DEVELOPING A MOBILE CART FOR DATACENTER FLUID SERVICING

Revision 1.0

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Executive Summary

As Thermal Design Power (TDP) for processors continues to increase, more datacenters are making the transition from air-based cooling to liquid cooling using cold plate-based technologies (Shenkar, 2020). While liquid-cooling provides more effective cooling capabilities, there are certain datacenter requirements that become apparent in a liquid-cooled datacenter that are not needed using air cooling. One such important consideration for the facility operator is fluid serviceability. In order to effectively maintain the liquid-cooling fluid throughout a datacenter, a mobile cart should be considered so that this fluid-servicing maintenance can be done at the location of each rack. The aisle and rack configuration in the data center white space requires a mobile cart that can charge, flush and purge liquid cooled racks with minimal fluid leakage. This paper covers key aspects of a cart that a datacenter operator should consider when designing to service their datacenter.

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Scope & Overview

This paper is focused on sharing design considerations for a fluid-servicing cart to be used in liquid-cooled datacenters. The goal of this effort is to provide a background on the need for such a cart and to give a starting point so liquid-cooling datacenter operators can design a cart that meets their facility's needs. This paper will begin by sharing key requirements for a fluid-servicing cart based on Facebook's expected fluid-maintenance needs within a datacenter. Note that these requirements are given as an example only to give an idea about some key requirements to consider. Each datacenter would need to design a servicing cart based on their own requirements. The paper will then describe various key areas to consider when designing a cart. These design learnings are shared from experience in developing a cart for use in liquid-cooling testing and metrology maintenance within Intel. These learnings are then generically applied to give applications and considerations specific to datacenters.

Terms & Definitions

Flush	Rinsing a liquid-cooled rack or cold-plate with a rinse-fluid. Used to clean the fluid loop of contaminants or old cooling fluid.
Charge	Filling a liquid-cooled rack or cold-plate with new cooling fluid.
Purge	Pushing out all fluid from a liquid-cooled rack or cold-plate with air or nitrogen. This can also be used to dry the fluid loop.

Introduction and Background

Rack level Liquid Maintenance Need

For servicing liquid cooled racks integrated with cold plates, both treated water and inhibited propylene glycol fluid related maintenance needs to be considered. For newly deployed liquid cooled racks this would require the ability to charge and flush the manifold, hosing, quick connectors and cold plates to remove potential contamination and foreign object debris (FOD). Typically, fluid is run through the loop for at least thirty minutes prior to replacing any filters in the system. In scenarios where complete fluid replenishment of the liquid cooled rack is required, the mobile cart would be switched to a purge function to remove the existing fluid. Once complete, the flush function would be enabled to pass deionized water or inhibited propylene glycol through the liquid cooled rack before charging with the new fluid. This would require at least two reservoirs, one filled with deionized water and one filled with the treated water or inhibited propylene glycol, as preferred by the data center operator.

Mobile Cart for Liquid Cooling Testing

To meet the need for fluid maintenance within liquid-cooled cold-plates, servers, and liquid-cooling metrology, Intel designed and built a mobile cart specifically to support liquid-cooling testing. This cart can charge, flush, and purge liquid-cooled test samples and liquid-cooling metrology to prepare for testing as well as storage. The learnings from designing this cart can be readily applied to a datacenter specific application. This whitepaper will begin by discussing the datacenter requirements for such a cart before describing key considerations that should be accounted for in designing a mobile fluid servicing cart. Images and diagrams within this paper are taken from the Intel-designed mobile cart.

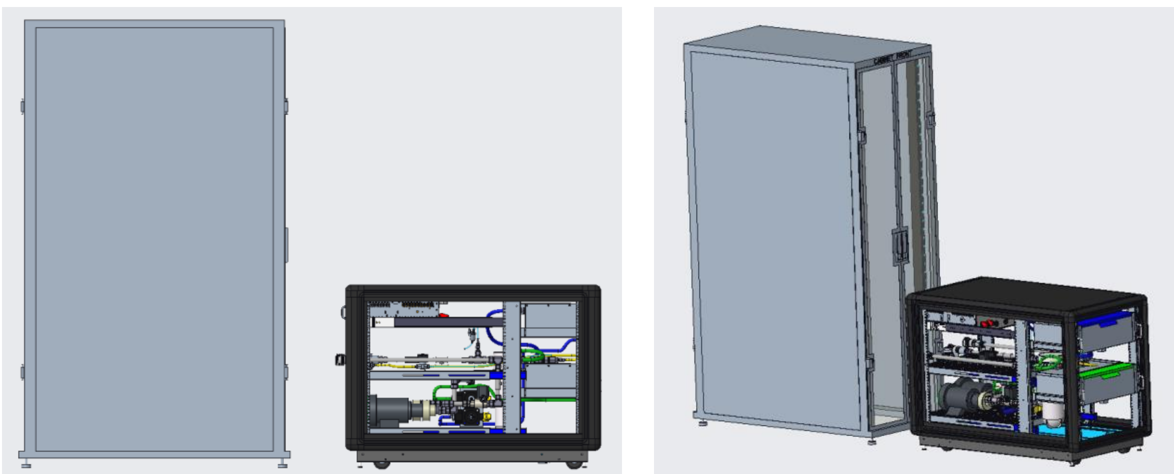

Figure 1. Mobile fluid-servicing cart next to generic cabinet

Datacenter-Specific Requirements

The mobile cart will serve to provide maintenance and servicing capabilities for the liquid cooled racks in the data center. The section below outlines the necessary baseline functionality of the cart and captures the intended behavior of the system. It also discusses the different use cases that the cart will serve.

