Observer design for a nonlinear two-dimensional pool boiling system

Observer design for a nonlinear two-dimensional pool boiling system

R.W. van Gils*,[1], M.F.M. Speetjens[2] and H. Nijmeijer[1]
Eindhoven University of Technology, PO Box 513, 5600 MB Eindhoven
Department of Mechanical Engineering,[1]Dynamics and Control, [2]Energy Technology
Email: *r.w.v.gils@tue.nl

1 Introduction

In pool-boiling systems heat is extracted from a heater by a pool of boiling liquid. The heat flux between heater and fluid is highly nonlinear with respect to heater temperature, described by $q_F(T_F)$ (Figure 1) and results in a highly unstable regime which must be stabilised to allow for high heat removal rates. This can be accomplished by a control law based on the (nonmeasurable) spectral modes of the heaters temperature field [1]. Application of this control law requires an observer for the temperature profile of the heater.

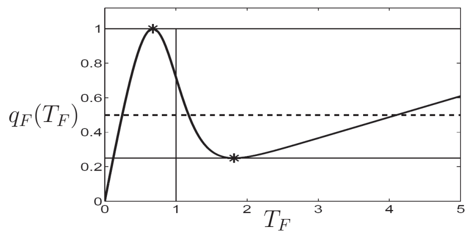

Figure 1 *Nonlinear heat flux q_F as function of interface temperature T_F.*

2 Pool boiling model description

The heat transfer in the 2D rectangular nondimensional heater $\mathscr{H} := \{(x,y) \in [0,1] \times [0,D]\}$, see Figure 2, is considered. Its temperature field $T(x,y,t)$ is described by

$$\frac{\partial T}{\partial t}(x,y,t) = \kappa \nabla^2 T(x,y,t). \tag{1}$$

The boundary conditions comprise adiabatic, i.e. perfectly isolated, sidewalls on $\Gamma_A := \{(x,y)|x = 0,1\}$, a controlled heat supply on $\Gamma_H := \{(x,y)|y = 0\}$ and the nonlinear heat extraction on $\Gamma_F := \{(x,y)|y = D\}$, i.e.

$$\left.\frac{\partial T}{\partial x}\right|_{\Gamma_A} = 0, \ \left.\frac{\partial T}{\partial y}\right|_{\Gamma_H} = -\frac{1+u(t)}{\Lambda}, \ \left.\frac{\partial T}{\partial y}\right|_{\Gamma_F} = -\frac{\Pi_2 q_F(T_F)}{\Lambda}. \tag{2}$$

Here $T_F(x) := T(x,D)$ is the fluid-heater interface temperature, Λ, D, Π_2 and κ are positive parameters, $q_F(T_F)$ is the boiling curve and $u(t)$ is the input, i.e. an additional heat supply at the bottom of the heater, see [1].

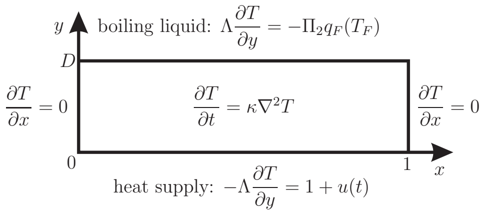

Figure 2 *Two-dimensional rectangular heater.*

3 Observer design

The temperature can be measured at $R+1$ points on the heater surface, given by $\tilde{x}_r = r/R$, $r = 0,\ldots,R$, i.e. the system output equals $y_r = T_F(\tilde{x}_r)$ for $r = 0,\ldots,R$. The observer is designed to be a copy of the system with output injection only on the boundary condition where the measurements are available. The obtained observer is given by (1) and (2) with the state $Z(x,y,t)$, i.e. the estimate of $T(x,y,t)$, instead of $T(x,y,t)$ and with the boundary condition on Γ_F as

$$\left.\frac{\partial Z}{\partial y}\right|_{\Gamma_F} = -\frac{\Pi_2 q_F(Z_F)}{\Lambda} + \sum_{r=0}^{R} p_r(x)\left(T_F(\tilde{x}_r) - Z_F(\tilde{x}_r)\right), \tag{3}$$

with $p_r(x)$ the observer gain functions. The observer error dynamics of $E = T - Z$ are analysed by linearisation of system and observer, with which local stability of the nonlinear error dynamics can be obtained. Figure 3 shows the evolution of the output, for $R = 2$, meaning the output equals $T(0,D,t)$, $T(0.5,D,t)$ and $T(1,D,t)$. The initial system state equals a uniform field of $T \approx 4$, whereas the initial observer state equals zero. Although the initial differences between system state, observer state and non-uniform equilibrium are large, the observer states converge to the system states and the equilibrium is stabilised.

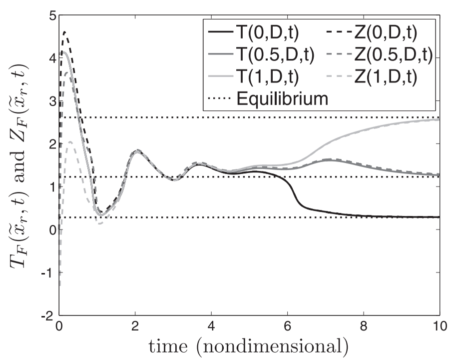

Figure 3 *Evolution of the system output and the observer output.*

4 Conclusion

An observer for a nonlinear PDE system is designed. The closed-loop system is stabilised by the control law discussed in [1] and this observer, even for large initial perturbations.

References

[1] R. van Gils, et al. Feedback stabilisation of a two-dimensional pool-boiling system by modal control. *Automatica*, submitted for publication, 2010