# Emergency Application of Turbine Operation

## Instruction Manual

August, 2022

TOSHIBA ENERGY SYSTEMS & SOLUTIONS CORPORATION

# Table of Contents

# 1. Introduction

This manual is written to ensure safe handling of the Turbine. Before maintenance, be certain to read this manual for proper use of the equipment. This manual should be kept near the equipment so it can be readily referenced.

# 2. Precautions for Safety

Signs and messages in this manual and on the equipment body are important for management, operation, maintenance and inspection. They are given to avoid possible injuries and damages as well as to ensure correct handling of the equipment. The following signs and short messages should thoroughly be understood before reading this manual. It is advised that you also read the instruction manuals of related equipment and components.

| **IMPORTANT MESSAGES**<br>Read this manual and follow its instructions. Signal words such as DANGER, WARNING, two kinds of CAUTION, and NOTE, will be followed by important safety information that must be carefully reviewed. | |
|---|---|
| ⚠ DANGER | Indicates an imminently hazardous situation, which will result in death or serious injury if you do not follow instructions. |
| ⚠ WARNING | Indicates an imminently hazardous situation, which could result in death or serious injury if you do not follow instructions. |
| ⚠ CAUTION | Indicates an imminently hazardous situation, which if not avoided, may result in minor injury or moderate injury. |
| CAUTION | Indicates an imminently hazardous situation, which if not avoided, may result in property damage. |
| NOTE | Give you helpful information. |

## APPLICATION

This equipment is designed for maintenance of turbine. Never use this for other purposes

## WARRANTY AND LIMITATION OF LIABILITY

Toshiba has no obligation to compensate for any damages, including collateral damages, caused by abnormal conditions or failures of this equipment and connected devices.

## QUALIFIED OPERATORS ONLY

This instruction manual is written for chief electric engineers of your company and competent persons authorized by the chief electric engineers (*).
For operation, maintenance and inspection, this instruction manual and other manuals of the associated devices and components shall be read and understood. Workers shall follow the directions of the chief electric engineers.

* Authorized people mean electric engineers who have received education offered by Toshiba.

## WARNING LABEL

(1) To ensure safety, all the warning labels shall be read and understood.
(2) Warning labels shall be kept in such a condition that they can be easily seen. They shall never be contaminated, removed or blocked from view by cover.

# 3. Emergency Turbine Operation Following Water Induction

The accidental introduction, or induction, of water in any part of the turbine can cause serious damage to the high pressure shells, rotors, buckets, and thrust bearings.

The extent of each type of damage depends upon the quantity of water induced, the point of entry, the initial temperature of the exposed metal parts, the turbine speed, and the rate of normal steam flow that can minimize the cooling effect. Turbine damage caused by water induction may occur in one or more of six general categories as described in the following.

# 4. Categories of Turbine Damage Caused by Water Induction

## 4.1 Thrust Bearing Failure

The purpose of turbine trip test is to verify the operation of emergency tripping system and all turbine steam valves before unit start up.

Water carryover from the boiler will increase the thrust load to the point where the thrust bearing may fail. The actual amount of thrust increase can be 10 times normal. The greater density of water, as compared to steam, prevents the proper acceleration and direction of the water by the turbine nozzles. The relative velocity of the water is therefore backward against the buckets instead of through them, and a large pressure drop develops across the buckets.

## 4.2 Damaged Buckets

As the point of water entry downstream from the turbine inlet, the length of the buckets in the stage first encountered by the water increases, and so does the likelihood of damaged or broken buckets, primarily due to impact. Last-stage bucket damage in the nature of numerous cracked tie wires or covers, and in extreme cases, broken buckets, almost always results when a turbine running at rated speed receives water from an extraction line at the low-pressure turbine stage.

## 4.3 Thermal Cracking

Thermal cracking results from either extremely high thermal stresses or from repeated thermal stresses of lesser magnitude. In some cases, there may appear to be no noticeable permanent damage after water or cold steam has been admitted, but if repeated several times, cracks may develop.

Water or cold steam from any source except one or two lowest pressure extraction lines can contact the turbine's metal parts normally at temperatures high enough to be subject to this kind of damage. Cracks developing in packing casings and in packing regions of rotor surfaces may result from repeated quenching by water or cold steam from the steam seal system.

