TOSHIBA



E K S 1 0 1 3 3 9 - a

# 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**

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.

## CAUTION

- **During cold start, do not over speed the turbine until it has carried 25 percent or greater load for at least 3 hours.**

  The temperature of the metal at the turbine rotor core will be below transition temperature when first coming to speed. The emergency governor should be oil-tripped when coming to speed to make sure it works satisfactorily.

- **Do not remain at or near rated speed or without load longer than necessary on hot starts.**

  Operating a hot turbine at full speed, no load, or at reduced speed, particularly with decreased steam supply temperature, may cause drastic cooling or quenching of the turbine inlet metal.

## NOTE

- Absolute limit is based on the thermal fatigue strength of 7,000 cycles and should not be exceeded.

- Normal operation is to be under the standard limit.
  If this is exceeded, continuous observation is required.
  And some operation such as unit hold is necessary when the absolute limit is being approached.

- If the absolute limit is reached, it is most desirable to then alter the operation procedures based on boiler characteristics.

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- Values on curves are life expenditure in percent per cycle.

- Shaded area is core stress limit and not to be entered during increases.

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- Values on curves are life expenditure in percent per cycle.

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- The shorter the period of the shutdown cycles, the greater must be the coordination and precision of the operation. To ensure the best conditions when the turbine is restarted, the shutdown procedure should remove the load in orderly fashion; perform any safely tests required; avoid undesirable stresses in the turbine metal; prevent distortions of the hot parts, including valves, shells, and rotors; and operate the unit and all auxiliary equipment during load reduction and shutdown.

| NOTE |
|---|
| ■ Do not operate the turbine with auxiliary load or no load at any speed through the admission of steam to the control valves after the unit has been running at or near rated temperature. This may cause quenching of the internal parts and result in cracking or excessive distortion. |
| ■ Motoring the unit by keeping it synchronized with the control valves closed, even with a good vacuum, may cause serious overheating of the exhaust hood and last-stage buckets. Although the exhaust hood spray can be operated to sufficiently cool this equipment, the steam path upstream the last stage buckets cannot be cooled. |
| ■ Operation of some reheat units without the proper use of water sprays may also cause overheating of the exhaust hood and last stage buckets. Normally, the manual selector valve for the water sprays in the hood will be placed in the "auto" position when the unit is rolled off turning gear on startup and will remain in this position until the unit has been returned to turning gear on a shutdown. The maximum hood temperature for normal operation should not exceed 80 °C.<br><br>If exhaust hood temperature is high because of the failure to place the manual selector valve in the "auto" position during startup, the sprays should be applied or regulated by changing the flow gradually to avoid sudden thermal changes. |
| ■ During starting, when bringing the unit to rated speed, minimize operation near or at the rotor critical speeds to reduce the possibility of excessive vibration. A continual increase of speed is usually desirable from turning gear to near rated speed.<br>Non-critical speeds at which the turbine may be held and operated are established for each turbine (Table 4-1 of EKS101341 “Turbine Operating Limits”). |
| ■ Operation of some reheat machines during load reduction for long periods at light load may lead to main steam temperature that is appreciably lower than reheat temperature, because of the boiler characteristics.<br>This should be avoided, because it may produce an undesirable temperature distribution within the turbine which may cause shell distortion and leakage. |
| ■ Starting a unit with wet insulation material on the shells tends to keep the outer surface of the outer shell cold. This may cause large thermal differences between the outer and inner metal surfaces and may lead to excessive thermal stress. Insulating material in contact with the turbine shell should always be dry before the turbine is run. Insulation can be dried using heat lamps or hot air blowers, or by applying the insulation several days before unit operation. Turbines should not be operated with uninstalled shell surfaces for similar reasons. |

# 3. Introduction

This section provides the procedure for routine startup and shutdown of the turbine. The recommended sequence for placing the turbine and its related equipment in or out of service is a practical procedure which can contribute to the satisfactory performance of the turbine generator.

It is extremely important that most of the operating steps be carried out in the sequence given here, and that recommendations be closely followed. Toshiba ESS Corporation acknowledges that the practices of different generating organizations may deviate from the sequence recommended in this manual, and it is not possible to address every deviation from the procedure and the conditions under which such deviations are permissible.

Therefore, any deviation from recommended operating procedure should be undertaken only by experienced personnel at the responsibility of the power generating organization.

The operator should use this procedure as a checklist to avoid omitting any necessary operation. Experienced operating personnel should exercise judgment in deviating from the operating practices recommended here.

For example, in turbine shutdown, if condenser vacuum is broken, deceleration of the turbine is greater because of the increased windage, and shut-down time is reduced. However, there is no reason vacuum must be broken at all, so long as the steam seal system remains in operation. Experienced personnel will know that this is highly advantageous for a shutdown of short duration, because if air is not drawn into the condensate system, condenser vacuum does not have to be reestablished for restarting. The steam seal system should never be shut down before zero vacuum is obtained.

The successful operation, maintenance, and long life of a turbine-generator are dependent, to a large extent, on the proper startup, loading, shutdown, and load changing procedures. These procedures become more important as units undergo frequent starting and loading cycles.

In many instances, a turbine may appear to start without difficulty, in spite of the use of improper methods. During early service trouble may not be evident, but unnecessary damage may be occurring that will not be identified until much later. These damages may include packing rubbing, shell distortion, or the cracking of turbine parts. These conditions can be avoided if proper operating methods are used.

Recent failures of major turbine components have been directly attributable to cracking from accumulated strain damage, which resulted from numerous heating and cooling cycles conducted frequently and at rates in excess of Toshiba's recommendations. Analysis further indicates that the thermal strains associated with quick cooling times are likely to swiftly drive cracks deeper.

These starting and loading instructions are designed primarily to minimize cyclic damage to the high temperature rotors, but they also limit cyclic damage to the shells. The turbine rotors are recognized to be the limiting equipment in most modern turbine generator units. When the shells are more limiting, it is by a small margin.

# 4. Limitations

During the starting of most turbines, the main limitations will be either thermal stress and distortion, vibration, or shell and rotor differential expansion, or any combination of the three.

Any of these limitations may be introduced by subjecting the turbine metal to excessive temperature mismatches or rates of temperature change or both. One limitation is likely to be reached before the others, depending on the turbine design and configuration, although the other two may be present to a significant degree.

## 4.1. Thermal Stress and Distortion

During steady state operation, the combined pressure and thermal stresses in the valves and shells, and combined centrifugal and thermal stresses in the rotors are maintained at a relatively low level. However, during transient operations such as startup, shutdown, load changes, and emergencies, large thermal stresses can be added to the pressure stress in the shells and valves and to the centrifugal stresses in the rotors. A severe transient may produce yielding, which consumes a certain percentage of the fatigue life of the yielded component. The amount of life expenditure depends on the level of combined stress reached during each operation. It is therefore important to limit these stresses to an acceptable level by controlling the rates of temperature change.

### 4.1.1. Temperature

Control. The primary objective during turbine starting and loading is the gradual, uniform heating of critical turbine parts to minimize thermal stress. The critical portions include the control valve chest, first-stage nozzle bowl passages, first-stage shell area, high-pressure and reheat rotors, and for most units, the stop-valve casing.

These parts are mainly in the hottest portions of the turbine in the high-pressure and reheat sections.

### 4.1.2. Temperature Limitations

Temperature differences across the thick walls of shells and valves should not exceed maximums recommended on separate curves of allowable temperature difference, Figures 4.1 and 4.2. These curves are designed to optimize the life expenditure per cycle in the stationary parts.

Rates of change of metal temperature should not exceed the maximums recommended on the separate curve of cyclic damage curve of rotor. This curve for the high-pressure section is shown on Figure 4.3.

These rates of change limits are based on limiting the life expenditure per cycle in the high-pressure rotor to satisfactory levels. Because dependable measurements of rotor temperature are not practical, the temperature of the closest stationary parts must be used as a substitute. The thermocouple closest to the high-pressure rotor is at the first-stage shell inner surface. The limitations are given in the form of curves of rate of metal temperature change as a function of the amount of metal temperature change expected, for various rotor surface cyclic life expenditures given in percent per cycle.

## NOTE

- Absolute limit is based on the thermal fatigue strength of 7,000 cycles and should not be exceeded.
- Normal operation is to be under the standard limit.
  If this is exceeded, continuous observation is required.
  And some operation such as unit hold is necessary when the absolute limit is being approached.
- If the absolute limit is reached, it is most desirable to then alter the operation procedures based on boiler characteristics.

