Best Practice Catalog

Raw Water System

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1.0 Scope and Purpose

This best practice addresses the technology, condition assessment, operations, and maintenance best practices for raw water systems focusing on cooling raw water with the objective to maximize performance and reliability. The raw water cooling system is a once–through (open loop) system in which water flows are discharged back to the tailwater. The primary purpose of the raw water system is to supply water sources to any or all of the following cooling and other water systems:

- Turbine and generator bearing coolers
- Turbine shaft seal
- Generator air coolers
- Generator fire deluge
- Transformer and/or exciter coolers
- Heating, ventilation, and air conditioning
- Service Water
- Source for potable water treatment equipment
- Fire protection [1]

1.1 Hydropower Taxonomy Position

Hydropower Facility → Powerhouse → Power Train Equipment → Balance of Plant/Auxiliary Components → Raw Water System

1.1.1 Raw Water System Components

The raw water system is critical to unit operation in its global plant cooling function. The reliability related components of raw water systems include the supply intake, strainers, pumps, valves, generator air coolers, piping, and instrumentation/monitoring. The raw water system is fed either from the units' forebay, penstock, or scroll case or pumped from the tailrace/tailwater. Tailrace/tailwater is normally the source for lower head plants. Forebays, penstocks, or scroll cases are normally the source for higher head plants. The water source is therefore defined as either gravity or pumped type cooling system. In all plants an intake for unit cooling sealing and lubrication water is provided for each unit with the supply lines between units manifold or cross-connected for flexibility.

Figure 1 is a typical schematic of the raw water system showing the comprehensive nature as it services a wide variety of other hydropower systems.

