Title: Systematic approach for universal commissioning plan for liquid-cooled systems

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Abstract. This study is a collaborative effort providing 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 principals are relevant for any liquid-cooled computing system.

The study includes cases from different data center sites and the varying approaches utilized in commissioning liquid-cooled solutions and 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 demand is met. Proper operation of liquid cooling systems is critical for liquid-cooled equipment because safety margins are very small and cooling fluid flow cannot be disrupted without causing a system outage and/or damage to computing equipment.

The objective is to develop a comprehensive approach to commissioning liquid-cooled systems that can ideally be incorporated into a universal commissioning plan. This universal plan will be presented to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) data centers committee (TC 9.9) for adoption to establish the guideline for commissioning of liquid-cooled computing systems.

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1 System Design Description (SDD)

System Design Description (SDD) - an overview of what the system is intended to deliver. A SDD will establish design parameters, controls characteristics (including sequence of operation), and performance requirements.

1.1 Requirements, Features, and Operating Conditions

1.1.1 Piping must be flushed with an adequate amount of water (full design flow in all branches is recommended) 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 do we 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. Non-HPC (low density) loads can be located in a less-costly space than that required for HPC equipment, verify need for space dedicated to housing high-density equipment.

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, etc.

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 pipe material selection.

1.1.5 Describe controls, including settings for temperature, water flow, and differential pressure.

1.1.6 Describe methods to achieve system balancing including balancing controls settings for parallel systems or multiple systems with different requirements, and valves specifications and performance. 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, 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 CTs, and cooling loops (all systems). Some computing equipment vendors might have special water quality requirements, so the design must include strategies to provide the required water quality and materials compatible with the water treatment specified.

1.1.9 Describe use of alternative cooling fluids such as refrigerants or dielectric fluids.

1.1.10 Ensure that all necessary sensors, gauges, instrumentation, and ports are installed at all 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 points.

1.2 Analysis and Verification

1.2.1 Load simulation for commissioning is recommended to match the actual design loads in terms of both 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.

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 them and the design intent. CFD is for both air and liquid. 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 the ASHRAE guidelines the design intent incorporated.

1.2.4 Review specifications regarding Noise and noise mitigation for adjacent spaces.

1.3 Site Preparation Considerations

1.3.1 Have the RFP include facility specifications so HPC equipment better matches the existing facility.

1.3.2 Maintenance scheduling and redundancy for uninterrupted operation (design considerations).

1.3.3 If 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 that it may not be practical to simulate all types of liquid cooling systems.

2 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 initial fill is properly treated). Ensure that the system maintains proper water 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 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 Proper water 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 while one standard or finer mesh strainer screen should be utilized at the pump inlet.

2.1.4 Controls, especially settings for temperature, water flow, and differential pressure, must be tested under design conditions and proper 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 from sources of chilled 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 (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.

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. don't create water hammer by closing too fast; three-way valves are ported properly)

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.

2.2 Commissioning Prerequisites and Requirements

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

2.2.2 Work closely with each vendor 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 hitches can be resolved without delaying installation. Items to verify include fittings (type and size), tile cuts (use template), flanges, electrical cord caps, etc.

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

2.2.4 Take the necessary time 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 install 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 Static pressure all piping systems and record results. Perform a visual check for leaks, preferably done 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 There may be 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 specs and record. 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 or auto mode. Test the ramp time of your pumps, tower fans, etc. (if on a VFD) and modulate the automated valves through your local plant control system ensuring visual and automated verification is completed. Along with the latter, you can test pressure and temperature gauges to ensure these instruments are operating correctly. You can also check operation of hand valves by watching gauges and, if pumps are in auto mode, you can watch the VFD's react to the manual valve movement and record results.

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) with some type of flexible connection to test operation of all components. Check all operational schemes, testing flows and temperature and pressure gauges with calibrated external sources to verify accuracy and record. 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.

3 System Acceptance Test Procedure–

[A detailed, step-by-step procedure as an outline. Includes feedback on deficiencies - a post mortem.]

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, include primary and secondary systems, 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 guidance for establishing procedures.

3.8 Test these as individual units either on-site or at the factory prior to testing the operating system (see load simulation):

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):