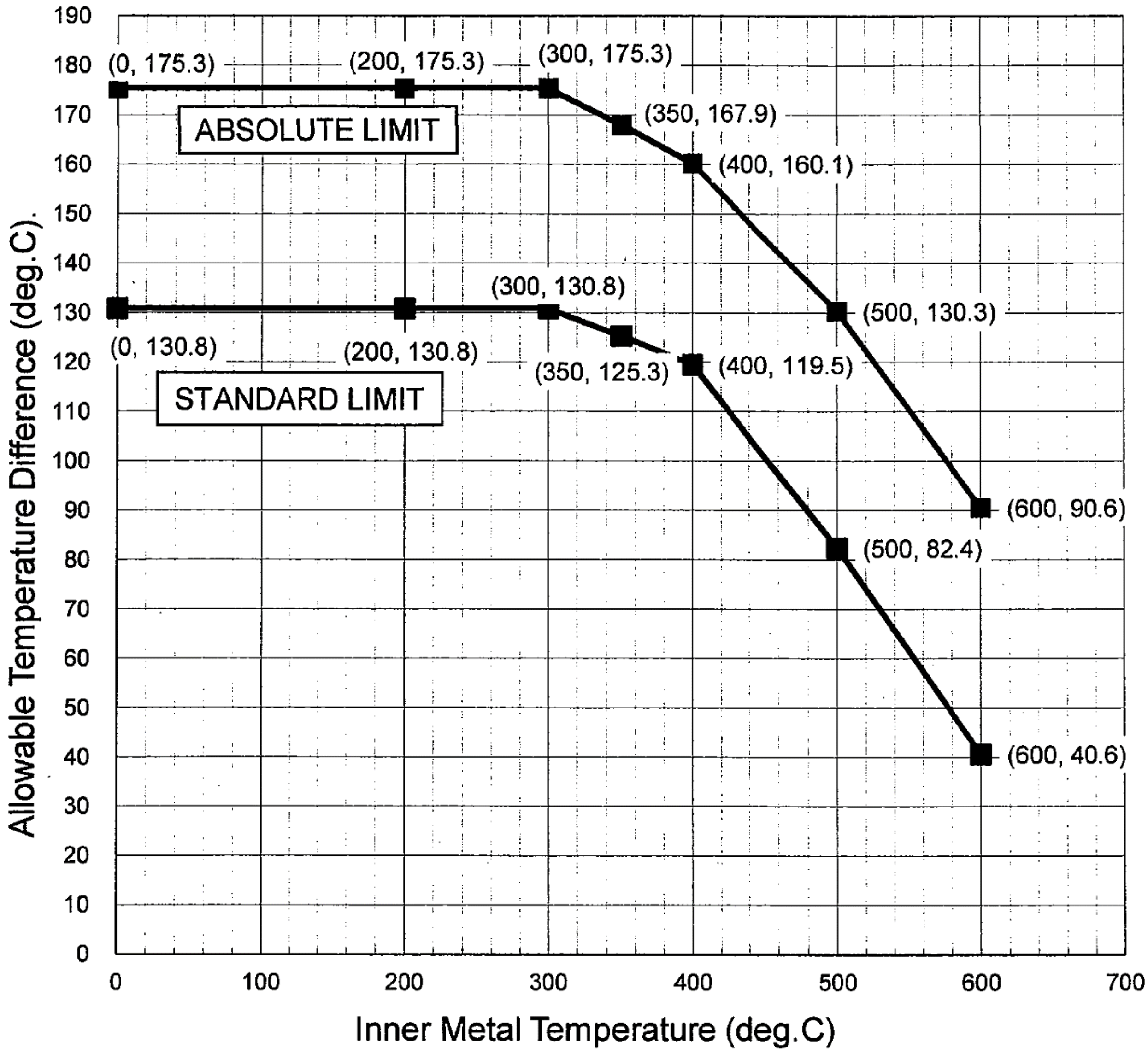



**Figure 4.1 Allowable Temperature Differences—Main Stop Valve / Control Valve Body**

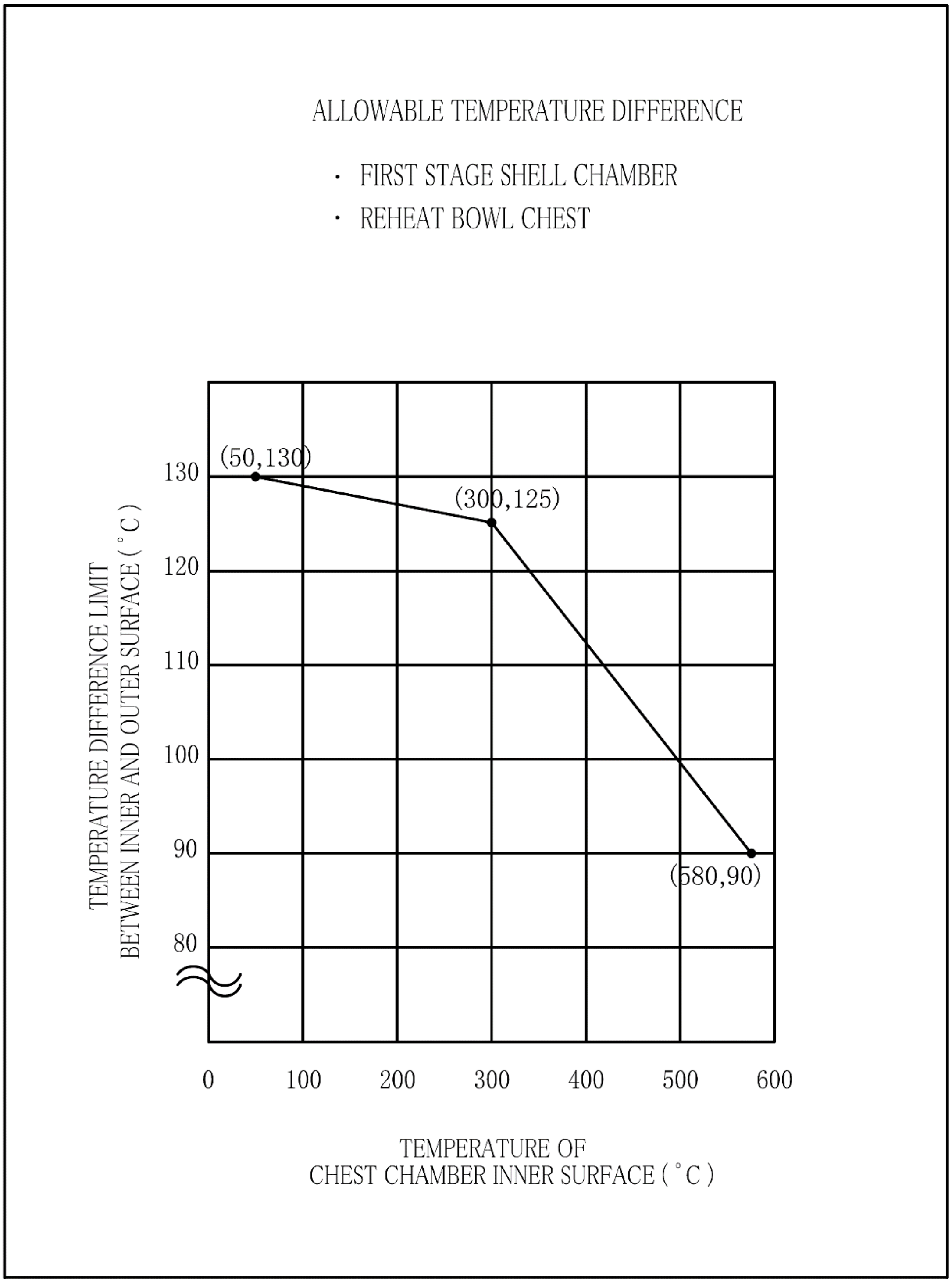



**Figure 4.2 Allowable Temperature Differences—First-Stage Shell Chamber and Reheat Bowl Chest**

Apply to rate of temperature change vs. amount of change anticipated for various cyclic life expenditures.

| Rotor section | High pressure section |
|---|---|
| Rotor nominal diameter | 736.6 mm (29") |
| Thermocouple location | First stage shell inner |

