TOSHIBA

EKS101341-c

Turbine Operating Limits

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.

⚠ WARNING
■ **If the vibration amplitude remains in the alarm range for two minutes, the turbine should be tripped.**
■ **After reaching rated speed, if the vibration amplitude remains in the alarm range for five minutes, the turbine should be tripped.**
■ **If the vibration amplitude is in the alarm range for more than 30 minutes in any one hour, trip the turbine immediately.**
■ **If the vibration amplitude persists in the alarm range, it is preferable to trip the turbine.**
■ **The turbine should be tripped immediately when the low oil pressure alarm signals any abnormal condition. Oil pressure loss may be caused by leakage from piping and by trouble with the pumps.**
■ **When deviations, especially sudden changes, in metal temperatures are observed during steady-state operating condition with constant bearing feed oil temperature, then damage in bearing metal is suspected. The temperature gauge must be inspected, and the state of the local instruments should be determined. If the cause cannot be identified, the turbine must be tripped when the temperature gets to the upper limit.**
■ **When increasing the speed to more than 50 percent of the rating, it is better to trip the turbine, provided the vacuum does not become higher than the limit.**
■ **If the gland condenser exhaust fan is stopped, the turbine must be tripped immediately to prevent the following.**

CAUTION
■ Generally, the oil cooler water side pressure is higher than that on the oil side, and can contaminate the oil when there is cooling tube trouble. If the high oil level alarm indicates the possibility of this condition, the standby oil cooler should be put in service and the oil purifier should be checked.
■ The low oil level alarm is generally caused by leakage from the main oil pump feed line and/or oil drain system. Therefore, if low oil levels are observed, leakage from the drain line, and tank surroundings should be investigated and repaired.

NOTE
■ When turning operation is required, the feed oil temperature should be kept as low as possible, unless the power required by the oil pump is causing it to overload. c ■ Before starting up the turbine, the feed oil temperature should be 27 °C – 35 °C (Recommended oil temperature range), if impossible, 27 °C – 39 °C (Allowable oil temperature range).
■ When turning operation is required, the feed oil temperature should be kept as low as possible, unless the power required by the oil pump is causing it to overload.
■ Curves show the relation between reheat steam conditions and turbine exhaust pressure to get the 12 percent wetness of saturated steam at the last-stage buckets. ■ Any of two factors among reheat steam pressure, reheat steam temperature, and exhaust pressure should be controlled so that the 12 percent wetness line is not exceeded. ■ Dotted line shows the allowable lowest exhaust pressure owing to the exhaust hood deformation, and this limitation is to be followed in preference to the above.

3. Shaft Eccentricity

Shaft eccentricity is the amount of deviation from the normal condition of the rotor. The eccentricity detector shows the tendency of the rotor bows and indicates whether or not the turning operation should be continued. Under turning gear operation, shaft eccentricity should not exceed 10 percent of normal value, or an absolute value of 110 percent.

To ensure the smooth acceleration of the unit, the turning gear should remain in service continuously for more than one hour after the absolute value of 110 percent is reached. If this is not possible, turbine speed can be increased when the readings of shaft eccentricity become stable, providing that shaft vibration is carefully monitored by the operator during acceleration. Although it may be possible to increase turbine speed beyond this limitation, it is not recommended because of the possibility of severe vibration due to rotor rubbing.

The normal eccentricity value should be determined during the initial turning operation after 5 hours or more of continuous operation on turning gear. Before rolling the turbine off turning gear, check the eccentricity reading on the eccentricity detector and compare it with this predetermined value.

After rolling off, the eccentricity shown on the eccentricity detector is the degree of the shaft vibration amplitude rather than the measurement of the eccentricity itself. Therefore, the indication on the eccentricity detector depends on the turbine speed range.

Specifications for rotating speed are shown in Table 4.1.

4. Shaft Vibration

4.1 General

Vibration of the turbine generator rotor is the result of several phenomena. These phenomena include inherent imbalance of the rotor, oil whipping, and bearing rubbing. When vibration is determined to be abnormal, it is important to determine the cause of this vibration.

Table 4.1 Rotating Speed Specifications

Rotor first critical speed (On multi-span flexible supported condition)	
Generator rotor	980 rpm
LP A rotor	1,720 rpm
LP B rotor	1,700 rpm
HIP rotor	1,680 rpm

Heat soak speed	
Low speed heat soak	800 rpm
High speed heat soak	3,000 rpm
The rotating speed must not be held between 900 rpm and 2,700 rpm.	

Speed zone for vibration monitoring	
Low speed zone	0 to 900 rpm
Critical speed zone	900 to 2,700 rpm
High speed zone	2,700 to 3,000 rpm and higher
Recommended vacuum breaking point	2,300 rpm

Permissible continuous operating speed	
Turbine speed	2,850 to 3,120 rpm
Line frequency	47.5 to 52.0 Hz
Turning speed	Approximately 6 rpm

4.2 Vibration Level

To determine the limit of acceptable vibration during normal operation, consideration should be given to mechanical imbalance of the rotor, change of bearing alignment, and the stability of turbine operating conditions. The alignment of bearing tends to change slightly under lower loads, higher vacuum, and other transient conditions, since the normal bearing alignment is established under steady-state conditions. The change of vibration amplitude in these levels should occur slowly, and the total amplitude achieved under these conditions should not exceed the permissible range. If for some reason the turbine is forced to operate under a severe transient condition, the operators should monitor the vibration level closely throughout the operation in that condition.

High vibration amplitudes can be reduced by rebalancing the rotor or remachining the rotor journal. However, it should be noted that a balanced rotor at one set of operating conditions does not ensure a balanced rotor at all conditions.

The following should be used as a guideline to determine if balancing the rotor is required.

Standard Criteria for Judging Rotor Balance Status

Speed range	**Vibration amplitude μm**	**Judgment**
Rated speed	38	Excellent
	75	Good
	125	Balancing is required as soon as possible if exceeded
Critical speed zone	175	

The vibration amplitudes used in the above criteria must be determined from steady-state conditions. Vibration amplitude must also be classified as normal or abnormal during acceleration or deceleration through the critical speed zone.

4.3 Abnormal Vibration

Abnormal vibration caused by bearing characteristics such as oil whipping can be reduced by avoiding operation conditions that cause the abnormal vibration. These operating conditions should be identified during the initial operating period of the turbine. It is also important to determine when bearing rubbing contributes to abnormal vibration levels. Shaft movement inside the bearing or casing distortion during construction can cause rubbing, but these causes are extremely unlikely since care is taken during construction to prevent both conditions. However, in rare cases, rubbing may be experienced during initial or transient operations because of tight clearances between the rotor and casing. The preferred way to determine if bearing rubbing is causing the abnormal vibration is to carefully observe the vibration amplitude and its rate of increase during startup and shutdown. The operator may want to consider monitoring this amplitude by computer. If turbine startups and shutdowns are infrequent, observation of the vibration amplitude is adequate; it is not necessary to observe the rate of increase.

4.4 Observation of Vibration Amplitude

Vibration is categorized by three speed zones: near critical speed, up to critical speed, and above critical speed, defined respectively as critical-, low-, and high-speed zones. These zones are specified for each unit in Table 4.1, Rotating Speed Specification. The high-speed zone includes no-load operation until rated speed, no-load operation at rated speed, and over-speed operation. The on-load operation after synchronizing is categorized with other limits. Limits of vibration amplitude for various operating zones are listed below in Table 4.2.

The following sections are based on the information in Table 4.2. Throughout the sections, the alarm range is defined by vibration amplitudes between the alarm value and the trip value, and the safety range is defined by vibration amplitudes less than the alarm value.

4.4.1 Low-Speed Zone

If the vibration amplitude enters the alarm range, hold the turbine speed constant.

⚠ WARNING

- **If the vibration amplitude remains in the alarm range for two minutes, the turbine should be tripped.**

If the vibration amplitude decreases to the safety range and remains there, it is possible to continue accelerating the turbine. If the vibration amplitude at constant speed fluctuates between the alarm range and the safety range, it is permissible to accelerate the turbine only if the operation time in the safety range is greater than the operation time in the alarm range.