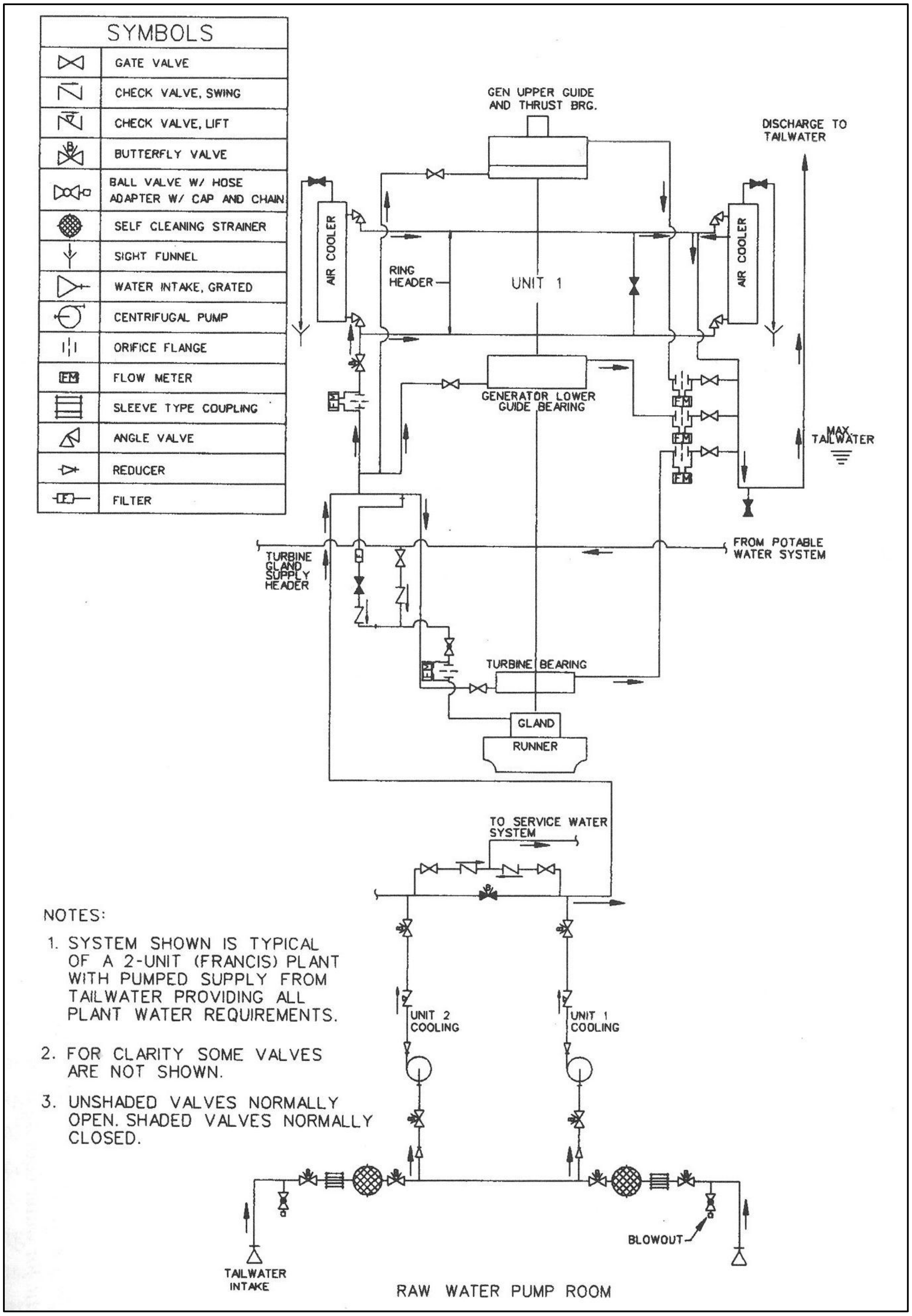

Figure 1: Typical Raw Water System Piping Schematic [2]

Supply Intake: The function of the supply intake is to feed the raw water system with river, dam, or untreated water. Unit cooling, lubricating, and sealing water pressure is usually supplied at a maximum pressure of 40 pounds per square inch (around 28 m of water) to prevent damage to the generator air coolers and other equipment.

Strainers: The function of the strainer is to remove suspended solid material (wood, rocks, sand, biological matter, etc.) from the raw water to minimize fouling of the generator air coolers and oil cooler heat exchangers. The strainer must be back flushed when the differential pressure across the strainer reached a set point value to ensure the raw water flow rate is not reduced due to blockage of the strainer.

Pumps: The function of the raw (cooling) water pumps, if so equipped, is to develop sufficient flow and head to meet the requirements of the equipment it services. This ensures the water in the piping, strainer, valves, and air coolers will be supplied at required flow and pressure. The design must allow for the operation of the raw water component in a fouled condition. Higher head plants/units normally do not require pumps.

Valves: The function of the valves within a raw water cooling system is to route, regulate, or isolate as required the flow of water. There are multiple types of valves and designs based on their specific application. Chief among these are gate, butterfly, globe, control, ball, and check valves. In high head plants pressure must be reduced by pressure regulating valves for most raw water services. A relief valve on the low-pressure side of each pressure regulating valve protects against piping or equipment damage which might result from over pressurization resulting from faulty operation of the valve. A proportioning valve is used to control the flow of cooling water to the generator air coolers.

Generator air coolers: Generator air coolers, which are considered as part of the generator, are heat exchangers located in the generator air housings which employ raw water to cool circulating air which in turn cools the generator. Cooling water is delivered to a header serving all air coolers. This header is sized by the generator manufacturer to distribute approximately equal flow to each cooler. From the air cooler, water returns via another header to a discharge chamber designed to keep the air coolers full of water at all times. The cooling water headers are normally circular.

Piping: The function of the piping is to connect supply water from the forebay/ penstock/scroll case/tailwater to the rest of the system at the design water flow rate and pressure to achieve optimum cooling of system components.

Instrumentation/Monitoring: The function of the instrumentation is to measure, monitor, and regulate the process variables of the raw water such as flow, temperature, and pressure. Pressure indicators, flow meters, temperature indicators, differential pressure transmitters, and/or sightglasses are examples of key instruments.

1.2 Summary of Best Practices

1.2.1 Performance/Efficiency & Capability - Oriented Best Practices

- Refer to the associated best practices for generators, turbines, and transformers that are served by the raw water system.