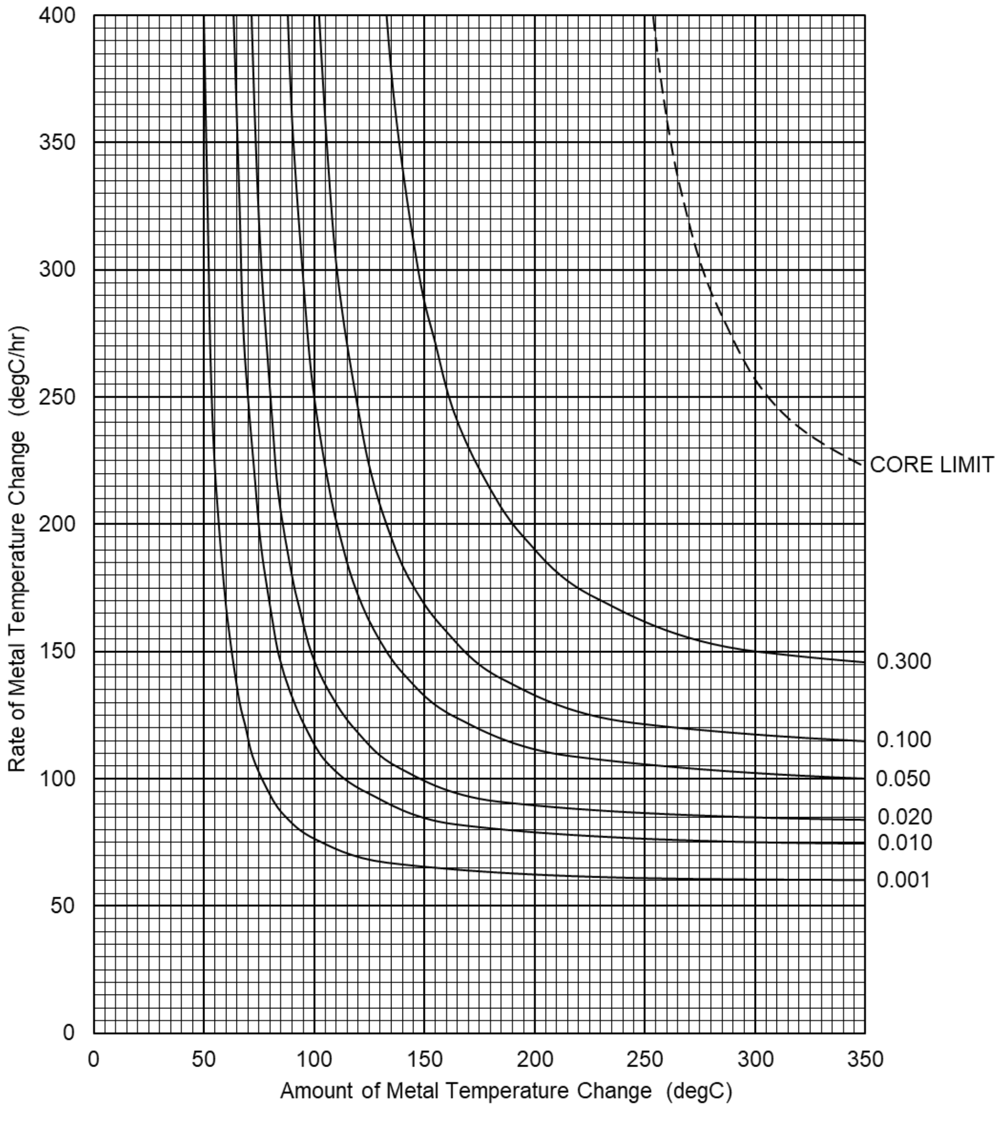



**Figure 4.3 Cycle Damage Curve of Rotor--High-Pressure Section**

| NOTE |
|---|
| ■ Values on curves are life expenditure in percent per cycle. |

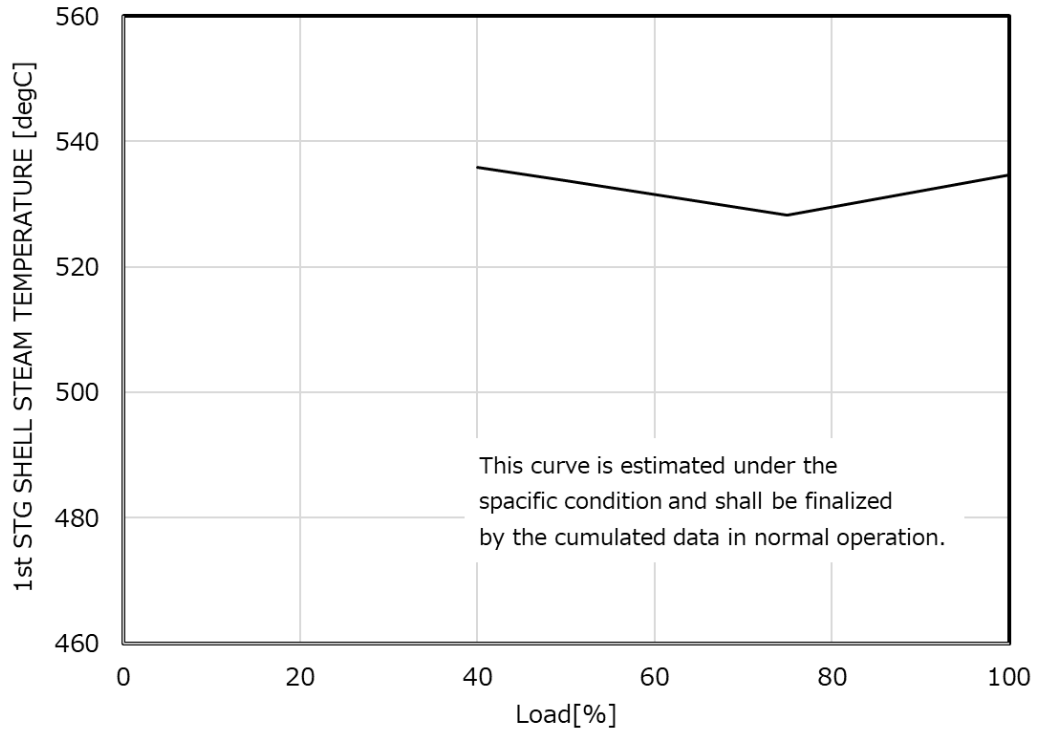



**Figure 4.4 First-Stage Shell Temperature vs. Percent Load**

### 4.1.3. Use of Allowable Rate Curves

Before the curves can be used to obtain an allowable or desired rate during any transient operation, information must first be known on the following three items (information sources are indicated in parentheses).

- Steady-state metal temperature in the first-stage shell when the transient operation begins. (Source: Metal temperature recorder)
- Predicted metal temperature. (Source: Curves of first-stage shell vs. load or percent load. These curves can be obtained by plotting actual metal temperature vs. load from station instrument data)
- Desired life expenditure in percent per cycle for the operation planned.

### 4.1.4. Selection of Life Expenditure Value

Life expenditure per cycle is defined as the contribution of one complete cycle toward the initiation of a crack. A complete cycle, for example, if the unit is on line at full load and steady state, includes a shutdown from full-load, time on turning gear, plus a startup all the way back to full load, steady state. If the unit is on turning gear, a complete single cycle includes a startup to full load, steady state, and shutdown back to turning gear. Theoretically, when the sum of these individual contributions reaches 100 percent, there is a possibility that a crack will start in either the high-temperature stationary or rotating parts.

The selection of a life expenditure value in percent per cycle takes many factors into consideration:

1. Total transient cycles throughout the unit's life. If the unit is expected to undergo 5000 major transient operations such as startup and major load change cycles during the expected 30-year life cycle, then each cycle, if equally severe, would consume $\frac{100}{5000}$ percent = 0.02 percent per cycle.

   If it is certain that units will not undergo this may cycles in 30 years, a larger life expenditure per cycle can be used. If more cycles are anticipated, a smaller life expenditure per cycle can be selected.

2. Load increase and load decrease rate during transient cycles.

   The curves of rate of change of metal temperature assume that the selected life expenditures are the same during the heating and cooling halves of the cycle.

   However, if the startup or load increases will be slow, consuming say 0.01 percent per cycle, and the shutdown or load reductions will be faster, consuming say 0.02 percent per cycle, the net life expenditure during a complete cycle of this type would be approximately the average of 0.01 and 0.02, or 0.015 percent per cycle.

   The rate of change of temperature in the first-stage shell is therefore a basic consideration during starting, loading, and unloading. In general, the rotors have higher combined stresses than the stationary parts and tend to be the limiting item. For this reason, operators should pay attention to the rates of change limitations. The most desirable way to limit valve and shell metal temperature differentials, rates of change, and thermal stress is to match steam temperature to metal temperature. During cold starts, more time must be taken at low flow rates to bring the metal up to steam temperature. Figure 4.5 which include recommended starting times, provide information to help the operator select proper acceleration rates and soak times to maintain the rates of change and differentials within limits through the initial load soak.

| | | Starting mode | Hot | Warm | Cold | Initial Cold |
|---|---|---|---|---|---|---|
| **Item** | | **Unit** | | | | |
| Turbine start conditions | Main steam press. | MPa(a) | 8.5 | 8.5 | 8.5 | 8.5 |
| | Main steam temp. | °C | 500 | 440 | 400 | 350 |
| | 1st stage discharge steam temp | °C | 426 | 353 | 300 | 223 |
| | 1st stage shell inner metal temp | °C | 445 | 320 | 296 | 150 |
| | Mismatch temp | °C | -19 | 33 | 4 | 73 |
| Accelerating Rate | | rpm/min | 300 | 150 | 150 | 100 |
| Low speed heat soak | | min | 0 | 0 | 10 | 20 |
| High speed heat soak | | min | 0 | 5 | 5 | 60 |
| Load up rate 0% to initial load | | %/min | — | 0.5 | 0.5 | 0.5 |
| Initial load | | % | 7 | 7 | 7 | 3 |
| Hold time at initial load | | min | 0 | 5 | 10 | 60 |
| Load up rate initial load to full load | | %/min | 0 to 15% 1.0<br>15 to 50% 1.0<br>50 to 100% 2.0 | 0 to 15% 0.5<br>15 to 50% 0.5<br>50 to 100% 1.0 | 0 to 15% 0.5<br>15 to 50% 0.5<br>50 to 100% 1.0 | 0 to 3% 0.5<br>3 to 15% 0.5<br>15 to 50% 0.5<br>50 to 100% 1.0 |

**Figure 4.5 Summary of Turbine Startup Recommendations**

This table does not include time required for boiler feed water control, induction steam control and any routine inspection work (if any).

## 4.2. Vibration

During the rolling period, particularly on new turbines with tight packings, light packing rubbing may develop regardless of optimum procedures and thermal conditions. This is more likely to occur when operating near critical speed when the midspan rotor deflections are at maximum. If the rubbing exists because of increased vibration while operating below or near a critical speed, the turbine should be shut down immediately and put on turning gear for one or two hours. This procedure will straighten the shaft, and a restart usually can be accomplished without further rubbing.