## 4.4 Rub Damage

Water introduced from the main steam and reheat lines can cause differential expansion problems between the rotating and stationary parts in the form of axial rubbing. Water backing up from extraction lines and cold reheat lines will cause contraction of the shell lower half, giving a humping effect that can lift diaphragm packings against the rotor, causing radial rubs. Bowing of the rotor results when packing rubs cause uneven heating on the rotor surface. This additional distortion further increases the intensity of rubbing. Packings, spill strips, and bucket covers are the most frequently damaged parts, but permanently bowed rotors are not unusual.

## 4.5 Permanent Warping or Distortion

Metal parts may be permanently warped or distorted when subjected to severe quenching. Steam leaks in valve and shell joints may result.

Diaphragms have become concaved and rotors have been bowed by contact with water on one side of a hot rotor after heavy rubbing caused by distortions had stalled the turning gear.

## 4.6 Secondary Effects

In addition, there may be secondary effects such as axial rubbing after a thrust bearing failure, or damage to bearings, foundations, and oil lines caused by turbine vibration that accompanies heavy rubbing or bucket damage.

# 5. Detection of Water Induction with Thermocouples

Frequently, the first signs of water induction into a turbine are rough starts, hammering of steam lines, high rotor eccentricity, or large differential expansions. During repair work there will be evidence of damage such as heavily rubbed packing and small cracks in rotating and stationary parts. To better determine if water induction is causing these symptoms and to help identify the source of the water, turbines should be equipped with detection thermocouples.

Thermocouples should be provided in the steam seal header near the admission valve to record the steam temperature at this point on the turbine metal temperature recorder. Water or cold steam in the steam seal header can be detected by very low temperatures or abrupt changes in temperature indicated on the recorder. The cause can be easily established by relating temperature changes to operation of the admission valve or transfer of the sealing steam source.

Thermocouples are provided for the detection of water in high and reheat turbine shells. Located in pairs top and bottom at several points axially in the outer shells, recorded temperatures from these thermocouples make it possible to determine at which opening in the turbine the water enters.

Under normal conditions the top and bottom thermocouples in a pair will indicate approximately the same temperature. An abrupt decrease in temperature of the bottom thermocouple, or a substantial differential between the top and bottom temperature of a pair, indicates the presence of water and resulting shell distortion.

Thermocouples cannot prevent water from entering the turbine but they can detect it when it does. If excessive temperature differentials are detected, the source should be located and this problem corrected to prevent further damage.

# 6. Factors Affecting The Extent of Damage

Once water has entered the turbine, the point of entry and the initial temperature of exposed metal parts are beyond control by the operator. The degree of damage potential from the other factors, however, can be greatly influenced by what the operator does. The station operating records often show clearly that the most serious damage was done a considerable time after the first indication of water induction.

Three factors for which the operator may affect the extent of damage from water induction are quantity of water, steam flow, and speed.

## 6.1 Quantity of Water

The quantity of water entering the turbine directly affects the extent of damage caused by quenching and distortion. Steps should be taken immediately upon the first indication of water induction to shut off the source and drain the water out of the turbine and steam lines. Water sources and procedures for preventing further damage are discussed in Section 7.

## 6.2 Steam Flow

When a turbine is running under load the steam flow will be of some benefit in uniformly distributing the water and minimizing distortion.

Also, the casing will straighten more quickly when the water is removed if steam flow is maintained. For these reasons, a turbine carrying load when water enters should be kept running unless high vibration, high differential expansion, or some other serious condition requires shutting down. The source of water must be immediately shut off.

## 6.3 Speed

The extent of rub damage caused by thermal distortion depends upon the speed of operation. Slow rotation of the rotor on turning gear is best because the heat generated at the rotor surface by rubbing will not be enough to cause permanent bowing. If the turbine is accelerating below rated speed when water enters, is should be tripped. Rubbing at speeds in the range of rotor critical speeds and below can be very destructive because the rotor tends to bow in a direction that increases the intensity of the rub.

