NEW TECHNIQUE FOR ONLINE WASHING OF LARGE MECHANICAL-DRIVE CONDENSING STEAM TURBINES

by

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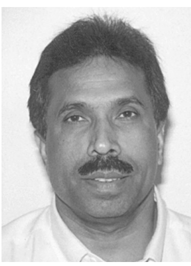

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ABSTRACT

To compete in today's economic climate, petrochemical plants are strategizing on continuous long-term operation to reduce maintenance costs and increase productivity. This strategy has led some plants to go from eight years between turnarounds to 10 years. For rotating machinery such as mechanical-drive steam turbines, one factor that affects this strategy is heavy deposition on steam turbine internals, caused by impurities in the steam. These impurities result in fouling on the blade and nozzle path surfaces due to contaminated materials such as silica and sodium in the steam. As a result, turbine performance tends to deteriorate gradually.

This paper introduces an innovative online washing technique to minimize the impact caused by fouling of the steam path for large multistage condensing steam turbines. This technique, although applied here to extracting-condensing turbines, is also applicable to large condensing turbines. The new technology has water injection nozzles located in the steam chest of the extraction valve rack. The injection nozzles are manifolded to a water supply source, which controls a setpoint temperature, by controlling the water injection rate. The objective is to directly wash off deposits adhering to the blades and nozzles on the low-pressure side with minimal power turndown, and without impacting the turbine's long-term performance. Erosion damage and thermal stress of internal parts such as chest valves and blades due to the injected water had to be taken into consideration.

To properly achieve this objective, and considering the potential for damage during the online wash, a new extraction valve box had to be designed.

The new design had to consider the effects of optimizing the mixing zone of the steam and water injection to generate a specific particle size, moisture propagation through the condensing section, mechanical deflection of stationary components, and the overall thermodynamic analysis of each stage during the online wash. A prototype model was built and several experiments carried out based on the practical operating condition of actual steam turbines. This paper discusses the evaluations made from the model, by presenting the thermodynamic analysis results, and the finite element analysis (FEA) that was used to evaluate the strength of the internal parts during actual online washing.

The final design was a compact extraction box that could replace existing models without any machining of the casing. To date there are two such installations worldwide. These are operating effectively

without incident. This paper also discusses online washing test results, which were obtained using an actual steam chest with the special injected nozzle and a risk assessment of online washing in general.

INTRODUCTION

During steam turbine continuous long-term operation, steam contaminants, such as silicate and sodium, deposit on the internals as solids. This occurs under certain operating conditions related to steam pressure and temperature for each of the stages. These contaminants foul the surfaces of nozzles and blades and gradually build up during steam turbine operation. Figure 1 shows the typical steam turbine operating condition for an ethylene plant application. Figure 2 shows the fouling condition after seven years of continuous operation.

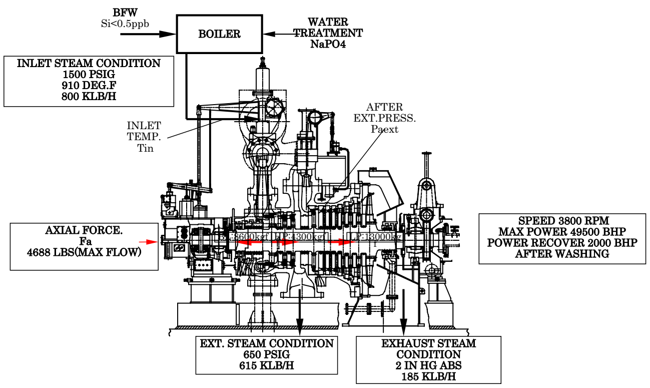


Figure 1. Typical Operation Condition.

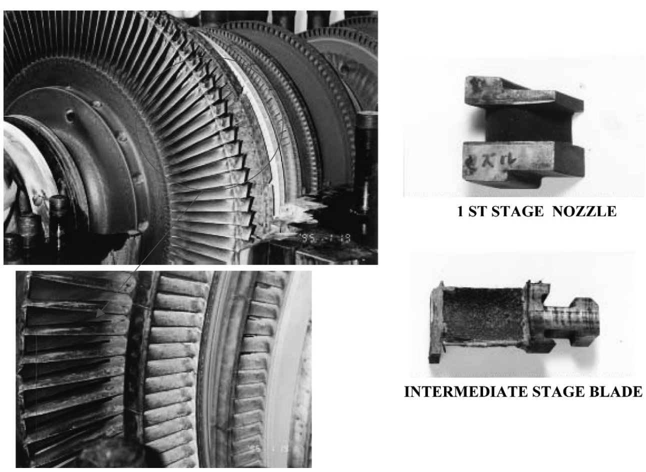


Figure 2. Fouling Condition after Seven Years' Continuous Operation.

The composition and characteristics of the fouling materials are different along the steam path as we move from the high-pressure stages to the low-pressure side, as shown in Figure 3. Under these fouling conditions, the pressure profiles across the nozzles, blades, and throat areas are increased. These profiles in turn result in deterioration of turbine performance, and will continue to do so over time if left unattended.

Current online washing techniques involve dropping the steam inlet temperature to increase the moisture at the condensing stages for the purpose of generating enough moisture to wash the soluble salts. This procedure cannot eliminate insoluble contaminants, especially in the high-pressure stages. By reducing the steam inlet temperature, enthalpy across the turbine drops significantly—this can result in production losses.

In order to resolve this fouling problem, an innovative online washing technique was developed. This new technique incorporates

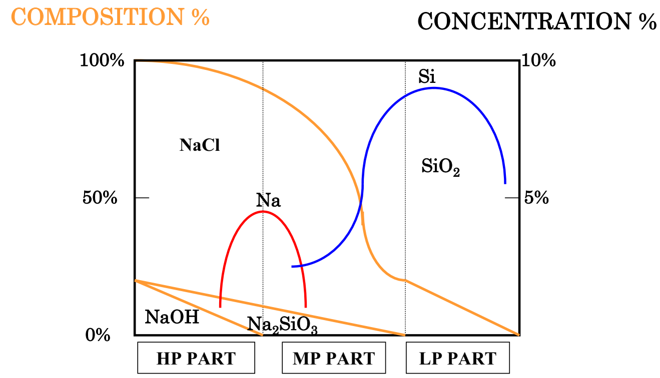


Figure 3. Distribution of Compounds along Steam Path.

the application of new technologies in the design of the extraction valve rack. The injection nozzles are manifolded to a water supply source, which controls a setpoint temperature, by controlling the water injection rate.

This new technology places water injection nozzles in the extraction steam chest with a controlled water supply source. The advantage of this compact design is its ability to directly wash off deposits adhering to blades and nozzles in the low-pressure zones, by controlling the amount of moisture at each stage. Consideration for this new design factored in erosion damage and thermal stresses of internal parts, such as chest valves and blades, induced by the water injected.

A prototype model was built and several experiments carried out based on the practical operating condition of actual steam turbines. This paper discusses the evaluations made from the model, by presenting the thermodynamic analysis results and the finite element analysis (FEA) that was used to evaluate the strength of the internal parts during actual online washing.