Functional Requirements

Depending on the various use cases and application, Table 2 outlines the functional requirements of the cart.

Requirement	Priority
Full system drain The cart should be able to drain the entire rack	High
Material Compatibility The cart should be compatible with the coolant being used.	High
Drain container size The drain container should be able to hold the entire rack's liquid volume.	High
Interface with Rack The connections on the cart that will charge/purge fluid should be compatible with the rack.	High
Pumping capability The cart should be able to pump fluid into the rack for the filling/top off process.	High
Fresh Fluid Storage The cart should be able to store the entire rack's liquid volume of fresh coolant.	High
Power Supply The cart should have pluggable power.	High
Leakage Detection The cart should be able to detect if there is an internal leak and cut power to the pumps and alert the user.	High
Pressure Monitoring The cart should be able to detect if the connected loop is not pressurizing to the proper spec and notify the user.	High
Coolant Overflow and Air Displacement The cart should have a return line for air and coolant overflow.	High
Compressed Air The cart should have compressed air delivery to ensure the coolant has been drained completely.	High
Movable with locks The cart should have wheels that will allow it to be moved in the data center. The wheels should be lockable.	High
Part Storage The cart should have features to store replaceable components.	Low-Medium

Use Cases and Application

The mobile cart can serve the following use cases:

1. Top off or charge liquid cooled racks
2. Full system drain
3. Replace fluid in the rack

Accessibility and Reservoir Capacity

The cart would connect to a fluid inlet socket on the rack. An external pump on the cart will pump coolant into the rack. It is preferred to have accessibility in the cold aisle since servicing and maintenance could take longer. Depending on the fluid capacity on the rack and the pump, it could take several minutes to service. Doing this in the hot aisle can be a cause of concern from a safety and serviceability standpoint.

The reservoir capacity on the cart will vary according to the total fluid capacity of the rack. The following needs to be taken into consideration when calculating total rack capacity:

1. Reservoir and pumping unit
2. Tank (if applicable)
3. Hoses
4. Manifolds
5. Heat exchanger

In addition to the total rack capacity, an additional 3-5 L of fluid buffer should be considered in the fluid storage capacity for the cart.

Mobile Cart Interface

The interface of the mobile servicing cart should be appropriate for the rack connection points. In this case it is recommended to use quick disconnect couplings for quick and easy connection (Mitchell D. M., 2021). Further, universal connectors would allow for easy connection to many racks even if the datacenter is using multiple Universal Quick Disconnect suppliers (Sprenger, 2020).

Size Constraints

In addition to the functional requirements, it is important to consider the overall dimensions of the cart. To be able to service racks in the data/server halls, the cart should be movable. It should be able to move within aisles and from halls to halls without interfering with any equipment.

Mobility

As mentioned above, the mobile cart will move through the data/server hall aisles. From a safety perspective, it is important to ensure that the keep out areas are well defined. Any features that are outside the frame of the rack and can be hit by this cart during movement. Furthermore, the width of the cold and hot aisle may vary. In case the cart needs to move in the hot aisle, it needs to be designed for the minimum aisle width.

Storage and Logistics

One of the main functional requirements of the cart is to have fluid storage capability. This would approximately be the sum of total fluid in the rack and a buffer. Once all the fluid in the cart is exhausted, it needs to be taken to a location in the data center where it can be re-filled. The mobile cart should have the capability to fill its storage tank with fluid either using a pump or by having an opening to pour fluid in through containers. This location is preferred to be away from the data/server halls to avoid safety issues with leakages and spillage.

Mobile Cart Key Capability Considerations

A mobile cart must provide versatile functionality to meet various datacenter requirements and provide liquid-cooling maintenance capabilities to a wide variety of liquid-cooled products. Figure 1 shows a high-level piping and instrumentation diagram (P&ID) of a cart that could meet these requirements, as well as a depiction of the front and rear panel of the control box. At a high level, this shows the basic layout of the key piping and instrumentation that allows for the following functionality to service liquid-cooled components: flush, charge, purge/dry, and self-drain/rinse/dry.