Table 4.2 Limits of Vibration Amplitude for Various Operating Zones

Operating zone	Limit of vibration amplitude		Time limitation in alarm zone*
	Alarm value μm	Trip value μm	
Low-speed 0 to 900 rpm	100	175	2 minutes
Critical-speed 900 to 2,700 rpm	150	175	Reduce speed immediately
High-speed 2,700 to 3,000 rpm and higher	125	175	5 minutes
After synchronizing	125	175	30 minutes
Shutdown	Only alarm		

* If counting time exceeds these limitations, change to indication of trip.

4.4.2 Critical-Speed Zone

If the vibration amplitude enters the alarm range, decelerate immediately at the allowable speed reduction rate and apply the directions for the low-speed zone described in Subsection 4.4.1 after entering the low-speed zone.

4.4.3 High-Speed Zone

If the vibration amplitude enters the alarm range, continue to accelerate the turbine at the allowable speed increase rate to rated speed.

WARNING
■ **After reaching rated speed, if the vibration amplitude remains in the alarm range for five minutes, the turbine should be tripped.**

The five-minute period should start from the time the turbine reaches rated speed. If the vibration amplitude at rated speed fluctuates between the safety range and the alarm range, it is permissible to synchronize the generator if the operation time in the safety range exceeds operation time in the alarm range.

4.4.4 After Synchronizing

WARNING
■ **If the vibration amplitude is in the alarm range for more than 30 minutes in any one hour, trip the turbine immediately.**

4.5 Recommendations for Operation in Alarm Range

4.5.1 During Speed Increase

The holding time during speed increase is for checking to see if rubbing exists and to reduce the severity of this rubbing.

⚠ WARNING

- **If the vibration amplitude persists in the alarm range, it is preferable to trip the turbine.**

4.5.2 During Load Change

Monitor vibration levels and the trend. Check for rubbing sounds at the load where the abnormal vibration occurs. Be prepared to trip the turbine while making these checks.

4.5.3 During Speed Reduction

Generally, no action is required during speed reduction. The alarm limits are those given under Section 4.4 for the three speed zones. If it is necessary to suppress the vibration amplitude, vacuum control may be effective.

4.6 Monitoring with Supervisory Instruments

The vibration amplitude can be monitored with supervisory instruments with an alarm function. For this purpose, some of the appropriate amplitude limits described under Section 4.4 may be used to cover the whole speed range. In this case, it is important to recognize the above mentioned background of vibration limitations.

Generally, the following alarm and trip setting are recommended.

Alarm for abnormal vibration	125 μm
Trip recommendation	175 μm

5. Shell and Differential Expansion

5.1 Shell Expansion

Excessive rotor to shell temperature differentials can lead to differential expansions large enough to cause internal rubbing. This could cause high vibration, possibly damaging the turbine internals.

It is important to check turbine shell expansion to turbine conditions during transient operation of the unit. Shell expansion data taken at various steady-state operating conditions provides useful information regarding turbine operation. For example, when considerable turbine differential expansion occurs during turbine startup, it is possible to estimate the future tendency of this expansion by comparing the current expansion to the compiled expansion data at similar startup conditions. The operator can then determine if the startup procedure should be suspended by estimating the total expansion. It is not necessary to observe the shell expansion during turbine startup unless the differential expansion exceeds the limits. If the difference from the design value is too great, even at steady-state conditions, grease or lubricant should be supplied to sliding parts. The value of shell expansion at the turbine rated condition for this equipment is provided at the end of this section.

5.2 Differential Expansion

Differential expansion is a measure of the rotor expansion relative to the turbine shell expansion. Differential expansion is measured to check the axial clearance between rotating and stationary parts during operation.

The detectors are mounted as far as possible from the thrust bearing to assure the maximum differential is read. Detectors are essential for indicating all axial clearances in the casings. However, the degree of differential expansion is not always proportional to the distance of the detector from the thrust bearing, but it may be affected by the relative location of a fixed point on the casing to the detector, and also the method used to support the inner casing.

Therefore, the axial clearances at each turbine stage are determined by all of these variables. This is why the display board can monitor all clearances in the turbine by indicating the maximum differential expansion.

In some cases, additional detectors are mounted at intermediate locations for monitoring.

The indicator of differential expansion is as shown on Figure5.1.

Green mark ......The cold setting (turbine at room temperature throughout) of the turbine with zero clearance of the front or turbine side of the thrust bearing is the base point for measuring differential expansion. The differential expansion meter should be adjusted to indicate the green mark on its scale at the cold setting. Uniform temperature distribution and no temperature difference between the casing and the rotor are required to verify this point.

Red band..........The red bands indicate axial contact between rotating and stationary parts in the turbine. The limits of contact are the positions at maximum rotor short (1st alarm point) and maximum rotor long (2nd alarm point). Rotor long means the condition of the rotor when the rotor length is relatively long compared with the casing. Rotor short means that the rotor is relatively short when compared with the casing. Either condition indicates reduces turbine clearance.

Red mark ....The distance between the first alarm point and the red mark indicates the rotor length is reduced as a result of the centrifugal force.

Orange band.....The orange band indicates the degree of rotor expansion caused by release or decrease of the centrifugal force. The length is the same as the distance between the first alarm point and the red mark.

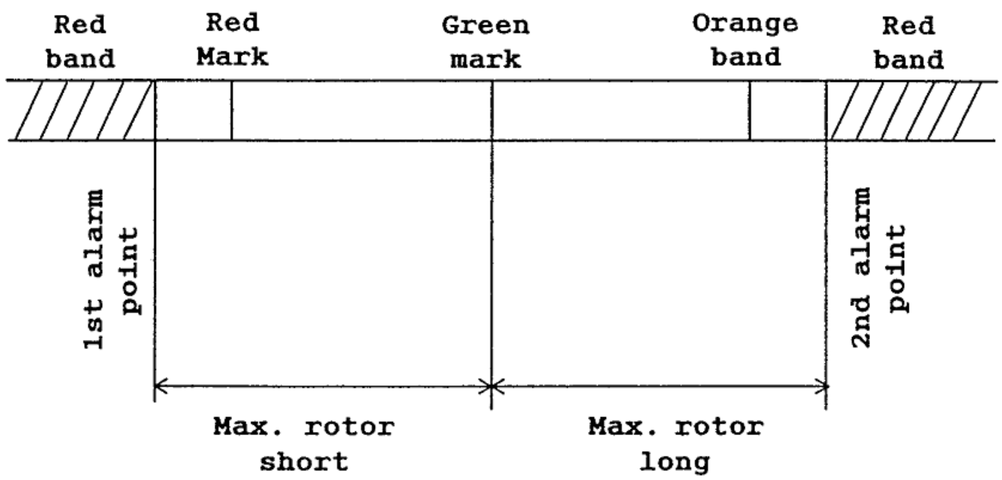
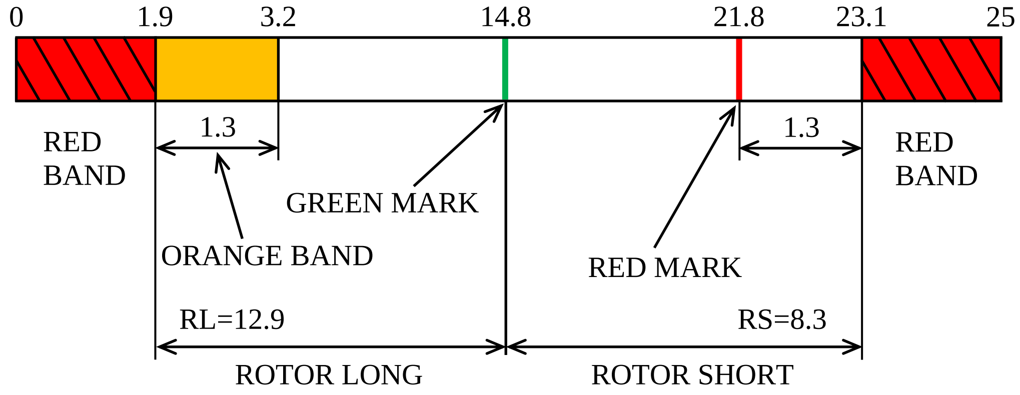


