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DIII-D Water-Cooling System Upgrades Through Modeling and Power Saving Projects

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Abstract— **The DIII-D water-cooling system for the fusion facility at General Atomics consists of the vessel and coil cooling water systems (DIII-D water), components cooling water systems (power supplies, ion-sources, diagnostics and gyrotrons), and heat rejection system (cooling tower and heat exchanger) for the operation of the fusion facility. Since 2005 the water-cooling systems have undergone major upgrades, resulting in average power savings of over 50%. The water-cooling system is now capable of handling future heat loads for long pulse duration (10 s) while operating at lower cost.**

This paper describes the design, installation and startup of energy efficiency upgrades which include:

- **Installation of new cooling towers, and upgrades to primary and secondary heat exchanger loops**
- **Reducing power consumption of cooling water system by installing variable frequency drives (VFDs) for the cooling water pumps, implementing PLC monitoring of energy usage in the facility, systems modeling, and by automatic adjustment of system flow to better meet needs**
- **Changes to control logic by the identifying systems and flows, such as fast wave and ECH operations, that can be shut off or reduced depending on operational status**
- **Reducing parasitic power loss through pressure drop reductions in filters, strainer components, heat exchanger cleaning programs, and performing preventive maintenance for equipment to improve operating efficiency.**

Modeling and thermal performance results of the upgraded DIII-D cooling water system will be discussed.

Keywords-DIII-D; Water cooling system; Heat removal

I. INTRODUCTION

The DIII-D water-cooling system for the fusion facility at General Atomics consists of the vessel and coil cooling water systems (DIII-D water), components cooling water systems (power supplies, ion-sources, diagnostics, gyrotrons), and heat rejection systems (cooling tower and heat exchanger) for the operation of the fusion facility. Since 2005 the water-cooling systems have undergone major upgrades, resulting in average power savings of over 50%. The water-cooling system is capable of handling future heat load for long pulse (10 s) while operating at lower cost.

II. LTOA HARDWARE UPGRADES

During the 2005 to 2006 long torus opening activities (LTOA) period, the water cooling systems have undergone installation of new cooling towers and upgrades to primary and secondary heat exchanger loops.

Cooling Tower 1 (CT1) and Cooling Tower 2 (CT2) were failing due to internal corrosion. The towers were replaced with two stainless steel Evapco cooling towers to minimize internal corrosion, blockage, and designed for higher heat removal capacity. The Evapco cooling towers shown in Fig. 1 are partitioned into two cells each to economize on water usage. The partition allows the user to shut off tower cells when additional cooling is not necessary. Also, to improve cooling flow capacity, the corroded carbon steel pipes connected to the cooling towers were replaced with new PVC piping having low friction loss which improves pumping power.

Figure 1. New stainless steel Evapco cooling towers with new PVC piping.

To increase volumetric cleanup rate and higher heat load from gyrotron cooling, the electron cyclotron heating (ECH) high pressure heat exchanger and the polishing loop pump system (Fig. 2) were replaced.

Sensors and control hardware were added to the DIII-D water-cooling system to provide monitoring functions from a central control room. This gave us the ability to identify problems ahead of time and prevent damage.

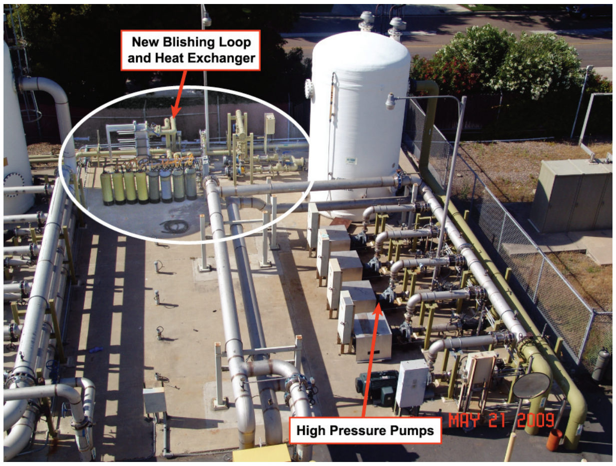

Figure 2. ECH polishing loop heat exchanger and pumps.