The turbine should be left on turning gear until the source of water is identified and shut off and the shaft eccentricity is normal. Unless there has been permanent bowing of the rotor, the eccentricity will return to normal in 2 to 6 hours; however, a humped shell may require a much longer time to straighten. A period of 24 hours on turning gear is recommended before starting up after water has entered a turbine casing initially above 260℃.

Shell humping may cause such hard rubbing that the turning gear motor cannot turn the rotor. When this happens, the best procedure is to make sure all water is drained from the shell and then make periodic (approximately once per hour) attempts to place the unit back on turning gear. A restart should not be attempted until the eccentricity is normal.

Where rubbing occurs at speeds well above the range of rotor critical speeds, a rotor will tend to bow in a direction which reduces the intensity of the rubbing. This is another reason it is better to continue running the turbine if conditions permit when water enters during operation at rated speed, instead of tripping and coasting down through the critical speed range.

Operating recommendations following water induction are as follows:

(1) Take action at the first indication of water induction.

(2) If operating at rated speed, keep the turbine running unless high vibration, high differential expansion, or other serious condition requires shutting down.

(3) If operating below rated speed, shut down immediately.

(4) In any case, shut off the source of water and drain the area immediately.

(5) Once on turning gear, never attempt to restart until shaft eccentricity is normal and the temperature between the upper and lower casing is within normal operating range, the source of water has been identified, shut off, and the problem resolved.

(6) If the turning gear motor cannot turn the rotor, make periodic (once per hour) attempts to place the unit back on turning gear.

# 7. Source of Water

The problems of detecting and preventing water induction are associated with five main source categories as described in this section.

## 7.1 Extraction Systems

Extraction systems are the most frequent source of water involved in turbine mishaps. With numerous extraction openings in the turbine and the presence of water a short distance from each, many combinations of equipment failure, operating error, and system design weakness can lead to serious consequences. Experience has shown that there are four basic causes of water induction involving extraction systems.

(1) Leaking feedwater heater tubes.

(2) Failure or inadequacy of heater level controls.

(3) Inadequate or improper arrangement of heater and extraction line drains.

(4) Leakage or faulty operation of valves where extraction lines are interconnected with such sources of steam as startup supply for deaeration.

Heater high-level alarms (N.W.L +160mm) often precede water induction from an extraction line. When this is the case, water detection is only a matter of heeding the alarm, and identifying the source is usually easy. Water detection thermocouples are the best means of identifying the source.

Dependable high-level (N.W.L +160mm) alarm switches are essential because turbine damage can be minimized or prevented if action is taken immediately when a high level alarm occurs. Level switches must be tested on a regular schedule. A complete test that raises the water level in the sensing line and actuates the switch by moving the float is time consuming, but is the only adequate test.

Heater level controls regulate the flow of condensate from the heater to maintain a constant heater level. The rate of flow varies greatly over the full load range of the plant and must be changed rapidly at times during startup, load changes, and tripping of the turbine. The level controls must not permit level surges in the heater that will actuate the level alarms. As soon as possible after a new unit begins operation, the level control system should be tuned and modified, if necessary, to completely eliminate these false alarms.

Any malfunction in the level sensor, valve controller, actuator and associated air lines that shut off the flow of condensate will cause the water level to rise. The rising level reduces and eventually stops the condensation of steam in the heater. This situation is dangerous. Unless all flow of water into the shell side of the heater from higher pressure heaters and other sources such as leaking feedwater heater tubes is shut off, the level will continue to rise and cause water to enter the turbine.

This can happen very quickly if the heater is at an elevation above the turbine.

A heater should be bypassed immediately when improper functioning is indicated either by a high-level (N.W.L +160mm) alarm or thermocouples in the feedwater line. Where heaters are not bypassed individually and a bank of several must be bypassed to remove any one from service, load may need to be substantially reduced because of turbine restrictions on operation with heaters out of service. Bypassing each heater individually provides more freedom for prompt operator action.