Continued operation at or near the critical speed will usually increase the bowing at an accelerating rate, damaging the turbine packings and reducing turbine efficiency. In extreme cases, permanent rotor bowing can result.

Rubbing during rolling is minimized by steady, smooth acceleration, particularly through the critical speeds. Below critical speeds, unbalance caused by rotor bow increases the bow, leading to harder rubbing and, consequently, more bowing. At speeds above critical, unbalance caused by bowing tends to decrease the bow and relieve rubbing.

Rubbing at speeds above critical is not as troublesome as at lower speeds. Through the critical speed range, deflections of the rotor may be greatly amplified; therefore, operators should accelerate through the critical speeds quickly.

Operators of a particular unit will quickly learn its starting characteristics, and will be able to differentiate normal and abnormal vibration levels at any given speed. As the unit is accelerated, for example, it is perfectly normal for the vibration at the generator journal bearings to increase in amplitude at the generator's first critical speed. Amplitudes less than 150 $\mu$ m might be considered normal and 200 $\mu$ m acceptable. This value is usually constant for a particular unit and will not vary much with operating circumstances. In some cases, the last turbine bearing will respond in part with the generator, and this may also be normal.

The 3000 rpm turbine shaft vibration amplitudes, especially HP shafts, will rarely be higher than 75 $\mu$ m at low speeds under 900 rpm. If they should reach 125 $\mu$ m it indicates severe rubbing. Modern large steam turbines for 3000 rpm operation have first rotor critical speeds in the range between 900 and 2700 rpm. At these speeds some increase in shaft vibration amplitude is normal.

In deciding whether normal vibration exists, operators should consider whether the peak vibration speed has been reached or approached, and how fast the vibration is changing. In general, at or near the turbine's first critical speed, shaft vibration amplitudes should not exceed twice the normal amplitudes.

In a few cases, vibration amplitudes near 150 $\mu$ m are normal for a particular unit, and slightly higher than this is tolerable for a few moments while the turbine is accelerating through the critical speed range.

At the first indication of abnormal vibration levels while below the critical speed range, or while passing through it, the unit should be instantly tripped and placed on turning gear. After a well balanced unit has passed through the critical speed range, the vibration amplitudes will diminish.

The vibration energy is an exponential function of speed, and at higher speeds less displacement is tolerable. Over 2700 rpm, the vibration amplitudes in general should be less than 125 $\mu$ m.

At 3000 rpm, 175 $\mu$ m vibration amplitude is tolerable for brief operation; 100 to 125 $\mu$ m is acceptable until corrective action can be taken, and levels under 75 $\mu$ m are satisfactory.

## 4.3. Shell and Rotor Differential Expansion

High temperature rotors usually change temperature faster than the shells. Excessive rotor-to-shell temperature differentials can lead to differential expansions large enough to cause rubbing. Differential expansion should be monitored and controlled within the range indicated on Figure 5.2 of “Turbine Operating Limits”. It should not cause difficulty when thermal stress is controlled.

## 4.4. Supervisory Instrumentation

The turbine is provided with supervisory instrumentation which records speed, valve position, eccentricity, shaft vibration, shell and rotor differential expansion, metal temperatures, and turning gear engagement.

Supervisory instruments should be continually observed for any unusual conditions. When a turbine is first installed or overhauled, the packing clearances are purposely set somewhat less than experience indicates can be maintained in operation. Some rubbing may be expected during initial operation when the unit may be operated under a variety of conditions.

During this period, load should be changed more slowly than described in these instructions. Unusual characteristics of the boiler and auxiliaries or other station conditions may require modification of these instructions.

# 5. Recommended Procedures

## 5.1. Prestart Precautions and Considerations

- Listen for rubs at low speed.
- Check vibrations, oil pressures and temperatures, steam seal pressure, and differential expansion.
- Observe main steam and reheat steam pressures and temperatures, exhaust pressure and temperature, etc., as described in these instructions.
- Prior to rolling, verify that the rotor shaft is straight.

  Determine this by operating the unit on turning gear for a specified period, as described in EKS101338 "General Description for Special Condition Turbine Operation" of these instructions, and by checking the shaft eccentricity, as described in EKS101341 "Turbine Operating Limits".

Improved methods for matching steam temperature to metal temperature will allow starting the turbine-generator units with greater ease in minimum time. These methods include the following:

- Use of full arc admission during the rolling, synchronizing, and initial loading period. Since all of the control valves are open, the parts downstream of the valves are exposed to the same steam temperature. Full arc admission should be used for all starts in accelerating, synchronizing, and initial loading.
- Use of a steam supply having a controllable steam temperature over a wide range of flow.

## 5.2. Startup Procedure

All thermal operations should be undertaken in accordance with the temperature change rates prescribed in the Cyclic Damage Curve of Rotor. The startup parameters shown on the curve, Recommended Starting Times (Figure 4.6), are determined based on the Cyclic Damage Curve of Rotor, and are provided as operator guidelines.

On normal starting and loading, the following procedures are recommended.

### 5.2.1. Turning Operation before Rolling

Turning operation before rolling prevents temporary rotor bows due to thermal distortion. It is desirable to have continuous operation maintained since the previous shutdown.

Following long periods off turning, a 4-hour minimum operation period is essential to get smooth trouble-free starting. Generally, an eight-hour period is preferable. However, the unit on which rotor eccentricity detectors are installed can be started following a one-hour minimum operation period after the eccentricity has reached 10 percent of the normal value specified.

In any event, following a shutdown period, the rotor should be turned on gear 10 minutes for each minute it was shut down, until it has turned for 8 hours.

### 5.2.2. HP Turbine Casing Prewarming Before Cold Start-up

Before Cold Start-up HP turbine casing prewarming is required before rolling for the cold start-up, such as the start-up after long-term turbine shut down and after turbine overhaul. The means of accomplishing this prewarming is HP casing pressurization by admitting steam from the cold reheat pipe through the prewarming valve, and the target temperature is higher than 150 °C (minimum required 130 °C) of the first stage shell metal temperature. During prewarming operation, HP casing shell pressure (1st stage shell pressure) must not exceed 0.588 MPa(g). During this prewarming operation, the phenomenon of turning disengagement and rotating speed increase in excess of turning speed may be caused by excessive warming steam. This phenomenon is not an exceptional matter at all in view point of the protection for turbine rotating and stationary parts. When the rotating speed decreases and the rotor stops rolling, the turning gear is automatically re-engaged.

### 5.2.3. Preparation for Starting

The following turbine metal temperatures and steam conditions should be recorded:

- Main steam temperature.
- Main steam pressure.
- First-stage shell inner surface metal temperature.
- IP turbine exhaust chamber upper inner surface metal temperature.

### 5.2.4. Allowable Temperature Change Rate

Allowable rate of change of the first-stage shell metal temperatures should be determined before rolling in accordance with cyclic damage curve of rotor, Figures 4.3 and 4.4.

To use these curves, it is necessary to know the first-stage shell steam temperature which will exist at the completion of the startup. First Stage Shell Temperature vs. Percent Load, can be used to determine the first-stage temperature at the startup termination, assuming rated steam conditions exist at this point.

The owner should plot this curve after the characteristics of the boiler have been established.

### 5.2.5. Startup Parameters

On the Recommended Starting Times chart (Figure 5.1), each startup parameter can be ascertained by using main steam pressure, temperature, and first-stage shell inner surface metal temperature recorded under Step 2.

Applying Area ② of Recommended Starting Times, Figure 5.1, the first-stage shell discharge steam temperature is determined by using the main steam temperature ⑴a and the main steam pressure ⑴b. Draw a straight line downward from steam temperature ② to Area ④. Read the crossing point between the straight line and the oblique line of first-stage shell inner surface metal temperature ⑴c. The vertical axis is the mismatch temperature ③.

The preferable range of mismatch temperatures that do not adversely affect the turbine components is from –111 °C to +167 °C. The boiler should be controlled to get dry steam, with an enthalpy above 2810 kJ/kg and a temperature within the previous range. For a smooth warm-up of the turbine, the mismatch temperature should be set between +28 °C and +56 °C .

The accelerating rate is determined by using Area ④. The accelerating rate will be either Slow, Medium, Fast, or Do Not Start.

If the crossing point is in the Do Not Start region, turbine starting should be postponed unless there is a special demand. Considering the steam generator characteristics, Slow rate is used to prevent an undesirable drop of the main steam temperature. It is preferable to hold the turbine startup in this region. The main steam temperature will be expected to rise in this area.

On the recommended starting times chart, the suggested duration of hold at 800 RPM ⑤, length of hold at rated speed ⑥ and the suggested amount and duration of initial load ⑦, ⑧, ⑨ can be ascertained by drawing a straight line directly to the right from the mismatch point found previously. Where this straight line intersects with the dark, bold line is the point from which information can be found. The four charts are prepared with the first-stage shell inner surface metal temperature TFS; that is, TFS =< 296 °C; 296°C < TFS =< 320 °C; 320 °C < TFS =< 445 °C; and 445 °C < TFS.

The exact speed chosen for the 800 RPM hold is defined as the low-speed heat soak and is specified in Table 4.1 of “Turbine Operating Limits”.