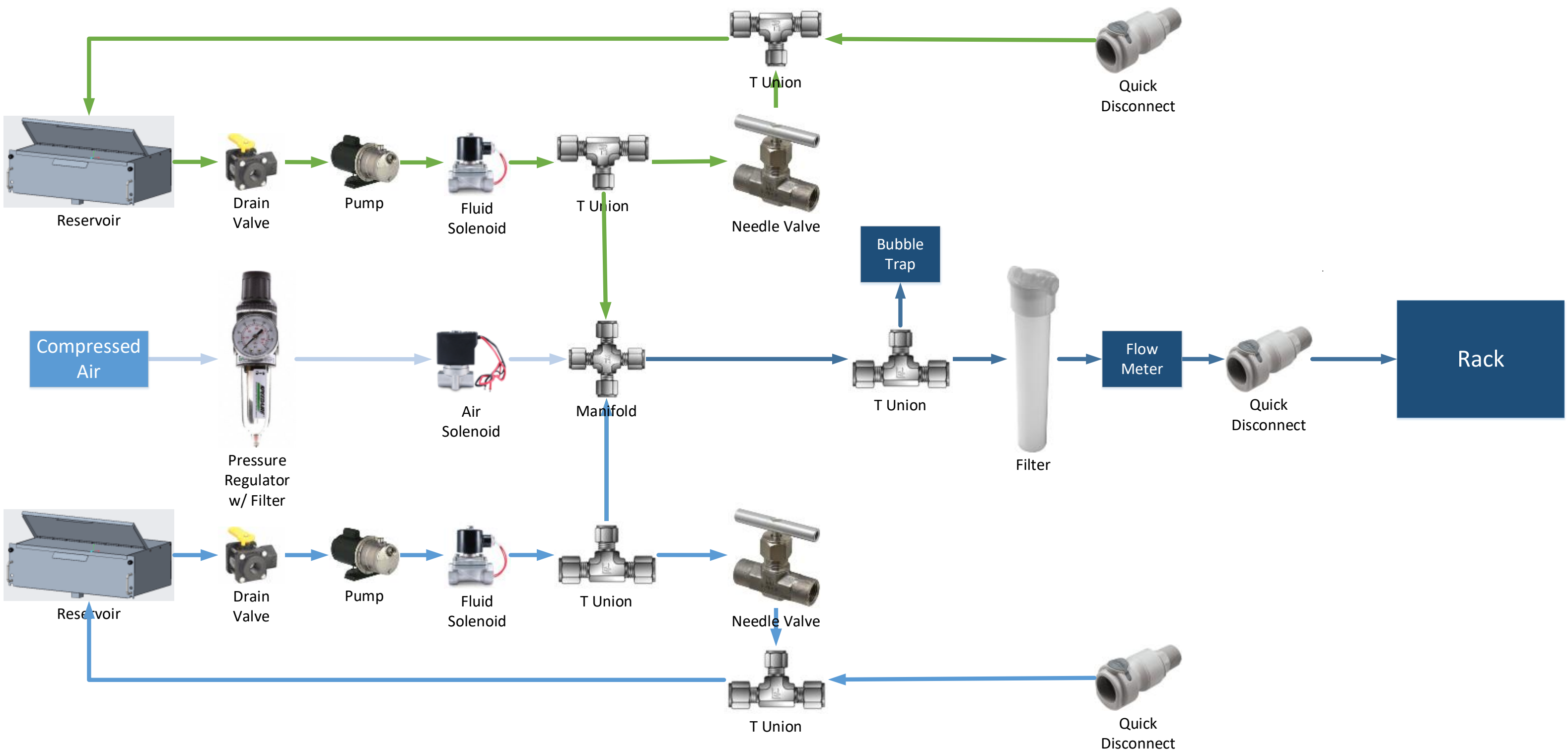

Figure 2. High-level P&ID of a mobile fluid-servicing cart

Flush Cycle

The flush cycle of the mobile fluid servicing cart is simply activated by pressing a momentary switch on the front panel of the control box. While the method of control would be up to the datacenter operator, momentary switches were chosen in this case for safety reasons to ensure the pump would not run without an operator present. This simultaneously turns on the pump and opens the fluid solenoid valve, which then pushes fluid (in this case, likely water) through the cart and through the liquid-cooled server or rack that needs to be flushed. Figure 2 shows an example of how this would work on the piping and instrumentation diagram (P&ID).