Figure 5.1 Indication of Differential Expansion

HIP ROTOR: DETECTOR AT FRONT STANDARD



LP ROTOR: DETECTOR AT No.6 BEARING

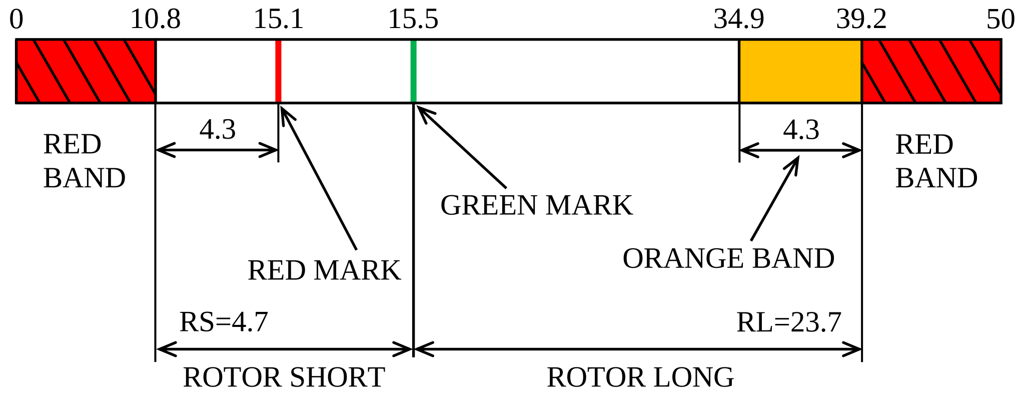


Figure 5.2 Shell and Differential Expansion

In the above indications, the locations of the red mark and the orange band are based on the size of the rotor and the turbine type. When the expansion resulting from the centrifugal force is very small, the red mark and the orange band can be considered as included in the red band.

The red mark is the limit for turbine startup condition. However, because thermal expansion and centrifugal contraction are both occurring during startup, the board will not indicate contraction if thermal expansion is greater. In such cases, the red mark may be disregarded, provided the operating condition remains within the maximum rotor short range.

These deviations should be referred to the Toshiba Turbine Design Division.

Display boards are plant specific. For some cases, the orange band and the red mark are revised. An indicator showing differential expansion is shown on Figure 5.2.

It is essential to operate the turbine so that the indicator never enters into the red band. To ensure this does not happen, the operator should observe the indicator for differential expansion tendencies, especially during transient operating condition. For satisfactory startup, the indicator must be positioned between the red mark and the outside of the orange band, or second alarm point, provided the red mark and orange band are indicated on the board. If there is still a possibility of turbine trip when operating at the rated speed, the indicator should be between the first alarm point and the inside of the orange band.

Appropriate actions should be considered for all operating conditions under which the indicator nears the red band. To determine the appropriate action, is should be remembered that the turbine rotor will change temperature faster, and expand faster, than the shell. Therefore, if the indicator is near the red band of the rotor long side, cooling is effective; if the indicator nears the rotor short side, heating is effective. A practical way to heat or cool the turbine rotor is to change the steam condition and turbine load. If the indicator nears either red band during load change, the load should be held to determine the tendency of the indicator and then the operation should be changed accordingly.

If the indicator enters the red band following every possible measure to correct the condition, the turbine shall be manually tripped. In this case, slight contact may be unavoidable during turbine speed coast down.

Shell and Differential Expansion are shown on Figure 5.2.

The full expanded shell at the front standard, near No.1 Bearing under steady state operation with rated conditions is 29.2 mm.

5.3 Thrust Position Detector

The thrust position detector is located at the thrust bearing to measure a relative movement between the thrust bearing and the rotor thrust collar by a gap sensor. The assembly drawing of the thrust position detector shows its construction and gap setting. Any abnormal indication by this detector may announce an excessive thrust force and abnormal axial shift of the rotor.

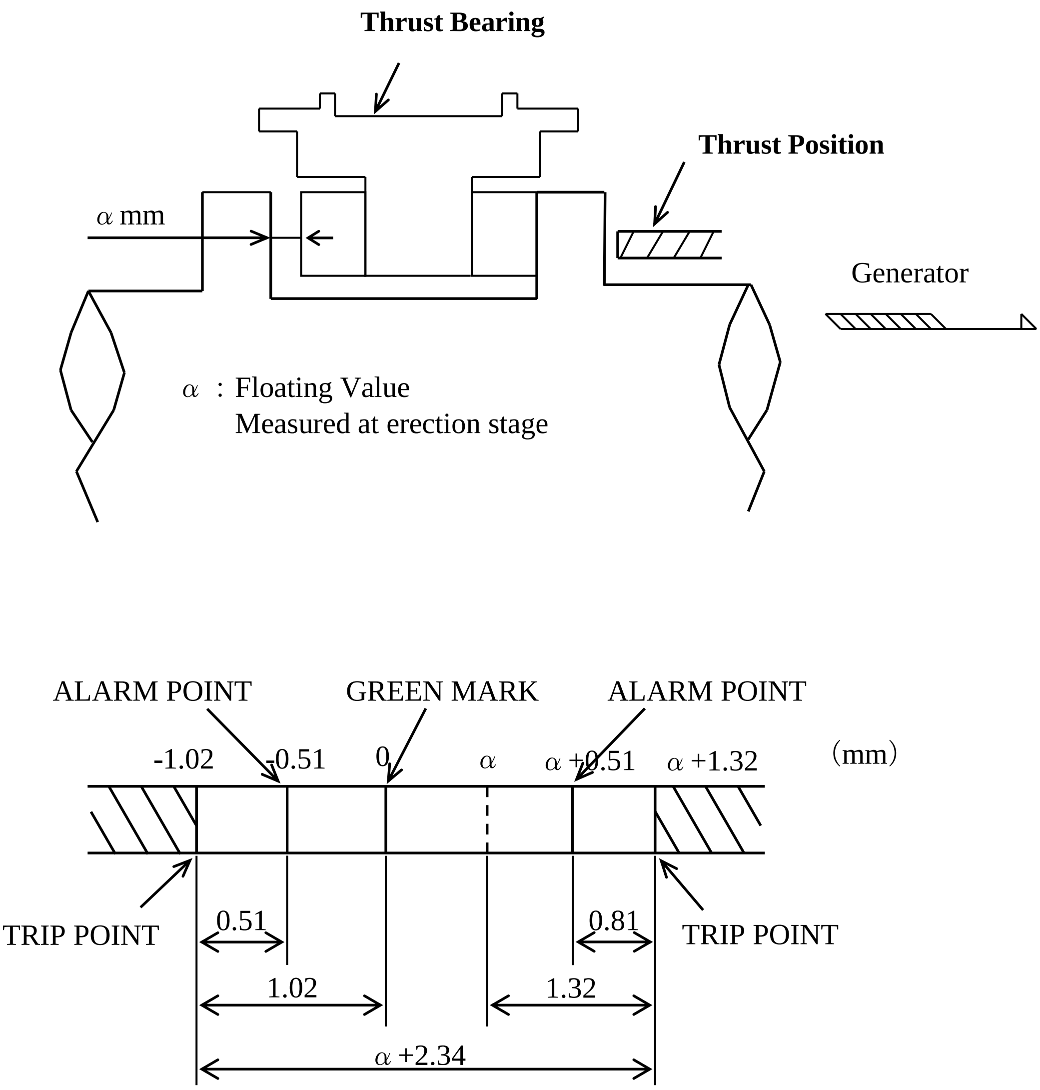


Figure 5.3 Indication of Gap setting

6. Lubricating System

The lubricating system supplies lubricating oil to the turbine and generator bearings and to the generator seal oil system. The system regulates the oil temperature and pressure and collects all bearing drains.

The system also conditions the lubricating oil by removing particulate and water, and provides lubricating oil storage.

6.1 Lubricating Oil Reservoir

6.1.1 Temperature

During operation, verify that the turbine lube oil in the lube oil reservoir remains within the following limits.