1.2.2 Reliability/Operations & Maintenance - Oriented Best Practices

- Follow the best practices in the Best Practice Catalog - *Trash Racks and Intakes* for the raw water supply.
- Use Remote Operated Vehicle (ROV) for internal condition inspection on large pipes (diameter > 4”).
- Install isolation valves at selected locations for raw water pipelines so key equipment can be isolated and removed for internal inspection as necessary.
- Develop, implement, and maintain a raw water instrumentation calibration and verification program for instrumentation such as generator air cooler thermocouples, flow meters, and proportioning valve controllers and differential pressure gages.
- When replacing raw water piping, select materials such as carbon steel or stainless steel for construction of generator cooling water parts and base decisions on specific generating units requirement (such as water quality and plant economics).
- Observe the strainer unit. It will give the operator a good indication of the quality of the raw water supply.
- Operate centrifugal pumps within the Equipment Reliability Operating Envelope (EROE) to achieve maximum Mean Time between Failures (MTBF).
- Change impeller diameter, if required, to ensure that every raw water centrifugal pump operates inside its EROE.

- Keep EROE range between (+)10% to (-)50% in flow from the pump best efficiency point.
- Keep raw water centrifugal pump curves in the control room. Operators should be trained and instructed on their use for optimizing centrifugal pump safety and MTBF.
- Monitor the raw water pump flow range by inputting the pump shop test curve and collecting transmitter signals (inlet pressure, discharge pressure, and flow) into spreadsheets to calculate the pump head and flow.
- Adjust head of the raw water supply as required to facilitate the pumps operation within the EROE.
- Label raw water system piping with colored tape to help personnel to understand system operation and how to take corrective action quickly to prevent unit performance or availability issues.
- Installation of raw water strainers with automatic backwash capabilities will reduce labor intensity associated with maintaining acceptable strainer pressure differentials especially at locations that are not continuously staffed.
- Place a higher priority on removal of generator air cooler bio-fouling than the bio-fouling of the raw water pipe unless it has reduced the flow to a level below the design flow.

1.3 Best Practice Cross-references

- I&C - Automation
- Mechanical – Francis Turbine
- Mechanical – Propeller/Kaplan Turbine
- Mechanical – Pelton Turbine
- Electrical – Generator
- Civil – Trash Racks and Intakes

2.0 Technology Design Summary

2.1 Material and Design Technology Evolution

Early designs for raw water systems consisted mainly of carbon steel and cast iron pipe fittings, pumps, valves, and other fixture components. Controls and instrumentation were rudimentary, analog, and predominately manually operated. Piping embedded in concrete was cast iron with bell and spigot joints requiring leaded joints at connection points with external piping. Piping insulation where used contained asbestos fibers.

Valves used for isolation and routing were predominately manually operated gate or globe type valves. Air-operated, thermostatically controlled proportioning valves were used to regulate flow through the generator air coolers to control generator temperature. A manually operated, single strainer served the entire raw water system. For lower head plants, centrifugal pumps were used to provide forced circulation to generator air and oil coolers.

Generally few provisions were made for back-flushing air or oil coolers. Water for fighting fires was provided by elevated storage tanks. Fire protection systems were manually actuated.

2.2 State of the Art Technology

The basic design concepts for raw water systems at hydro plants have not changed substantially. However, there are a number of component design improvements for raw water systems that have become state of the art. Most of these changes have been driven by technical improvements in construction materials and material cost such as stainless steel and copper/copper alloys.

Construction material selection for raw water piping systems and components is based on the specific characteristics of the system such as the water quality of the raw water supply (suspended solids, tendencies to scale, potential bio-fouling, potential for corrosion, etc.). Exposed, large bore piping (diameter > 4”) can be flanged or butt welded carbon steel or stainless steel. Flanged piping allows disassembly of piping systems for cleaning out internal build-up. Small bore piping is made from non-corrosive materials such as stainless steel. Embedded piping is stainless steel or cement lined ductile iron (for larger bore piping) with flanged joints for external piping connections.

Valves larger than 6” in diameter are normally gate valves. Isolation valves (2½” to 6” diameter) are normally butterfly valves. Stainless steel ball valves are normally used for 2” diameter and smaller valves. Valves are manually operated or automated based on the process requirements, staffing levels, etc. Closed cell foam piping insulation systems which eliminate external piping condensation have replaced systems containing asbestos. Raw cooling water pump design has been changed very little over time. However, mechanical seals have replaced packing glands. Advances in pump construction materials, impeller design and manufacturing, and more efficient motor design provide improvements in pump reliability and operating costs. See Figure 2 for a modern raw water pump set-up.

