NOTES & REFERENCES

Module 234-14

TURBINE OPERATIONAL PROBLEMS

OBJECTIVES:

After completing this module you will be able to:

14.1 For turbine generator rotor vibration, describe:

- a) Three ways in which it can damage the machine; ⇔ ***Pages 3-4***
- b) Its five major causes; ⇔ ***Pages 4-8***
- c) Two general operating practices used to prevent its excessive levels; ⇔ ***Pages 9-10***
- d) Three protective actions performed when the vibration is excessive. ⇔ ***Pages 10-11***

14.2 a) State three major operational causes of accelerated wear and failure of turbine generator bearings. ⇔ ***Pages 12-13***

- b) Describe three ways in which bearing overheating can result in damage. ⇔ ***Page 13***
- c) Explain the effect of each of the following on bearing metal temperature: ⇔ ***Pages 14-15***
  - i) Shaft speed;
  - ii) Bearing load;
  - iii) Bearing oil flow rate and inlet temperature;
  - iv) Bearing surface condition.
- d) State two operational factors affecting the bearing load. ⇔ ***Page 14***
- e) State three actions that should be taken in response to high bearing metal temperature. ⇔ ***Pages 15-16***
- f) Explain two ways in which bearing metal temperature monitoring can provide an early indication of bearing deterioration. ⇔ ***Pages 16-17***

14.3 a) i) Describe three adverse consequences/operating concerns caused by blade failure. ⇔ ***Pages 18-19***

- ii) List the two most common causes of turbine blade failure.

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Pages 19-21 ⇔

b) For turbine blade vibration:

  i) Explain its three major causes;

  ii) State two factors that may accelerate blade failure.

Page 22 ⇔

c) Describe two general operating practices used to prevent blade fatigue failures.

Pages 22-25 ⇔

d) i) State two reasons why underfrequency/overfrequency operation can result in high blade vibration levels.

  ii) Describe how turbine operation is limited by underfrequency/overfrequency conditions.

* * *

INSTRUCTIONAL TEXT

INTRODUCTION

In this module the following turbine operational problems are discussed:

- Rotor vibration;
- Bearing problems;
- Blade problems, with emphasis placed on blade vibration.

Many other operational problems are covered elsewhere in these notes. For example: excessive axial thrust and turbine steam wetness are discussed in module 234-1; operation at poor condenser vacuum – in module 234-5; and thermal stresses and axial differential expansion – in module 234-11.

TURBINE GENERATOR ROTOR VIBRATION

The spinning turbine generator rotor is the major source of pulsating forces which cause vibration not only of the rotor itself, but also of the other parts of the machine (eg. casings and bearings). Adjacent equipment and structures, such as steam pipelines and the foundation, are also excited to vibrate.

Turbine generator rotor vibration can be divided into three categories: bending (flexural), torsional and axial. In most turbine generators, the axial and torsional vibrations cause no operational concern, except for abnormal incidents such as out-of-phase synchronization. Therefore, the remaining part of this section deals only with flexural vibration.

Rotor vibration has a significant effect on turbine generator operation. If excessive, the vibration **can cause serious damage**. On the other hand, at lower levels, it **can provide an early warning of potentially dangerous conditions** such as water induction, rubbing or cracks in the rotor. For both these reasons, rotor vibration is continuously monitored, at each major bearing, during turbine generator operation.

In this section, the following aspects of turbine generator rotor vibration are discussed:

- Damage mechanisms due to excessive vibration;
- Major causes;
- General operating practices used to prevent its excessive levels;
- Protective actions when the vibration is excessive.

It is assumed here that you know the meaning of the basic terms used in vibration theory such as: forced vibration, natural vibration, vibration frequency, resonance, critical speed. If you have forgotten, a review is recommended before you proceed further.

Damage mechanisms due to excessive rotor vibration

⇔ Obj. 14.1 a)

Regardless of its cause, excessive rotor vibration can result in any one or more of the following types of damage:

1. **Rubbing and impact damage.**

   Contact between moving and stationary parts can result in their damage due to impact and rubbing. Turbine seals are the primary candidate for this type of damage due to their small radial clearances. Severe rubbing can also cut grooves in the shaft surface. Less likely sites for vibration-related impact and rubbing damage are turbine blades and generator internals where clearances are larger.

   Through heavy rubbing in the machine, high vibration can overload some bearings, causing the oil wedge to break. Bearing damage due to rubbing and overheating then follows*.

2. **Fatigue damage.**

   Recall that fatigue failure occurs when a high cyclic stress has been exerted a sufficient number of times. In a turbine generator, this type of damage can occur in many different components in which the vibrating rotor generates high cyclic stresses. Examples are long moving blades in the latter stages of the LP turbine, coupling bolts, oil, FRF and instrumentation lines. The concrete foundation and the babbitt lining in the bearings can experience fatigue cracking, too.

3. **Loosening of wedges, shims, nuts, bolts, etc.**

   The wedges that support generator rotor windings are an example.

* More information on bearing damage is given on page 13.

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Any of the above can further increase the vibration levels, and hence aggravate the resulting damage.

Often, the initial damage precipitates other problems. For example, damage to a generator hydrogen seal or an oil line can result in fire.

Obj. 14.1 b) ⇔

Major causes of rotor vibration

The most common causes of turbine generator rotor vibration are:

- Weight unbalance;
- Bearing misalignment;
- Other bearing problems;
- Unbalanced electromagnetic forces in the generator;
- Resonance.

Each of these causes is described separately below.

1. Weight unbalance.

This is the most common source of vibration. In each part of the rotor – such as a blade wheel or a coupling – unbalance causes the centre of gravity to be offset relative to the axis of rotation. As a result, an unbalanced centrifugal force is created in the component when the rotor is turning. Similar forces are created in the other parts of the rotor. As the forces rotate with the rotor, they cause it to vibrate at the frequency of rotation.

It must be stressed that due to high turbine speed, even a relatively small weight unbalance can produce a large centrifugal force. At 1800 rpm, the force can be up to 10,000 times as large as the weight of the unbalanced mass, depending on how far from the axis of rotation the mass is located. Thus, a 1 kg unbalance can generate a force in the order of several percent of the weight of a large turbine rotor*.

* These numbers are quoted only for your orientation, and you do not have to memorize them.

Even a new turbine generator rotor has some residual unbalance due to factors such as machining and assembly tolerances, material nonuniformities and a finite accuracy of balancing by the manufacturer. Normally, the residual unbalance is not a problem; it merely explains one of the reasons why rotor vibration cannot be eliminated entirely.

Many **operational factors** influence the rotor unbalance. Some of these factors change the unbalance permanently, others temporarily. The following are examples of major operational causes of **permanent** changes in the rotor unbalance:

- Deposits (salts, rust, etc.) on the rotor surface;
- Erosion of moving blades;
- Shifting of windings in the generator rotor;
- Loss of a blade shrouding, lacing wire, erosion shielding, etc.