III. REDUCING POWER CONSUMPTION OF COOLING WATER SYSTEM

CT1 and CT2 cooling water pumps are variable frequency drive (VFD) controlled and respond to users' demands by preset pressure control. The controls are set up to activate dual pumps when a single pump is not adequate to supply users' preset demands (Fig. 3).

CT1 and CT2 cooling fans are VFD controlled to maintain the basin temperature at 24ºC. In addition, the fans for each partitioned cell will come on only when load demands more cooling. VFD driven booster pumps for helium compressors' cooling maintain a constant differential pressure across the compressor's heat exchanger regardless of the down stream pressure fluctuation.

Instead of using a cheaper constant speed motor when expanding the ECH high pressure cooling water system for six gyrotrons, a second VFD motor controler was installed on the four pump system to work in tandem with another VFD pump to lower operating cost and flexibility in operation.

IV. PROGRAMMABLE LOGIC CONTROLLER (PLC) MONITORING OF ENERGY USAGE, SYSTEMS MODELING, AND AUTOMATIC SYSTEM FLOW ADJUSTMENT

DIII-D has long shutdown periods of ~4 months every summer. During shutdown, maintenance and upgrades are conducted throughout the facility. During plasma operation, the closed loop system supplies a total of 260 gpm to the neutral beam internal components, cryogenic helium liquefier, and ECH helium compressors. During facility maintenance, the neutral beam internal components and cryogenic helium liquefier are not in operation. Running the closed loop pump at full speed is unnecessary; only 9 gpm is needed to support ECH helium compressors. The closed loop system was modeled using Pipe Flo software to determine the optimum solution when only the helium compressors required cooling. Several designs were modeled into the closed loop system. The model indicates that an increase in savings can be achieved during the shutdown period if a VFD is installed on the closed loop pump. The VFD also offers the closed loop system additional flexibility in terms of future cooling requirements for the shutdown period. Running a VFD, San Diego Gas & Electric (SDG&E) offers incentives for reduced energy usage. Through PLC monitoring and automatic flow adjustment based on demand, it is observed that the closed loop system has reduced power usage by 70% in shutdown mode, saving over 50,000 kW-h or $6,075 annually.

PLC also monitors heat removal rates from each of the cooling towers. The MG2 cooling loop removes the most heat load from the facility, but it can be further optimized through VFD fans temperature control and flow adjustment through each MG2 circuits. This future upgrade is discussed in Section VIII.

V. LOW PRESSURE WATER SYSTEM CONTROL LOGIC CHANGES

The low pressure water system (LPWS) has five pumps in parallel which supply de-ionized and de-oxygenated (DI/DO)

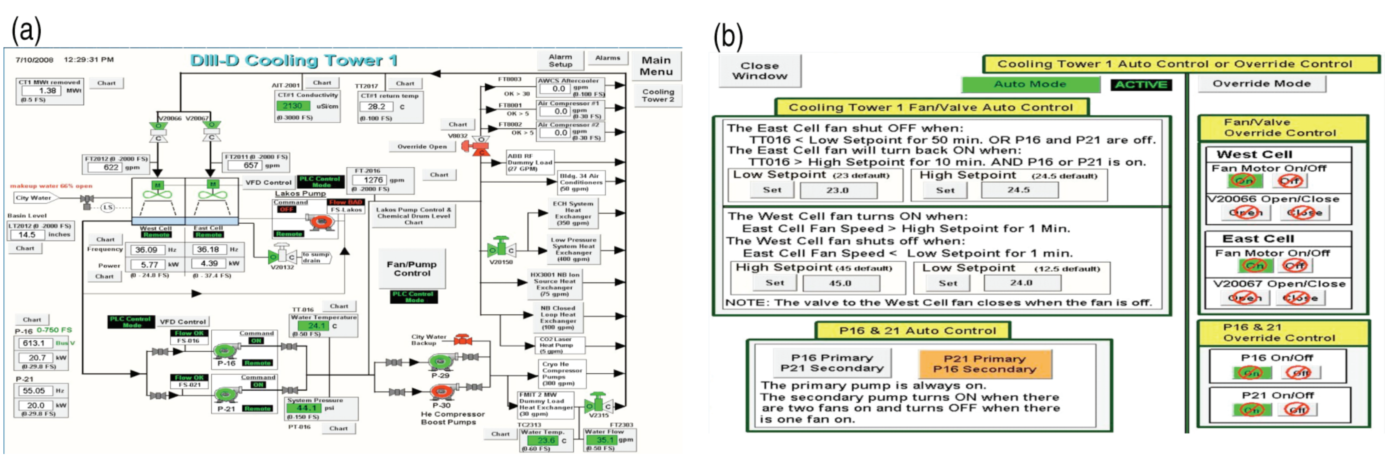

Figure 3. (a) CT1 PLC schematic and (b) CT1 controls.