Figure 2: Typical Dual Raw Water Pump Set-Up

Current raw water system designs include stainless steel duplex automatic backwash strainers (Figure 3). Subsystems such as turbine seal water and fire protection can be equipped with finer mesh automatic backwash strainers for additional reliability. These automated features are used as labor saving methods and are especially suitable for facilities that are not continually staffed.

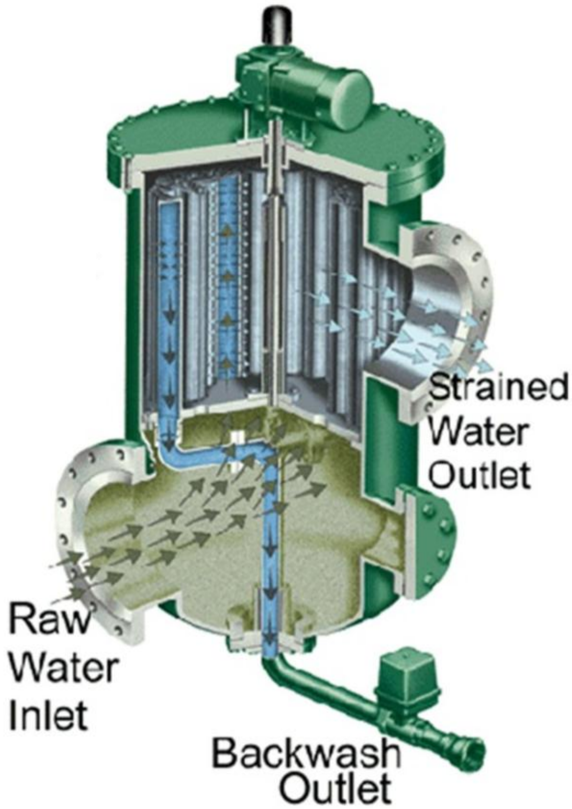

Figure 3: Section View of Typical Automatic Backwash strainer [SERFILCO]

Automated backwash strainers include instrumentation and controls to initiate strainer cleaning based on a time cycle or a pre-established strainer pressure differential.

Fire protection systems are equipped with diesel driven booster pumps which replaced the traditional elevated fire water storage tanks. Depending on the individual hydro plant economics, booster pumps may be able to provide increased volume and pressure in fire fighting situations than elevated water storage tanks. Fire protection systems are now automated with designs mandated by fire codes that were nonexistent in the early twenty century.

3.0 Operation & Maintenance Practices

3.1 Condition Assessment

The supply intake for the raw water system can be assessed at two locations depending on the plant layout. If the penstock is tapped for the raw water supply, then the trash rack condition assessment becomes critical for the same reasons that the turbines must be supplied debris free water. If the raw water is drawn from the tailwater, then the intake structures of raw water supply become important. In both cases see the condition assessment best practices in the Best Practice Catalog *Trash Racks and Intakes*. Unusual biological fouling by plants, fauna, fish and flood debris is a serious issue and must be evaluated for specific sites since it can vary significantly from plant to plant.

Raw water piping is difficult to evaluate for wall thickness or pinhole leaks. “D” meter readings of wall thickness are considered unreliable due to fouling on the inside of the pipe that may be ½”-¾” on a 6”-8” diameter pipe. Pinhole leaks may ultimately develop along the length of the piping system so replacement is typically justified.

The best practice for assessing the internal condition of the larger sized raw water pipe line is a camera mounted Remote Operated Vehicle (ROV), Figure 4.

Manual valves can be operated to determine proper operation. Condition assessment of disc, seats, and other internal components requires the removal of the pipe connections. A system that uses strategically located isolation valves enables this removal. Therefore, it is best practice to install isolation valves at selected location throughout the raw water system so that key equipment can be isolated and removed for internal inspection and/or repaired as required. The additional valve has little or no impact on the efficiency of the raw water system except for the head losses across the valve.

Figure 4: Remote Operated Vehicle (ROV) for Pipeline Inspection of Raw Water System [Substructure, Inc.]

