller mass of water relative to clothes load, the impact of abnormal clothes loads and of start-up disturbances in water supply temperatures (e.g. cold slugs in hot water supply) on the bulk temperature is greater. Thus a thorough review of temperature regulation strategies is well motivated.

Temperature regulation is achieved through feedback of signals from temperature sensor(s) and manipulation of the inlet valves for hot and cold water. The temperature should be regulated throughout the fill cycle since significant deviations from the set point at any time during the fill have negative consequences. Generally, once the fill cycle is complete, the temperature will not fall significantly unless further load is placed on the system (wet, cold clothes added after 'fill' is complete). There is no simple way to ameliorate the effects of such disturbances without using additional water which is undesirable. The merits of the actions that can be taken after the end of the fill cycle were only briefly considered and are effectively outside the scope of this project. It should be noted that an 'exception case' is when the clothes are virtually saturated and cold at the start, in this case the mass of water added may not be sufficient to regulate the temperature.

Specifically, F&P want a better understanding of the impact of disturbances such as abnormal clothes loads and of start-up disturbances in water supply temperatures on the bulk temperature, this is provided by the model produced. Further, they need to design the most effective control strategy. This includes selecting the best placement of the temperature sensor and a benefit analysis of the use of multiple temperature sensors.

The machine is connected to hot and cold water supply lines with throttling valves. These valves are on/off type and when on have a throttle which gives flowrates which are effectively independent of supply pressure as long as it is above a threshold of ~ 1 bar. The supplies mix in a small mixing chamber then enter the sump. The detergent is placed in the sump. From the sump the water is pumped through a recirculation line and is sprayed onto the clothes which reside in the rotating bowl above the sump. Water which is not absorbed by the clothes drips back into the sump.

It was established that the sump temperature is the ‘process variable’, i.e. the thing that needs to be regulated as this represents the temperature at which water is sprayed onto the clothes and this is where detergent is entrained and needs to be dissolved in the water. A mass and energy balance analysis was developed which relates sump temperature to energy from water supplies, clothes loads and energy losses. It was determined that energy losses to ambient are negligible (as long as the lid is not opened for long periods of time) and that the heat load of the clothes is dominated by how much cold water is input with the clothes. The steady state balance is mathematically represented as a set of algebraic equations which can easily be analysed by spreadsheet. This describes the envelope of water supply temperatures and load characteristics which can be tolerated whilst attaining the target sump temperature. The dynamic balance describes the time history of sump temperatures and is mathematically described by a set of differential equations. Simulation software was developed for these equations in the software packages Mathematica and MATLAB. The dynamical model can be used to determine if the system dynamics permit the control strategy to reject the impact of disturbances sufficiently quickly to avoid significant temperature deviations from the target value.

The dynamical model included a model of water and heat flow to and from the clothes. This model considered the clothes to be layered. Upon application of the recirculation water, the top layer becomes completely saturated and only then does it start releasing water to the next layer down and to the sump through its sides (via the perforations in the drum). In this model, therefore, the upper portion of the clothes becomes completely saturated while the lower portion remains untouched, and the constant application of the recirculation water causes the junction between the two phases to constantly move downwards. The top layers will also be close to the temperature of the recirculation water, with the temperature decreasing for deeper layers, while the lower, untouched layers will be at their initial temperature. This model predicts that the drip rate will be small initially, as the upper layers absorb most of the recirculating water. This rate will increase with time as more and more of the clothes start dripping from their sides through the perforated drum to the sump. The model also predicts that the temperature of the drip water stays roughly constant during the fill. The control implications of this model are that, during the early and middle stages of the fill, it is likely that the impact on the sump temperature of the cool drip-down flow can be controlled by manipulation of the hot feed. However, towards the end of the fill when the drip-down flowrate is higher and still cool, it may not be possible to completely control the sump temperature since the feed flowrate will be low relative to the drip-down flowrate. In particular, during the final stages of the fill when there is oscillation between sump full, feed disabled and sump not full, feed enabled modes it may be difficult to control the sump temperature. So, for wet, cold clothes loads a critical issue requiring further model validation effort, is whether the drip-down flow is still cool, i.e. how early in the fill any cold water in the clothes can be displaced down to the sump where its impact will be measured and controlling measures taken.

A simple control strategy was suggested which uses feedback from a sump temperature sensor was presented. The dynamic model and analysis thereof via the MATLAB code will determine if this strategy is sufficient. Preliminary simulations using this code suggest that in most situations the sump temperature can be controlled to within F&P's specifications (± 2 degC).

Enhancements suggested to this include, additional measurement and feedback (in a cascade strategy) of the temperature in the supply mixing chamber to assist rejection of supply side disturbances, on-line identification of supply temperatures, load identification using information from the load cell and use of system memory to tune the machine to a particular installation and assist with diagnostics.

The filling algorithm was also reviewed and found to be effective and should result in the clothes being saturated at the end of the fill with an appropriate level of water in the sump. The temperature control strategy will determine the relative opening times of the hot and cold valves but the greater the overall openings, the shorter the ‘fill’. However, fast filling will make phase lags incurred due to sensor and actuation dynamics more significant and will impact negatively on the timely rejection of disturbances, the significance of these impacts can be determined from analysis of the dynamic model.

CONCLUDING REMARKS

MISG2005 was sponsored by the list on the next page. They, along with the organisations presenting problems, provided the financial support which made it all possible. This is gratefully acknowledged by all of us in CMI. The Director’s prize for the best remark “Overheard in passing” was awarded to Ron Thatcher and Ken Russell who were heard to say…

“Have we seen the plot yet?” Ron Thatcher

“No we have lost the plot.” Ken Russell

The ANZIAM organisation has asked us to do MISG2006 which will be in the same style and location as MISG2005. The dates for this are: -

30 January – 3 February 2006
at Massey University, Auckland.

Graeme Wake, Director, May 2005

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