The first two phenomena result in gradual changes in vibration levels, while the last two can cause an abrupt change, possibly forcing a turbine trip.

A **temporary** change in the rotor unbalance is caused by **rotor bowing.** Listed below are a few operating conditions that can produce it:

- Residual shaft sag or hog due to insufficient time on turning gear prior to turbine runup;
- Excessive heatup or cooldown rates during startup or load changes*;
- Rubbing which causes thermal bowing of the shaft due to frictional heat produced in the site of rubbing (recall that if rubbing is severe, the bowing may become permanent);
- Shorted field windings or uneven cooling (due to obstruction of passages) of the generator rotor, leading to its thermal deformation.

* Recall from module 234-11 that fast heating or cooling of the rotor can produce slight circumferential temperature differences in the rotor. These are caused by uneven deposits on the rotor surface and minor local differences in the thermal conductivity of the rotor material.

Most of these causes of rotor bowing can be prevented by proper operating practices. More information on that topic is given later on in this module.

2. Bearing misalignment.

Bearing misalignment can increase rotor vibration in a few ways. One of them can be easily understood if you notice that bearing alignment affects the bearing load by changing the distribution of the shaft weight between individual bearings. For example, when a bearing is lowered, its load is reduced, with the other bearings picking up the slack. While this situation can result in failure of the overloaded bearings, it can also lead to **oil whip* in the lightly loaded bearing.** Note that it is easier for the oil wedge to whip the shaft around the bearing when the steady load pushing the shaft towards the bearing surface is reduced.

* Oil whip is described in module 234-10.

Another way in which bearing misalignment can increase vibration levels is by changing the rotor natural frequencies (and thus, its critical speeds). This **reduces the margin to resonance** when the turbine operates at the rated speed. Such a change in the rotor natural frequencies can happen due to two factors.

First, the rotor natural frequencies depend on the stiffness of its support on the bearings and the foundation. The **oil wedge** in the bearings is an important component of this support. Its size – and with it, its **stiffness and vibration dampening properties** – depend on the shaft position in the bearing. The latter is affected by bearing misalignment.

Second, a gross misalignment can cause a bearing to stop supporting the shaft altogether. This increases the length of the shaft span between the bearings that are actually supporting it, as shown in Fig. 14.1 on the next page.

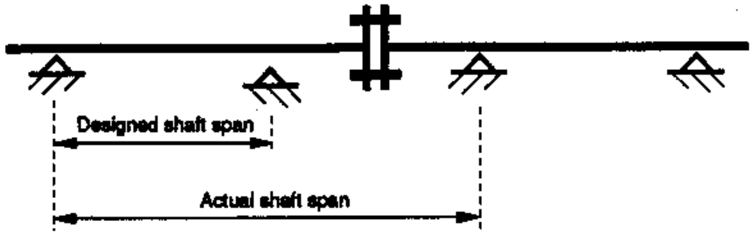

Fig. 14.1. Effect of a misaligned bearing on the shaft support.

In Fig. 14.1, the second bearing from the left is misaligned. This **change in the shaft support** reduces the stiffness of the shaft span and increases its mass. As a result, the shaft's natural frequencies are lowered. This decreases the margin to resonance with the shaft's critical speed that is normally above the rated speed. When this margin is reduced significantly, vibration increases.

Some residual misalignment always exists. This is mainly because of the limited accuracy of the correction factors used to account for a change in the bearing alignment that is expected to happen between the cold shutdown state (when the alignment is performed) and the full power operating state. Normally, the residual misalignment has a negligible effect on rotor vibration.

Much larger changes in the bearing alignment can be caused by the following **operational reasons:**

- **Thermal and/or mechanical deformations of the turbine casings.** The deformations shift the loads the casing exerts on the bearing pedestals and foundation. Under these loads, the pedestals and foundation deform, changing the bearing alignment.

  Such deformations of the turbine casing can be caused by a variety of reasons. Thermal deformations result from heating or cooling that occurs during load changes. In turn, mechanical deformations can be caused by steam piping forces or blocking of the casing thermal expansion*.

  In some units, mechanical deformations of the LP turbine bearing pedestals and foundation are affected by changes in condenser vacuum. This applies to the units where a flexible rubber joint is used between the LP turbine exhaust cover and the condenser shell, the latter supported on its foundation. Drawing condenser vacuum inside the exhaust cover is equivalent to adding an extra load of about a few hundred thousand kg. Because the flexible rubber joint cannot transfer this load to the condenser shell, it is carried solely by the bearing pedestals and the turbine foundation. Their deformation under this large load causes bearing alignment changes that cannot be ignored.

* Blocked expansion of the turbine casing is described in modules 234-8 and 234-11.

- **Thermal expansion or settling/cracking of the concrete foundation.** Aging of the equipment may cause settling and cracking of the foundation. Excessive thermal expansion of the foundation may be caused, for example, by heat radiating from a hot steam pipe nearby if, for some reason, its thermal insulation is removed.

3. **Other bearing problems.**

Recall that a bearing may develop **oil whip** when its lubricating oil temperature is too low. The tendency for oil whip is increased when the bearing load is light.

Rotor vibration can also be increased due to a **faulty bearing**. Worn babbitt lining, out-of-round journal or loosened bearing bolt are typical examples of such failure. Worn babbitt spoils the shape of the oil wedge*. An out-of-round journal produces additional vibration exciting forces. And a loosened bolt can prevent the bearing from providing an adequate support for the shaft.

* This is explained on page 15.

4. **Unbalanced electromagnetic forces in the generator.**

A classic cause is a double ground fault in the generator rotor windings which produces an asymmetrical rotating magnetic field. A detailed explanation of this cause is available in electrical courses.

5. **Resonance.**

Recall that resonance occurs when the frequency of a vibration exciting force coincides with one of the natural frequencies of the vibrating body, causing the vibration amplitude to increase.

One difference between resonance and the other four causes of rotor vibration described above is that resonance, on its own, cannot generate vibration. It merely amplifies the vibration sources (unbalance, misalignment, etc.) that are already present. Sometimes, this amplification can produce damaging vibration. This can happen when the vibration exciting forces are too large and/or vibration dampening is poor.

Because the HP turbine, LP turbine and generator rotors differ from one another, each of them has its own set of natural frequencies corresponding to different modes of vibration. In our turbine generators, some of these frequencies are below 30 Hz which is the frequency corresponding to the normal speed of 1800 rpm. As a result, a few **resonances occur during turbine runup or rundown**. For example, at a certain speed, the HP turbine rotor is in resonance. At another speed, an LP turbine rotor is in resonance. And so on. Combined together, these speeds form 1-2 **critical speed ranges**.

Despite resonance, passing through the critical speed ranges is safe if done properly. Details on this topic are given later in this module.

Normally, critical speed ranges are far enough* from the rated speed to prevent resonant vibration during normal operation. But certain conditions can change it. For example, as mentioned above, a gross bearing misalignment may shift the natural frequencies of the rotor so much that a critical speed range may approach the normal turbine speed.

