RFQ Thermal Control Overview

Daniel Bowring
on behalf of the RFQ control group

March 16, 2015

Statement of work & interface control document

Overview of statement of work

"RFQ water system activities for Fermilab"

Sponsor	FNAL
Sponsor points of contact	B. Chase, J. Steimel
PI	S. Biedron
Institution	CSU Dep't. of Electrical & Computer Engineering
Period of Performance	12 Jan. 2015 - 11 Feb. 2016

Statement of work: specific tasks

1. Assist with formulation of commissioning, test, verification strategies for RFQ
2. Based on prior work at LBNL, FNAL on cooling system, simulate system and design local H_20 temperature control loop.
3. Work with LLRF to interface water temperature and LLRF systems, with goal to control RFQ frequency.
4. Assist in implementation, verification of control systems.
5. Develop interfaces for operators (auto start-up, e.g.)
6. Help with documentation & reviews

Statement of work: Deliverables

1. ≥ 2 publications; ≥ 1 archival $+ \geq 1$ conference proc.
2. Simulation tool for resonant control system.

Statement of work: Cost breakdown

Effort	$74,925
Fringe	$10,852
Domestic travel	$15,720
Total direct costs	$101,497
Overhead (48.7%)	$49,429
Total	$150,926

Interface control document: power, cooling requirements

Table 1: Total Power and Flow Requirements on Cooling System

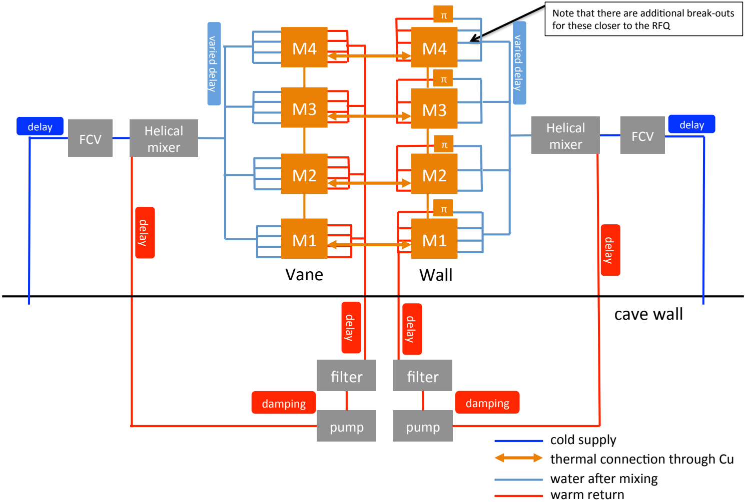
Parameter	Vane Circuit	Wall/Pi-rod Circuit	Comments
Heat Load			
Nominal Load	29kW	50kW	[4]
Maximum load	38kW	65kW	30% Contingency [4]
Flow Rate			
Minimum Flow	44 GPM	88 GPM	
Nominal Flow	65 GPM	128 GPM	Design Condition [4]
Maximum Flow	87 GPM	172 GPM	
Supply Temperature at Interface			
Nominal Supply Temperature	35°C (TBR)	35°C (TBR)	Proposed to allow mixing architecture for cooling system Currently in conflict with [1]

Table 4: Cooling System Requirements on RFQ

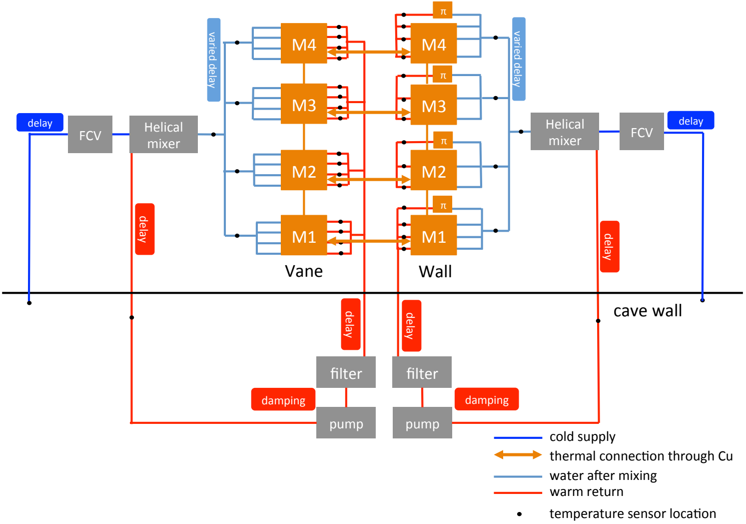
	Vane Circuit	Wall/Pi-rod Circuit	Comments
Pressure Drop At Maximum Flow Rate	<60psig	<60psig	Pressure drop at the interface location
MAWP	100psig	100psig	
Hydrostatic Test Pressure	1.5X MAWP	1.5X MAWP	B31.3