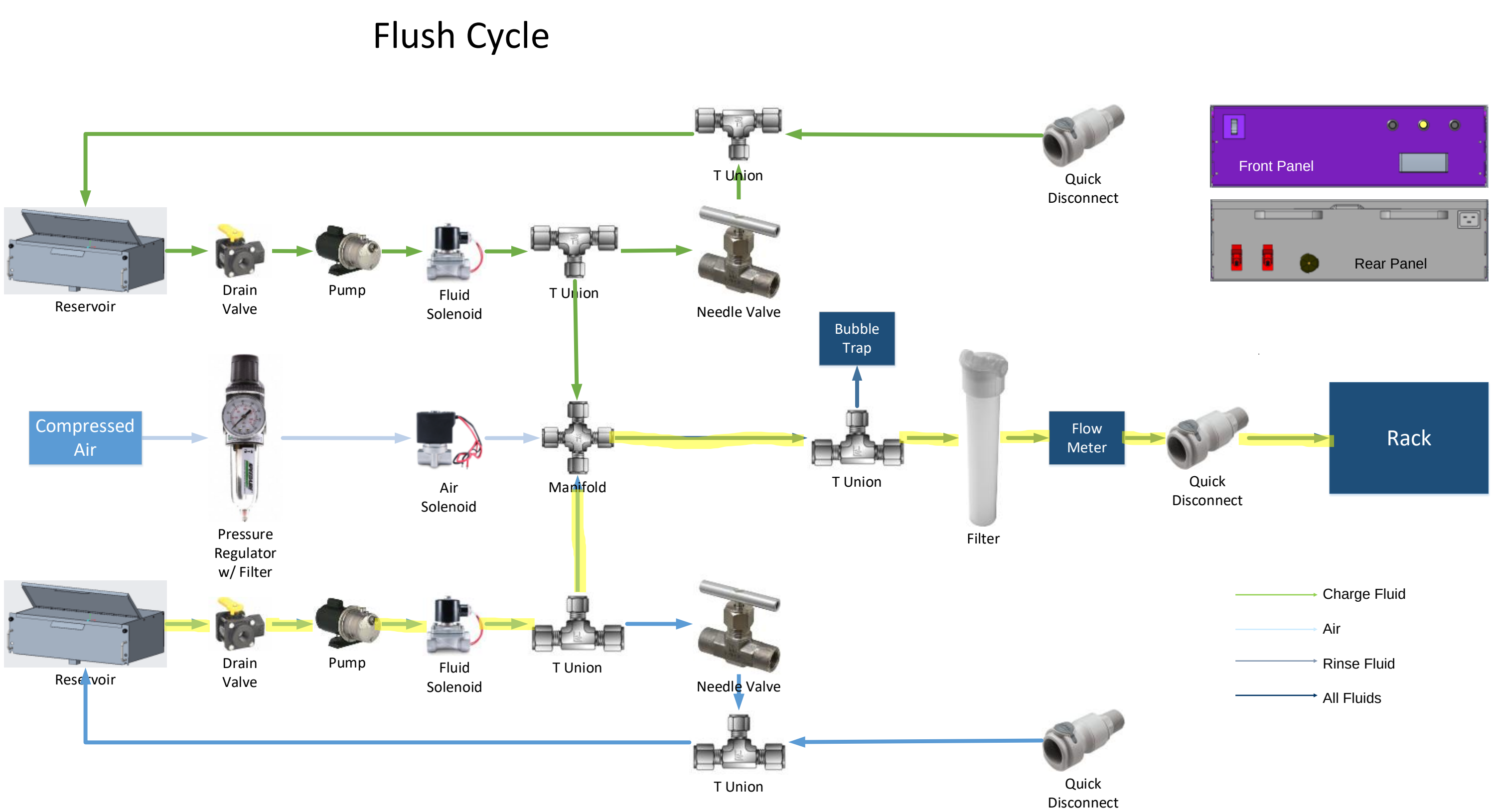

Figure 3. Flush cycle flow path, pushing rinse fluid (e.g., water) through system

As discussed in the requirements section, a fluid servicing cart must be designed to allow for multiple different use cases, depending on the needs of the cart operator. While flushing, it is likely that the operator would push fluid through the rack and into some sort of waste-fluid reservoir. This waste-fluid reservoir could be external to the cart or it could be an additional reservoir housed within the cart. In the case of the mobile cart described above, there is an option to use the second reservoir for waste-fluid if needed.

Also, note here that the interface of this cart can be Universal Quick Disconnects (UQDs) that meet the requirements specified in the Universal Quick Disconnect Specification Rev 1.0 (Sprenger, 2020). The UQD size will be dependent on the size present in racks to be serviced, though adapters could also be easily made to adapt between different-sized UQDs within a datacenter. This would allow operators to connect directly to any liquid-cooled system that also uses UQDs, resulting in ease of use across many different racks. Additionally, the rack could be hooked back up to the return line of the cart to allow for continuous cycling of fluid. This could be used in the Flush Cycle, though it would likely be more useful in the Charge Cycle, described next.

Charge Cycle

Before a liquid-cooled component or server can be integrated into the full cooling loop within a datacenter, it must be charged with clean cooling fluid and there must be negligible air within the system (Mitchell, Menoch, Gross, & Musilli, 2021). The mobile cart should enable this with its charge cycle, which is similar to the flush cycle described above. Figure 3 shows how, when the appropriate momentary switch is pressed in this example cart, fluid is pushed through a bubble trap, 10 micrometer filter, and flow meter before cycling through the rack.