* At least 15-20% away.

Also, piping forces or foundation distortion, etc. can change the turbine casing support conditions to an extent that the casing's natural frequencies are altered. As a result, the casing may operate in a resonance. Its vibration is then transmitted to bearing pedestals, increasing bearing vibrations, and thus, rotor vibration.

SUMMARY OF THE KEY CONCEPTS

- Excessive rotor vibration can cause rubbing and impact damage to components such as turbine seals, blades or bearings. Fatigue damage of some turbine blades, coupling bolts, steam or oil lines, etc. can also occur. Finally, the vibration can loosen some parts, eg. generator rotor windings supporting wedges. When damage occurs, the vibration levels can rise further, causing more damage.
- The most common causes of rotor vibration are weight unbalance, bearing misalignment, resonance, bearing malfunction and unbalanced electromagnetic forces in the generator.
- Permanent changes in rotor unbalance can be caused by deposits on its surface, erosion of moving blades, shifting of windings in the generator rotor or a loss of a rotating mass such as a blade shrouding or lacing wire.
- Temporary changes in rotor unbalance result from its bowing which can be caused by a number of reasons. These include residual shaft sag or hog, excessive heatup or cooldown rates, rubbing and, shorted field windings or blocked cooling passages in the generator rotor.
- Bearing misalignment can unload some bearings to a point at which oil whip can occur. Also, a resonance can be approached due to changes in the natural frequencies of the rotor. This can be caused by changing the stiffness and vibration dampening properties of the oil wedge and, by reducing the number of bearings that are actually supporting the rotor.
- Operational causes of bearing misalignment include thermal/mechanical deformations of the turbine casing and thermal expansion or settling/cracking of the foundation. Turbine casing deformations result from casing heating/cooling, steam piping forces or forces exerted on the LP turbine exhaust cover when condenser vacuum is established. The latter cause applies only to the units where a flexible joint is used between the exhaust cover and the condenser shell.

- Improper bearing lubrication, particularly when combined with a light load, can cause oil whip. Other bearing problems such as faulty babbitt lining, out-of-round journal or loosened bolts can also increase vibration.
- Unbalanced electromagnetic forces acting on the generator rotor can increase its vibration. A double ground fault in the generator rotor field windings is a typical source of such forces.
- During turbine runup or rundown, the rotor passes through 1-2 critical speed ranges in which a few resonances occur. In rare cases, a resonance can occur even at the normal turbine speed, eg. due to large changes in the natural frequencies of the rotor caused by bearing misalignment.

General operating practices used to prevent excessive rotor vibration

⇔ Obj. 14.1 c)

In the previous subsection, you noticed that some of the causes of rotor vibration are directly related to the way in which the turbine generator is operated. For instance, improper lube oil temperature can result in oil whip. You might also notice that some of the vibration causes are specific to turbine startup, power manoeuvres or shutting down. During these operating conditions, the turbine generator experiences transient heating or cooling – which can increase rotor unbalance and bearing misalignment – and may have to pass through critical speed ranges, to name just a few reasons.

This knowledge of the operation related causes of rotor vibration allows us to use proper operating practices that prevent excessive vibration. These practices include:

1. **Proper startup, loading, unloading and shutdown techniques:**
    a) **Sufficient time on turning gear** to roll out the residual sag or hog of the shaft.
    b) Proper runup, loading and unloading rates to **avoid excessive heating/cooling of the turbine** which could lead to excessive thermal deformations and ADE of the casing and rotor, thereby resulting in bearing misalignment, increased rotor unbalance and possibly rubbing.
    c) During turbine runup and rundown, **proper techniques of passing through the critical speed ranges** (CSRs), including:
        i) During runup, careful evaluation of turbine operating parameters (with emphasis on bearing vibration, HP turbine rotor eccentricity, lube oil temperature, ADEs) before passing through each CSR. The purpose of this evaluation is to ensure that the vibration exciting forces are minimized, and that no important

parameter is so close to its trip level that passing through the CSR could result in or be coincident with a turbine trip. If a margin to trip is small, holding turbine speed for several minutes can often alleviate the problem, eg. bearing vibrations can decrease due to equalization of temperature distribution in the turbine.

ii) During runup, passing through the CSRs as fast as other concerns allow for. If further runup is inhibited, turbine speed should never be held inside a CSR.

iii) Breaking condenser vacuum right after tripping the turbine on high vibration, or low lube oil or generator seal oil pressure. This shortens the duration of passing through the CSRs.

2. **Proper bearing lubrication** (oil temperature, pressure, purity). This prevents oil whip and bearing failure, eg. due to overheating or dirty oil.

Note that many other operating practices, performed mainly for other reasons, can also contribute to prevention of excessive rotor vibration. For example, this applies to operating practices used to prevent upsets and incidents – like water induction or loss of a reheater – which, among other serious problems, could cause very high vibration. Proper turbine maintenance (ie. accurate balancing and alignment following overhauls and repairs) is also important.

Obj. 14.1 d) ⇔

Protective actions performed when rotor vibration is excessive

Recall that rotor vibration is measured at each major bearing. Thus, in a large turbine generator, there might be up to 10-12 vibration signals that are continuously monitored by the turbine supervisory system. The signals are checked against the alarm and trip limits, and appropriate annunciations are given when any of these limits is reached or exceeded.

In most stations, some vibration limits are time and/or turbine speed dependant. This approach reflects passing through critical speed ranges and reduces chances for a spurious annunciation. In some stations, the operator can adjust some vibration alarm limits to a certain margin above the normal running vibration levels. Such "floating" alarm limits more accurately reflect the actual vibratory condition of the machine. If the condition is good, the limits are fairly low, increasing the margin to the trip limit. Hence, when an alarm is received, the operator has more time to react before the vibration reaches the trip limit.

In most stations, the vibration signals are also monitored by the unit DCC control software known as Unit Power Regulator (UPR) and Turbine Runup Program (TRU). This software has its own limits on bearing vibrations and generates its own annunciations when any limit is exceeded. Thus, the operator is well informed about the status of turbine generator vibration.

Depending on the vibration levels, the following protective actions (listed in the order of decreasing vibration levels) are performed:

1. **The turbine generator is tripped** when any vibration has reached the trip limit.

   In most stations, the trip is not automatic. Rather, it is performed manually after the operator has received an annunciation advising him/her to do it. Unless the vibration increase is very sudden, the operator should check, prior to tripping the turbine, that the high vibration signal is legitimate. This approach reflects operational experience with spurious trips due to instrumentation malfunction.

2. **Further runup and loading is inhibited.**

   This action is taken during turbine startup when the appropriate bearing vibration limit has been reached. Normally, this is an automatic action performed by TRU/UPR. In the nontypical case of manual startup, the operator should observe these limits and hold turbine speed/load until the vibration level has decreased satisfactorily.