Condition	**Limit**	**Remarks**
Main oil pump start	Minimum 10 °C	The pump will be overloaded if the oil viscosity is below 800 SSU
Normal operation	Minimum 54 °C	Temperatures greater than 54° C will enhance oil/water separation

6.1.2 Pressure

Check the pressure in the lube oil reservoir to verify that the vapor extractor is in service to prevent the lube oil from flowing out at the bearing oil deflector. The normal operating range is –0.25 to –0.37 kPa(g). The normal operating range ensures no air leakage from the lube oil reservoir drain line.

6.1.3 Oil Level

During normal operation, the high oil level alarm point is +100 mm, and the low is –100 mm, with each number indicating the amount of deviation from the design level. During operation, oil level must remain within the limit between high and low oil level alarm.

CAUTION

- Generally, the oil cooler water side pressure is higher than that on the oil side, and can contaminate the oil when there is cooling tube trouble. If the high oil level alarm indicates the possibility of this condition, the standby oil cooler should be put in service and the oil purifier should be checked.

The low oil level alarm point indicates the limit for oil leakage from the lubricating system. The lubricating system includes the control oil feed line, the lube oil feed line, and the oil drain line.

CAUTION
■ The low oil level alarm is generally caused by leakage from the main oil pump feed line and/or oil drain system. Therefore, if low oil levels are observed, leakage from the drain line, and tank surroundings should be investigated and repaired.

If the oil level is not kept above the permissible low level, the units should be tripped to avoid bearing damage.

When double piping construction is used to lube oil feed line, the leakage from those lines can be detected as the alarms of low lube oil pressure.

When a very slow increase of the oil level has been observed over time, a small quantity of water injection may have occurred. If this is suspected, the oil cooler, vent fan, lube oil conditioner, vapor extractor, oil deflector, and characteristics of the oil itself all should be checked.

6.2 Lubricating Oil Conditioner

The lube oil conditioner is intended to operate continuously to keep the oil in good condition while the turbine is in service. However, short-term outages of the lube oil conditioner should not allow the lube oil to degrade to a level that will damage the turbine bearings. The lube oil conditioner will occasionally be used to clean lube oil when the turbine is out of service.

6.3 Lubricating Oil

6.3.1 Pressure

During turbine operation the following lube oil pressure limits should be observed.

Name of system	Standard		Lower limit at normal condition
	startup	Continuous	
Lube oil feed	Approx. 250 kPa(g)	Approx. 180 kPa(g)	108 kPa(g) Alarm 69 kPa(g) Trip

The locations for pressure measurement is the front standard for the lube oil pressure. System is equipped with low oil pressure alarms. Normally, the automatic startup sequences for the main oil pump, and the emergency bearing oil pump maintain the oil pressure required. Standby pump start switch should be set at the automatic start position even after the turbine has been started.

WARNING

- **The turbine should be tripped immediately when the low oil pressure alarm signals any abnormal condition. Oil pressure loss may be caused by leakage from piping and by trouble with the pumps.**

6.3.2 Oil Feed Temperature

The feed oil temperature should be controlled to the limits shown on Figures 6.1 and 6.2. The temperature is measured at the outlet of the oil cooler or the common piping of the oil feed. When long-term turning operation is required, the oil temperature should be kept as low as possible, unless the power required by the oil pump is causing it to overload. Oil film thickness should be limited to the degree required to prevent metal to metal contact. However, the oil temperature should be adjusted to the proper conditions required to start the Auxiliary Oil Pump at the turbine startup. During turbine acceleration, the upper and lower oil temperature limits should be observed as an indication of metal to metal contact and oil whip. The lower limit can be ignored unless an abnormal condition such as oil whip is observed. The lower limit is sensed by the monitoring system for shaft vibration, because the abnormal condition caused by oil whip appears as an increase in vibration level. During acceleration it may be difficult to keep the oil temperature within its lower limit because of the variations of oil flow and bearing characteristics. In this case, the lower limit setting can be modified unless the problem occurred during initial trial operation.

The upper limit cannot be modified easily because of difficulties in obtaining sufficient oil film thickness between parts. For any modifications to this condition, the Toshiba engineer should be consulted. During turbine shutdown, the same pattern is applied as for startup. It is possible to start the turning gear with the oil temperature below the limit if the recommended limit will be reached within 15 minutes and the oil cooler is operating. These considerations are made by regarding the shutdown process being performed uniformly, without a holding speed, and in a short time compared to the starting conditions. However, trouble occurs in the lubricating system when the temperature of the turning gear start is much higher than the upper limit or if it does not drop to the upper limit within 15 minutes. When either condition occurs, countermeasures should be taken, and the information should be sent to the Toshiba design section.

In addition, the permissible maximum feed oil temperature for the turning gear start condition may be considered 39 °C and lower, even though the limit is determined on the basis of operating conditions for each specific unit.

c

Start-Up

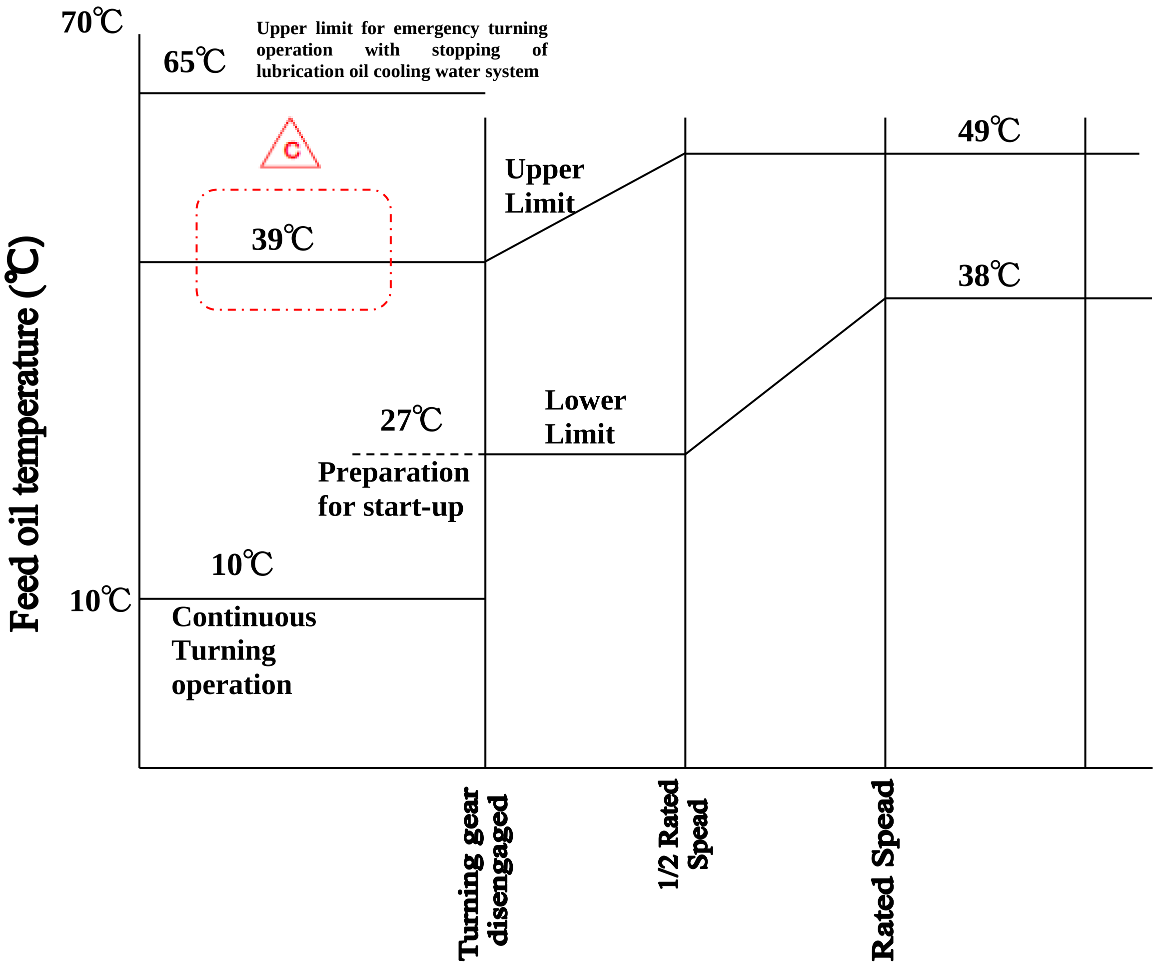


Figure 6.1 Startup Feed Oil Temperature

NOTE
■ When turning operation is required, the feed oil temperature should be kept as low as possible, unless the power required by the oil pump is causing it to overload. ■ Before starting up the turbine, the feed oil temperature should be 27 °C – 35 °C (Recommended oil temperature range), if impossible, 27 °C – 39 °C (Allowable oil temperature range).