System overview

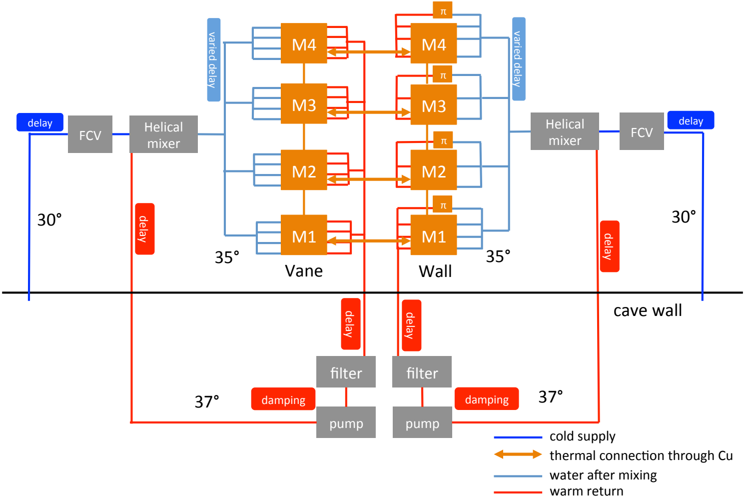
RFQ water layout



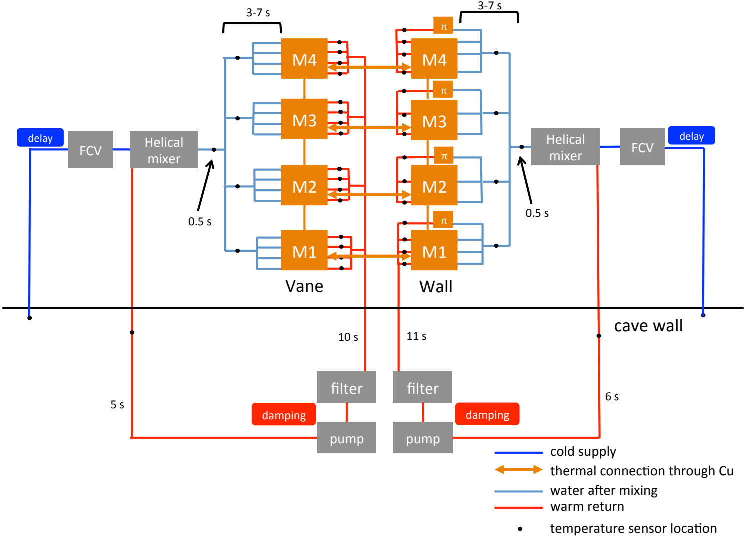
RFQ water layout + locations of temperature sensors



RFQ water layout + locations of temperature sensors



RFQ water layout + line delays

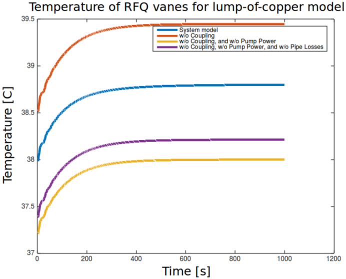


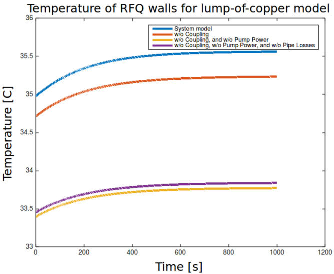
See subsequent slides for determination of mixing point location.

Model status and current work

Start simple and add complexity

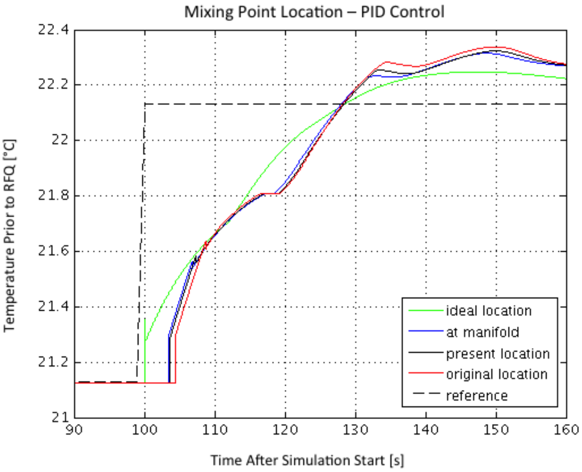
Temperature response to a 10% decrease in water flow rate:



