Title: Systematic Approach for Universal Commissioning Plan for Liquid-cooled Systems

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Abstract. This document is the result of a collaborative effort to provide the methodology for commissioning liquid-cooled High Performance Computing (HPC) solutions. While the main focus of this effort is directed at HPC cooling, the same commissioning principles are applicable and relevant for any liquid-cooled computing system.

The document includes examples from different data center sites and the various approaches utilized in commissioning liquid-cooled solutions; it establishes the fundamentals for liquid-cooled commissioning. Techniques employed include: a) pressure testing for leaks, b) flow tests to ensure proper valve operation, flow rates, and controls sequencing, and c) load simulation to ensure cooling demand is met. Proper operation of liquid cooling systems is critical for liquid-cooled equipment because safety margins can be very small. Either a disruption of cooling fluid flow or a temperature spike will cause an unplanned outage.

Introduction. The objective of this guideline is to develop a comprehensive approach to commissioning liquid-cooled systems that can ideally be incorporated into a universal commissioning plan. This universal approach will be presented to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) data centers committee (TC 9.9) for adoption and inclusion in their data center book series in order to establish a peer reviewed guideline for commissioning of liquid-cooled computing systems. Each major section in the document is intended to serve as a stand-alone reference guide for sites that are designing, building, and commissioning liquid-cooled systems.

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1 Liquid Cooling System Design Description (SDD)

System Design Description (SDD) - an overview of what the liquid cooling system is intended to deliver. A SDD will establish design parameters, controls characteristics (including sequence of operation), and performance requirements. This section introduces topics, concepts, and systems issues to the Design team that could impact the functionality of the facility.

1.1 Requirements, Features, and Operating Conditions

1.1.1 Describe requirements for assuring internal passageways of coolant piping and components are clean and design flows are achieved. Piping must be flushed with full designed fluid flow utilizing the appropriate cleansing agent for a period of not less than 24 hours. An adequate amount of fluid (full design flow in all branches is recommended) must be used to remove debris and contaminants introduced during manufacture or construction.

1.1.2 Describe the assumptions and goals that drove the decision to implement a liquid-cooled system. At what point is it necessary to switch from an air-cooled to a liquid-cooled system? Examples at UIUC showed that about 16 kW was the upper limit for air-type cooling without aisle containment. Up to about 30 kW is reportedly achievable with aisle containment. But, with aisle containment, fire protection and safety egress become more difficult to achieve. Verify need for space dedicated to housing high-density equipment; non-HPC (low density) loads can be located in a less-costly space than that required for HPC equipment. [Ref: ASHRAE's Liquid Cooling Guidelines book, Chap. 6.].

1.1.3 Describe the computing equipment and its method(s) of cooling - direct liquid cooling, indirect liquid cooling, air cooling, rear-door heat exchangers, hybrid systems, etc. [Ref: ASHRAE's Liquid Cooling Guidelines book, Chap. 4-5.]

1.1.4 Describe components in the cooling system including chillers, cooling towers, dry coolers, heat exchangers (to protect sensitive equipment from water contaminated with debris, such as cooling tower water), pumps (pumping strategies, redundancy, pressure and flow control), and material selection (pumps, piping, fittings, gaskets, etc.).

1.1.5 Describe how controls, including settings for temperature, water flow, and differential pressure will interface with facilities and computer control systems.

1.1.6 Describe methods to achieve system balancing including balancing controls settings for parallel systems or multiple systems with different requirements. Describe specifications and performance requirements for valves. For example: merging flows from multiple chilled water sources, multiple cooling loops with different loads, etc.

1.1.7 Describe environmental conditions and unique features such as use of ponds, rivers, aquifers, synergy with local sources of cold water or loads to use rejected heat.

1.1.8 Describe water chemistry and treatment, quality of water in Cooling Towers, and cooling loops (all systems). Some computing equipment vendors could specify special water quality requirements, so the design must include strategies to provide the required water quality and materials compatible with the water treatment specified. The water quality of both open and closed loop systems should be defined in the cooling design phase and implemented and validated during commissioning.

1.1.9 Describe use of cooling fluids such as refrigerants or dielectric fluids if these are required for the liquid-cooled HPC system.