The raw water system requires instrumentation to monitor and provide information to help control system equipment such as pumps and strainers. Instruments should be checked and re-checked for accuracy especially air cooler thermocouples, stator core Resistance Temperature Detectors (RTDs), flow meters, shunt voltage readings, proportioning valves controller, and isolation valve operators. Operability of the proportioning valves can be readily determined as to whether the valves are adjusting water flow for variations in air temperature. The correct function must be determined by the supplier's Original Equipment Manufacturers (OEMs) engineering documents. Some temperatures can be checked with hand held thermocouples, heat guns, and thermal imaging equipment depending on accessibility. Differential pressure gauges should be checked to ensure operability and accuracy. A common problem with differential pressure gauges is fouled or blocked pressure tubing.

Materials for generator cooling system piping may be cast iron, carbon steel, or stainless steel. The hydraulic performance for each type is detailed in numerous piping industry handbooks; Cameron Hydraulic Data is highly regarded [5]. As a best practice, the most common material would be ASME B36.10 Welded and Seamless Wrought Steel Pipe [6] constructed to ASME B31.3 Process Piping [7] standard.

The strainer unit will give the operator a good indication of the quality of the raw water supply. The best practice for evaluating the raw water strainer condition is based on two indicators: 1) pressure differential trend data across the unit and 2) the strainers performance after a back flush to operate at rated pressure drop or lower.

3.2 Operations

When it comes to the operation of a raw water system, how the pumps are efficiently used is critical to the cooling process. It is a best practice to operate centrifugal pumps within the Equipment Reliability Operating Envelope (EROE) to achieve maximum Mean Time between Failures (MTBF). The EROE, also called the heart of the curve (Figure 5), assures maximum centrifugal pump MTBF by avoiding all operating areas of hydraulic disturbances. An established best practice for the EROE range should be (+) 10% to (-) 50% in flow from the pump best efficiency point.

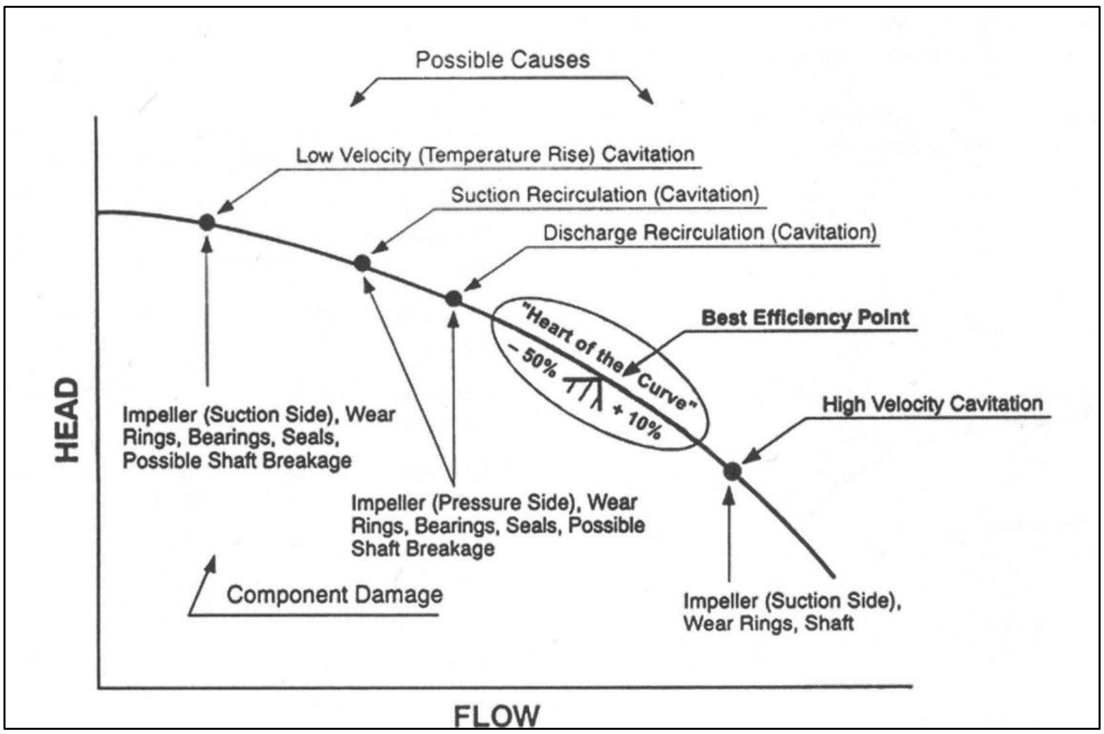

Figure 5: Centrifugal Raw Water Pump - component damage as function of operating point