In addition, online washing test results were obtained by using actual steam chest conditions equipped with these special injection nozzles, and a risk assessment produced.

CONVENTIONAL STEAM TURBINE ONLINE WASHING PROCEDURE

Figure 4 shows the trend over time of the relationship between condensing flow and after-extraction pressure, comparing design pressure and actual pressure measured during operation. The after-extraction pressure increases due to the decrease in throat area caused by the deposition of chemical materials.

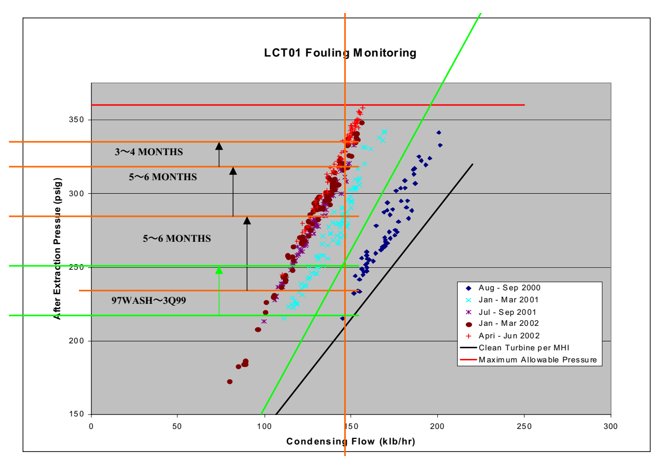


Figure 4. Internal Deposition Trending.

As mentioned previously, current online washing techniques involve dropping the steam inlet temperature to increase the moisture at the condensing stages for the purpose of generating enough moisture to wash the soluble salts. This procedure cannot eliminate insoluble contaminants, especially in the high-pressure (HP) stages. By reducing the steam inlet temperature, enthalpy across the turbine drops significantly, which can result in production losses.

The effects of this conventional procedure can be seen from the deposition and pressure profile in Figure 5. The inlet steam temperature is decreased thereby increasing the moisture within the low-pressure (LP) stages in order to wash several kinds of fouled materials off the nozzles and blades. The concentration and composition of these chemicals under dry and wet conditions are shown in Figure 3.

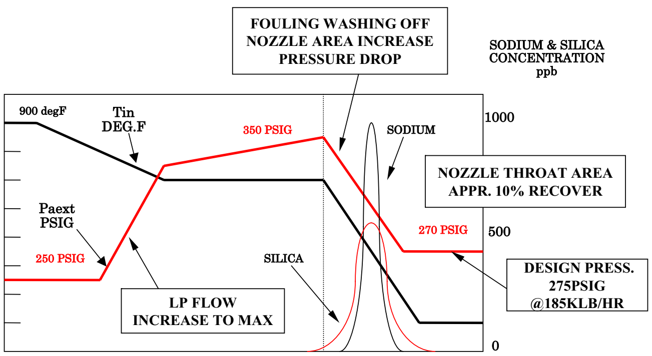


Figure 5. Deposition and Pressure Profile for Conventional Online Washing.

THERMODYNAMICS ANALYSIS RESULTS FOR A CLEAN CONDITION

When applying conventional online washing, the turbine power and after-extraction pressure do not recover to their original levels, but rather to some lower level. The extent of this recovery will now be related to the lowering of the inlet steam temperature. Changes in moisture distribution for each stage during washing have to be analyzed in order to determine how much moisture is needed for effective washing. Figure 6 shows stage exit moisture levels in relation to inlet temperature changes (910°F to 800°F).

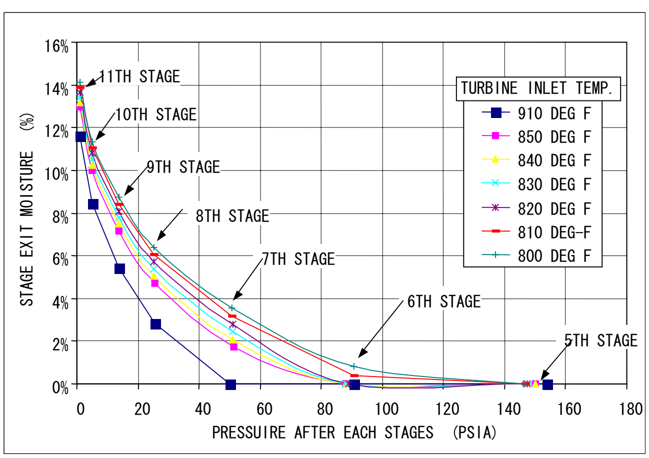


Figure 6. Moisture Distribution Across Each Stage for Clean Condition.

Knowing the moisture distribution with respect to changes in temperature, other thermodynamic properties, such as specific volume, delta-P across diaphragms, and nozzle exit velocities can be determined. Except for moisture contents, the calculation of these thermodynamic properties showed no significant changes for a clean turbine when inlet temperature was changed. In addition, it was found that the extraction stage and after-extraction stage remained in the superheated zone.

THERMODYNAMICS ANALYSIS RESULTS FOR A FOULED CONDITION

It is well known that when fouling occurs, it increases the pressure drop across the particular stage. This increase then cascades through the steam path causing backpressure. This backpressure can be monitored at the stage after extraction, as previously shown in Figure 4. Knowing the after-extraction pressure, the thickness of the cumulative deposits can be determined both before and after washing. Figure 7 illustrates the fouling profiles generated from these findings. This chart shows that a change in nozzle area for the stages after extraction has a definite effect on pressure rise resulting from deposition thickness. The deposition thickness up to the maximum operating pressure limit for the fouled stages can range from 0.5 mm to 0.6 mm (0.02 inch to 0.024 inch). Figure 7 also illustrates that stages downstream of the extraction stage have minimal impact on pressure rise.

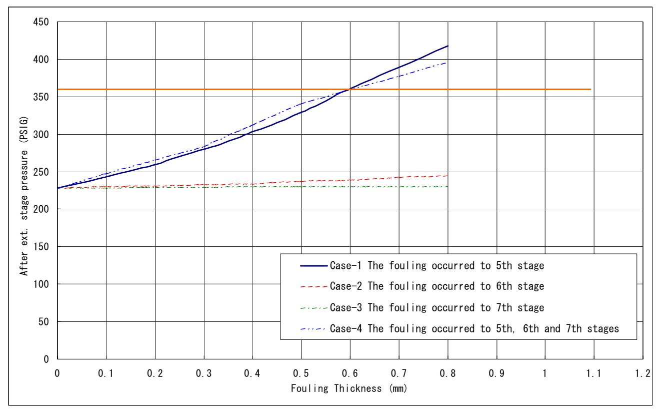


Figure 7. Deposition Profile Across Steam Path for Fouled Condition.

METHODOLOGY TO DESIGN ONLINE WASH NOZZLES

As mentioned previously, conventional online water washing involves decreasing the inlet temperature thereby increasing the moisture content of each stage, resulting in power losses and ultimately affecting production.

In the new online washing system, pressurized water is injected directly into the extraction valve chest. Figure 8 shows a schematic of the new water injection valve box installation. Table 1 shows the procedure implemented to design and evaluate the new injection nozzles. The effects of mass flow, erosion damage, and structural integrity were some of the criteria used in this design evaluation. This evaluation took into account that the after-extraction pressure can get close to the operating pressure limit during a wash.