1.1.10 Ensure that all necessary sensors, gauges, instrumentation, and ports as designed are installed at locations necessary to provide a complete data set for building automation systems and for all commissioning and verification requirements. Required data typically includes pressure, temperature, flow, Btu, kW, kWh, valve position, differential pressure, and other metrics.

1.2 Analysis and Verification

1.2.1 Load simulation for commissioning is recommended to match the actual design loads in terms of both coolant flow and heat load. It is critical that testing the cooling fluid distribution system is done to ensure it will provide full flow, as designed, throughout the system at the pressures required.

1.2.2 CFD Modeling can be used as a design tool if funding is available. Reference CFD modeling results (when available) so the commissioning plan can determine how closely the implementation adheres to the model and the design intent. CFD modeling is for both air and liquid systems. Hydronic flow network modeling is another option for liquid systems design and analysis.

1.2.3 Check ASHRAE liquid cooling guidelines. Does the design take into consideration the ASHRAE liquid cooling guidelines? Describe which of the ASHRAE guidelines are incorporated in the design.

1.2.4 Identify potential health and safety concerns that can affect facility occupants. Implement strategies to mitigate these problems and include signage to inform occupants of potential hazards. Specific examples include noise (db limits) and noise mitigation for adjacent spaces and water treatment and Legionella concerns when cooling towers are operated at the facility.

1.3 Site Preparation Considerations

1.3.1 Ensure that the facility liquid cooling system specifications match those specified for the HPC equipment.

1.3.2 Maintenance scheduling considerations highlight the need for equipment redundancy to ensure the facility can maintain uninterrupted operation (design consideration). Examples include: Change of water filters, a full flow bypass; primary and secondary pumps will have N+1 redundancy to allow for maintenance, etc.

1.3.3 Once the computing equipment vendors are known, utilize their site preparation requirements during facility design.

1.4 Accommodations for Commissioning

1.4.1 Describe how the design will accommodate load simulation for commissioning. Testing using a simulated load will help ensure that adequate cooling is provided. Define the means and methods to complete commissioning with full load simulation. Note: it may not be practical to simulate all types of liquid cooling systems. Ex : if your system had a heat recovery unit installed you could reverse flow the heat recovery unit and use this as a load simulator to vary the inlet temperatures. If your system is primary secondary you could simulate a false load on your cooling source by manipulating the cooling sequence .

2 Commissioning Plan

This section introduces topics and concepts to the Commissioning planning team that can affect system commissioning. A Commissioning Plan provides the testing plan required to prove the system performs to design specifications. It establishes the roles, responsibilities, and manner in how the system will be tested that becomes the basis for developing a System Acceptance Test Procedure. It includes requirements for the System Acceptance Test Procedure and includes necessary references, including those from ASHRAE, such as Table 5.2.

2.1 Elements of the Commissioning plan include:

2.1.1 Water Chemistry. Ensure that flushing fluid and initial coolant fill are properly treated. Ensure that the system maintains proper water or fluid treatment during operating conditions for all systems.

2.1.2 Load simulation for commissioning is recommended to match the actual design loads in terms of both coolant flow and heat load. Testing the cooling fluid distribution system to ensure it will provide full flow at the extents of the system (at the pressures required) is critical.

2.1.3 Flushing of pipes. Proper fluid flow is required for flushing of pipes prior to commissioning. Full design flow in all branches is recommended. Ensure that connections between supply and return pipes at all load connection points are line size so full flow and complete flushing are achieved throughout the piping system. Strainer screens and sensitive controls units can be removed during this process; one standard, or finer, mesh strainer screen should be utilized at the pump inlet. Back (reverse flow) flushing might be necessary in some cases.

2.1.4 Controls, especially settings for temperature, water flow, and differential pressure, must be tested under design conditions and load simulation. Demonstrate that the systems can provide the required amount of cooling fluid at the required temperature and pressures and flow rates under all operating scenarios (load variances, seasonal issues, fast rate of change in load, etc.). Test and adjust controls settings for parallel cooling water supply sources and/or multiple cooling systems with different requirements to ensure that transitions between sources of cooling water are seamless in terms of flow, temperature, and pressure requirements at the load being served. For multiple, varied heat loads, ensure that the controls maintain required flows, temperatures, and pressures at each load.