At cold start, when TFS =< 296°C, low-speed heat soak is the longer time between ⑤a and ⑤b. After the hold, confirm that the IP turbine exhaust chamber upper inner surface metal temperatures have reached above 85 °C or one hour has passed with temperatures being above 80 °C.

As noted earlier, the holds should be lengthened if metal temperature go up too quickly and should be shortened if they go up too slowly compared with the temperature change times allowed by cyclic damage curve of rotor.

All low-speed holds increase the possibility of higher vibration due to rotor bowing by rubbing. Temperatures should be matched as closely as possible to eliminate the need for this hold. During low speed heat soak, shaft vibration amplitudes should be continuously observed for sharply higher trends.

Acceleration of the unit to rated speed at the end of the low-speed heat soak can be accomplished with the desired rate. Usually, the rate determined as described above is satisfactory unless for some special purpose.

Speed hold at the rated speed is referred to as high-speed heat soak.

This hold should be extended or shortened as necessary to maintain the allowable rate of temperature change limit determined from cyclic damage curve of rotor.

The initial load should be applied and held for the time indicated on the chart ⑨. This load hold should be extended or shortened as necessary to maintain the allowable rate of change of first-stage shell inner surface temperature within the limits prescribed on the cyclic damage curve of rotor curve.

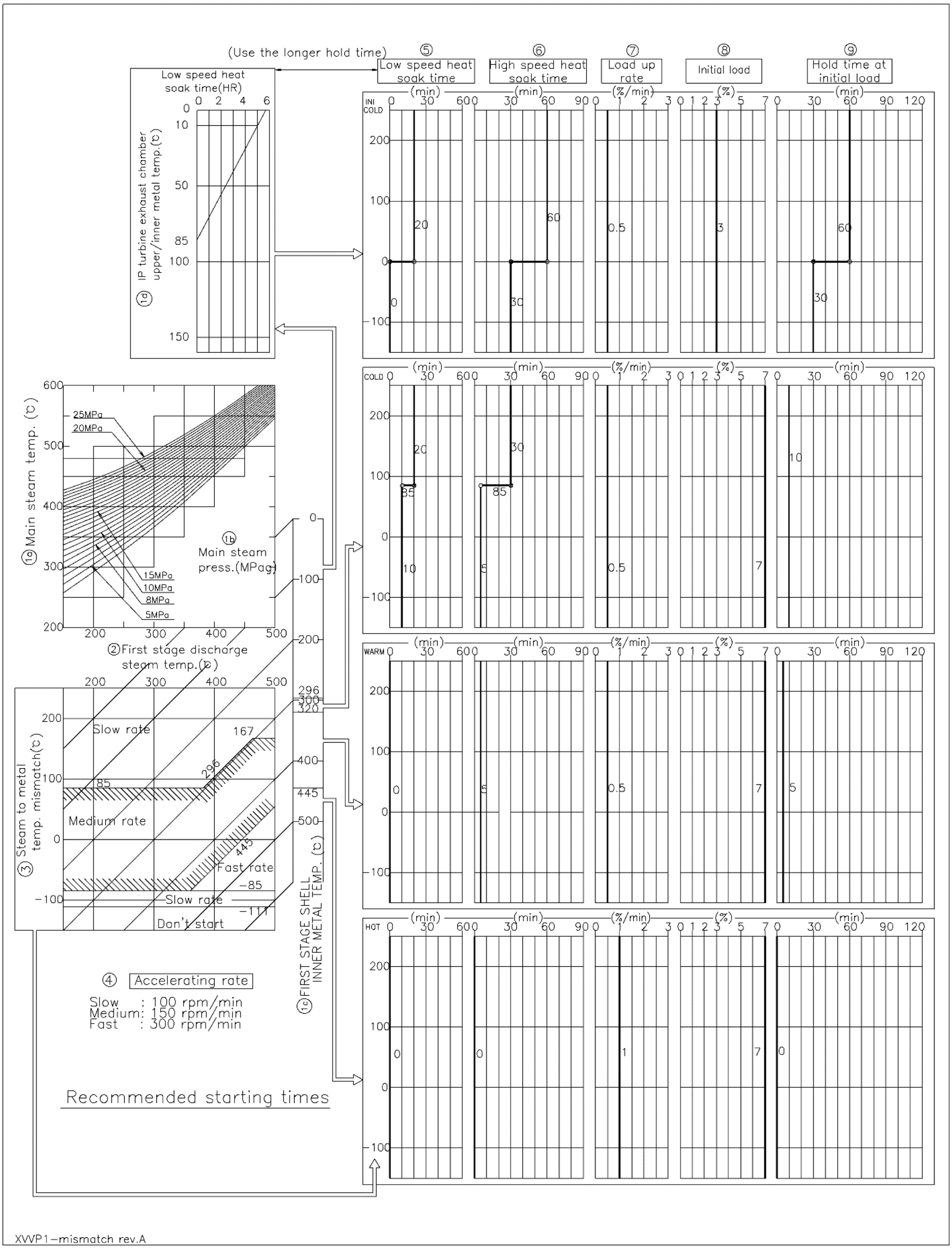



Figure 5.1 Recommended Starting Times

## 5.3. Loading Up

Loading rate after the initial load hold may be determined from the curves on Figures 5.2 through 5.5 or from the summary recommendations on Table 5.1. This rate should be modified, if necessary, according to the limitations selected on cyclic damage curve of rotor.

The unit should be loaded to the transfer point observing the rate of metal temperature change with the loading rate specified.

The operator should go to increase the load by raising the main steam pressure and/or by opening control valves while still observing the rate of metal temperature change limits.

Throughout the starting and loading of the unit, differential expansion should be monitored and kept within the recommended limits described in "Turbine Operating Limits". The loading rate selected should be determined by experience to keep expansion within these limits.

**CAUTION**

- **During cold start, do not over speed the turbine until it has carried 25 percent or greater load for at least 3 hours.**

  The temperature of the metal at the turbine rotor core will be below transition temperature when first coming to speed. The emergency governor should be oil-tripped when coming to speed to make sure it works satisfactorily.

- **Do not remain at or near rated speed or without load longer than necessary on hot starts.**

  Operating a hot turbine at full speed, no load, or at reduced speed, particularly with decreased steam supply temperature, may cause drastic cooling or quenching of the turbine inlet metal.

## 5.4. Steady State Load Changes

Steady state load changes are defined as changes from one steady state load to another. In making changes of this type, observe the maximum allowable rates of temperature change of temperature difference across walls in accordance with section 5.2.5 "Allowable Temperature Change rate". Curves of first-stage shell steam temperature versus percent load assuming constant initial conditions are an aid to predicting temperature changes in the first-stage shell region.

## 5.5. Startup Procedure Examples

Examples of parameters for the four types of startup - hot, warm, cold, and initial cold - are shown on Table 5.1. Using the known first-stage shell inner surface metal temperature, the main steam temperature and pressure, and Figure 5.1, the remaining values can be found.

## 5.6. Emergency Operation

Any unit may be tripped in an emergency. If less drastic action is indicated, load may be reduced, provided the recommended emergency rate of temperature decrease is followed. Load increases, on the other hand, should not exceed the normal increase rate, even in emergencies.

Do not run the turbine at high main steam pressure with auxiliary load or no load at any speed, especially at reduced temperature, after the unit has been operating at or near rated steam temperature. This kind of operation occurs after an emergency electrical tripout. Avoid this operation whenever possible because it may result in a sudden, severe cooling of the internal surfaces of the hottest portion of the high-pressure section.