3. **The operator responds promptly to vibration alarms.**

   The **cause of the alarm should be investigated and corrected**, if possible. For example, the vibration could be caused by loading the turbine too fast, in which case a temporary load holding or a reduction in the loading rate may solve the problem.

   The vibration trend should be closely monitored, particularly when its cause is still unknown or cannot be rectified. Depending on the trend, the operator may have to take further actions as specified in the operating manual. For example, the turbine may have to be unloaded and tripped if the vibration rises too much. Other, less drastic, actions are covered in the station specific training.

   One thing that must be emphasized here is that **any unusual increase in vibration levels**, even if they are still below the trip limit, **must not be ignored**. Remember that this may be an indication of deteriorating operating conditions (eg. water induction in progress) or a mechanical failure (eg. cracks in the rotor)* in an early stage.

SUMMARY OF THE KEY CONCEPTS

- During turbine startup and power manoeuvres, excessive rotor vibration can be prevented by sufficient time on turning gear, selection of the correct rates of turbine runup, loading and unloading, and proper techniques of passing through the CSRs.
- Excessive rotor vibration, caused by oil whip or bearing failure, is prevented by proper lubrication of the turbine generator bearings.

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* For example, in 1990 abnormal vibrations were experienced in the generator bearings in a new CANDU unit. The investigation that followed discovered dangerous cracks in the generator rotor. Should the vibration had been ignored, rotor failure and severe damage to the machine would, sooner or later, have occurred.

- For adequate turbine generator protection from excessive vibration, the operator must respond promptly when a vibration alarm is received. The cause should be identified and corrected, and the vibration trend closely monitored.
- A turbine trip is likely to occur when any bearing vibration reaches the trip limit. In most stations, the trip is done manually after the operator has checked (if circumstances allow) that the high vibration signal is not caused by instrumentation failure.
- When a high vibration occurs during turbine startup, further runup or loading are inhibited.

Pages 27-30 ⇔

You can now answer **assignment questions 1-9**.

BEARING PROBLEMS

Bearing-related problems are one of the main causes of turbine generator outages. While faulty design or manufacturing can be occasionally responsible, the most frequent cause of these problems is improper operating conditions. Information presented in this section will help you understand how various operating conditions affect bearing performance, and what the operator can do to minimize the occurrence of bearing failures.

More specifically, the following topics are discussed in this section:

- Major operational causes of accelerated wear and failure of turbine generator bearings;
- Bearing metal temperature, factors affecting it, its monitoring and actions to be taken when the temperature is too high.

Obj. 14.2 a) ⇔

Major operational causes of accelerated wear and failure of turbine generator bearings

Accelerated wear and failure of turbine generator bearings are usually a result of any one of the following:

1. **Improper lubrication** (inadequate flow, dirty oil, improper oil temperature) which can result in bearing overheating, corrosion by oil contaminants (eg. acidic oxidation products) or scoring of the bearing surface and the mating shaft surface by foreign matter. Improper oil temperature can also cause high rotor vibration which can damage the bearings on its own.
2. **Excessive load** (ie. the force pressing the shaft against the bearing) which leads to bearing overheating. Major causes of such load are described later in this section.

3. Prolonged operation at **high vibration levels** which can result in fatigue cracking of the bearing lining. In tilting pad bearings, the parts (eg. pivots) that support the pads can suffer damage by indentation or fretting. Very high vibration can disrupt the oil film, and the resultant metal-to-metal contact can quickly wipe* the bearing surface.

* Bearing wiping is discussed in more detail below.

One other cause of bearing damage that (due to its specific nature) does not belong to this course is shaft voltages. Through sparking across the oil film, shaft voltages can rapidly cause severe pitting of bearing and journal surfaces. More details on this topic are provided in electrical equipment courses.

⇔ Obj. 14.2 b)

From the above list, you can see that improper lubrication and/or excessive bearing load can result in **bearing overheating**, which can severely damage the bearing. Recall that in turbine generators, bearings are normally lined with a tin- or lead-based alloy known as babbitt or white metal. This alloy is much softer than steel and has good lubricating properties, thereby protecting the rotor in the event of metal-to-metal contact in the bearing.

However, babbitt is sensitive to elevated temperatures. In the extreme case, bearing overheating can result in **melting** of the babbitt lining. Depending on the composition of the alloy, this can happen at a temperature of about 190-240°C*.

* You do not have to memorize the numbers given in this and the next para graphs – they are quoted here only for orientation purposes.

But the bearing temperature does not have to get that high to cause damage. With rising temperature, babbitt strength and hardness decrease sharply, and at about 130-160°C, the metal becomes too weak to resist the shearing forces transmitted through the oil film. The result is smearing of the babbitt in the direction of shaft rotation – the process referred to as bearing **wiping**.

One other way in which overheating can damage a bearing is that it promotes **fatigue cracking** of the babbitt lining when the latter is under cyclic stress (due to vibration and thermal cycling). This is because the fatigue strength of babbitt is greatly reduced at high temperatures.

Of the above damage mechanisms, **wiping** is probably the most common one. Its most drastic cause is a metal-to-metal contact between the babbitt and the shaft when the latter is turning. But, as described above, wiping can also happen without such contact if the babbitt is weakened due to overheating so much that it cannot withstand the shearing forces transmitted through the oil film.

As some babbitt is wiped away, the bearing surface geometry is altered, causing the oil wedge to deteriorate. **High bearing metal temperature and/or vibration result**, possibly forcing a turbine trip. Another possible adverse effect of bearing wiping is that it **can spread babbitt across the jacking oil inlet opening(s)**. This may block or severely restrict the jacking oil supply during turbine rundown. Thus, the bearing will get wiped the second time. You will recall that such loss of oil supply would not only damage the affected bearing(s), but it would also likely trip the turning gear motor on overload, and thus lead to excessive hogging of the machine.

NOTES & REFERENCES

Bearing metal temperature

From the above description, you can see that the bearing metal temperature is a very important parameter that indicates if the bearing is operating in a safe condition. Note that the bearing oil inlet and outlet temperatures reflect the bearing thermal load and general lubricating conditions, and cannot indicate local overheating of the bearing metal.

Bearing metal temperatures are measured by temperature detectors (thermocouples or RTDs) imbedded in the bearing metal. Usually, one detector is installed in each journal bearing and 1-2 detectors on each side of the thrust bearing. An alarm is given when any one of these temperatures is too high.

Typical bearing metal temperatures are about 60-95°C in journal bearings, and about 50-75°C in the thrust bearing, depending on the station. These numbers are quoted here only for your orientation, and you are not required to memorize them.

Obj. 14.2 c) ⇔
Continued below

Bearing metal temperature is influenced by the following **major operational factors:**

1. **Turbine generator speed.**

   The higher the speed, the higher the temperature since more frictional heat is produced in the bearing. Therefore, bearing metal temperature changes are observed during turbine runup and rundown. More information on this topic is given later in this section.

2. **Bearing load.**

   Bearing metal temperature rises with increasing bearing load because more frictional heat is produced in the bearing when the shaft is pressed harder against the bearing surface.