Heat Balance Analysis

Figure 9 shows the method used for calculating the injected water mass flow using the energy conservation method around the extraction valve chest.

Evaluation of Erosion Damage Due to Water Droplets

Evaluation of erosion damage caused by water droplets is another factor considered in the methodology. To understand this phenomenon, it is necessary to evaluate the size of droplets along the steam path, from the valve chest through the nozzles and blades for each LP stage. Specifically, we need to know how these droplets are scattered, how they flow within the main steam stream, and what damage they cause to the nozzles and blades.

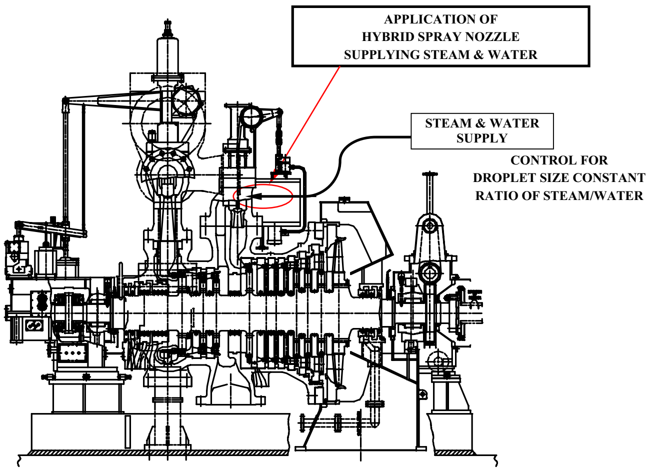


Figure 8. Schematic of New Water Injection System.

Table 1. Evaluation Procedure to Design Injection Nozzles.

ITEM	DESCRIPTION
REQUIRED MASS FLOW FOR WATER INJECTION	● HEAT BALANCE ANALYSIS ● EVALUATION FOR MASS FLOW OF WATER INJECTION
EROSION DAMAGE EVALUATION OF CASING NOZZLE AND BLADE	● WATER EVAPORATION DURATION TIME ANALYSIS ● PREDICTION OF IMPACT PRESSURE OF DROPLET ● OPTIMUM DROPLET DIAMETER FOR EROSION PREVENTION
SELECTION OF NOZZLE SIZE AND STRUCTURE DESIGN	● NOZZLE TYPE SELECTION ● NOZZLE ATTACHMENT DESIGN ● THERMAL STRESS ANALYSIS OF CASING PROVISION

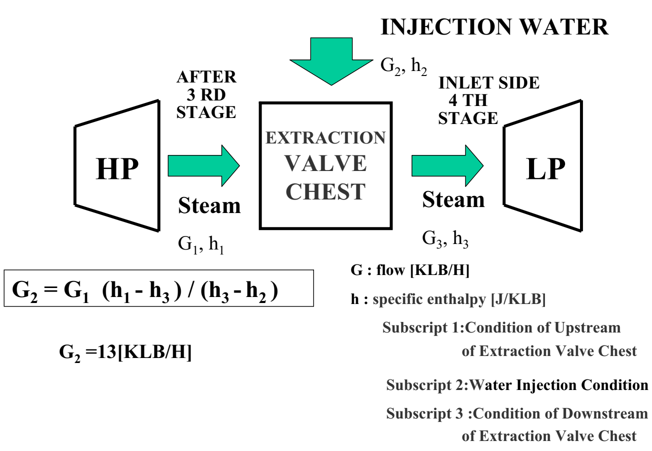


Figure 9. Heat Balance Analysis.

The basic theory to determine water droplet size and distribution is the balancing of drag and inertia forces. The drag force acts to slow down the droplets, whereas the inertia force is the force required to move the droplets along the steam path. The relative difference between the drag force and the inertia force is the shear force, which determines the size of the droplet. When the drag and inertia forces are equal, and the shear force is zero, the droplet size will be maintained and will flow with the main steam stream. Drag force is a function of Reynolds number calculated by steam velocity and droplet size. Since inertia force is also a function of droplet size, the balancing of these two forces will determine droplet size.

Figure 10 shows a flow diagram to determine the maximum droplet size, using Reynolds number to calculate the drag force and equating this to the inertia force. According to this analysis, the droplet diameter is expected to range between 10 µm to 1 mm.

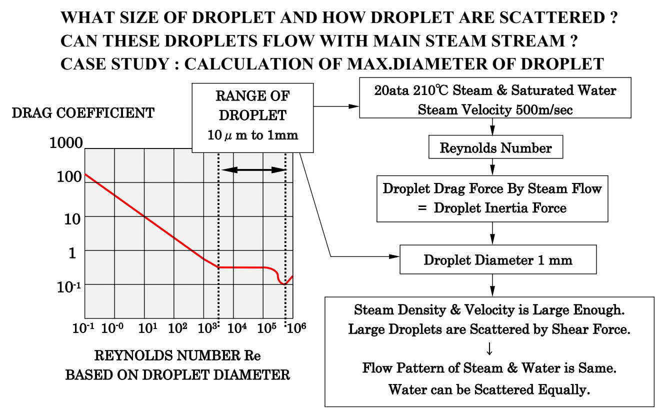


Figure 10. Water Droplet Size and Distribution.

The next step is to evaluate the mechanical damage caused by erosion. Erosion caused by water droplets is a fatigue phenomenon resulting from impact compression pressure on the surface of a given profile.

Erosion index is a parameter used to quantify the severity of the damage caused by erosion. This index relates to the cyclic impact compression stress divided by the fatigue endurance limit. The erosion index can be obtained by calculating the Mach number of a droplet and the fatigue impact pressure on the profile surface. When the erosion index parameter is less than one, erosion damage will not occur. A flow diagram illustrating the basic evaluation procedure is shown in Figure 11.

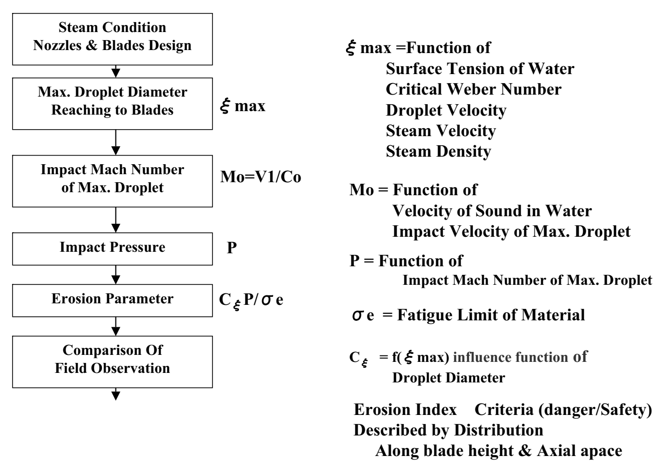
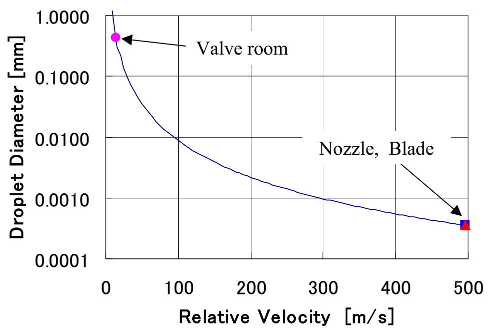


Figure 11. Erosion Evaluation Procedure.