water at 80 psig as cooling water to three main users, neutral beam ion source (NBIS), ECH power supplies, and fast wave current drive (FWCD) equipment. Each group uses the low-pressure water system for a different number of hours per year as shown in Fig. 4. Fig. 5 shows the gallons per minute each user requires when operating.

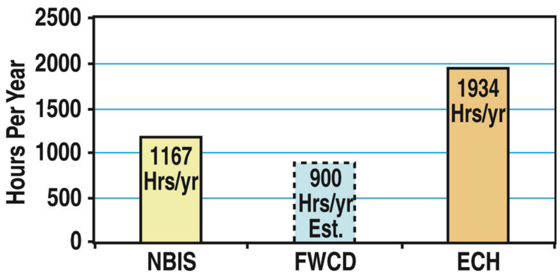

Figure 4. LP water users hours per year.

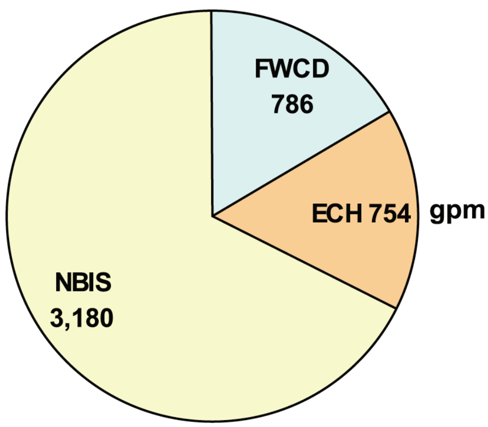

Figure 5. GPM for all existing LP water users.

Three pumps can support all users in the LPWS. When neutral beams are not operating, only one pump is required to run both ECH and FWCD. If NBIS is required then typically all other systems are also operating. However, ECH operates 40% of the year by themselves. Pipe Flo software was used to model energy saving conditions to guarantee that the pumps will satisfy each user's flow and pressure requirements. Actuator valves were installed to cutoff flow to unused systems. If NBIS is required then all other systems are also operating. ECH operates 40% of the year by themselves. A user-friendly interface has been integrated into the PLC; if operators need flow to their components, they simply click a button requesting water flow. By running one pump instead of three pumps for 40% of the year, GA spends half of the original amount of money on operating the low-pressure system; $41,000 and 250,000 kW-hr are saved per year from this change.

VI. IMPROVING COOLING SYSTEMS EFFICIENCY THROUGH MITIGATION OF PRESSURE DROP IN FILTERS AND HEAT EXCHANGERS

An additional method to save energy and increase the efficiency of the closed loop system cooling is to mitigate unnecessary pressure drop. After modeling the closed loop system with Pipe Flo, several bottlenecks were identified. The main bottleneck in the closed loop system is the cartridge filters, which had a pressure drop of 38 psi. To increase the flow in the closed loop system to meet future requirements and to save energy, the cartridge filter system was replaced. A cost saving analysis was done to compare the cartridge filters to Eaton flowline bag filters. Eaton flowline filters (Fig. 6) have a pressure drop of <1 psi. The cartridge filters were replaced with the Eatons flowline filters resulting in annual saving of 22,000 kW-h or $1,700.

The emergency city water system supplies water to the DIII-D system during pump failures or power outages. The emergency water system has been analyzed over the past several months to ensure that the system will meet flow requirements for the E&F coils, neutral beam internal components, cryogenic helium liquefier, and ECH helium compressors. This system was not performing as anticipated from the Pipe Flo Model flow restriction was mainly caused by a clogged (95%) strainer. After replacing this strainer, the emergency city water system cooling efficiency was tremendously improved. The emergency city water system can now supply sufficient emergency water to all vital components in the DIII-D water system when a pump failure or power outage occurs.