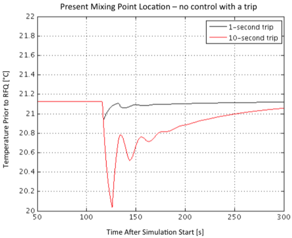


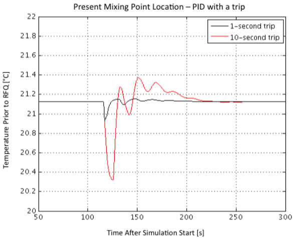
- Thermal mass of vanes $= 10^4$ J/K
- Thermal mass of walls $= 1.2 \times 10^6$ J/K
- Thermal mass of water in vane circuit $= 4.6 \times 10^5$ J/K
- Thermal mass of water in wall circuit $= 8.4 \times 10^5$ J/K
- Coupling between vane & wall ≈ 0.7 kW/K

Mixing point location is “optimized”

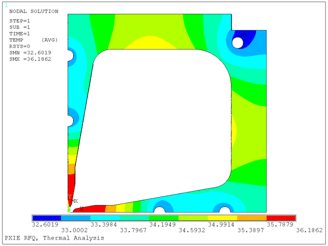


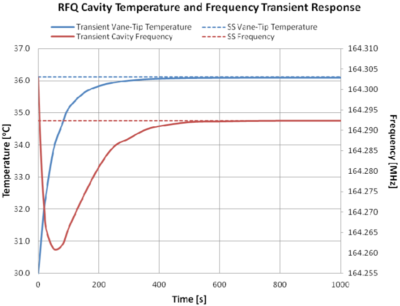
System model of trip recovery





Detailed RFQ simulation

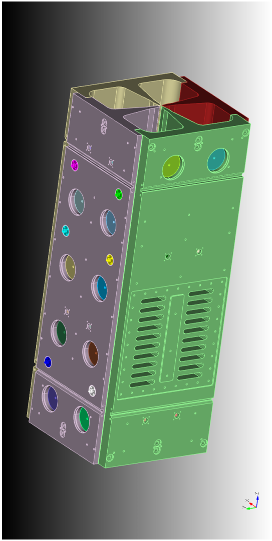


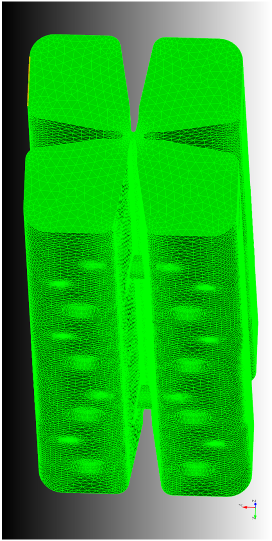


Ongoing work

- Accurate model of df/dT
- Improved estimates of thermal coupling between walls, vanes
- Thermal capacitance of pipes & effect on trip recovery
- Assessment of heat generated by pump
- Pulsed operation
- Heater to compensate changes in return H_2O temperature?