Charge Cycle

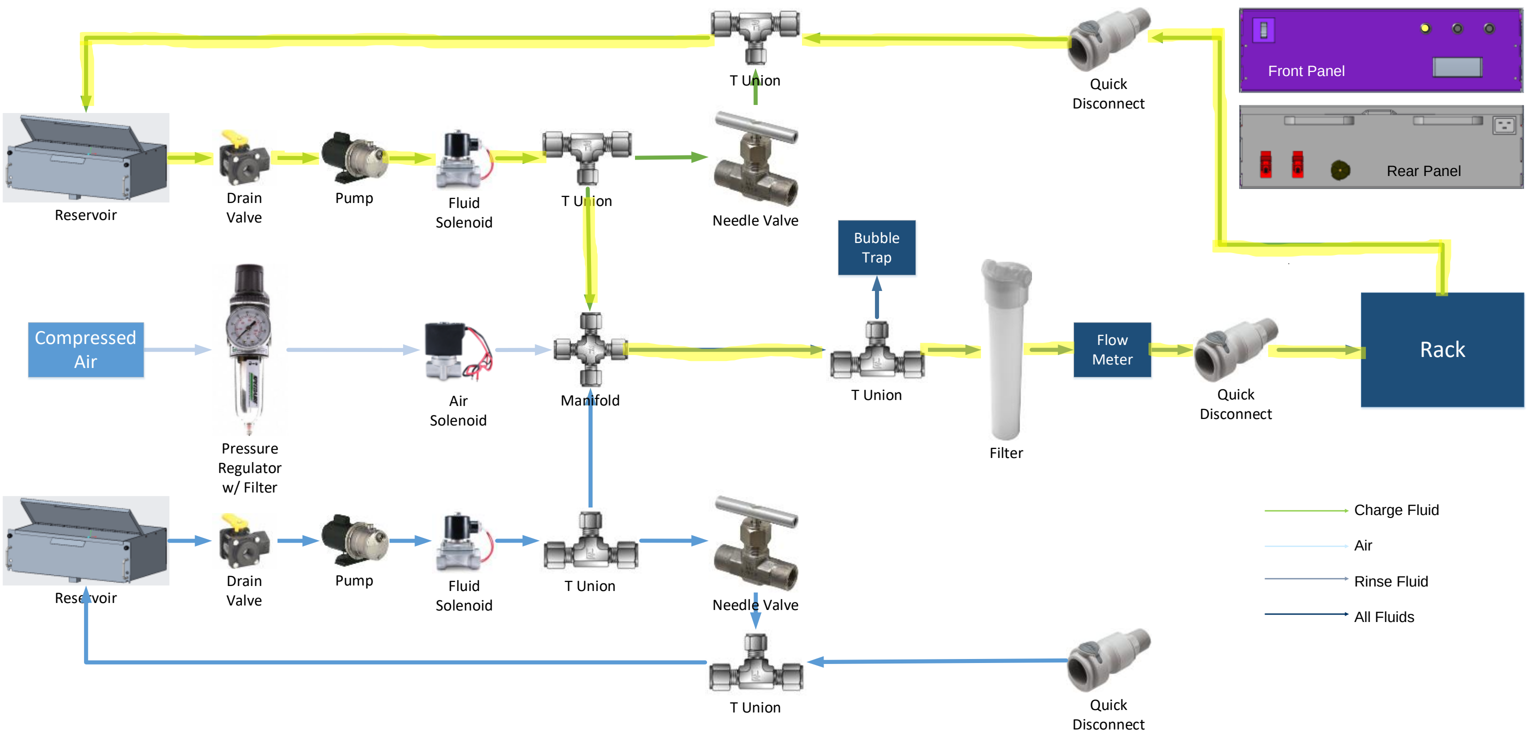

Figure 4. Charge cycle example, cycling liquid-cooling fluid

The bubble trap used in this cart simply consists of a tee in the fluid line within the cart. This then has clear tubing up to a ball valve, which allows the operator to see if there is air in the system (Figure 4). Since the bubble trap is at the top of the fluid-path, any air travelling through should settle within this clear tubing. The operator can then open the ball valve and bleed air out into the spill tray at the bottom of the cart.

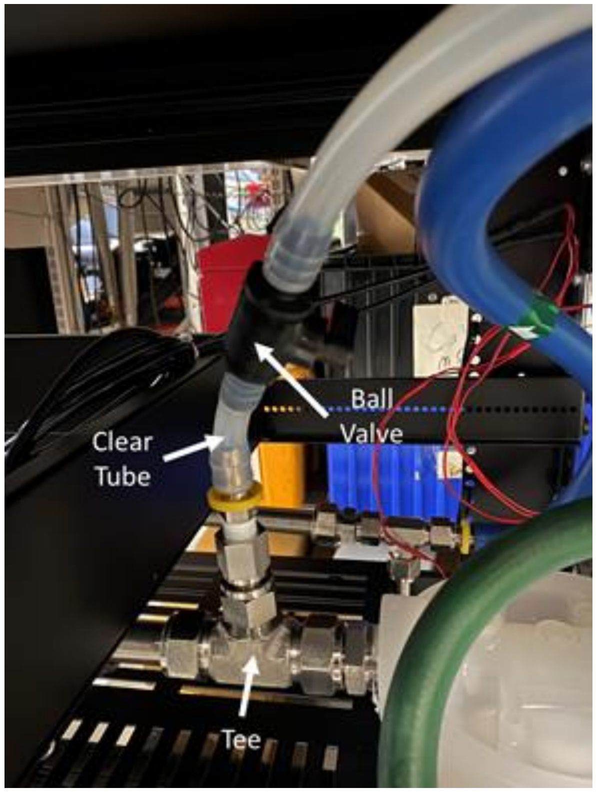

Figure 5. Bubble trap

The filter is a 10-micrometer filter that was chosen for its low pressure drop at high flow rates as well as its ability to capture small particles. These requirements are essential to minimize pressure drop through the cart, allowing for higher performance for the cart to flush and charge the rack. Careful consideration should be taken when selecting a filter for fluid cleanliness as well as how the pressure drop will affect the pump selection for the cart.

The flow meter used here is installed on metal tubing and uses ultrasonics to measure fluid-speed. This minimizes pressure drop and is more accurate than traditional in-line flow meters. For this mobile cart, the flow sensor has a panel-mounted display on the front-panel of the control box which allows the operator to easily see the flow rate of the fluid. To effectively charge the system, the operator can first fully open the bypass valve built into the cart so that the flow rate through the system is very low. Then the operator can close the bypass valve, increasing flow rate through the rack system, until a target flow rate is reached. This allows the operator to control the fluid velocity through the charging system to ensure the fluid speed is not so high as to cause damage to the fluid loop but is fast enough to push bubbles out of the system.