   Obj. 14.2 d)⇔

   In the thrust bearing, its load increases with rising **turbine generator output**. Recall that the main source of the axial thrust on the rotor is pressure differentials across each row of moving blades and blade wheel (if any). As these pressure differentials increase with rising turbine output, so does the bearing metal temperature. You may recall from module 234-1 that this temperature is also used as an indication of excessive axial thrust in the turbine.

   In all bearings, the most common factor affecting their load is usually **misalignment**. You will recall that apart from poor alignment following maintenance, thermal and/or mechanical deformations of the turbine casing and foundation are typical causes of bearing misalignment.

Obj. 14.2 c)⇔
Continued

3. **Bearing inlet oil pressure and inlet and outlet temperatures.**

   When bearing inlet oil pressure decreases, so does the oil flow through the bearing. For a given bearing thermal load and oil inlet temperature, this causes the outlet oil temperature to go up.

The higher the bearing oil inlet and outlet temperatures, the hotter the bearing metal. Recall that the oil inlet temperature, common to all the bearings, is maintained by a temperature controller that adjusts the rate of heat removal in the oil coolers. Loss of cooling water or control failure/malfunction can raise this temperature.

The outlet temperature varies from one bearing to another, depending on the bearing heat load and the oil flow through the bearing. The heat load increases with the bearing load (as more frictional heat is produced in the bearing) and turbine load (as more heat is conducted along the shaft when the turbine steam temperature increases). In turn, the oil flow decreases with dropping oil supply pressure or due to a flow blockage (eg. in the metering orifice in the oil inlet line to the bearing).

4. **Bearing surface condition.**

   Minor scratches in the bearing surface have a negligible effect on the bearing metal temperature. However, a significant deterioration of bearing surfaces can result in abnormally high bearing temperatures. Here is how it happens:

   When a bearing surface is severely scored, its once smooth and uniform oil wedge pressure profile is divided into segments. This impairs the ability of the oil wedge to support the shaft, whose weight squeezes the oil wedge. Since the wedge is thinner, the velocity gradient across it is increased. Therefore, the oil in the wedge is subjected to increased shearing stresses*. As a result, more frictional heat is produced. The thinner oil wedge also makes the bearing more susceptible to further scoring by solid impurities in the oil, or to metal-to-metal contact (wiping) due to high rotor vibration breaking momentarily through the oil film. In all these cases, the bearing metal temperature would rise, and particularly so in the case of wiping.

* Shearing stresses are tangential to the section on which they act. In a fluid, they cause its layers to slide one over another.

⇔ ***Obj. 14.2 e)***

When a bearing metal temperature has risen excessively, an alarm is given. In some stations, the high temperature alarm limits in the thrust bearing and the journal bearings are fixed. But in most stations, these limits are adjusted downwards to stay close* to the normal running temperature. This gives the operator an earlier warning about possible bearing overheating.

* 5-10°C above.

Since bearing overheating can result in serious damage and force a unit outage, the operator should respond **promptly** to high bearing metal temperature alarms. Generally, the operator should take the following actions:

1. **Check the bearing inlet oil temperature and adjust if necessary.** This action may detect and rectify one of the possible causes of the alarm.
2. **Monitor the bearing metal temperature trend.** Further actions depend on how high the temperature is and how fast it is increasing. In the extreme case, **the unit may have to be shut down** for bearing in-

spection and repair. Details on other possible actions are left for the station specific training.

3. **Monitor bearing vibration for increase.** An increase in the vibration levels combined with the increased temperature is a strong indication that the bearing has deteriorated and should be repaired before a more serious failure occurs. Thus, a prudent action would be to unload and shut down the unit before either the temperature or the vibration has reached the trip level.

Obj. 14.2 f) ⇔

Operational experience shows that monitoring bearing metal temperatures can provide an **early warning of bearing deterioration**. Depending on the turbine operating state, that warning can be either of the two following types:

1. **A temperature spike** (similar to the type shown in Fig. 14.2) indicating that the bearing is being wiped. The heat generated during this process causes the bearing metal temperature to increase. Usually, the wiping quickly terminates itself because the self-lapping process that occurs eliminates the metal-to-metal contact. Nonetheless, the bearing/shaft surface has already been damaged.

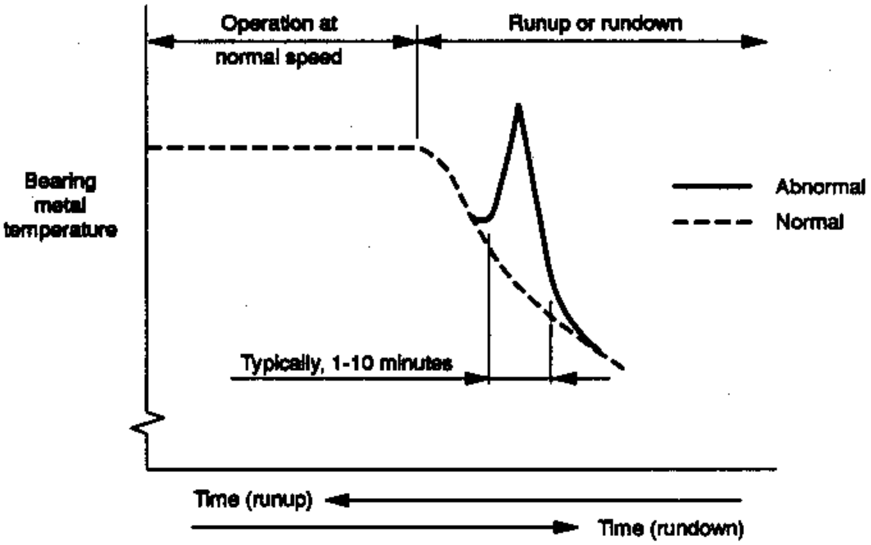

Fig. 14.2. Bearing metal temperature spikes during turbine runup or rundown.

You should recognize that Fig. 14.2 is somewhat generalized. In some cases, temperature spikes can be less pronounced because wiping may generate only a small amount of heat.

Such temperature spikes can sometimes be detected during normal turbine operation. However, they are much more likely to be detected **during turbine runup or rundown**. The reason: at reduced shaft speeds, the oil wedge is thinner, making metal-to-metal contact easier. In this way, it is possible to detect a bearing/shaft surface deterioration that is too small to affect bearing metal temperature during operation at normal speed.

Monitoring for such temperature spikes is **particularly** important during **rundown**, for two reasons:

- The spikes can be more easily detected than during runup because the machine spends more time at low speeds. Note that at low speeds, windage losses are very small, causing the rotor to coast down very slowly.
- Detecting such a temperature spike allows for modification of the outage program such that the bearing can be inspected and, if necessary, repaired. This minimizes chances for discovery of the bearing deterioration during the post-outage startup, which might force another outage.