Simulations with detailed, 3D model

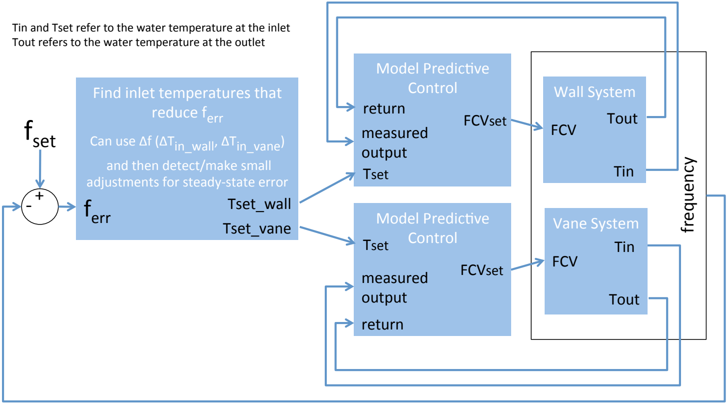




Control Concept: Two MPCs

Basic Conceptual Control Schematic for Water Temperature Loop: Individual MPCs

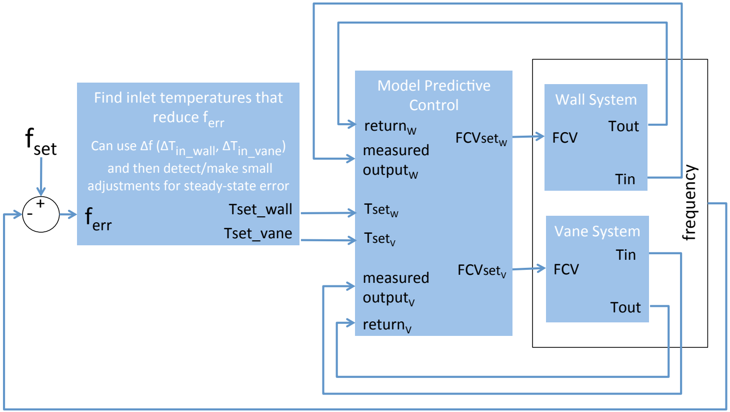
Tin and Tset refer to the water temperature at the inlet
Tout refers to the water temperature at the outlet



Note that the full schematic is more complicated:
1. Each MPC will need to know both temperature set-points in order to account for coupling
2. Would also include supply temperature input under each MPC
3. If Δf (ΔTwall, ΔTvane) ends up being more complicated than what we have from Andrew's technical report, then there will likely be additional inputs for that first block (e.g. related to the present operating point)
4. Will change as we incorporate more from the LLRF
5. Would need to expand to include startup routine

Control Concept: One MPC

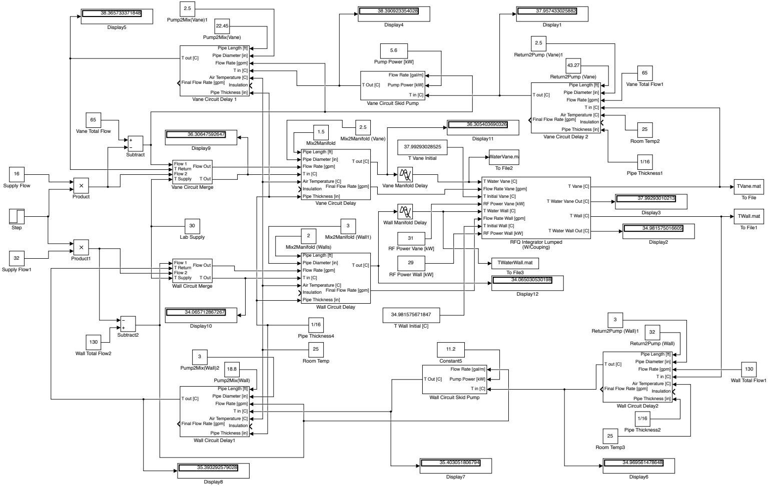
Basic Conceptual Control Schematic for Water Temperature Loop: One MPC



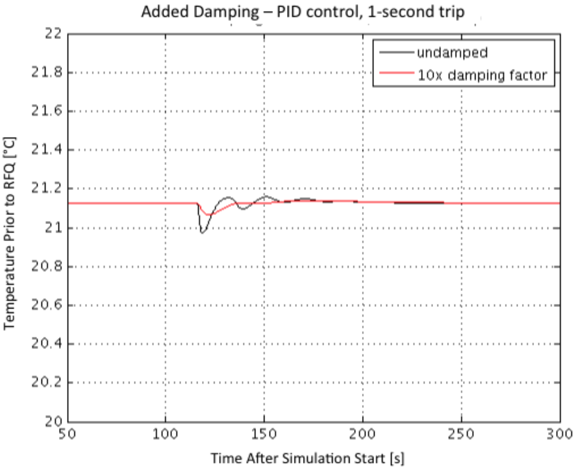
Would also include supply temperature input under MPC

Supplemental Slides

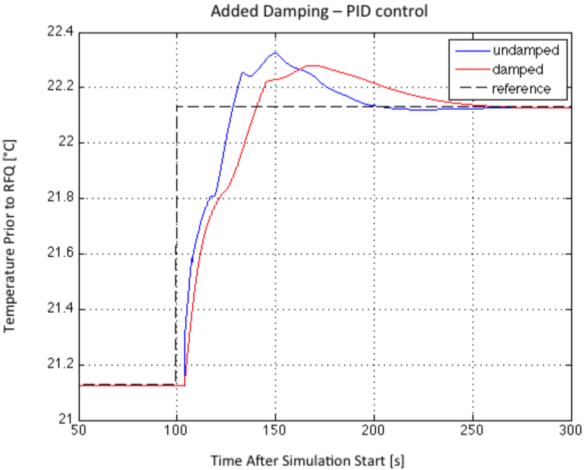
Simulink Model



Effect of damping on water temperature at RFQ input



PID control with damping added



10x damping