Purge/Dry Cycle

The purge/dry capability of the mobile cart refers to its ability to use pressurized air or nitrogen to push out fluid and dry for storage. Depending on the datacenter facility's needs and infrastructure, this pressurized air could be installed on the cart directly. Alternatively, if there is pressurized air readily available within the datacenter infrastructure, a connection can be put on the cart to readily access this are, as is the case in Intel’s mobile cart as shown below. Figure 5 shows how, when the appropriate momentary switch is pressed, air passes through a pressure regulator with filter before passing through the cart and then the rack. This air can push out any remaining fluid and help to dry out the system. The pressure regulator must be chosen based on the pressure requirements of the system that will be purged. Note that there are limitations to drying with compressed air. Low points in a system or parallel fluid-paths can make a complete dry difficult. In cases like this, the cart may be used to purge most of the fluid from the system. To ensure all the fluid is dried out and to prevent material corrosion and bacteria growth, additional disassembly of the system may be required. The operator may need to open additional points in the fluid-path to ensure complete removal of the fluid.

Purge/Dry Cycle

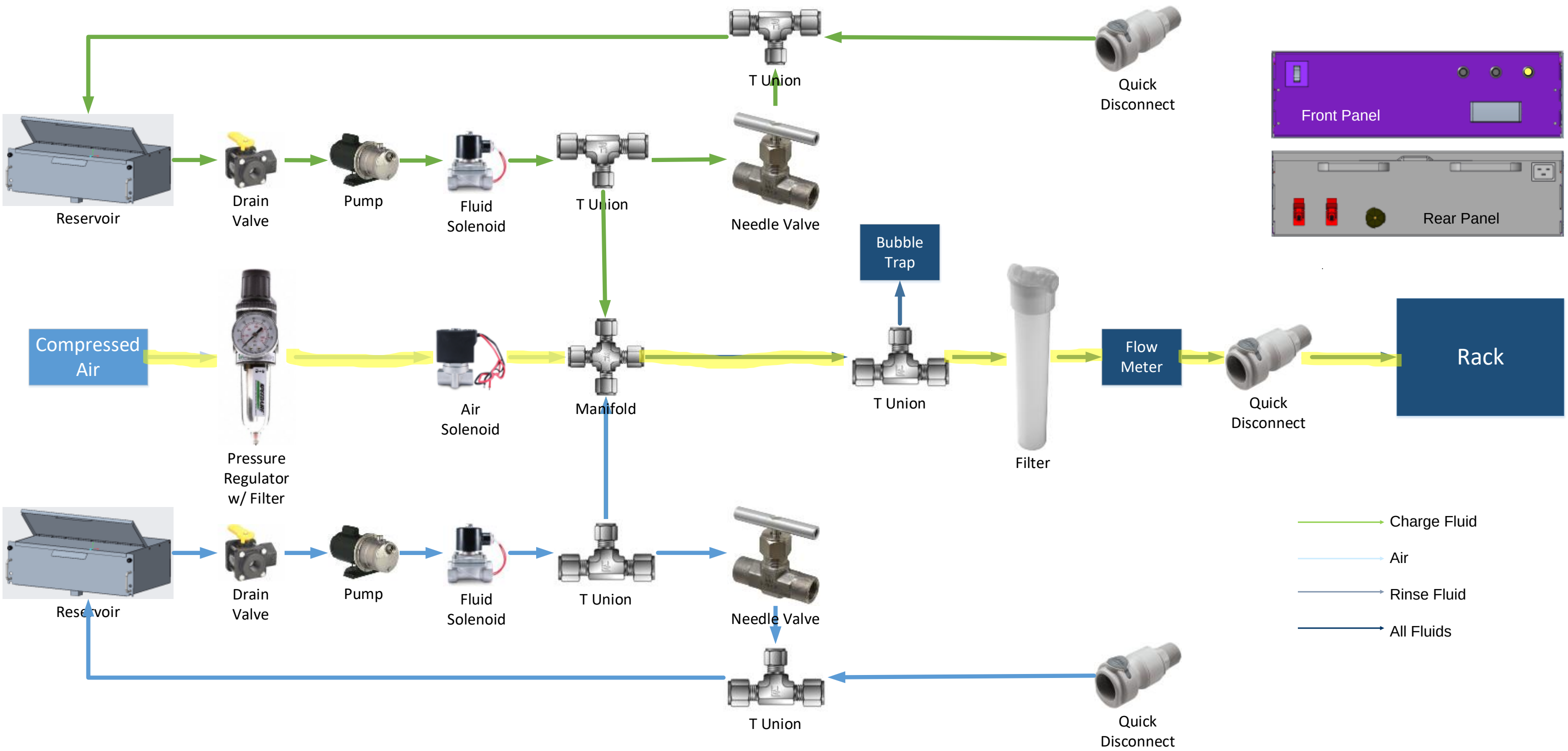

Figure 6. Purge/Dry cycle example. Used to dry and prep for storage or remove from service.

Drain and Self-Dry Capability

Similarly, the mobile cart should be able to perform many of the functions described above on itself. If the cart is not in use, its reservoirs should be drained to inhibit biological growth. Then air can be pushed through each branch of the cart via the air-line attachment. Figure 6 shows how the cart can have air push fluid out of the drain through the manifold, solenoid, and pump. To ensure no pump damage during this maintenance activity, the operator would flip the appropriate toggle switch on the back of the control box before simultaneously pressing the air and fluid momentary switches on the front. The toggle switch disrupts power to the pump so that the pump is not damaged by running with air inside. The air momentary switch then opens the air solenoid valve while the fluid momentary switch opens the fluid solenoid valve.