2. **A gradual increase in the bearing metal temperature during several weeks or months of normal turbine operation.**

With the shaft at the rated speed and normal lubricating oil temperature and pressure, a gradual increase in the bearing metal temperature indicates slow changes in the bearing load or surface condition. These effects have been explained earlier.

In practice, such a slow trend may go unnoticed for a long time. This is particularly true in the stations where bearing metal temperature alarms are fixed, and some of them happen to be well above the normal running temperatures. Therefore, a good operational practice is to compare periodically the actual bearing metal temperatures against a reference temperature profile for all the machine's bearings.

SUMMARY OF THE KEY CONCEPTS

- Accelerated wear and failure of turbine generator bearings are usually caused by improper lubrication, excessive bearing load or high vibration levels. Such operating conditions can result in bearing overheating, scoring or corrosion of bearing surfaces by oil contaminants, or fatigue damage.
- Bearing overheating can ultimately result in melting of the babbitt lining. Less drastic overheating can lead to wiping of the babbitt as it becomes too weak to withstand shearing forces transmitted through the oil film. Also, overheating promotes fatigue cracking of the babbitt lining.
- Bearing metal temperature increases with rising shaft speed and bearing load as more frictional heat is generated in the bearing. Also, the bearing becomes hotter, when the oil inlet and outlet temperatures are increased.

NOTES & REFERENCES

Severe scoring of the bearing surfaces can also raise the bearing metal temperature.

- The thrust bearing load increases with turbine output as it causes pressure differentials across each row of moving blades to rise. In journal bearings, the most common factor affecting their load is misalignment.
- When a high bearing metal temperature alarm is received, the operator should do the following: check (and adjust if necessary) the bearing inlet oil temperature, monitor bearing vibration for increase and monitor the temperature trend. The turbine may have to be shut down for bearing inspection and repair when the temperature is too high or rising too fast or if it is accompanied by high vibration.

Pages 30-33 ⇔

You can now answer **assignment questions 10-16.**

BLADE PROBLEMS

Typical operational problems that impair turbine blade performance and may result in their failure are **deposits, erosion, corrosion and vibration**. The first two of these problems have already been covered in modules 234-1 and 234-2. Recall that blade deposits and erosion reduce turbine efficiency, increase maintenance costs and probability of blade failure.

Obj. 14.3 a) ⇔

Speaking of **blade failures**, it is usually a part of the blade shroud, a lacing (tie) wire or an erosion shield that breaks off. But in the extreme case, a whole moving blade can crack at its root. Due to high stress levels, the **long moving blades in the LP turbine** are the most susceptible.

The **adverse consequences/operating concerns** caused by blade failure vary, depending mainly on the mass of the broken off fragment.

1. In **the worst case**, one or more of the long moving blades in an LP turbine may break off, pierce the turbine casing and become **turbine missiles.**
2. In a **less severe case**, no turbine missiles are created but damage can still be substantial as the broken blade(s) can **shear off or bend many other moving blades** when interfering with their motion. The resultant unbalance can produce **very high vibrations** which can easily result in extensive damage to the whole machine as described earlier. An extended outage, costing millions of dollars in lost revenue and repairs, would result.
3. In the **least severe case**, only a small fragment of a blade (such as a piece of a blade shroud, lacing wire, erosion shield, etc.) breaks off. Driven by steam, the broken fragment can cause **impact damage** to other turbine components (blades, discs, etc.). Even if no damage results, bearing **vibrations can rise** due to increased unbalance, possibly forcing a turbine trip. Also, cracking or loss of the blade's shroud or

lacing wire **changes the natural frequencies of the blade.** This can lead to a serious blade fatigue failure due to resonant vibration.

The most common causes of blade failures are stress corrosion cracking and fatigue cracking due to excessive blade vibration*.

* Together they are responsible for about 50% of all blade failures.

Stress corrosion cracking (SCC) is described in chemistry courses. You will recall that SCC is caused by a combination of high tensile stresses and a corrosive environment to which the stressed component's material is susceptible. In large steam turbines, potential conditions for blade SCC exist in the last stages of the LP turbine where the long moving blades are subjected to large centrifugal stresses and the wet steam can deposit corrosives (eg. chlorides) in highly stressed areas such as blade roots or lacing wire holes. And the blade material (stainless steel) is susceptible to some of these contaminants. Therefore, an effective operating practice that, among other advantages, prevents SCC of turbine blades is maintenance of proper purity of boiler steam.

Discussed in the section below is the other common cause of blade failures, that is blade vibration. You will learn there about the major causes of blade vibration as well as the general operating practices that are used to prevent blade fatigue failures.

BLADE VIBRATION

⇔ Obj. 14.3 b)

Causes

Blade vibration can be induced due to any one of the following major stimuli:

1. **Nozzle impulse effect.**

   This is the most common way in which steam flow excites blade vibration. When moving blades pass through the aerodynamic wake of fixed blades (Fig. 14.3), they experience rapid changes in the steam forces. The pulsating forces stimulate the blades to vibrate.

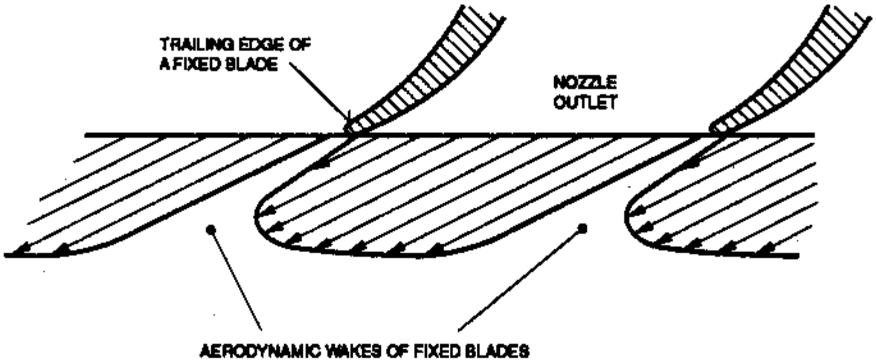

Fig. 14.3. Simplified steam velocity distribution at the nozzle outlet.

The nozzle impulse effect is present in **all turbine stages**. It can excite very high vibration levels if some blades are in resonance. While major resonances are prevented by proper blade design, some operational conditions may bring such a resonance about. This will be discussed later on in this section.

2. **Stall flutter** (also called *aerodynamic buffeting*).

   This term refers to flow-induced vibration of moving blades that can occur in the **last 1-2 stages of the LP turbine**. Recall that during runup and at very light/no load conditions (and particularly when condenser vacuum is poor), the volumetric flow of steam in the last stage(s) of the turbine is drastically reduced. As the blade passages are much too large to handle this flow, its pattern deteriorates. The pressure distribution over the blade surface becomes unstable, producing pulsating steam pressure forces that act on the blades.

   The resultant blade vibration, if large enough, can further contribute to the instability of the pressure distribution. When the frequency of these pressure pulsations coincides with a major natural frequency (as opposed to higher harmonics) of the moving blades, their vibration amplitude greatly increases due to resonance. Note that there is a large similarity between stall flutter of turbine blades and flutter of a flag caused by a wind.