An evaluation of erosion damage to valve, nozzles, and blades is shown in Figure 12 for different velocities along the steam path. This figure shows the correlation between droplet size and relation steam velocity, as well as the calculated erosion damage along the steam path. For example, a low velocity inside the valve chest results in larger droplet size, with a corresponding higher erosion index. However, downstream of the valve chest, erosion is influenced more by droplet size than relative velocity. Therefore, since the droplet sizes are smaller downstream the erosion condition is milder.

In each case, the erosion index parameter is much lower than 1.0, and therefore the authors can conclude that erosion damage will not occur. However, there is a potential for cavitation damage when injected water is mixed with steam in a narrow space such as



		Valve Chest	Nozzle	Blade
Relative velocity	m/s	14.3	496.0	496.0
Impact velocity	m/s	14.3	496.0	291.0
Droplet Diameter	mm	0.427	0.0004	0.0004
Impact Pressure	MPa	62	2381	1266
Erosion Parameter	—	0.320	below 0.001	below 0.001

Erosion Parameter < 1 then OK

Figure 12. Erosion Evaluation Results.

a valve chest. This mixture of water and steam is critical and a potential risk, requiring that the effects be quantified in the laboratory. The effects were quantified by conducting a shop test using an actual valve chest.

Selection of Injection Nozzles

A wide spray-angle type water injection nozzle was selected based on mass flow rate: spray angle, pressure, and temperature application ranges. As previously mentioned, the mass flow rate was determined based on heat balance of the steam and injected water.

The new design extraction valve with the selected water injection nozzles is presented in Figure 13. Figure 14 shows the detail of the selected nozzle as installed in the extraction box. The mechanical integrity of the welded nozzle arrangement was evaluated using FEA as explained below.

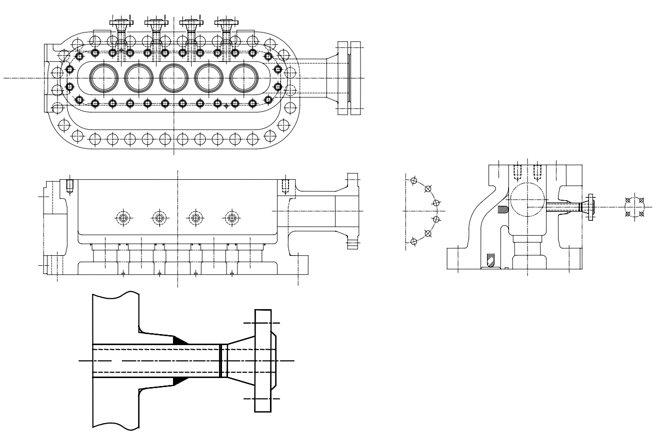


Figure 13. Injection Nozzle Arrangement.

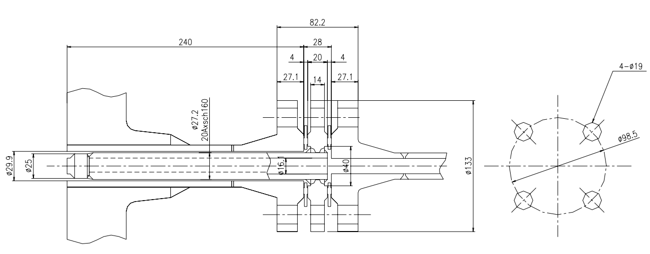


Figure 14. Injection Nozzle Details.

STRENGTH EVALUATION OF ONLINE WASHING NOZZLE

Strength evaluation using FEA was done on a component basis; namely the injection nozzles, the extraction steam chest, and the inner lift bar.

Wash Nozzles

Wash nozzles were evaluated in transient and steady-state conditions to determine temperature distribution and associated stresses during water injection. Figure 15 shows the temperature distribution in both states at low temperature water supply. As can be seen in the transient state, there is a large temperature gradient at the inlet flange of the water injection nozzle, compared to the steady-state where the temperature gradient is minimal. Conversely, the temperature gradient for the transient condition along the welded pipe between the valve chest and the inlet flange is minimal compared to the steady-state condition. The associated thermal stress distribution is detailed in Figure 16. Note, in the detail design process, stress can be decreased especially in the transient case by changing boss size, pipe length, groove size, groove location, and water supply temperature.

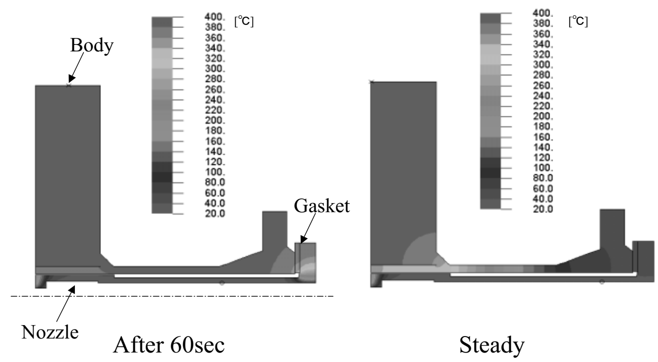


Figure 15. FEA Temperature Distribution—Nozzle Box.

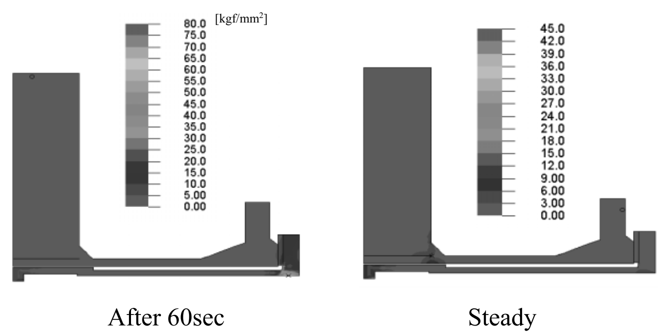


Figure 16. FEA Thermal Stress—Nozzle Box.

Figure 17 shows the peak stress point for both transient and steady-state. Based on these stress analyses, low cycle fatigue evaluation was carried out to determine the safety factor of the design during periodical online washing.

Figure 18, in accordance with ASME Code (Section VIII), shows that for the strain calculated, there is an inherent safety factor of 2. This corresponds to a life factor of 20 times the design criterion of 12 washes per year over 30 years.

Extraction Steam Chest

A 3-D computer-aided design (CAD) model was used as input to perform the FEA, and the stress and displacement were calculated based on actual operating conditions. Results are shown in Figures 19 and 20.