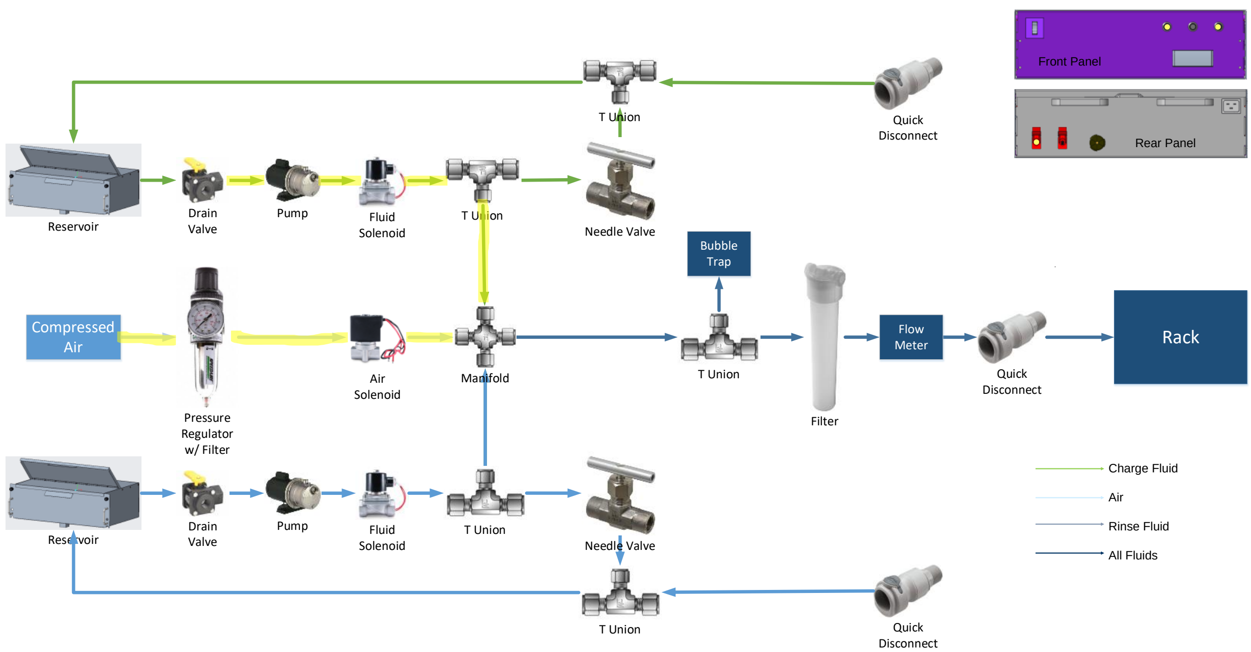

Figure 7. Cart self-cleaning and drying

Pump and System Performance

Another important thing to consider when designing a fluid-servicing cart is the performance required for the specific use-case. First, to select a pump it is recommended to calculate the expected pressure drop through the mobile cart itself at various flow rates, subtracting this estimate from the pump curve of various pumps under consideration. Once a pump is selected and the cart is built, it should then be tested at different flow rates to verify that its performance curve will intersect the pressure-drop curve of a representative system that the cart must push fluid through. An example of a representative pressure drop curve being compared to a mobile cart's performance curve is shown in Figure 7.

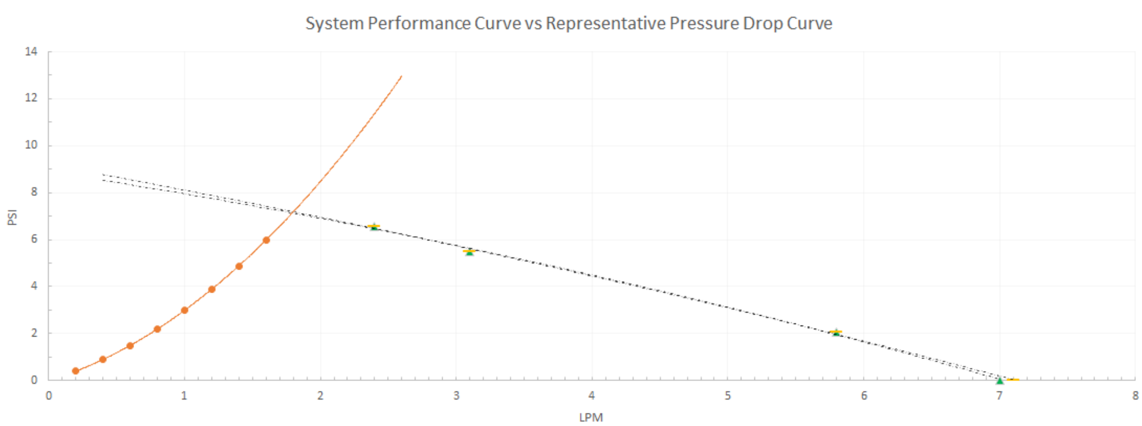

Figure 8. Example Cart Performance Curve vs System Pressure Drop Curve

It is recommended to source pumps that can meet or even exceed the performance requirements. Then, even if the pump only runs at a full duty cycle, a bypass valve can be opened to allow some fluid to recirculate back to the cart's reservoir. This would effectively reduce the output flow rate to ensure the fluid velocity is not too high for smaller components. This also gives the mobile cart more versatility to service a variety of liquid-cooled systems

Other Mobile Cart Design Considerations

In addition to providing the functions described above, there are further design considerations around the many requirements for any fluid system that will be a part of the same fluid-loop as liquid-cooled servers. Some of the key considerations are described in this section.