2.1.5 Ensure that controls that cross system boundaries are coordinated and working correctly. Examples or a drawing may help to clarify matters (ex. District chilled water system and building cooling loop controls.)

2.1.6 Verify that chillers, dry coolers, cooling towers, heat exchangers, and pumps each meet their design intent through testing. Factory performance testing can satisfy this requirement for individual pieces of equipment.

2.1.7 Perform balancing of flows in piping systems and ensure that flows are balanced per design specifications in all branches.

2.1.8 Verify the specifications and performance of all valves. Ensure that all valves are oriented properly, that activation is properly controlled, and that the time for actuation during both opening and closing is appropriate (e.g. Ensure that water hammer isn't created by a valve closing too fast; three-way valves are ported properly, etc.)

2.1.9 Verify the function of cooling components supplied with the HPC equipment (direct liquid cooling, indirect liquid cooling, air cooling, rear-door heat exchangers, etc.). List the items included in the system design and plan accordingly. Vendors shall provide guidance/design on system specific equipment.

2.2 Commissioning Prerequisites and Requirements

2.2.1 Always protect all electrical equipment with plastic covering during installation to protect it from water damage.

2.2.2 Work closely with each vendor and the installation contractor to ensure that site preparation is correct. Have a representative of each vendor do a site check with the commissioning agent and/or customer's representative prior to arrival of equipment so any discrepancies can be resolved without delaying installation. Items to verify include cooling system fittings (type and size), tile cuts (use template), flanges for connecting cooling system components and pipes, electrical cord caps, etc.

2.2.3 Ensure that documents of record, especially piping arrangement and controls sequence of operation, are accurate and available during commissioning.

2.2.4 Take the time necessary to ensure that each vendor's site preparation manual provides all the information the site requires and to ensure that all requirements are fully understood. Hold regular meetings or telephone conferences to discuss issues that arise during infrastructure preparation.

2.2.5 Check hose lengths and flange attachments during vendor site inspection using a sample hose with connectors from the vendor to ensure that all are correct. Get the vendor to supply the flanges and/or connectors ahead of time so these can be connected and tested prior to installation or during commissioning.

2.2.6 Vendors that have special water quality requirements must provide all relevant information regarding their specifications for water treatment and quality. These specifications must be included in site planning, design, and commissioning documents when possible.

2.2.7 Ensure that the construction timeline includes time for a full cooling system flush prior to connection of computing equipment. This should be executed with flexible hoses provided by vendor ahead of time.

2.3 Required Procedures and Tests for Commissioning Checklist

2.3.1 Measure static pressure for all piping systems and record results. Perform a visual check for leaks, preferably before pipes are insulated.

2.3.2 Flush all primary and secondary piping systems (including cooling tower systems and/or dry cooler systems) utilizing the designated flushing agent. Ensure that flushing agents are compatible with all affected equipment, including computing equipment. Note: Running a closed loop system may generate internal heat on the working fluid. Also, if the system has sensitive control points not in thermostatic wells (paddle wheels for flow meters, etc.), they should be removed if possible during this operation to prevent damage by debris or flushing agents.

2.3.3 If the system has heat exchangers, these systems should be flushed separately from the rest of the piping system. This is to ensure that the heat exchangers do not get fouled with debris from the rest of the piping system.

2.3.4 Consider having a separate filter with a sight glass installed (on the secondary side) to provide a means to ensure flushing is working effectively.

2.3.5 When not in use for extended periods of time, ensure each water-filled system is in an appropriate wet or dry long-term storage program.

2.3.6 Flush and pressure test existing systems being reused as part of a new piping configuration.

2.3.7 Static fill all fluid systems and add appropriate chemicals and test systems. Run all systems for a 24-hour period to ensure chemical treatment is operating correctly and that chemical agents have been dispersed properly. Test all systems after 24 hours to ensure chemical treatment and blow down operations are operating within specifications and record the results of tests. Installation of a coupon rack is recommended as well as alarms to alert personnel about pertinent chemical treatment and water quality parameters.