C

Shut-Down

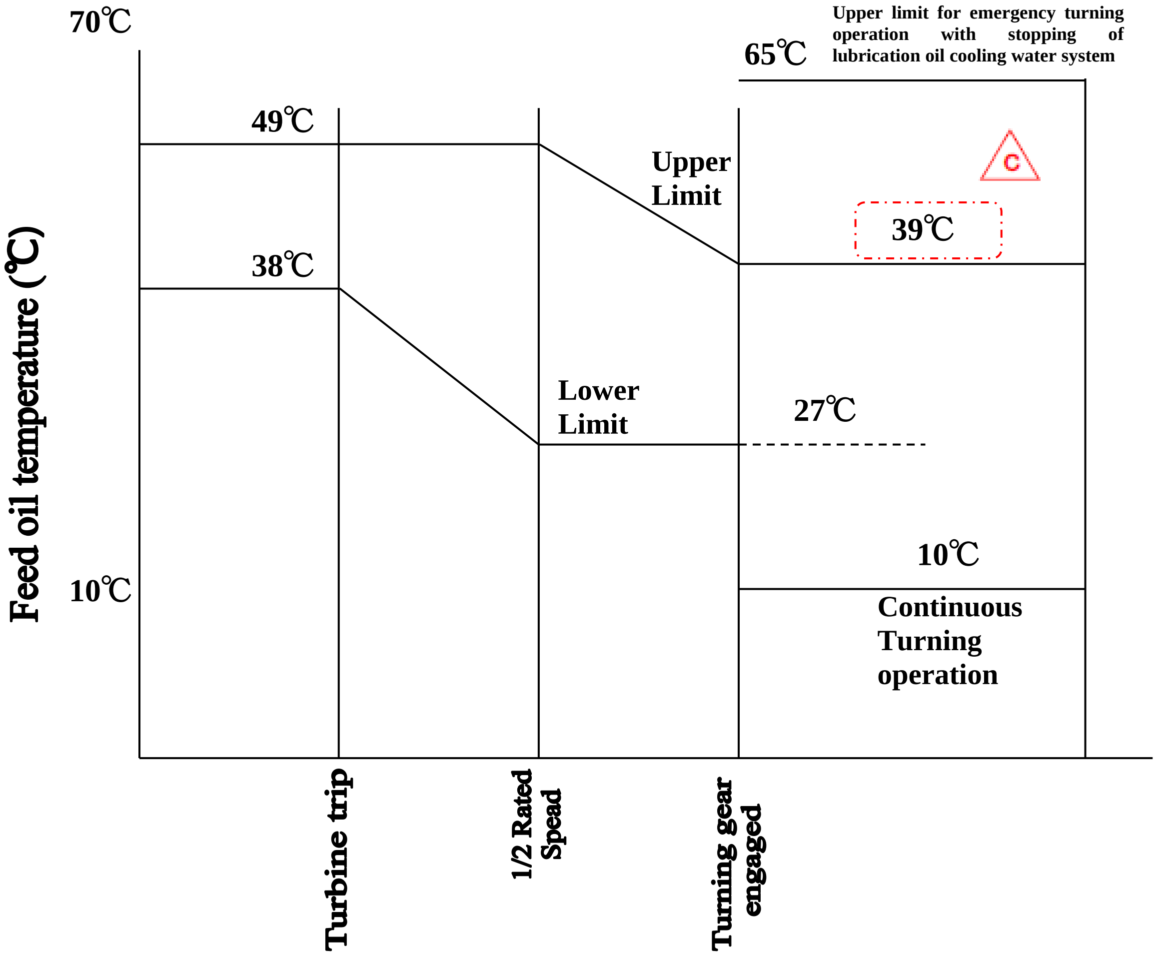


Figure 6.2 Shutdown Feed Oil Temperature

NOTE
■ When turning operation is required, the feed oil temperature should be kept as low as possible, unless the power required by the oil pump is causing it to overload.

6.4 Lubricating Oil Drain and Bearing Metal Temperature

6.4.1 Lubricating Oil Drain Temperature

Lube oil drain temperature should be determined based on the oil temperature at the oil sight. The following are maximum permissible temperatures for various operating conditions:

- Normal operation, Journal bearing:79 °C
- Normal operation, Thrust bearing:82 °C
- Difference between feed and drain, 28 °C
- Transient change in drain temperature, 3 °C

Any sudden increase in oil temperature of 3 °C and higher should be considered abnormal even though the temperature is within the stated limits, and the cause should be investigated thoroughly.

6.4.2 Bearing Metal Temperature

The following are limits of metal temperatures during continuous operation at rated speed.

Item	**Alarm ***	**Maximum**
Thrust bearing		
Active or inactive side	98 °C	105 °C
Journal bearing		
Elliptical type	107 °C	121 °C
Pad type	115 °C	121 °C
Transient change in metal temp, 5.5 °C/min		

* These alarm values are based on experience and may be corrected according to the actual operating condition.
The alarm value of elliptical type journal bearing in transient state except steady operation is 115 °C.

Any sudden increase in bearing temperature of 5.5 °C and higher should be considered abnormal even though the temperature is within the stated limits, and the cause should be investigated thoroughly.

Drain temperature and metal temperature are measurements used to determine whether bearings are in good condition. Damage of bearing metal can be detected by comparing the measured drain and bearing metal temperatures to temperatures under normal conditions. However, drain temperature measurement is not as accurate because the temperature is greatly affected by the quantity of overflow oil in the bearing housings. The drain temperature is also affected by the bearing friction loss, the orifice diameter in the feed line, and the feed oil temperature to the bearing. Therefore, the drain temperature during startup is not significant in determining the condition of the bearings. Instead, the drain temperature should be observed for deviations at the steady state condition.

On the other hand, metal temperature provides a more accurate measure of bearing condition. The data trend during normal operation should be determined so that abnormal conditions can be identified by comparing.

Although both the metal and drain temperatures are generally observed by their upper limits, these two are affected as well by the position of the thermocouple and the quantity of oil flow. Therefore, it is more important to check the temperature deviations from temperatures under normal operating conditions. A small deviation generally occurs when bearing alignment and thrust force change, induced by transient operation conditions at rated speed. However, deviations of this type do not generally influence the turbine operation.

WARNING

- **When deviations, especially sudden changes, in metal temperatures are observed during steady-state operating condition with constant bearing feed oil temperature, then damage in bearing metal is suspected. The temperature gauge must be inspected, and the state of the local instruments should be determined. If the cause cannot be identified, the turbine must be tripped when the temperature gets to the upper limit.**

If the speed reduction rates and normal operating conditions have been recorded, the bearing metal conditions can be estimated without visual inspection. If metal fatigue occurs, speed reduction rate at the abnormal condition might be faster than at the normal, and the rate of feed oil temperature decrease might not be normal. On this unit, temperature measurements on bearing metal are provided. The operator can precisely judge whether bearing metal damage is possible by comparing these temperature measurements with those at normal conditions.

During initial operation, if temperatures approach upper limits or if there are discrepancies among bearing temperatures the cause should be investigated immediately.

7. Low-Pressure Exhaust Hood

7.1 Vacuum

The low-pressure exhaust hood vacuum and absolute pressure for various operating conditions are listed below.

Operating condition	vacuum pressure
	kPa(a)
Before rolling off--minimum vacuum required	17
At half speed--minimum vacuum required	12
Before taking initial load--minimum vacuum required	12
After taking initial load--low vacuum alarm	17
After taking initial load--low vacuum trip	25

The vacuum achieved at the turbine startup is the required minimum. The higher the vacuum thereafter, the better the operating condition. The turbine should not be started at 17 kPa(a) and under, even if other staring conditions are satisfied.