3. **Rotor vibration.**

   High rotor vibration (not only flexural, but also torsional) can induce vibration of long moving blades, simply because they are attached to it. However, compared with the steam flow, rotor vibration is usually a much weaker stimulus.

The above list is limited to the most common causes of blade vibration. Other causes are ignored because either they cannot produce large blade vibration or they are station specific, ie. closely associated with the turbine design used in a particular station.

From the above description, you might notice that blade vibration becomes troublesome when a resonance occurs. This happens much easier in the LP turbine where, in the last stages, the moving blades are much longer than anywhere else in the turbine. As a result, their natural frequencies are relatively low, approaching the range of the major vibration exciting frequencies.

Factors accelerating blade fatigue failure

Operational experience shows that fatigue failure of a turbine blade can be **accelerated by** the following factors:

1. **Corrosion.**

   Recall that corrosion fatigue (ie. a combined action of a cyclic stress and a corrosive environment to which the material is susceptible) can expedite blade failure as compared with fatigue alone.

2. **Erosion.**

   By producing notches on the blade surface, advanced erosion of moving blades results in stress concentration. Another effect is that the blade's natural frequencies change as the blade material gets eroded away. This may promote a resonance.

SUMMARY OF THE KEY CONCEPTS

- Blade failure can cause large scale damage to the turbine. In the worst case, one or more of the long moving blades in an LP turbine may pierce the casing and become turbine missiles. In a less severe case, the broken blade(s), interfering with the motion of other blades, can shear off or bend some of them. The resultant very high vibration can destroy turbine generator bearings, seals, oil lines, etc.
- When only a small fragment of a blade shroud, lacing wire, erosion shield, etc. breaks off, some impact damage to the downstream components may follow. Even with no impact damage, bearing vibrations may rise, due to rotor unbalance, enough to force a turbine trip. Also, cracking or loss of a blade shroud or lacing wire can lead to a serious blade fatigue failure due to resonant vibration.
- Most turbine blade failures have been caused by their stress corrosion cracking and fatigue cracking due to excessive vibration. Long moving blades in the last few stages in the LP turbine are most susceptible to such failures.
- The most common causes of blade vibration are the nozzle impulse effect, stall flutter and rotor vibration. The latter is usually the weakest stimulus of blade vibration.
- The nozzle impulse effect excites moving blades to vibrate when they pass through the aerodynamic wake of the fixed blades where steam velocity, and hence thrust on the blades, rapidly changes. The effect is present in all turbine stages and can excite very high vibrations when some blades are in resonance.
- Stall flutter is caused by instability of the steam pressure distribution over the surface of moving blades, thereby producing pulsating pressure forces acting on the blades. When the frequency of these forces coincides with a blade natural frequency, the vibration amplitude rises considerably. Stall flutter can occur in the last 1-2 rows of moving blades in the LP turbine when the volumetric steam flow is drastically reduced.

NOTES & REFERENCES

This can happen during turbine runup or light/no load operation if condenser vacuum is poor.

- Blade fatigue failure can be accelerated if vibration is accompanied by a corrosive (like chlorides) to which the blade material is susceptible. Advanced erosion can expedite fatigue failure by concentrating the cyclic stress in the eroded areas and by changing the blade natural frequencies. The latter effect can lead to blade resonant vibration.

Obj. 14.3 c) ⇔

General operating practices used to prevent blade fatigue failures

The two major operating practices that are used in all stations to prevent blade fatigue failure are:

1. **Maintenance of proper condenser vacuum.**

   This practice prevents failure of the long moving blades in the last stage (s) of the LP turbine. Recall that these blades are heavily loaded by centrifugal stresses. Also, due to their length, the blades have relatively low natural frequencies which makes them susceptible to resonant vibration. For these reasons, these blades are more prone to failure than any other blades in the turbine.

   Maintaining proper condenser vacuum improves the operating conditions of these blades. As the steam temperature and density are reduced, so are thermal stresses in the moving blades*. During runup and operation at light/no load, proper condenser vacuum also minimizes **stall flutter**.

   * Details are given in module 234-5.

2. **Limitations on underfrequency/overfrequency operation.**

   For the reasons explained in the section below, underfrequency or overfrequency operation can result in resonant vibration of some turbine blades. To prevent their fatigue failure, the duration of these modes of operation is limited. In the extreme case, the turbine must be tripped.

In addition, blades are thoroughly inspected during turbine overhauls to detect unacceptably large cracks. Replacement or repair of such blades decreases a chance of their fatigue failure in the future.

Obj. 14.3 d) ⇔

Underfrequency/overfrequency operation

Modern technology allows us to keep the grid frequency oscillations very small*. On rare occasions, however, serious grid problems may cause a sustained deviation of the frequency slightly below or above 60 Hz. Such operating conditions of the grid are referred to as *underfrequency* or *overfrequency operation.*

* Normally, the oscillations do not exceed ±0.02 Hz.

These modes of grid operation can be caused, for example, by a severe grid upset that can break down the whole grid into isolated islands of generation and load. Inside these islands, a generation/load mismatch would result in abnormal frequency conditions. Severe shortage of generating capacity may also force the System Control Centre to deliberately reduce the grid frequency because each 1% decline in the grid frequency decreases the grid load by 1-2%. This may allow the System Control Centre to avoid blackouts.

During **these abnormal modes of grid operation**, the frequency deviation is up to ±4%, though usually it is much less. Consequently, the speed of all turbine generators connected to the grid varies accordingly. This change in speed **may result in dangerous levels of blade vibration** in some turbine stages due to resonance.

Here are the **reasons** why a few percent change in turbine speed may result in resonant vibration of some moving blades:

1. The nozzle impulse effect generates many vibration **exciting** (forced) **frequencies**, and they all **vary with turbine speed.**

   Recall that the nozzle impulse effect excites moving blade vibration due to their passing through the aerodynamic wake of the fixed blades. The higher the turbine speed, the larger the number of the wakes that each moving blade passes through every second, and therefore, the higher the blade vibration exciting frequencies.

   The individual wakes are somewhat different, mainly due to irregularities in the fixed blade shape and pitch. Therefore, passing of moving blades through these wakes generates vibrations at **several** exciting frequencies.

2. The moving blades have **many natural frequencies**, and some of them are **close to vibration exciting frequencies.**

   There are a few reasons for the large number of natural frequencies. First, the moving blades in different stages are of different shape and length. Thus, the blades in different stages have different natural frequencies.

   Second, each set of blades has infinitely many natural frequencies corresponding to different types of vibration (flexural and torsional) and their consecutive harmonics.

   Third, individual blades used in a given stage are not perfectly identical. Nor is the stiffness of their attachment to the rotor. As a result, individual blades in the stage have natural frequencies that can be a few percent different from those of some other blades in this stage. This increases chances for resonant vibration of some blades in this stage.