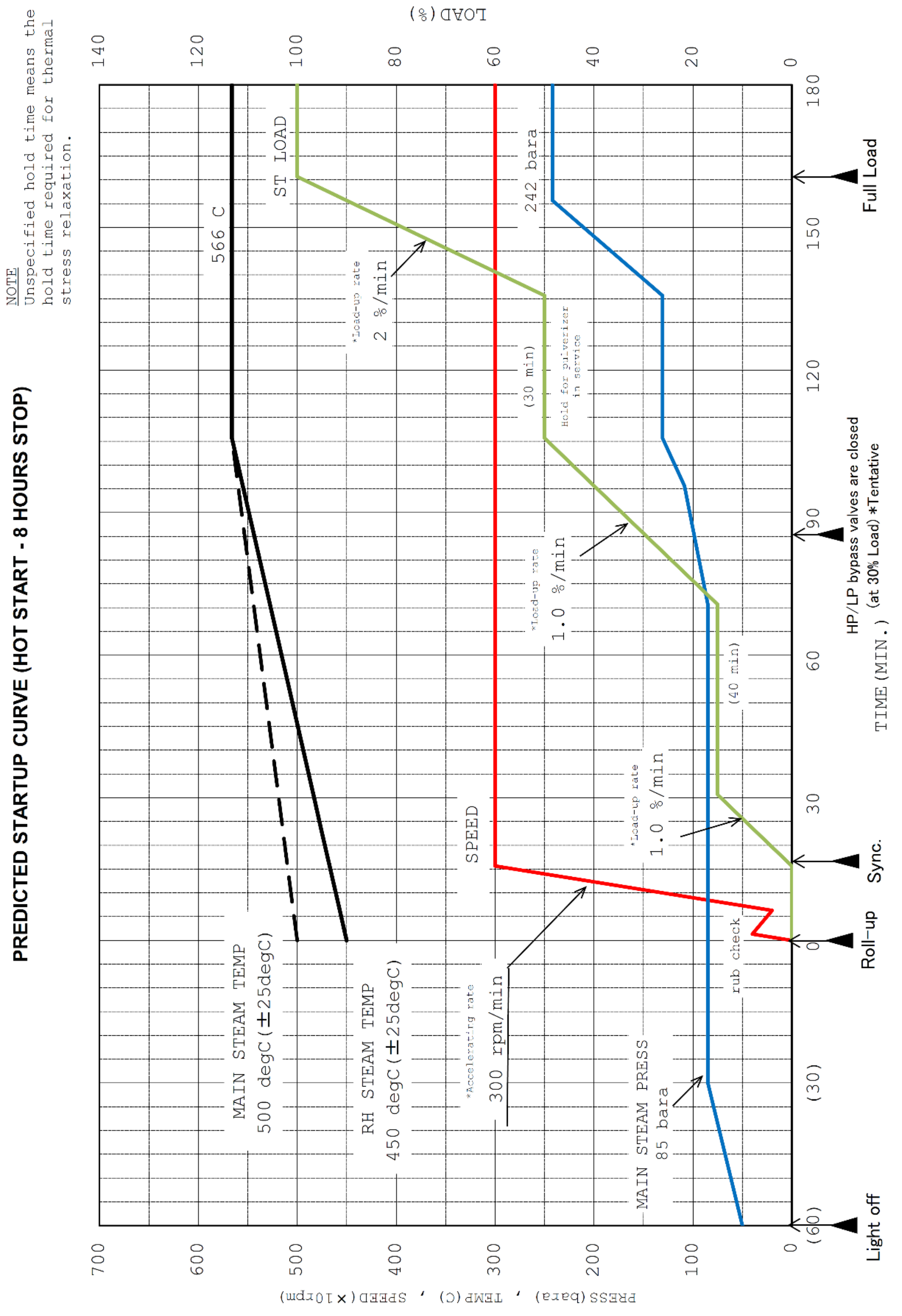
Cracking may ensue. After a tripout, if load can again be established quickly, trip and place the unit on turning gear in preparation for making a controlled hot restart.

**Table 5.1 Summary of Turbine Startup Recommendations**

| Item | | Unit | Hot | Warm | Cold | Initial Cold |
|---|---|---|---|---|---|---|
| | | **Starting mode** | | | | |
| Turbine start conditions | Main steam press. | MPa(a) | 8.5 | 8.5 | 8.5 | 8.5 |
| | Main steam temp. | °C | 500 | 440 | 400 | 350 |
| | 1st stage discharge steam temp | °C | 426 | 353 | 300 | 223 |
| | 1st stage shell inner metal temp | °C | 445 | 320 | 296 | 150 |
| | Mismatch temp | °C | -19 | 33 | 4 | 73 |
| Accelerating Rate | | rpm/min | 300 | 150 | 150 | 100 |
| Low speed heat soak | | min | 0 | 0 | 10 | 20 |
| High speed heat soak | | min | 0 | 5 | 5 | 60 |
| Load up rate 0% to initial load | | %/min | — | 0.5 | 0.5 | 0.5 |
| Initial load | | % | 7 | 7 | 7 | 3 |
| Hold time at initial load | | min | 0 | 5 | 10 | 60 |
| Load up rate initial load to full load | | %/min | 0 to 15% 1.0<br>15 to 50% 1.0<br>50 to 100% 2.0 | 0 to 15% 0.5<br>15 to 50% 0.5<br>50 to 100% 1.0 | 0 to 15% 0.5<br>15 to 50% 0.5<br>50 to 100% 1.0 | 0 to 3% 0.5<br>3 to 15% 0.5<br>15 to 50% 0.5<br>50 to 100% 1.0 |

**TOSHIBA**

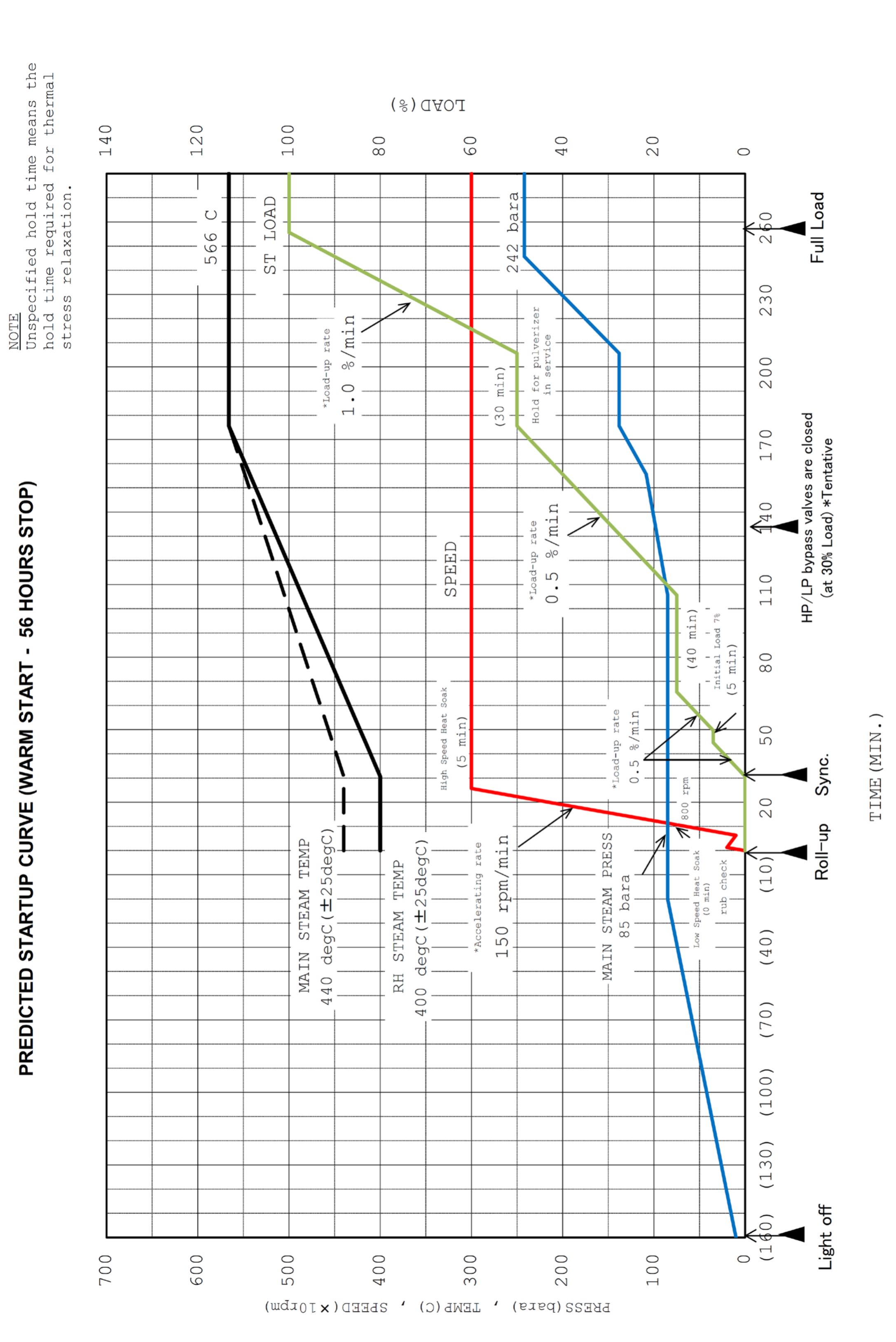





Note : The time to establish the water quality is not included in the curve.



Figure 5.2




Note : The time to establish the water quality is not included in the curve.