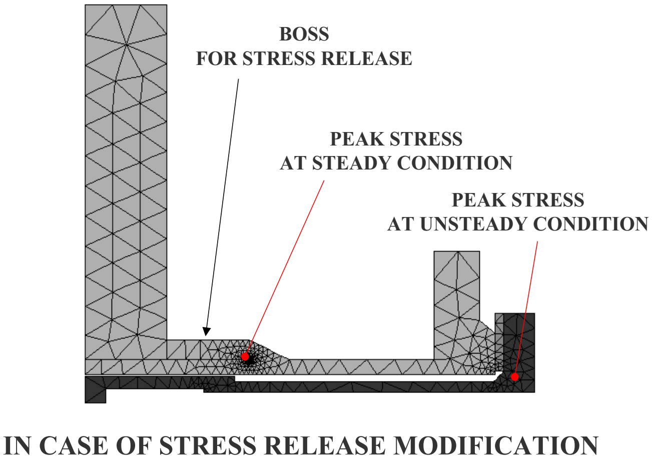


Figure 17. Thermal Stress Relief Modification—Nozzle Box.

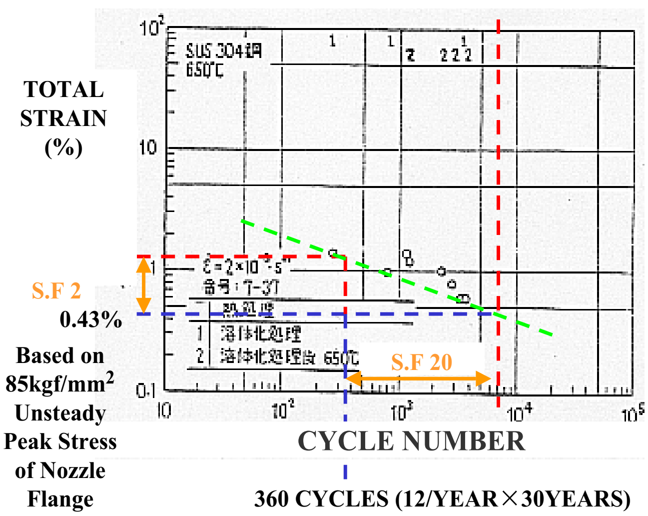


Figure 18. Low Cycle Fatigue Evaluation.

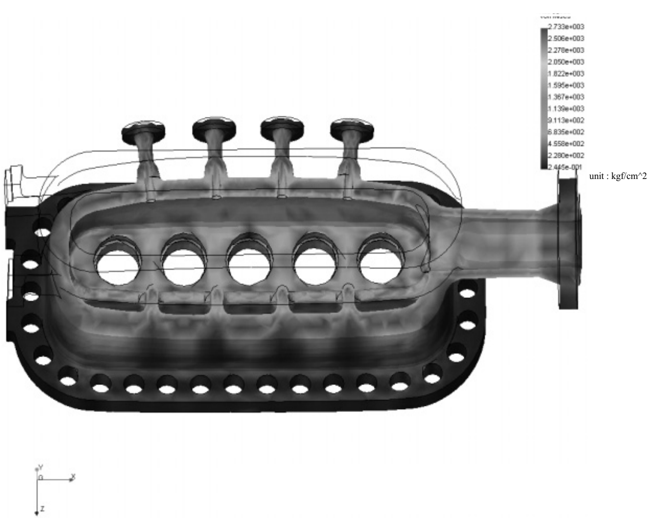


Figure 19. Analysis Results of Valve Chest Stresses.

The results of this analysis of the extraction box, which is made from chromium molybdenum (CrMo), show the stress to range from 2.3 to 4.6 kgf/mm^2 (3271.4 to 6542.7 lbf/in^2). This range provides adequate margins when compared to the allowable stress of 9.8 kgf/mm^2 (13,938.9 lbf/in^2) based on creep rupture.

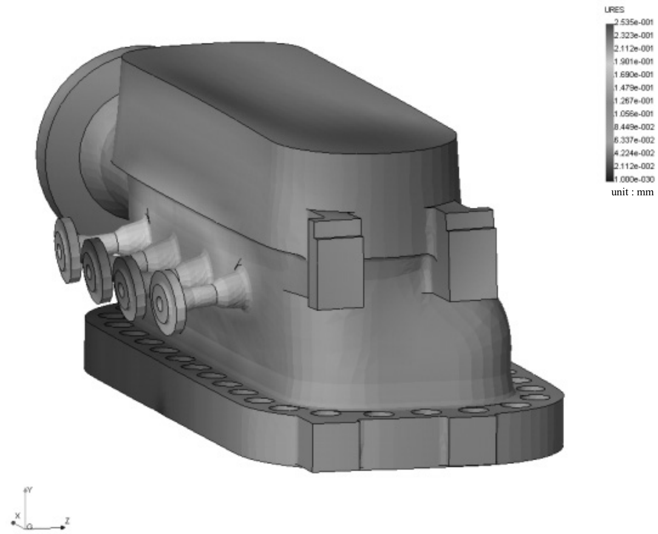


Figure 20. Analysis Results of Valve Chest Displacement.

Inner Lift Bar

During online washing, the inner lift bar is exposed to a temperature gradient caused by low temperature water injected on one side, while the other side is exposed to a higher steam temperature. This results in deformation and thermal stress occurring in both transient and steady-states.

The lift bar was modeled using FEA, and was based on a temperature distribution calculated over a two hour wash period with an inlet temperature of 20°C (68°F). Based on this inlet temperature, it was estimated that the temperature difference between the water injection spot area and the opposite side was about 250°C (482°F) for the model. Actual shop testing showed that the temperature of the injected spot area was close to the mixture temperature of the water and steam. However, during real operating conditions, because the actual temperature difference is not large between the water injection spot area side and the opposite side, the thermal stress is not particularly severe.

Using 250°C (482°F) delta-T for the model, the thermal stress distribution was calculated for a two hour wash period as mentioned above. The maximum stress in tension was approximately 60 kgf/mm^2 (85,340.1 lbf/in^2) and compression stress was 20 kgf/mm^2 (28,446.7 lbf/in^2). A low cycle fatigue evaluation was also carried out. This confirmed a safety factor of 2 for a total stress of 60 kgf/mm^2 (85,340.1 lbf/in^2), resulting in a life factor of 20 times the design criterion of 12 washes per year over 30 years. Figure 21 and Figure 22 show the contours of deformation and stress for the inner bar. The maximum deformation is 1.2 mm (.045 inch) and equivalent stress is 58 kgf/mm^2 (82,495.4 lbf/in^2).

Although the model used a larger than normal delta-T of 250°C (482°F), the stress and deformation calculated were well within the acceptable range. Expected actual stress and deformation will be about 1/10 of the calculated values.

SHOP TESTING EVALUATION AND RESULTS

In order to verify the results of the design calculation, a static shop test was conducted on the newly designed extraction steam chest.

Actual steam conditions were simulated. Injected flow rates were adjusted during the test to determine whether or not the injected water steam mixture was completely vaporized. Nonvaporized mixture could cause damage such as breakage or deformation of internal parts in the valve box or turbine casing due to heavy drain erosion under the condition of insufficient vaporization of water.