Drip Containment

A self-contained drip-containment system is recommended to be within the cart to capture any minor leaks or drips from mating and breaking fluid connectors. It is recommended that the method of draining this drip-containment system be considered to ensure no standing water. The mobile cart designed by Intel achieved this with a tray that slopes down to the drain from all directions. A section cut showing this example can be seen in Figure 8. If the full fluid capacity of the cart cannot be contained in the drip containment system or the probability of leak or condensation is high, consider leak-sensing capabilities within the drip tray (Berktold, et al., 2021). Additionally, baffles within the drip tray could be added to prevent water sloshing while transporting with fluid in the tray.

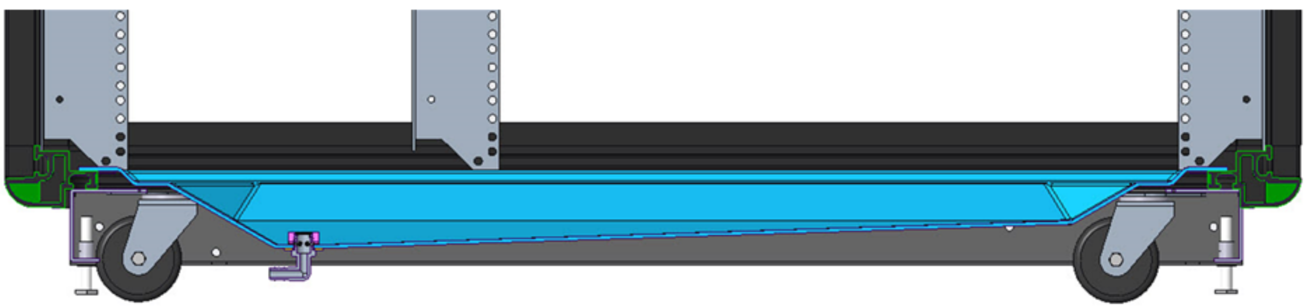

Figure 9. Example Drip-Tray within Cart

One other safety measure is the use of level-sense within the fluid reservoir. The level sensor can be implemented into the electronic controls to shut turn off the cart's pump when the reservoir is low on fluid. This helps ensure the cart's pumps are not damaged by pushing air and lets the operator know that the reservoir needs to be refilled before continuing.

Usability

It is also important to consider the usability of the cart for an operator. To aid in usability, designers should consider putting the cart controls in a consolidated location and ensure they are clearly labelled. One way to achieve this would be to have a control box mounted near the top of the cart with the appropriate switches, buttons, and displays on the front panel. In the case of the example cart described in this paper, the front panel consists of three momentary switches to activate each of the three different lines: air, charge, and rinse. It also has a display for the flow rate and a circuit breaker to shut down the mobile cart electrical system.

In addition to this, it is important to measure the required force to move the cart during usage. Assuming the cart will be pushed using a handle on the cart, the total weight, hand distance away from the body, angle of push, frequency of use and force required to overcome limiting friction are some of the important considerations. These need to be accounted for upfront during the first wedge of the design. Once deployed, it is important to monitor them for any performance issues and introduce required servicing for wear and tear. For example, casters may wear out or bearings might need lubrication.

When placing the electronics, it is recommended to minimize any risk of contact with fluid by keeping the control box above the fluid path. Also, switches that are unlikely to be used in normal operation should be clearly labelled and separated from switches that are used regularly. This can be done by placing switches in the back that are used only for cart maintenance, such as the switches that bypass electricity to pumps to run a self-drying cycle. Implementing best practices for industrial ergonomics can lower risk of injury and increase operational efficiency. Also, make sure to consider the use of AC and DC power within the cart, as many valves may be DC while the pumps may require AC.

Material Compatibility

Since the mobile servicing cart will be used within the liquid-cooling loop of various racks throughout a datacenter, material compatibility of each component within the cart's fluid loop must be considered. It is up to the datacenter operator to ensure that there will be no adverse chemical reactions between the mobile cart materials and the cooling fluid in use.

Pressure Ratings

When selecting fluid components for the mobile cart, ensure that each component is rated to meet or exceed the operating and burst pressure of the datacenter application. This is especially important when selecting electronic valves and pumps. The pressure ratings will also depend on factors including desired flow rate and pressure ratings of the quick disconnects and hoses.

Safety and Regulatory

In order for systems to comply with end-product Information Communication and Technology (ICT) equipment safety standards, liquid filled component (LFC) component manufacturers need to ensure parts are compliant with IEC 62386-1:2018 (or later) standard, clause G.15. For electrical safety compliance within a datacenter, refer to UL 3223.

Conclusion

Developing a mobile fluid-servicing cart for a datacenter using liquid-cooled systems requires an accurate assessment of the datacenter's unique requirements. These requirements will inform some of the aspects of a servicing cart, such as reservoir size, pump power, fitting materials, and more. However, the primary functions of the cart to be able to flush, fill, and purge fluid must be present to effectively maintain the cooling fluid as well as to commission and decommission racks and other liquid-cooled systems.

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