Many new raw water pumps are selected with impeller diameters that are incorrectly sized for field operation parameters. The hydraulic calculations used to determine the pump head required for centrifugal pumps will only approximate the field conditions and can be conservative which will result in different field head required than noted on the pump data sheet. This can result in driver overload/underload and possible cavitation. Failure to establish EROE limits will lead to low MTBF of centrifugal pumps. Approximately 80% of centrifugal pump reliability reductions (causes of low MTBF) are due to process changes which cause the pump to operate in either a high flow or low flow range. This exposes the pump to hydraulic disturbances resulting in low MTBF. Establishing operator EROE targets for all critical site pumps and all “bad actor” pumps (pumps with one or more components failures per year) will ensure optimum centrifugal pump safety and MTBFs.

It is a best practice to ensure that every raw water centrifugal pump operates inside the EROE and change impeller diameter if required. Lower pump head required can force centrifugal pumps to operate at greater flow than the design point. Most centrifugal pump drivers are sized for +10% power and can be overloaded if the pump flow is greater than the design flow. The most cost effective solution to prevent driver overload is to reduce (cut or trim) the pump impeller diameter to arrive at the desired pump flow under the required conditions of actual field process head.

The safety and reliability of all centrifugal pumps is optimized if pumps are operated within the EROE. It is best practice to have raw water centrifugal pump curves available in the control room, and operators need to be trained for using pump test curves to optimize centrifugal pump safety and MTBF. Centrifugal pumps produce flow inversely proportional to the required process head. This flow range is obtained by having operators aware of the centrifugal pump characteristics, providing process targets, and having the pump test curves available for each pump for operator use and understanding. Unnecessary centrifugal pump maintenance and pump failures result from operators not checking the pump test curves, not confirming that the pump operates within its EROE, and not understanding the test curves significance.

It is an instrumentation best practice to monitor (in the control room) the raw water pump flow range by inputting the pump shop test curve and collecting transmitter signals (inlet pressure, discharge pressure and flow) into spreadsheets to calculate the pump head and flow. Even if flow meters are not installed for each pump, EROE targets should be established by other methods (i.e., control valve position, motor amps, pump inlet, and discharge piping differential temperature). Critical centrifugal and ‘bad actor pumps’ require constant surveillance by operators to ensure optimum safety and reliability.

It is a best practice to adjust head as required. Head required in raw water pumping system can be changed by adjusting the discharge system resistance using pressure control, flow control, or level control. Each of these methods results in closing a throttle valve in the discharge piping which increases the head (energy) required and reduces the flow rate. This action requires more energy (head) to overcome the increased system resistance.

Using colored labels or paint to define each individual line of the system (supply lines, return lines, bypass lines) involves personnel and promotes ownership thus increasing system safety and reliability. It is a best practice to label raw water system piping to

ASME A13.1 [8] with correct colored labels. This will help personnel understand the system operation.

Color coded and identified piping greatly increases site personnel awareness of raw water system operations. See Figure 6 for an example of piping labels. Many critical machine unit shutdowns are the result of not monitoring the local instrument and components in the system. Failure to properly label piping, instruments, and components leads to neglect and corresponding low system reliability.