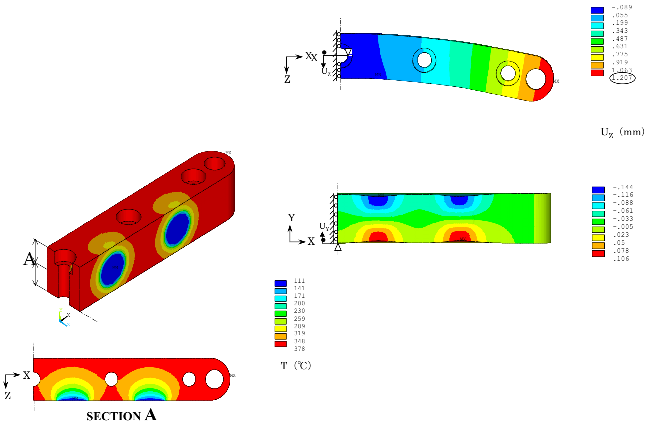


Figure 21. Deformation Analysis for Inner Lift Bar During Online Washing.

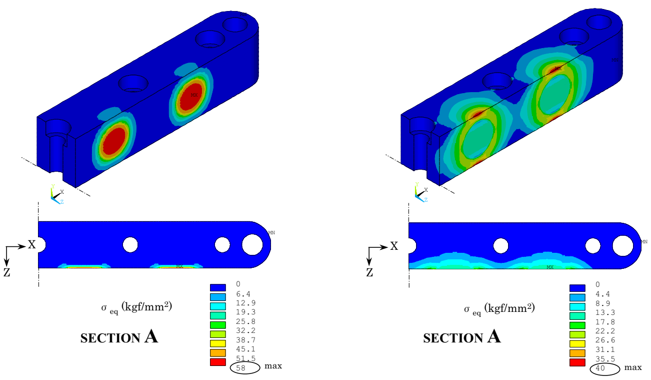


Figure 22. Stress Analysis for Inner Lift Bar During Online Washing.

Description of Test Setup

The flow diagram in Figure 23 illustrates the shop test setup for the valve chest. Figure 24 shows a photograph of the actual test facility. As can be seen, the testing arrangement can simulate the actual online washing condition by varying measured water injection flow rates and steam temperature distribution along the steam path internals including the valve box.

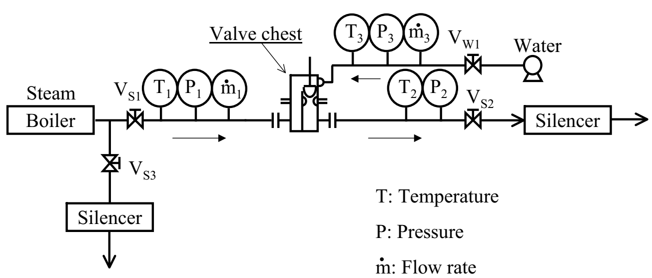


Figure 23. Testing Flow Diagram.

Test Conditions

Figure 25 is a schematic showing the points of measurement for the various parameters. Actual operation conditions are used in the simulation, including steam velocity. Since only one injection valve is used compared to four in a real turbine, the flow rate is a quarter of the actual steam flow. Table 2 shows a comparative summary of the parameters used in the tests versus the conditions for a real turbine. *Note:* Point is equivalent to the actual position of the first LP stage nozzle, i.e., the extraction stage.

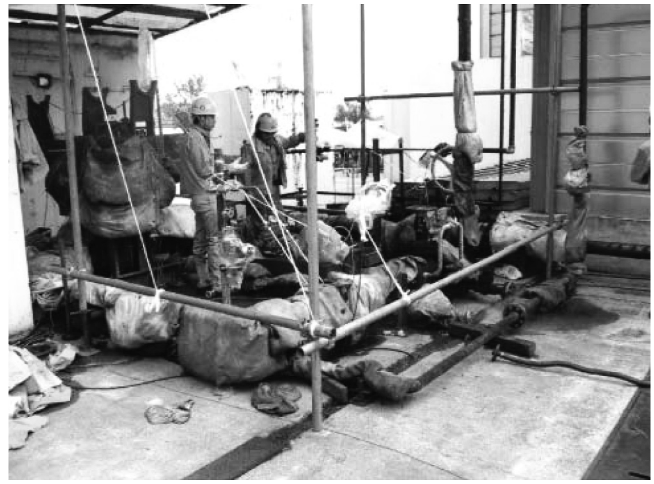


Figure 24. Test Setup for Online Washing.

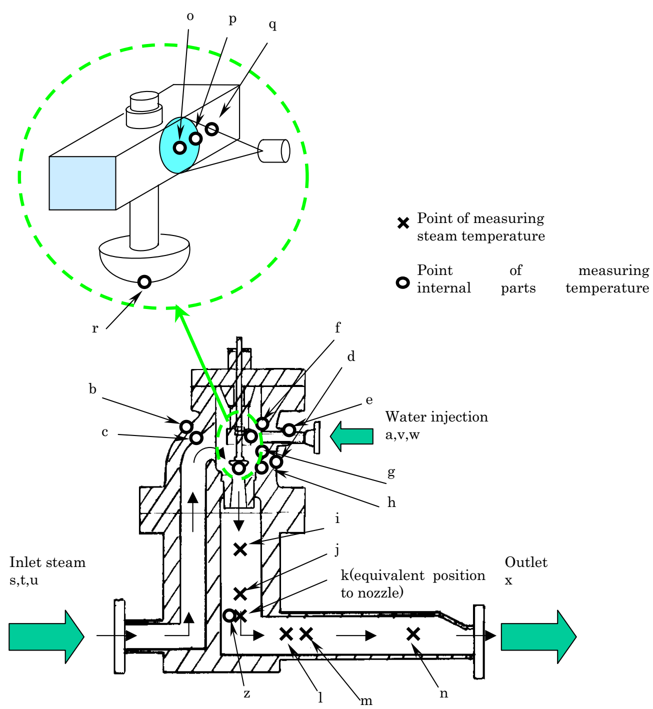


Figure 25. Valve Chest Schematic.

Table 2. Test Conditions.

Item	Testing machine	Actual turbine
Steam pressure[MPa]	4.6	4.6
Steam temperature[K]	651	651
Steam flow rate[kg/s]	4.7	23
Water pressure[MPa]	4.9	4.8
Water temperature[K]	373	373
Water flow rate[kg/s]	0.38	1.9

* Same steam velocity as the actual turbine

Results

The temperature profile along the steam path downstream of point “k” at varying water flow rates is shown in Figure 26. Under increasing flow rates, steam temperature gradually drops to saturation temperature (250°C, 482°F). As can be seen, for flow rates below 18 l/min (4.8 g/min), the temperature profile is fairly constant along the flow path downstream of "k." Whereas, flow rates above 18 l/min (4.8 g/min) result in temperature increases along the same flow path, leading the authors to conclude that water is therefore not vaporized completely.