2.3.8 While running the chemical treatment system test, the pumps can be operated in hand (manual) or automatic mode. Test the ramp time of pumps, tower fans, etc. (if on a VFD) and modulate the automated valves through the local plant control system, ensuring visual and automated verification is completed. Along with the latter, pressure and temperature gauges should be tested to ensure these instruments are operating correctly. Hand valves can be checked by watching gauges and, if pumps are in auto mode, VFD's should be checked to verify reaction to the manual valve movement and the results recorded.

2.3.9 Open all valves to heat exchangers and replace all control components removed during flushing. Start and test the full system. This will test sequencing of the total system including controls, programs, etc. The piping system from the cooling source to the computing equipment should be connected (supply to return) e.g. through the use of flexible connections to test operation of all components. Check all operational schemes, testing flows and temperature and pressure gauges with calibrated external sources to verify accuracy; record results. This is also a good time to set circuit setters where applicable.

2.3.10 Validate variable speed operation of cooling towers or dry coolers and simulate heat rejection performance for various environmental conditions when possible. See 1.4.1

3 System Acceptance Test Procedure

This section introduces topics and concepts to the Commissioning agent and/or team that can be required components of a comprehensive commissioning test procedure and help ensure that design intent and commissioning plan are fulfilled. These items will help the team develop their detailed set of commissioning procedures.

3.1 Proper water flow for flushing of pipes prior to commissioning is extremely important (full design flow is recommended). Install full size supply-to-return connections during flushing and cleaning of pipes, leave in place for load simulation if needed. Routinely monitor water quality and record results.

3.2 Water Chemistry, including primary and secondary systems, and cooling towers systems. Check initial chemical mix and test operation of chemical treatment system.

3.3 Safety interlocks and alarms. Test these in conjunction with load simulation activities or use ice or hot water for individual checks. Testing is necessary at 2 levels: first, does each one work; and second, verify that the exact settings and tolerances are correct. Systems to be tested include leak detection systems, refrigerant detection systems, those associated with HPC equipment, and infrastructure alarms. Review the notification system and ensure that all necessary personnel are alerted by the reporting system for each alarm (via text, page, e-mail, call, etc.).

3.4 Perform full fluid flow testing regardless of heat load simulation to ensure pressure and flow requirements can be met at all locations and complete flushing of the system is achieved.

3.5 Load simulation for commissioning. Simulate design load when feasible. Utilize primary and secondary load banks (reverse flow if applicable with HXs). Test under exception or failure conditions (e.g. simulate loss of CHW). Complete “failover” tests (e.g. simulate loss of a pump or a chiller for N+1 systems). Evaluate system response time to change in load and to loss of equipment during “failover” scenarios. Simulate likely failures and record all pertinent results.

3.6 Controls, especially settings for Temperature, Water flow, and Differential Pressure, sequencing of equipment, start/stop, transitions from one system to another, smooth ramping up and down. Test separately and during load simulation tests and record results.

3.7 Reference ASHRAE for establishing specific commissioning procedures.

3.8 Test the following equipment items either on-site or at the factory prior to testing the operating system (see load simulation below):

3.8.1 Dry Coolers, vibration, modulate fan speed, water distribution, overflow, valves

3.8.2 Cooling Towers, vibration, modulate fan speed, water distribution and balance, overflow, valves, makeup water, seasonal variations (e.g. ice on fan blades, humidity levels);

3.8.3 Chillers, factory test results, manufacturer's checklist, vibration;

3.8.4 Pumps, vibration, cavitation (inlet adequate), differential pressure meets spec, VFD, dead head, test bank of pumps together including response when one fails (sequencing), staging, maintaining DP at end of system under changing flow rates and/or load;

3.8.5 Valves: verify open and close operation, modulation where applicable, and test to be sure closing is 100%;

3.8.6 HPC equipment with direct liquid cooling and/or indirect liquid cooling. Test and verify flows, modulation, temperature, pressure: check for leaks at the site or via witnessed factory test.

4 Lessons Learned (aka Common conditions/problems found):

Reference to lessons learned documents needed