Extraction check valves (or nonreturn valves) are provided in most of the extraction lines from a steam turbine. Their primary function is to prevent steam from entering the turbine on loss of load, and thus they are an important element in the control which protects the turbine against excessive overspeed. For this purpose, they are not required in the extraction line on reheat turbines where steam is extracted from the cold reheat line because the reheat stop valves and intercept valves protect the turbine from energy in that heater. In addition, by restricting water storage in the shell side of the lowest pressure heaters, it is generally possible to permit the omission of extraction check valves for overspeed protection. However, extraction check valves also provide an important means of protecting the turbine against water induction. Therefore, the best practice to protect the turbine is to provide check valves, power closed on heater level, in every extraction line.

Check valves may not seal tightly when needed to stop the backflow of water into the turbine. This may be the result of distortion arising from the colder water coming in contact with only a portion of the body. For this reason, it is important to open the extraction line drain on the turbine side of the extraction check valve whenever the presence of water is indicated.

Shutoff valves in the extraction lines provide the tightest shutoff to prevent water induction. These valves should be motor-operated and equipped with controls to run the valves closed on induction of high level in the heater. If high level is caused by leaking heater tubes, it is still necessary to bypass the heater to prevent the heater shell safety valve from opening. In any event, the turbine is protected.

The extraction line drains on the turbine side of a check valve or shutoff valve must prevent moisture from accumulating in the line and backing up into the turbine. These starting drains should be motor-operated and may be closed with the heater in service. These drain valves should go open on a signal from the heater high-level switch. The drain valves in extraction lines may be closed above 15 percent load. Steam traps in these lines are not considered adequate protection and should only be used in parallel with the extraction line drain valve. These drains must be connected to the condenser.

Any isolation valve not normally used during startup and operation should be locked open.

Recommendations for operation are as follows:

(1) Instruct operators to heed all level alarms by taking prompt action to prevent water entering the turbine.

(2) Instruct operators in specific operating procedures to respond to high level alarms.

(3) Periodically test alarms and valves.

(4) Do not operate heater if some of the protective devices are known to be faulty.

## 7.2 Boiler and Main Steam Leads

The main steam leads are the second most frequent source of water or cold steam involved in forced outages. The usual cause is loss of control of steam temperature or boiler drum level due to misoperation or equipment malfunction. The risk may increase as units are put on cyclic duty.

Sudden, very large load increases such as might occur with a major system disturbance can cause water carryover. An initial pressure regulator to close the turbine valves as boiler pressure decreases will reduce the likelihood of carryover in this event. It is recommended that the turbine not be run for long periods with the initial pressure regulator out of service.

When boiler operating conditions are unstable and could lead to water carryover or cold steam entering the turbine, the unit should be tripped.

Continuing to admit steam to a turbine when fires have gone out in the boiler is particularly hazardous and is almost never justified.

Some once-through boilers produce water at full rated boiler pressure against the turbine stop valves during the boiler startup cycle. Quenching of the stop valves and water admission from misoperation or leaking valves can be serious problem on these units. The feedwater heaters in many of these cycles are pressurized during startup, increasing the possibility of water entering the turbine from these sources. The design and maintenance of the controls and equipment with these systems should be carefully considered.

Several outages have been attributed to inadequate draining of the main steam leads or boiler superheater. Turbine stop valve before-seat drains will drain the valve body and a portion of the main steam leads.

They are not sized to drain the entire linen from boiler to turbine, and additional steam lead drains must be provided.

Several cases of severe turbine quenching have not been fully explained, but are believed to have been caused by moisture from the super-heater or main steam leads. These incidents occurred during hot startup which were made a very short time after tripping. It may be that the boiler fires are extinguished when the turbine trips, the boiler is purges, and the superheater is cooled, causing condensation. The turbine is then restarted before satisfactory drainage has occurred, and the water is carried into the turbine by the steam flow.

Instrumentation sensitive to temperature, pressure, or density in the steam lines might detect passage of several pounds of water, but the responses would be too slow to protect the turbine by tripping. For warnings of impending water induction, operators must rely upon indications of drum level instability and rapidly decreasing temperature and pressure that precede actual carryover. Connecting the thrust failure relay or thrust bearing wear detector to trip the turbine will usually limit the damage to the thrust bearing. Otherwise, extensive damage from axial rubbing will accompany a thrust bearing failure.