Figure 6. Eaton Flowline Multi-Housing Bag Filters.

PLC monitors the overall heat transfer U coefficient in heat exchangers (in helium compressors, HP and LP HX section) to track the gradual fouling and blockage from floating sludge and debris in the cooling water. At appropriate scheduled maintenance shutdown, citric acid will be used to dissolve and flush out sludge buildup in the heat exchangers.

VII. PERFORMANCE AND REBATE RESULTS

At DIII-D, the fluid system goal is to provide cooling water for the tokamak while lowering energy consumption. Since 2003, we have collaborated with SDG&E to upgrade our cooling system for future requirements while reducing our overall energy utilization. We have spent a total of $400,000 on these upgrades. Through the SDG&E rebate program we were able to collect a $124,940 from SDG&E for these upgrades.

Table I summarizes the power and cost savings from the improved performance of the cooling water system.

TABLE I. ENERGY AND COST SAVINGS

Year	***Title***	***Project Hardware Cost ($)***	***SDG&E Refund***	***Power Savings/Year (kW-h)***	***Savings/Year ($)***
2003	DIII-D water system night/weekend mode and P5,6,12 VFDs	$50,000	$52,000	87,691	$7,000
2004	HXs fouling monitor with U coefficients and periodic cleaning	$5,000	$0	40,000	$3,000
2005	CT1 and CT2 installation with VFD fans and pumps	$250,000	$40,910	511,360	$42,000
2005	P29/30 cryo-booster pumps & FMIT dummy load isolation	$10,000	$2,500	40,000	$3,000
2006	ECH/LP isolation valve for P47,48, 51,58: CT1 P21 reduction	$8,000	$4,000	204,501	$16,360
2007	ECH P5 pump with VFD	$45,000	$9,930	156,552	$12,520
2008	LP isolation valves control of NB mod/reg. and fast wave transmitter	$5,000	$11,000	250,000	$41,000
2008	NB closed loop VFD	$11,000	$3,962	50,000	$6,075
2008	Closed loop multi-housing filter upgrade	$6,000	$0	22,000	$1,700
	Total	$400,000	$124,302	1,362,104	$132,655

Since 2006, there was no delay or missed plasma shot in DIII-D due to thermal load related waiting time between shots attributable to water cooling system. There was no temperature ratcheting in the F-coils (shaping) due to thermal buildup.

VIII. SUMMARY AND FUTURE UPGRADES

There are two proposed future upgrades in 2010 and 2011 for the cooling water system. Budget pending, these projects will help eliminate the following deficiencies.

A. *MG2 and CT3 Cooling Loop Piping Corrosion*

- CT3 galvanized tower internal support frame is corroded. The plenum frame needs replacement to stainless steel upper casing with VFD controlled fans;
- The badly corroded carbon steel pipes to CT3 will be replaced with PVC piping and with stainless steel sch10 piping inside the MG2 pit;
- The oil cooler sludge clean out ports will be rebuilt to allow access for cleaning which increases heat transfer efficiency and reduces pumping power;
- RTD temperature, flow and pressure sensors will be strategically located to monitor the heat load distribution between the MG2 bearings and the liquid rheostat circuits via wired or wireless transmitters to the control room PLC. Significant power could be saved with this energy-monitoring program.

B. *DIII-D Water System Pump Addition to Supplement Marginal Flow for Longer Pulse*

The extension of the tokamak discharges to longer pulse operation is approaching the limit of the current thermal load of the DIII-D water system. A 4th cooling pump circuit will be required to provide redundancy in case of unexpected pump failure. To evaluate the various operating modes in the DIII-D cooling loop with the 4th pump installed, detailed Pipe-Flo modeling of the DIII-D water loop is in progress. The 30 year old fiberglass pipes will be replaced with PVC piping and a new DI/DO rack will replace the existing fragile polishing loop.

The water-cooling system in the DIII-D National Fusion Facility is now capable of handling future heat load for long pulse (up to 10 s) while operating at lower costs. At the same time, DIII-D has complied with the DOE mandate of environmental and energy efficiency for the new upgrades.

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