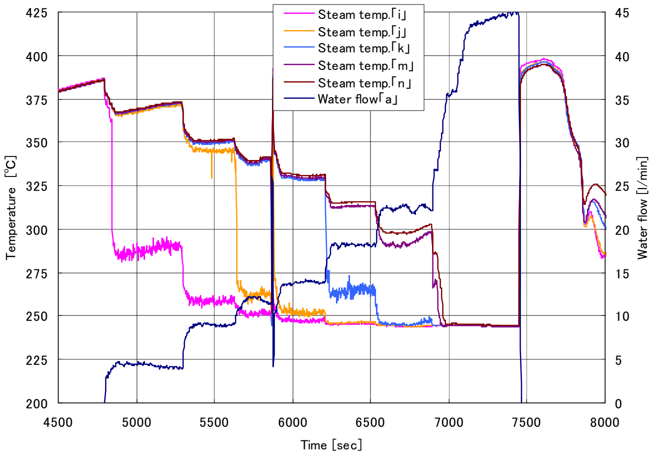


Figure 26. Test Results for Steam Temperature Profile.

Figure 27 shows the temperature profile in the upper portion of the valve box at varying water injection rates. Temperature in this area does not decrease even during water injection. On the other hand, just below this area, the temperature falls to saturation. Based on this observation, the authors found that the injected water does not vaporize completely in the extraction valve box and the surface of the valve box gets wet at saturation temperature.

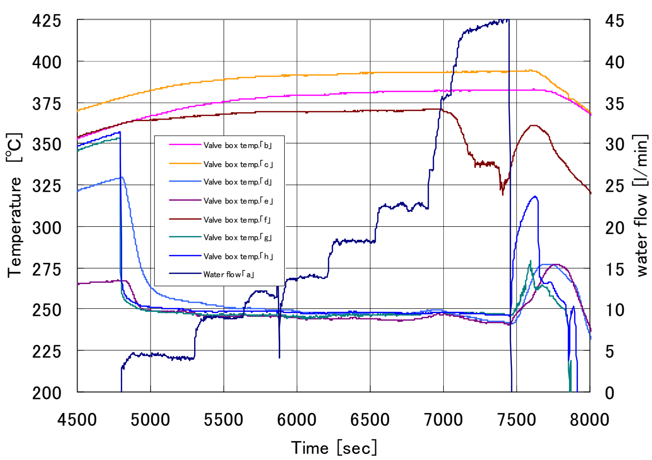


Figure 27. Test Results for Valve Box Temperature Profile.

Figure 28 shows the temperature profile on the surface of the inner bar and valve disc for varying water injection rates. The temperature gradually decreases to saturation temperature (250°C, 482°F) with increasing water flow. The temperature of the valve disc is lower than that of the inner bar. Therefore from the test results, the authors can see that the surfaces of these parts are wet and the injected water will be heated to saturation temperature before reaching the turbine internal parts.

Relation Between Water Injection Flow Rate and Mixing Temperature

Figure 29 shows the relationship between water injection flow rate and mixing temperature at point "k" in comparison to the calculated values. As can be seen, the measured mixing temperature is almost the same as that of the calculated value.

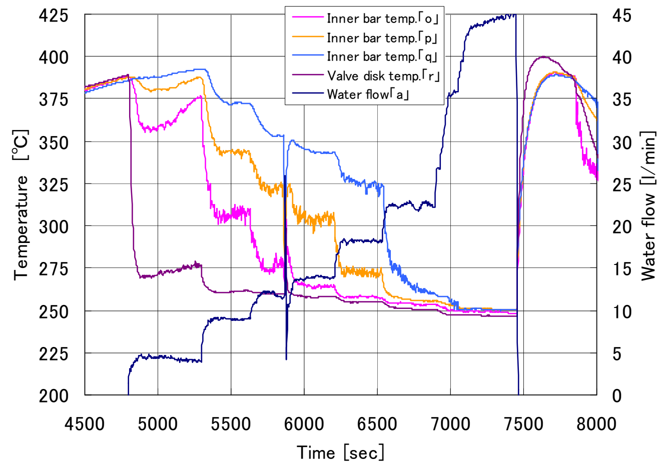


Figure 28. Test Results for Inner Lift Bar Temperature Profile.

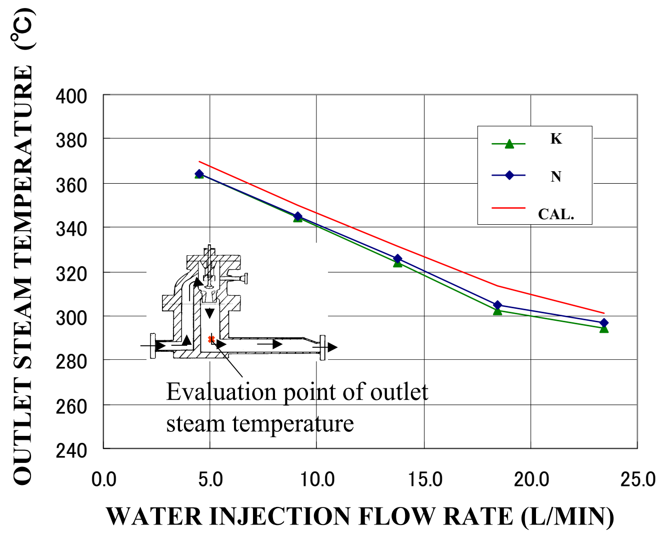


Figure 29. Comparison Test Results for Mixing Temperature.

Transient Temperature Comparison—Calculated Versus Tested

Figure 30 shows transient temperature during water injection, comparing calculated and measured figures at different points along the valve chest. It is evident that the test results match very well with the calculated values.

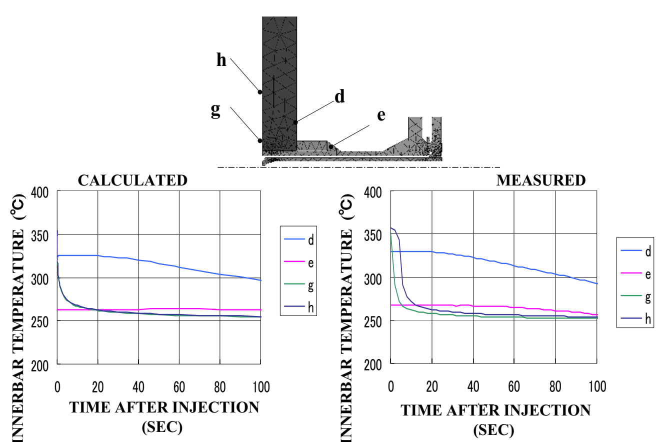


Figure 30. Temperature Comparison of Nozzle Box—Calculated Versus Tested.

NDE Testing

For inner bar, control valve, and water injection nozzle, Figure 31 shows nondestructive evaluation (NDE) results, and no defects were found in any of these parts. As there is no appreciable thermal deformation caused by water injection, the inner bar and valve will operate normally.

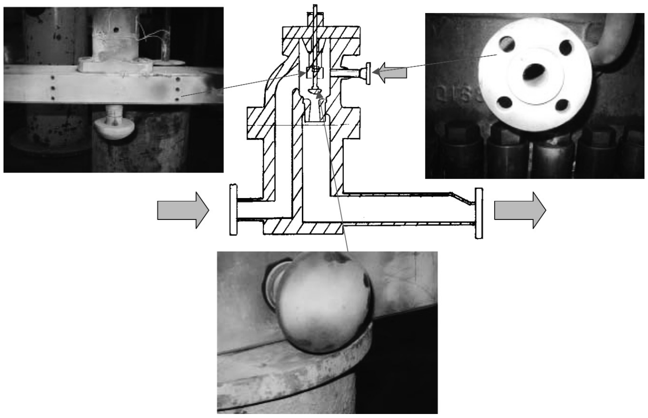


Figure 31. NDE Results after Water Injection Test.