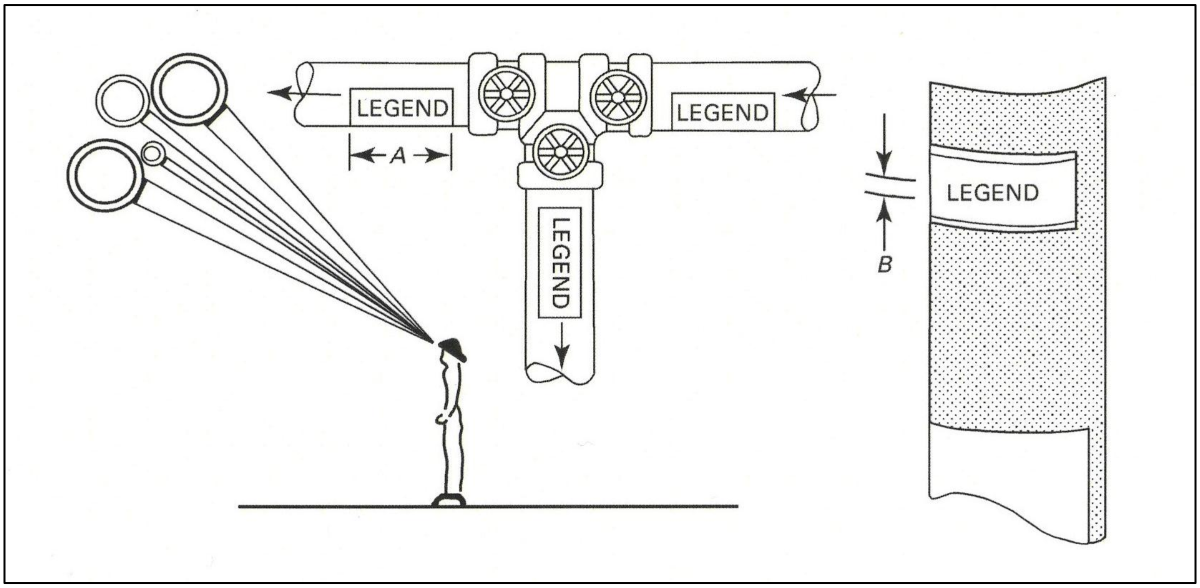

Figure 6: Piping Labeling from ASME 13.1 [8]

Proportioning valves control the raw water flow to the generator air coolers for maintaining proper generator air temperature. The benefit of the proportioning valve is when the generator is operating in load following mode with significant changes in MVA output. The valve controller would be set to the desired air temperature. Generator air cooler flow balancing is a common operational procedure and should be readily accomplished by plant staff. Air cooler discharge temperature should be checked from each cooler to ensure uniform cooling.

3.3 Maintenance

The raw cooling water to the strainer performance condition is typically judged by the differential pressure across the strainer (Figure 7).

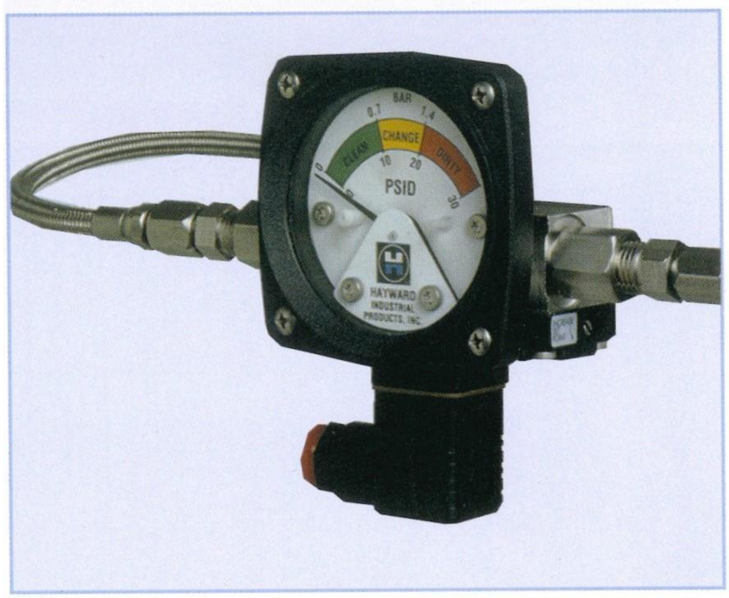

Figure 7: Typical differential pressure gauge with feedback switch [EATON]

However, high differential is due to fouling of the strainer which can be corrected by installing a back flush feature. Most strainers are designed with a 1/16” to 1/32” screen size to allow small particles to pass for scouring action in the pipes and heat exchanger tubes. If the strainer elements fail, the strainer is essentially a piece of pipe which does not remove the large, harmful debris. Unusual biological fouling, including small fish (shad) and flood debris, can present a problem but will normally be corrected with a well designed back flush system. The strainer should require minimal maintenance except to replace the internal elements that may degrade with time.