Figure 5.3

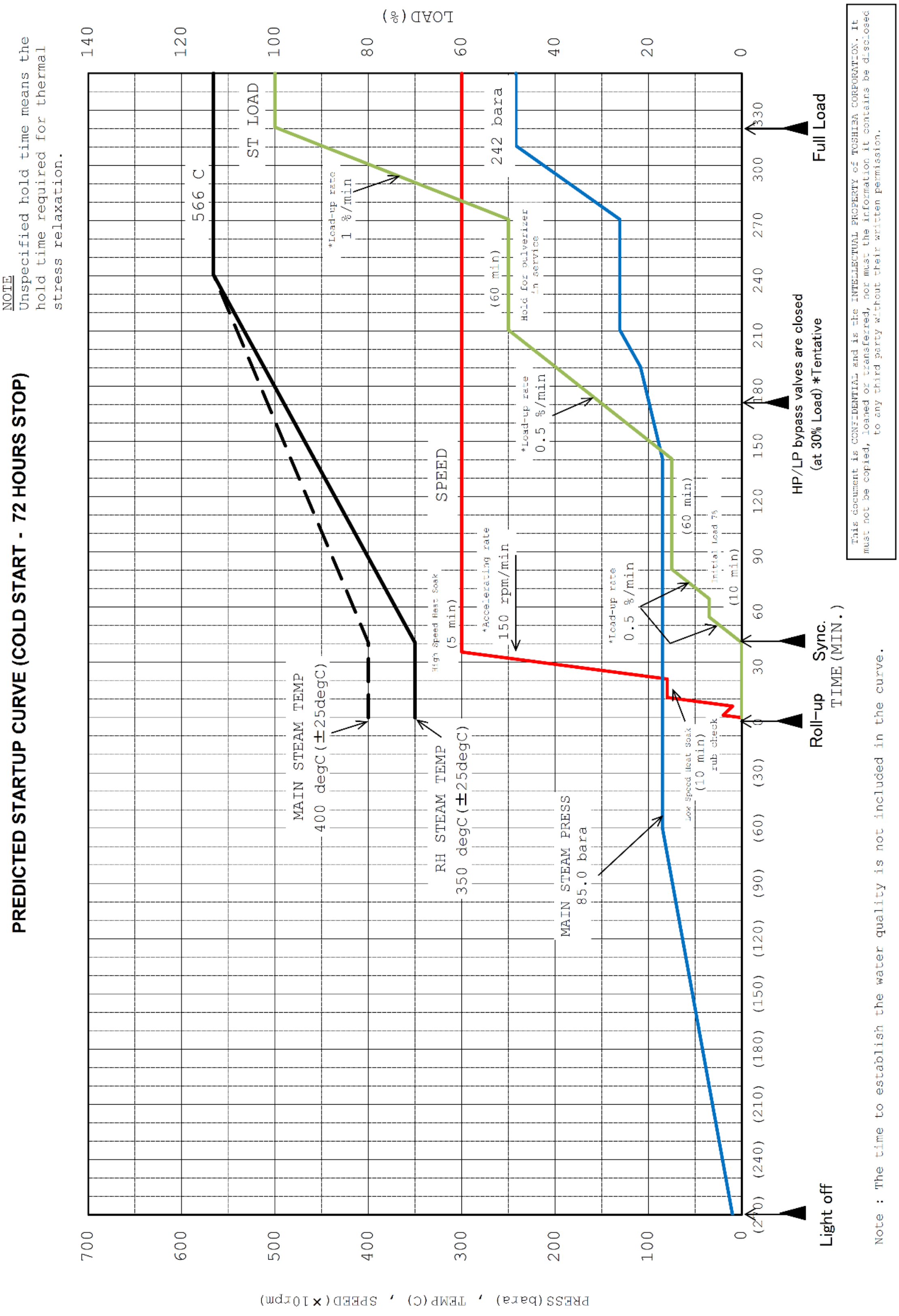

PREDICTED STARTUP CURVE (COLD START - 72 HOURS STOP)
NOTE
Unspecified hold time means the hold time required for thermal stress relaxation.
LOAD (%)
PRESS (bara) , TEMP (C) , SPEED (×10rpm)
566 C
ST LOAD
242 bara
*Load-up rate 1 %/min
(60 min) Hold for pulverizer in service
*Load-up rate 0.5 %/min
SPEED
(60 min)
*Accelerating rate 150 rpm/min
High Speed Heat Soak (5 min)
*Load-up rate 0.5 %/min
Initial Load 7% (10 min)
MAIN STEAM TEMP 400 degC(±25degC)
RH STEAM TEMP 350 degC(±25degC)
MAIN STEAM PRESS 85.0 bara
Low Speed Heat Soak (10 min) rub check
TIME (MIN.)
Light off
Roll-up
Sync.
HP/LP bypass valves are closed (at 30% Load) *Tentative
Full Load
Note : The time to establish the water quality is not included in the curve.
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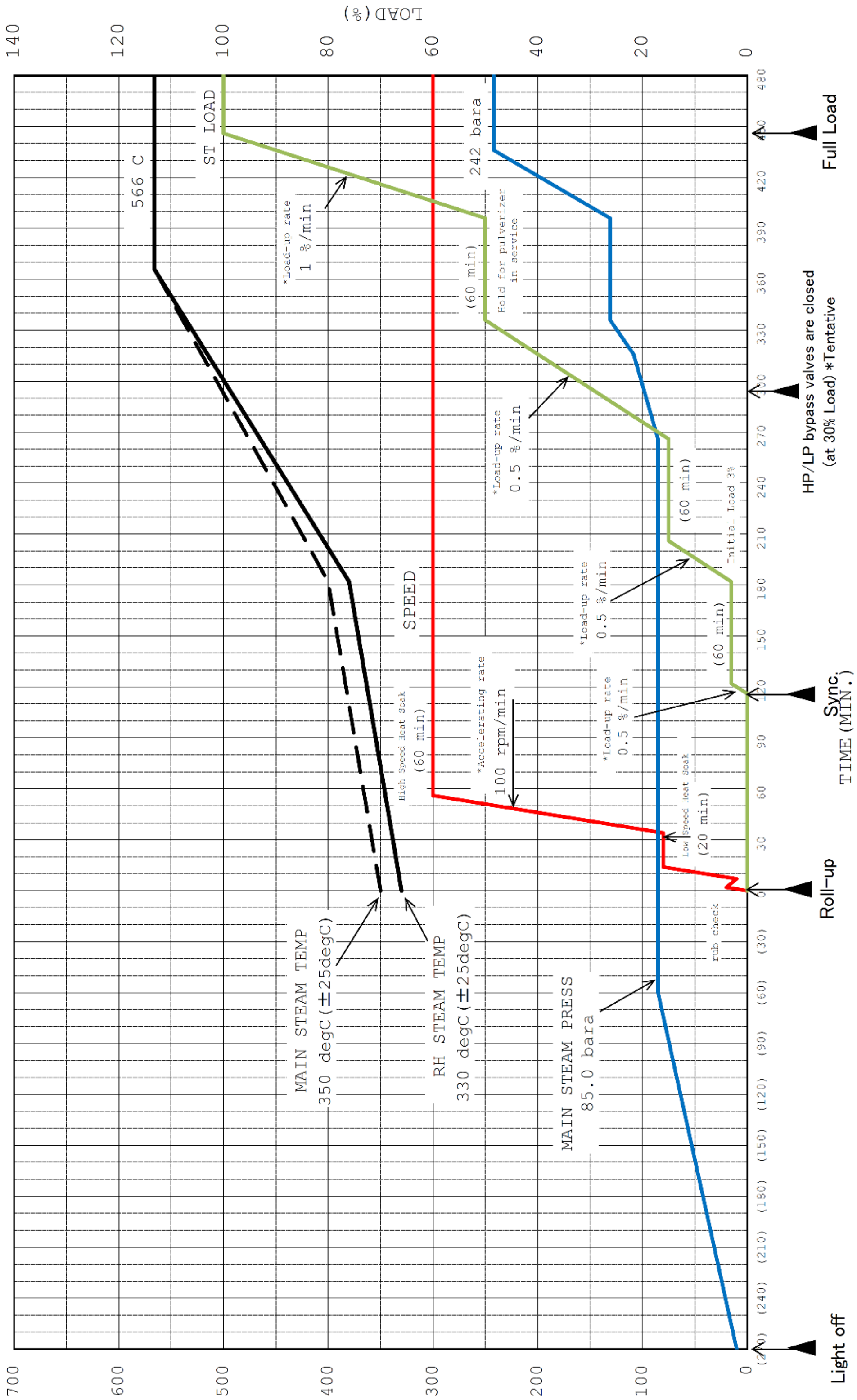
Figure 5.4

## PREDICTED STARTUP CURVE (INITIAL COLD START )

NOTE
Unspecified hold time means the hold time required for thermal stress relaxation.




Note : The time to establish the water quality is not included in the curve.