When water flow causes a thrust bearing failure, several effects will help verify that water was the cause. If the temperature has been in the superheat region, it will suddenly drop to saturation temperature and the temperature recorders will show it. If it has occurred at startup when temperatures are low, it may be more difficult to detect. The sudden temperature drop may cause temporary leakage from the stop valve heads and the horizontal joints of the turbine casing because of the internal surface contractions. Flowmeters will generally indicate a sudden increase in flow. The flow does not increase but the passage of water through the flow nozzle causes a large pressure drop, giving a false indication.

## 7.3 Reheat Spray Attemperators

Spray water injection into the cold reheat line is frequently used to control steam temperature at the outlet of the reheater. A hazard of water induction exists from misoperation or leaking valves. Water is injected through nozzles that spray into venturi mixing tubes. With adequate water-to-steam pressure differential, rapid atomization and evaporation occur and only dry steam enters the reheater.

Even a very small steam flow will carry the atomized spray into the reheater. However, with no steam flow the spray will condense and, depending on the pitch of the steam line, either run back through the cold reheat lines into the turbine or accumulate in the reheater, possibly being blown into the turbine during startup. There has been no experience of damage from spray water entering the turbine at any time other than when the unit was shut down or starting up. Of course, with automatic temperature control of spray water flow, severe steam temperature changes are always possible, due to a control malfunction.

The flow of spray water must be stopped when steam flow through the reheater is interrupted. Tests for valve leakage and power operation of the closing circuits should be performed periodically.

## 7.4 Steam Seal System

Admission of water or cold steam from the steam seal system has not been the cause of many forced outages. Instances of severe thermal shocking of the turbine that did not cause an outage have been more frequent.

These instances have usually occurred with steam seal systems using an auxiliary steam source. Such systems have become more prevalent with the increased use of once-through boilers.

When the source of sealing steam is transferred from the man source to an auxiliary source after shutting down, there will be no steam from the HP packings to mix with the steam initially admitted. The initially admitted steam will go to both the higher temperature HP packings as well as the LP packings. The temperature of this auxiliary sealing steam must therefore be within the matching limits.

The line from the auxiliary source should be properly drained so that accumulated water will not be blown into the steam seal header when the auxiliary feed valve opens.

In some instances, spray water is used to attemperate the auxiliary supply steam, and additional precautions, such as the addition of moisture separators, are required.

The steam seal header has a continuous drain from its lowest point to the condenser, to prevent a gradual accumulation of water from flooding the header and entering the turbine. This drain can become plugged and therefore should be periodically checked. In any case, the drain is not sufficient to pass large quantities of water if admitted into the steam seal system. When there is a thermocouple in the steam seal header it is very useful for detecting either a plugged drain or problems with cold steam admitted into the header.

Excess steam from the steam seal system must not be discharged to an extraction line when there is no extraction steam flow in that line or moisture may be blown into the turbine. On units having a steam seal diverting valve, interlocks are provided which divert the flow of steam to the condenser in the event that conditions would force hot unloading steam back into the turbine, thereby causing shell distortion. It is the responsibility of the operator to divert this flow to the condenser when the feedwater heater is not functioning and there is no extraction steam flow.

A switch to the steam seal diverting valve relay is provided for this purpose.

Operating recommendations are as follows:

(1) If there is a possibility of water in the main steam leads, shut off the seals or transfer them to an auxiliary source.

(2) Periodically check the continuous drain from the steam seal header to be sure it is not plugged. A contact pyrometer may be used.

(3) If the feedwater heater receiving the steam seal header unloading flow is cut of service, switch the steam seal diverting valve to divert to the condenser.

(4) Observe the steam seal header thermocouple during various modes of operation and search out and correct the reasons for rapid temperature changes.

(5) If the transfer to an auxiliary steam seal source is done manually, blow down the auxiliary source line for a sufficient time to get rid of any water and heat the feed line.

## Revision History (for internal use)

| REV. | REV. ISSUED | PAGE | CHANGED PLACE AND CONTENT | APPROVED BY | REVIEWED BY | PREPARED BY |
|---|---|---|---|---|---|---|
| a | 19.Aug.'22 | — | 1st edition for XVVP1 | K.Asai 19.Aug.'22 | K.Asai 19.Aug.'22 | M.Yamada 18.Aug.'22 |