The generator raw water pipe and generator air cooler tubes foul in any system. The cleaning of the raw water pipe is probably of minimum value unless the fouling actually reduces raw water flow to below design value. The generator air cooler tubes are more critical and require periodic cleaning to maintain acceptable performance.

With modern air cooler design, the efficiency of the air cooler will be very similar to a counter flow heat exchanger. The old generator air coolers were similar to a cross flow heat exchanger with a reduced thermal efficiency. The best measure is the difference between the raw water cold inlet temperature and the cold air discharge temperature. The raw water temperature is the theoretical temperature as to how much the cold air temperature can be lowered.

Typical efficient coolers will have a cold air discharge temperature of approximately 5°C above the raw water inlet temperature. In the case of badly fouled tubes and degraded fins, the air temperature approach to the raw water temperature may be 15°C to 20°C. In the case of 30°C water inlet temperature, the maximum design air temperature of 40°C would be exceeded and the cold air temperature would be 45°C to 50°C.

4.0 Metrics, Monitoring and Analysis

4.1 Measures of Performance, Condition, and Reliability

The Raw Water System includes cooling water pumps (for plants/units that are so equipped), piping, valves, strainers, instrumentation, and controls. As an auxiliary system, the condition of the Raw Cooling Water system components can affect the performance and reliability of the generating plant/unit(s).

Plant/unit performance measures include Equivalent Availability Factor (EAF), Equivalent Forced Outage Factor (EFOR), Maintenance Outage Rate (MOR), and Planned Outage rate (POR). These indicators are used universally by the power industry. Many utilities supply data to the Generating Availability Data System (GADS) maintained by the NERC. This database of operating information is used for improving the performance of electric generating equipment. It can be used to support equipment reliability and availability analysis and decision-making by GADS data users.

Periodic fielding testing/evaluation of Raw Cooling Water System components that are noted as contributors to decreases in plant/unit availability should be conducted. Periodic testing includes cooling water pump flow tests, pipe/cooler fouling investigations, internal valve and/or strainer inspections, or other tests identified.

4.2 Analysis of Data

The reliability of a generating unit, including its auxiliary support systems, can be monitored through reliability indexes or performance indicators as derived according to NERC’s Appendix F, Performance Indexes and Equations [9].

4.3 Integrated Improvements

As raw water system components are identified as contributors to decreases in plant performance and availability or increases in maintenance costs, field testing of the specifically identified raw water system component(s) is performed. The field test results are trended and analyzed. Using the collected/analyzed data, projects to eliminate or mitigate any identified degradation or high maintenance component issues are developed, ranked, and justified in the Capital and Maintenance funding programs. Capital and Maintenance projects that are approved are implemented to return the component to an acceptable condition and performance level. Post implementation testing of components that are replaced/modified or otherwise repaired is conducted to verify that issues that resulted in decreased unit/plant performance and/or reliability have been addressed.

5.0 Information Sources:

Baseline Knowledge:

1. EPRI, *TR-112350-V4 Hydro Life Extension Modernization Guides: Volume 4-5 Auxiliary Mechanical and Electrical Systems*– Palo Alto, CA – 2001
2. ASME, *The Guide to Hydropower Mechanical Design*, HCI Publications Inc., 1996
3. TVA, *Technical report No.24 Mechanical Design of Hydro Plants*, US Government Printing Office – Washington - 1960

State of the Art:

4. Forsthoffer, W., E., *Best Practice Handbook for Rotating Machinery* – 2011
5. Heald, C., C., *Cameron Hydraulic Data* – Nineteenth Edition -2002

Standards:

6. ASME A36.10, *Welded and Seamless Wrought Steel Pipe* - 2004
7. ASME B31.3, *Process Piping ASME Code for Pressure Piping* – 2008
8. ASME A13.1, *Scheme for Identification of Piping Systems* -2007
9. NERC, Appendix F, *Performance Indexes and Equations* - January, 2011

It should be noted by the user that this document is intended only as a guide. Statements are of a general nature and therefore do not take into account special situations that can differ significantly from those discussed in this document.

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