**Figure 5.5**

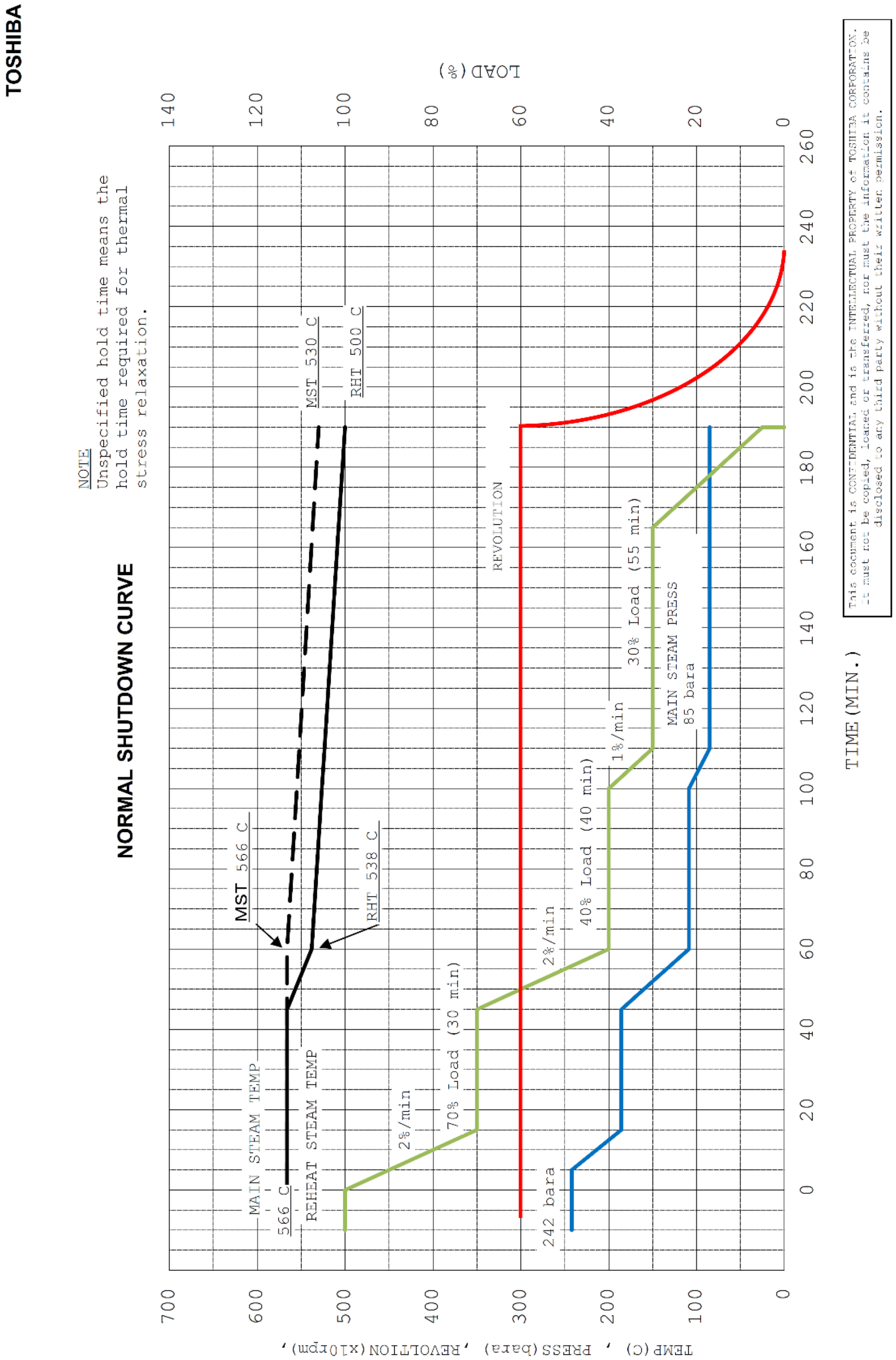

TOSHIBA
NORMAL SHUTDOWN CURVE
NOTE
Unspecified hold time means the hold time required for thermal stress relaxation.
MAIN STEAM TEMP
566 C
REHEAT STEAM TEMP
MST 566 C
RHT 538 C
MST 530 C
RHT 500 C
REVOLUTION
2%/min
70% Load (30 min)
2%/min
40% Load (40 min)
1%/min
30% Load (55 min)
MAIN STEAM PRESS
85 bara
242 bara
TIME (MIN.)
LOAD (%)
TEMP (C) , PRESS(bara) ,REVOLTION(x10rpm),
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**Figure 5.6**

## 5.7. Turbine Shutdown Procedure

A controlled shutdown procedure is desirable for the proper operation of the turbine during load reduction and subsequent shutdown of the unit.

As in turbine startup, the control of turbine metal temperature is extremely important since this will affect thermal stress, differential expansions, distortion or alignment of parts, and the flow of heat from one portion of the turbine to another.

Various procedures should be developed for each system. These procedures should be governed by the conditions desired at shutdown, or which are later desired at restarting.

Identical turbines may require different procedures adapted to the related equipment and controls. The emergency or trip functions of the control equipment, and the normal turbine control operation are described in the description instructions. In addition, the tests to be performed periodically during shutdown are described in “Surveillance Test”.

Load should be reduced at a uniform rate of decrease of inner surface metal temperature, as given on the cyclic damage curve of the rotor chart.

When the desired minimum load has been reached, trip the machine off line to stop the steam supply to the turbine. If it is necessary to open the vacuum breaking valve, open it below the recommended speed. If emergency conditions dictate that the shaft be stopped as quickly as possible, break the vacuum immediately. When the unit is tripped while operating under any appreciable load, do not open the circuit breakers until the main stop valves are closed. This should provide the best protection against overspeed within the turbine if the main stop valves fail to close properly.

| NOTE |
| --- |
| ■ The shorter the period of the shutdown cycles, the greater must be the coordination and precision of the operation. To ensure the best conditions when the turbine is restarted, the shutdown procedure should remove the load in orderly fashion; perform any safely tests required; avoid undesirable stresses in the turbine metal; prevent distortions of the hot parts, including valves, shells, and rotors; and operate the unit and all auxiliary equipment during load reduction and shutdown. |

### 5.7.1. General Shutdown

For many units, the characteristics of the main steam supply enable relatively small changes in main steam temperatures to take place during a large portion of the load reduction period. This is frequently advantageous because if the steam temperature is to remain about constant during the unloading, the temperature changes within the turbine will be held to a minimum. The temperature of the parts in the region of the first stage will change the greatest amount.

As load is reduced at constant throttle conditions, the first-stage temperature will decrease by the amount given by the curve of first-stage temperature versus load. Below the control point of the boiler, the unloading rate should be reduced to compensate for the decrease in main steam temperature to remain within the metal temperature rate of change limit.

### 5.7.2. Shutdown Producing Cooling of Turbine Metal

It is sometimes useful to produce as much cooling of the turbine metal as possible prior to a shutdown. This is desirable when only a short time is available for an outage and work is to be performed on the turbine. This will permit the shortest time between shutdown and disassembly, lessen the possibility of thermal distortion of the parts, and reduce the discomfort of operating personnel.

Cooling may be accomplished during the load reduction by decreasing the main steam temperature. This decrease should be gradual and uniform, not exceeding the allowable rate of metal temperature decrease nor the allowable metal wall differentials. To accomplish the greatest decrease in temperature, it may be necessary to reduce steam pressure as well.

This method of cooling will produce the greatest temperature decrease in the high-pressure section of the turbine, and the effect on the portion of the turbine from the crossover point to the exhaust will be progressively less.

### 5.7.3. Shutdown in the Shortest Period

When a shutdown is required in the shortest period of time, the emergency rate of temperature change decrease limit may be used. The time required to shut down can further be reduced by tripping the unit as soon as load has been reduced to 1/3 rated.

### 5.7.4. Load Removal and Shutdown

Load should be reduced in such a way as to limit the rate of change of first-stage shell inner surface metal temperature to the values given on the cyclic damage curve of rotor chart.

Although other methods are used, some of the most desirable are described below in the order of general preference:

1. Reduce the load to minimum, approximately 5 percent of rating.
   Trip the unit with the master trip valve. Open the circuit breaker.
2. Reduce load to minimum, approximately 5 percent of rating. Hand operate the trip lever. Open the circuit breaker.
3. Reduce load to near zero, approximately 1/2 percent of rating.
   Open the circuit breaker. Trip all valves with master trip.

### 5.7.5. Turing Operation

Engage the turning gear as soon as the turbine stops rolling. It should remain in operation until the turbine is restarted. However, if the shutdown is for an indefinite period, or if the unit is to be disassembled, operate the turning gear until the turbine is thoroughly cooled.

If the turbine is to be disassembled, the turning gear should remain in operation until the upper shell is to be lifted. Whenever a turbine is to be opened soon after a shutdown, or the unit must be removed prematurely from turning gear, it is beneficial to cool the turbine during the shutdown. This may be accomplished primarily by reducing the main steam temperature as much as possible during the period of the load reduction.

If the unit is too hot when the turning gear is stopped, the turbine rotor and shell will become distorted, which may cause high thermal stresses or subsequent interference of the moving parts. Details of the turning operation are described in "General Description for Special Condition Turbine Operation".

### 5.7.6. Removal of Lagging

Do not remove turbine lagging and heat retention material from the high and intermediate-pressure sections of the unit until these portions have cooled for 24 hours or longer. This will prevent overstress or deformation of the shells, including flanges. However, if time is at a premium, a minimum of eight hours should elapse between the removal of the unit from service and the uncovering of the main flange bolting.

# 6. Restart Conditions

The controlled starting and loading of any unit requires a desirable correlation between the steam and turbine metal temperatures. At the time of restarting, this correlation may be significantly influenced by the control of the shutdown procedure. For example:

1. The steam temperature prevailing at the time the machine was operating under minimum load, immediately before tripping of the unit, directly affects the rate of turbine cooling, as well as the final temperatures during a shutdown of a weekend or less.

2. The bottled-up pressure maintained in the steam generator during shutdown affects the temperature to which the main steam leads and valving are subjected. The final temperature of the turbine shell is affected by the transmission of heat through these parts if the shutdown is of about 8 hours or longer. The steam temperature upon restarting may also be dependent upon the heat stored in the boiler and the main piping.

3. The blowdown quantity, drain locations, and main piping configuration also affect the temperature of the main piping and the turbine shell. The amount of steam bled to the turbine exhaust or condenser during shutdown or immediately before restart affects both the main steam temperature and the exhaust hood temperature. The ambient temperature surrounding the boiler, main piping, and turbine--particularly for outdoor stations--may affect the cooling of the machine during shutdown.

The need for these procedures is primarily determined by the frequency of the shutdown cycles. Precise procedures are especially desirable for repeated operations, such as overnight or weekend shutdowns.

# Revision History (for internal use)

| REV. | REV. ISSUED | PAGE | CHANGED PLACE AND CONTENT | APPROVED BY | REVIEWED BY | PREPARED BY |
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| a | 24.Aug.'22 | — | 1st edition for XVVP1 | K.Asai 24.Aug.'22 | K.Asai 24.Aug.'22 | M.Yamada 23.Aug.'22 |
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