WARNING

- **When increasing the speed to more than 50 percent of the rating, it is better to trip the turbine, provided the vacuum does not become higher than the limit.**

It is not necessary to trip the turbine if the vacuum is extremely lower than the limit. However, exhaust hood temperature, differential expansion, vibration, and the other limitations should be closely watched.

In this case it would be better to continue to accelerate the turbine and observe the tendency of the vacuum to increase. This is why the vacuum limit of 12 kPa(a) should be checked again when the initial load is reached.

The vacuum should not decrease to the alarm value (17 kPa(a)) after initial loading.

The alarm value should be considered carefully after initial load. The values listed above are the limit for low vacuum phenomena resulting from abnormal conditions which may occur during the normal operations, and not the values for the startup procedure.

If low vacuum alarm occurs during operation, the cause must be immediately investigated and repaired.

The atmospheric relief diaphragm on the low-pressure casing is designed to blow apart if steam in the casing reaches 34 kPa(g) and all steam at 103 kPa(g) or greater pressure is relieved to ensure that the turbine low-pressure casing and condenser are not over-pressurized.

The maximum vacuum is about 26 kPa(a) because of the strength of the casing construction in the exhaust hood. Vacuum operation above this limit may deform the bearing housing projected in the low pressure exhaust hood and change the vibration level.

The vibration recorder must be observed closely during low load operation. The upper vacuum limit should also be determined on the basis of moisture at the turbine last stage buckets. Since the moisture at the last stage is a function of LP casing inlet pressure and temperature, Figure 7.1 can be used for consultation. The limit of moisture at the last stage is about 12 percent because of the bucket erosion rate.

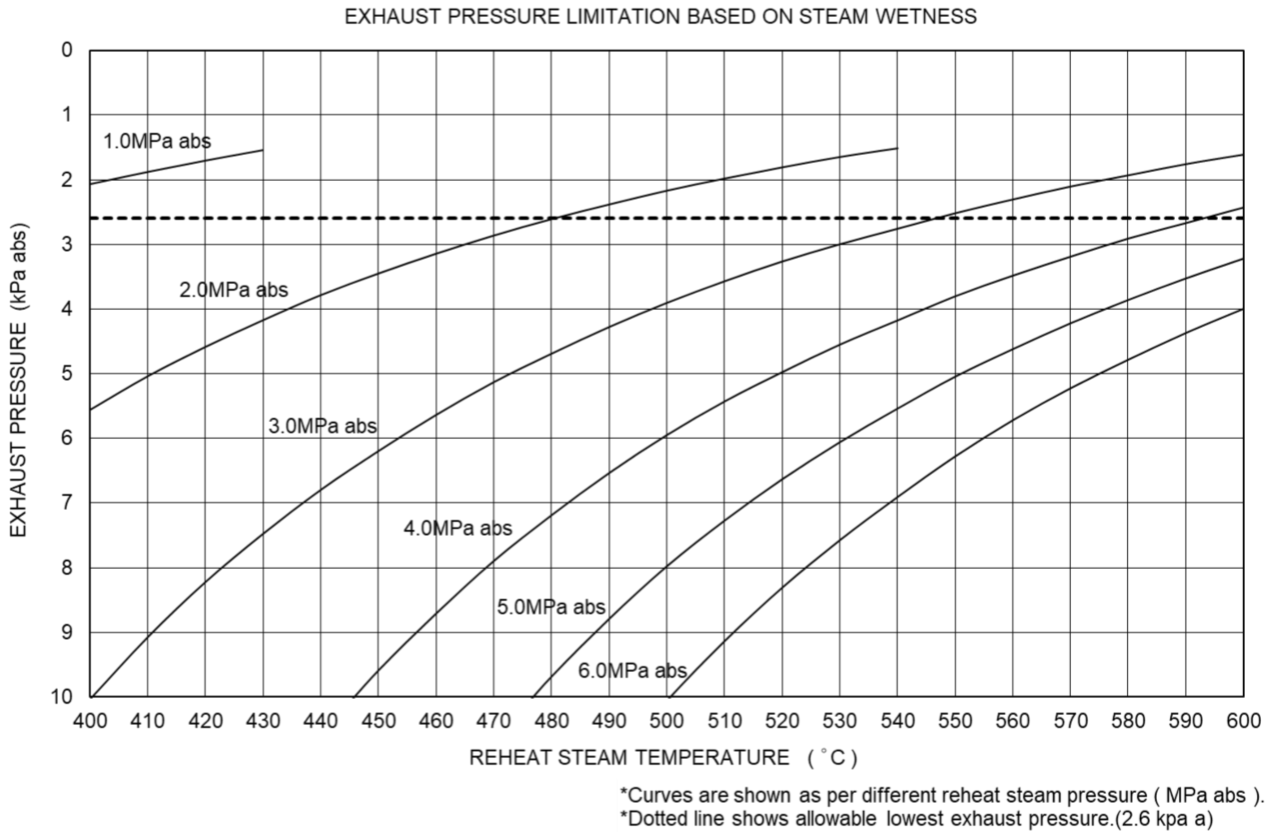


Figure 7.1 Exhaust Pressure Limitation Based on Steam Wetness

NOTE
■ Curves show the relation between reheat steam conditions and turbine exhaust pressure to get the 12 percent wetness of saturated steam at the last-stage buckets. ■ Any of two factors among LP casing inlet steam pressure, LP casing inlet steam temperature, and exhaust pressure should be controlled so that the 12 percent wetness line is not exceeded. ■ Dotted line shows the allowable lowest exhaust pressure owing to the exhaust hood deformation, and this limitation is to be followed in preference to the above.

7.2 Temperature

Operating condition	Upper limit	Remarks
Form rolling off to taking initial load	52°C	With exhaust-hood spray
Continuous load operation	80°C	High temperature alarm
	107°C	High temperature trip

During startup and other periods of low load operation the turbine removes little energy from its driving steam. This results in high exhaust hood temperatures which adversely affect turbine components such as the exhaust hood.

The primary turbine temperature limits relate to overheating in the exhaust hood. This is caused by rotational friction loss at or near the last stage buckets during low load or no load operation. In normal conditions, the exhaust hood temperature is the saturation temperature corresponding to that vacuum. Overheating has occurred when the exhaust hood temperature is higher than the saturation temperature. In such cases the exhaust hood spray is placed in service automatically to cool the exhaust hood. Operators should carefully observe the exhaust hood during special conditions. For example, when held at low load or no load after rapid unloading from high load, overheating may easily occur near the last stage, because the temperature of the boiler reheater and turbine steam path is not cooled immediately after the trip. This should be carefully watched because the recorder indicates values lower than actual as a result of the automatic exhaust hood spray.

These abnormal conditions can be detected in some degree by observing the tendency of differential expansion. However, the stress of last stage bucket and casing must be carefully analyzed to know the severity of this effect. Thus, such an operation should be avoided.

7.3 Exhaust Hood Spray

To prevent overheating of the low-pressure exhaust hood, the exhaust hood spray should always be set in a position to operate effectively. The exhaust hood spray regulating valve is adjusted to provide the design spray nozzle flow sufficiently under spray feedwater pressure of 343 kPa(g) at valve wide open with normal vacuum. Therefore, when the spray is placed in service, the feedwater pressure should be kept higher than the lower limit of 206 kPa(g), and the spray switch should be set at AUTO position to ensure the adequate operation. Spray feedwater pressure over 490 kPa(g) will cause severe erosion problems. Thus, the pressure must be closely observed to maintain normal safe operation of the spray nozzle. The spray feedwater pressure is determined by the nozzle type installed. The following is recommended for this turbine:

0.343 MPa(g) spray nozzle	
Normal	343 kPa(g)
Maximum	490 kPa(g)
Minimum	206 kPa(g)

8. Steam Seal System

To prevent air leakage into the turbine or steam blowout from the turbine glands, the following pressure ranges should be held in the steam seal header and the gland steam condenser.