RISK ASSESSMENTS ANALYSIS

Based on hazard and operability (HazOp) and United States Department of Defense military (MIL) standards shown in Tables 3 and Figure 32, the authors designed the online wash system shown in Figure 33 for an actual field application.

Table 3. Risk Assessment.

ASSESSMENT FACTOR		HAZARD			COUNTERMEASURES ALARM SAFETY LOADING
ELEMENT	RISK SOURCE	GRADE	PROBABILITY	RISK INDEX	
WATER&STEAM MIXING	NON-EFFECTIVE HEAT BALANCE	Ⅱ	C	12	SHOP INJECTION TEST TIT LL CONTROL
INJECTION PROVISION	TRANSIENT THERMAL STRESS	Ⅲ	C	8	TRANSIENT STRESS ANALYSIS & NDE T/A
EXT. VALVE INNER BAR	TRANSIENT THERMAL STRESS	Ⅲ	C	8	TRANSIENT STRESS ANALYSIS & NDE T/A
INJECTION NOZZLE	TRANSIENT THERMAL STRESS	Ⅲ	C	8	TRANSIENT STRESS ANALYSIS & NDE T/A
	DRAIN INVASION	Ⅱ	C	12	EMERGENCY SHUT XV PDCV DOUBLE SHUT
	CHOKE FOR SOLID PARTICLE	Ⅲ	C	8	FLUSHING & HEATING DRYING
TURBINE NOZZLE PROFILE	DRAIN EROSION	Ⅲ	D	6	DAMAGE INDEX NDE T/A COATING FOR PROTECT
	THRUST FORCE UP IN CHOKE	Ⅲ	D	6	AFTER EXT. PRESS & AXIAL DISPLACEMENT MONITORING
TURBINE BLADE PROFILE	DRAIN EROSION	Ⅲ	D	6	DAMAGE INDEX NDE T/A COATING FOR PROTECT
	THRUST FORCE UP IN CHOKE	Ⅲ	C	8	AXIAL DISPLACEMENT & METAL TEMPERATURE ARE MONITORED
	LP SECTION MOISTURE UP	Ⅲ	D	6	TIT IS CONTROLLED TO MAINTAIN LP MOISTURE 14%
TURBINE THRUST BEARING	THRUST FORCE UP IN CHOKE	Ⅲ	C	8	AXIAL DISPLACEMENT & METAL TEMPERATURE ARE MONITORED
	AXIAL DISPLACEMENT UP	Ⅲ	C	8	AXIAL DISPLACEMENT & METAL TEMPERATURE ARE MONITORED
OPERATION	WATER FLOW UNCONTROL	Ⅲ	D	6	EMERGENCY SHUT XV PDCV DOUBLE SHUT
	PRESSURE RAISE IN SUPPLY LINE	Ⅲ	D	6	PRV IS INSTALLED IN WATER SUPPLY LINE

1. HAZARD GRADE

Ⅰ: CATASTROPHIC
Ⅱ: CRITICAL
Ⅲ: MARGINAL
Ⅳ: NEGLIGIBLE

2. HAZARD PROBABILITY

A: FREQUENT
B: REASONABLY PROBABLE
C: OCCUPATIONAL
D: REMOTE
E: EXTREAMLY UNLIKELY
F: IMPOSSIBLE

3. RISK INDEX

	Ⅰ	Ⅱ	Ⅲ	Ⅳ
A	24	18	12	6
B	20	15	10	5
C	16	12	8	4
D	12	9	6	3
E	8	6	4	2
F	4	3	2	1

4. CRITERIA FOR RISK INDEX

MORE THAN 13: NOT ACCEPTABLE
STOP AND RE-DESIGN REQUIRED

9 TO 12: BIG PROBLEM
TEST AND RE-DESIGN REQUIRED

5 TO 8: SEVERAL PROBLEMS
TECHNICAL MODIFICATION ONLY

LESS THAN 4: ACCEPTABLE

Figure 32. U.S. MIL Risk Assessment.

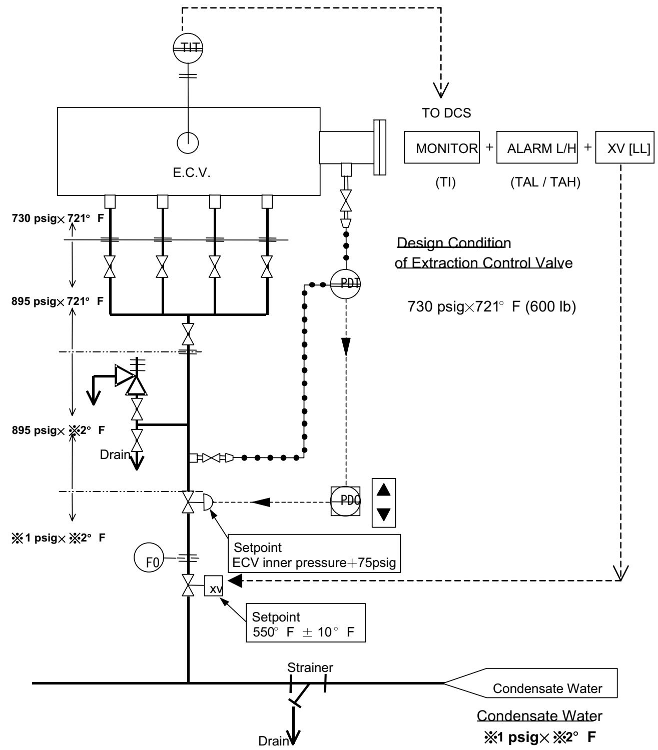


Figure 33. Water Injection Supply System.

The main risks are draining carryover, thrust force increase, drain-erosion, and thermal shock stress. The mixing temperature inside the valve chest is monitored and, if the system detects a low temperature close to saturated temperature, both the flow control and solenoid valves are immediately closed. Other risks are countered with appropriate alarms and relief valves.

CONCLUSIONS

This paper has introduced an innovative online washing technique to minimize the impact caused by fouling of the steam path in large multistage condensing steam turbines.

The methodology developed to effectively evaluate the design of the new online wash nozzles showed that the calculated parameters compared well with shop test results. This methodology evaluated the nozzle box on a component-by-component basis using FEA, which confirmed the mechanical integrity of the overall system. Life cycle calculations based on fatigue phenomenon showed the system to exceed the projected life by a factor of 20. Using HazOp and MIL risk assessment standards, the authors were able to design the supporting external facility.

The final design is a compact extraction box, which replaced an original design extraction box without machining of the turbine casing. This design was shop tested and proved effective in washing off deposits from LP blades and nozzles with minimal power turndown, and without impacting the turbine's long-term performance. This technique, although applied here to extraction-condensing turbines, is also applicable to large condensing turbines.

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