Position	Standard	Minimum	Maximum Upper Limit
Steam seal header	21 to 41 kPa(g)	11 kPa(g)	49 kPa(g)
Gland steam condenser	–2.2 to –3.1 kPa(g)	–3.1 kPa(g)	–2.0 kPa(g)

The steam seal header is held at 27 kPa(g) automatically by a gland steam feed valve and a steam packing unloading valve. Operations such as regulating gland steam supply valve and changing the source of steam during the turbine starting, loading, and unloading may cause pressure variations. For the various sources of steam and the associated valve, refer to Steam Seal Diagram.

The gland steam condenser pressure is manually adjusted by opening the exhaust fan outlet valve and is stable when the exhaust fan is in service. If the pressure deviates from the specified limit when the fan is in service, the exhaust fan outlet valve must be readjusted.

⚠ WARNING

■ **If the gland condenser exhaust fan is stopped, the turbine must be tripped immediately to prevent the following.**

1. Steam leakage from the HP turbine gland allows water to mix with the lubricating oil, deteriorating the oil characteristics and allowing rust to develop on the turbine control devices. Carbonized lube oil produced by hot steam at the tip of the oil deflector can cause rub or wear between stationary and rotating parts of the turbine. In severe cases, vibration problems may occur.
2. Air leakage into the turbine may reduce condenser vacuum and lead to damage of the last-stage bucket, resulting from the higher temperature rise.

9. Allowable Pressure and Temperature Variations

The following are descriptions of allowable pressure and temperature variations which may occur during operation. Steps should be taken to minimize their occurrence, and especially to prevent their simultaneous occurrence.

9.1 Allowable Initial Pressure Variations

	Turbine Inlet Pressure	
Normal Operation	Average pressure	Maximum pressure
	the average pressure at the turbine inlet, over any twelve months of operation should not exceed the rated pressure on load.	the maximum pressure at the turbine inlet is 110% of rating condition.
Abnormal Operation	the maximum pressure at the turbine inlet is 120% of rating condition, and the aggregate duration of such brief swings should not exceed 12 hours over the 12 month operating period.	

9.2 Allowable Reheat Pressure Variations

The steam pressure at the turbine reheat admission varies with load and is not controlled during normal operation. However, when it is necessary to close reheat stop and intercept valves, relief valves are required to protect the high-pressure turbine and the reheater from being subjected to main steam pressure. Pressure at the high-pressure turbine exhaust connection should not be greater than 20 percent above the exhaust pressure at rated flow with rated steam and operating conditions.

9.3 Allowable Temperature Variation

9.3.1 General

The average steam temperature at any turbine inlet over any twelve months of operation should not exceed the rated temperature. In maintaining this average, the temperature should not exceed the rated temperature by more than 8 °C except as follows:

- Temperatures swings not exceeding the rated temperature by more than 14 °C for a total of not more than 400 hours over any 12 months of operation.
- Temperature swings not exceeding the rated temperature by more than 28 °C for a total of not more than 80 hours over any 12 months of operation.

In either case, the temperature swing time should be within 15 minutes.

9.3.2 Differences Among Steam Leads

In maintaining the above listed temperatures, differences among different steam leads feeding a common valve casing or common turbine shell are not to exceed 17 °C, except during abnormal conditions. At those times it is acceptable to operate with temperature differences not in excess of 28 °C for periods totaling not more than 15 minutes per 4 hours operating period.

9.4 Allowable Temperature Difference between Upper and Lower Casing

The temperature difference between the upper and lower casings can be determined by using the thermocouples provided as the water induction detector. These thermocouples are mounted as a set on each main upper and lower steam chamber and provide signals to a recorder. These signals can be interpreted to provide a temperature distribution of the turbine casing in the axial direction.

9.4.1 Water Induction Limits

A rapid temperature decrease in the lower casing or an increase in the temperature difference between the upper and lower casings may indicate turbine water induction. It should be noted that a temperature difference between the upper and lower casings exceeding the difference indicated in Section 9.4.2 does not necessarily mean that water induction has occurred. The operator must consider the rate of temperature change in the lower casing and should observe other instruments associated with water induction detection, to determine the existence of water induction.

9.4.2 Limit of Upper and Lower Casing Temperature Difference

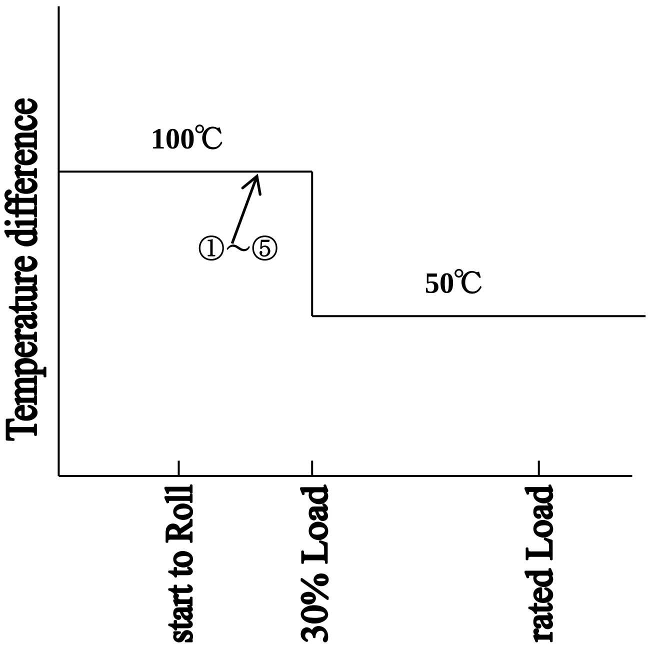
The allowable limits of temperature difference between the upper and lower turbine casings are summarized in the following figures. These allowable limits also indicate the possible detection of water induction. However, as discussed under Section 9.4.1, a temperature difference exceeding the allowable limit does not necessarily mean water induction has occurred.

Operational data must be observed to determine if water induction has occurred. Abnormal differential expansion or vibration can be expected to follow a water induction event.

9.4.3 Set Point

The change of set point indicated on Figure 9.1 is to take place when all feedwater heaters are in service and the turbine operates at a stable condition. (usually 30 percent load)

The change of set point indicated on Figure 9.2 is to take place when all feedwater heaters are removed from service. (usually 30 percent load)



①HP Heater8 Extraction
②HP Exhaust Chamber
③Reheat Bowl
④HP Heater6 Extraction
⑤IP Exhaust Chamber

Figure 9.1 Allowable Temperature Difference between Upper and Lower Casing During Startup

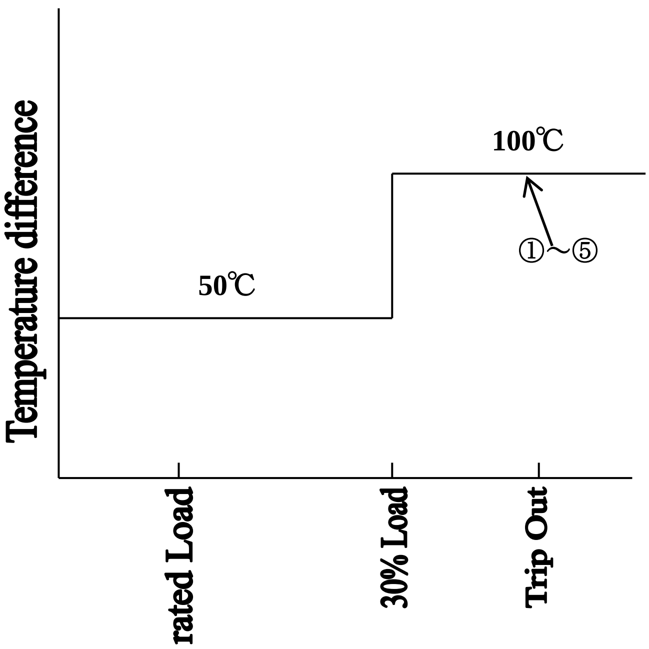


Figure 9.2 Allowable Temperature Difference Between Upper and Lower Casing During Shutdown

10. Operation-Permissible Time for Off-Frequency Operation

The long blades of turbine last stages and areas near them can be damaged from high cycle fatigue caused by the resonant vibration of the rotor. Usually, the natural frequency of these blades is sufficiently tuned that is does not cause resonance at rated speed or near it.

Some frequency variation inherent to the line to which the unit is connected is inevitable, and operation outside of the guaranteed continuous operating frequency should be held within the limitation of the curve shown on Figure 10.1. The curve is designed on the basis of the fatigue strength of blade material as discussed above. The cumulative damage should not exceed 1.0 during operation in service.

Therefore:

$$\Sigma \frac{t_f}{t_{f0}} \leq 1.0$$

where

tfo= Permissible operating time under frequency f (refer to Figure 10.1)

tf = Actual operated time under frequency f

The operating condition being controlled by the curve should be the whole load range including no load operation. This is based on the fact that the exciting force is not always small under no load operation but can be larger than that of the low load region. It is hard to cause resonance when passing the critical points during operations such as startup, shut--down, governor test, etc. Therefore, it is not necessary to account for the time it takes to pass through the critical points during these operations when calculating blade life. However, if for some reason the speed is held constant at an off-frequency during these operations, this time must be considered in blade life computations. When some speed holding is necessary, the previous equation should be applied and the speed run back into the safety zone as soon as possible.

On controlling the life of blades according to the previous equation, if the accumulating damage becomes 0.8 - 0.9, the possibility of crack initiation increases and the blades must be checked at the next periodic inspection.

When the damage exceeds 1.0 before the inspection, the crack may not develop into blade failure even if it may be initiated, due to the characteristics of fatigue phenomena. Generally, in this case the same operating routine as before is permissible until the next periodic inspection, if sufficiently long operation has been experienced by that time. Naturally, it is better, however, to operate carefully by intensive frequency control with confirmation of the individual turbine operating limitations.

Particularly during a special operation, such as under high exhaust hood temperature, high exhaust humidity, or lengthy operation with low pressure exhaust hood spray, much more careful observation is required.

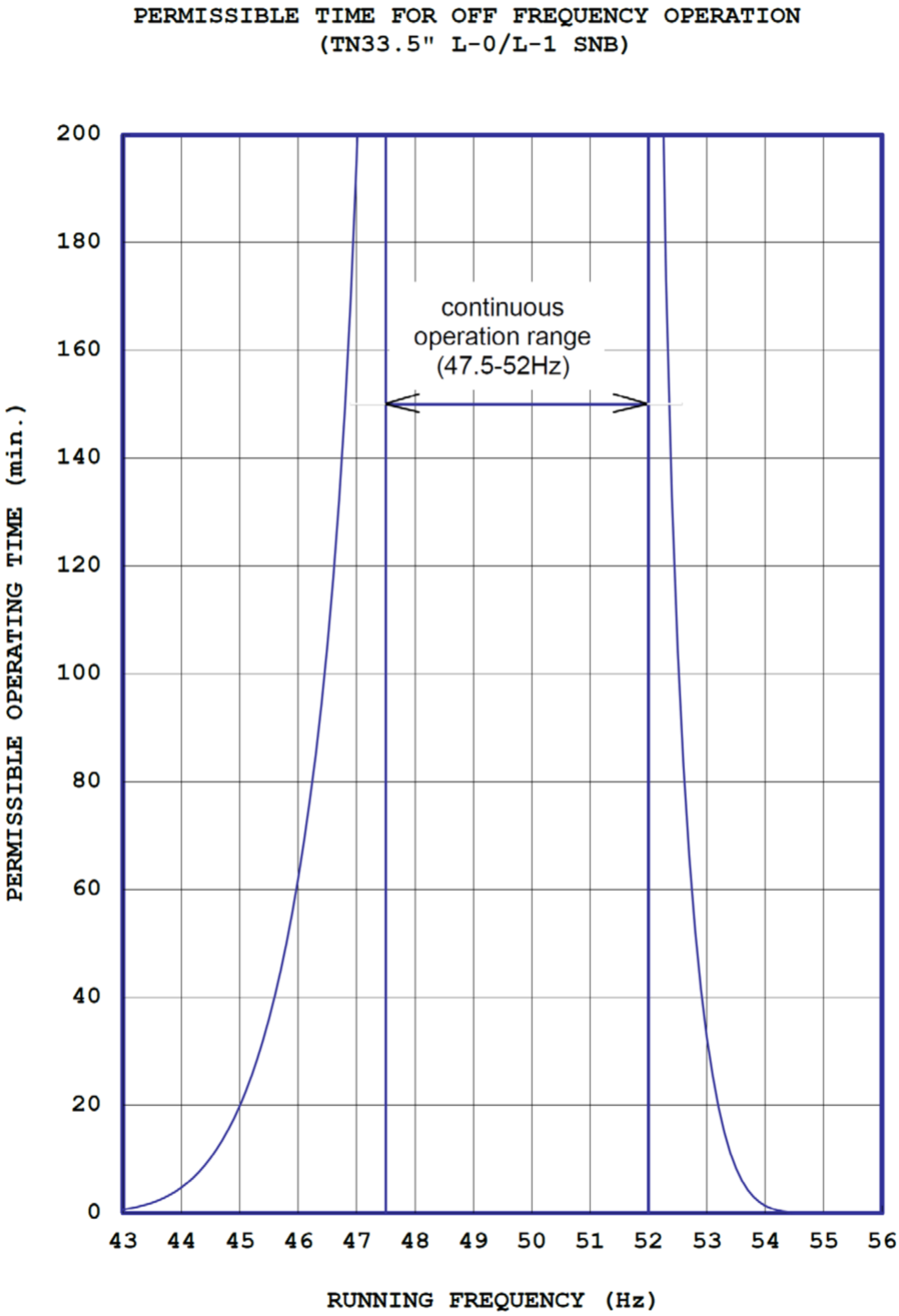


Figure 10.1 Permissible Time for Off-Frequency Operation

11. Prewarming Pressure before Cold Startup

Turbine prewarming is required before rolling for the cold startup, such as the startup after long term turbine shutdown and after turbine overhaul. The means of accomplish this prewarming is casing pressurization by admitting steam from exhaust pipe through the prewarming valve, and the target temperature is higher than 150 °C (minimum required 130 °C) of the first stage metal temperature. During prewarming operation, casing shell pressure (1st stage bowl pressure) must not exceed 0.588 MPa(g).

12. Last Stage Blade Tip Temperature

The temperature at tip portion of the last stage blade is monitored for its protection. The alarm and trip setting are shown below.

Alarm temperature	220 °C
Trip temperature	280 °C

13. HP Turbine Exhaust Temperature

During no load or low load operation, HP turbine exhaust temperature will easily rise due to rotational friction loss at or near the HP last stage. Because this overheating phenomenon may affect the HP turbine components, the HP differential expansion and shaft vibration, operators should carefully monitor the HP exhaust temperature during the special conditions. The alarm setting is shown below.

Hi Alarm temperature	480 °C
Hi-Hi Alarm temperature	500 °C

Hi Alarm temperature:

It indicates that the temperature is approaching to the maximum allowable temperature (Hi-Hi alarm). The operator is requested immediately to take corrective actions with the following manner to decrease HP exhaust temperature.

a) When the unit is at no load operation, the unit should be synchronized under all conditions at the ready for synchronization.

b) When the steam temperature is higher than normal condition at no load or low load operation, the boiler operation should be adjusted in order to decrease steam temperature.

Hi-Hi Alarm temperature:

When the temperature reaches Hi- Hi alarm value despite of the corrective actions, the turbine is strongly recommended to shut down by manual.

Revision History (for internal use)

REV.	REV. ISSUED	PAGE	CHANGED PLACE AND CONTENT	APPROVED BY	REVIEWED BY	PREPARED BY
a	24.Aug.'22	—	1st edition for XVVP1	K.Asai 24.Aug.'22	K.Asai 24.Aug.'22	M.Yamada 23.Aug.'22
b	8.Nov.'22	21,22	The upper limit of the feed oil temperature for emergency turning operation with stopping of lubrication oil cooling water was added.	K.Asai 8.Nov.'22	K.Asai 8.Nov.'22	M.Yamada 4.Nov.'22
c	17.May.'23	6, 20-22	The upper limit of the feed oil temperature for turning operation was revised.	K.Asai 17.May.'23	M.Yamada 17.May.'23	S.Suyama 17.May.'23