From the above, you can see that prevention of a major blade resonance (ie. a resonance involving a strong stimulus of blade vibration) is not easy. After all, with so many natural frequencies and strong forced frequencies present, it is not difficult for a resonance to occur. While at the normal turbine speed major blade resonances are avoided, some margins to resonance are fairly narrow. This is why a change in turbine speed, as small as a few percent, may result in some turbine blades approaching dangerous resonant vibration. As mentioned earlier, due to their relatively low natural frequencies, the moving blades in the last few stages in the LP turbine are primary candidates for resonant vibration.

When a resonance is approached or reached, blade vibration rises. The larger the grid frequency deviation *(Δf)*, the smaller the margin to resonance and hence, the higher the vibration.

As long as *Δf* does not exceed ±1%, operation can be continued without reducing blade life. For larger frequency deviations, the **duration of underfrequency/overfrequency operation is limited to prevent fatigue failure of turbine blades.** Typical limits are shown in Fig. 14. 4. While you do not have to memorize these limits, you should know that the allowable duration of operation decreases quickly with rising *Δf*, and that the turbine must be tripped immediately when *Δf* exceeds ±4%.

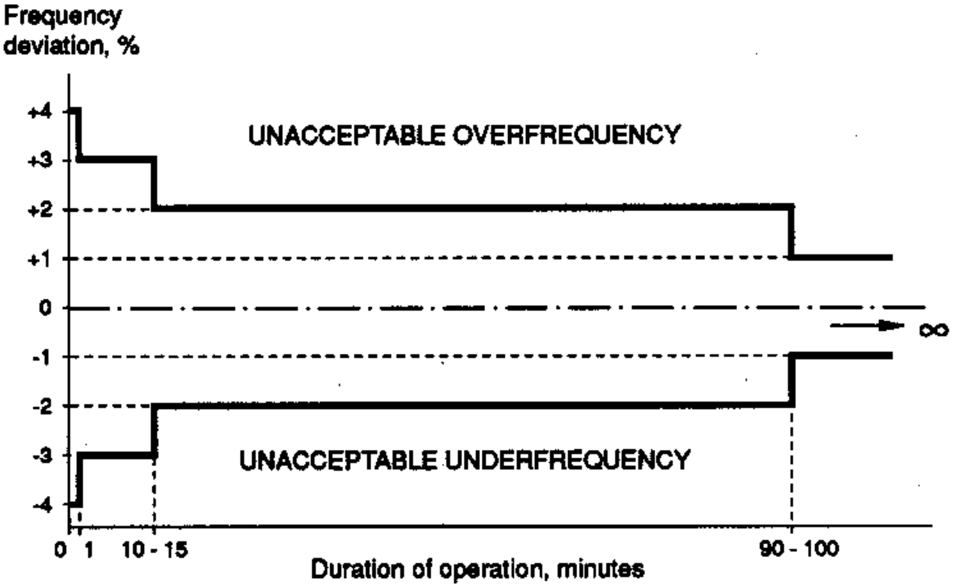

Fig. 14.4. Limitations on the duration of off-frequency operation.

A few extra comments are in order here. First, **the above limits apply only to full power operation.** At partial loads, the nozzle impulse effect is weaker due to reduced steam density*. Thus, for the same *Δf*, the vibration amplitude is smaller, allowing for longer operation. During runup and actual overspeed tests, the nozzle effect is so weak that it does not limit their duration.

Second, since fatigue damage is cumulative, **past incidents of underfrequency/overfrequency operation decrease these limits.** For exam-

* Recall from module 234-1 that turbine steam pressure (and thus, density) get smaller with decreasing turbine load.

ple, if the turbine has once operated for half a minute at 4% frequency deviation, then only half of these limits remains available for the rest of the life of the machine.

Third, the above limits are **generalized and somewhat conservative**. Their actual values, which vary slightly from one station to another, are specified in the turbine operating manual.

Finally, underfrequency operation can also cause some electrical problems in the generator and its output transformers. Details on these problems can be found in the appropriate electrical courses. While these problems result in some limits on generator operation, they are usually less restrictive than those imposed on the turbine to protect its blading from resonant vibration.

SUMMARY OF THE KEY CONCEPTS

- Fatigue failure of turbine blades is prevented by maintaining proper condenser vacuum and limiting the duration of underfrequency and overfrequency operation.
- Maintaining proper condenser vacuum minimizes mechanical and thermal stresses in the moving blades in the last stage(s) of the LP turbine. Stall flutter of these blades is also minimized.
- Underfrequency/overfrequency operation can easily cause resonant vibration of some moving blades, particularly in the last stages of the LP turbine. While at the normal turbine speed major resonances are avoided, margins to some resonances are fairly narrow. Two factors contribute to it. First, the blades have many natural frequencies that must be avoided. Second, the nozzle impulse effect generates many strong forced frequencies which vary with turbine speed.
- To prevent fatigue failure of some turbine blades, the duration of underfrequency/overfrequency operation is limited when the grid frequency deviation (*Δf*) exceeds ±1%. With increasing *Δf*, the allowable duration of operation rapidly decreases. And, when the *Δf* exceeds ±4%, the machine must be tripped immediately.

You can now answer the **remaining assignment questions**.

⇔ ***Pages 33-35***

ASSIGNMENT

1. Excessive turbine generator rotor vibration can damage the machine in the following ways:

   a) Type of damage: ____________________

   Examples of components that may suffer this damage:

   A ____________________

   b) Type of damage: ____________________

   Examples of components that may suffer this damage:

   ____

   c) Type of damage: ____________________

   Examples of components that may suffer this damage:

   ____

2. The most common causes of turbine generator rotor vibration are:

   a) ____________________

   b) ____________________

   c) ____________________

   d) ____________________

   e) ____________________

3. Permanent changes in the rotor unbalance can occur due to the following operational causes:

   a) ____________________

   b) ____________________

   c) ____________________

   d) ____________________

   e) ____________________

4. A temporary bowing of the rotor, leading to a change in its unbalance, can be caused by:

   a) ____________________

   ____

   b) ____________________

   ____

c) ______________________________

d) ______________________________

5. Bearing misalignment can cause increased rotor vibration in the following ways:

a) ______________________________

b) ______________________________

c) ______________________________

6. Bearing alignment can change due to the following operational causes:

a) ______________________________

b) ______________________________

7. a) Bearing malfunction can cause increased rotor vibration as follows:

____

____

____

____

____

____

____

b) A classic cause of unbalanced electromagnetic forces, that can excite vibration of the generator rotor, is ________________

____

____

8. a) To prevent excessive turbine vibration during runup, turbine supervisory parameters (especially: ____________________

____)

should be carefully evaluated before passing through each critical speed range (CSR).

i) How can this evaluation prevent excessive vibration?

____

____

____

____

____

ii) If, as a result of such evaluation, passing through the CSR is delayed and turbine speed held constant for several minutes, how can this help minimize turbine vibration?

____

____

____

____

b) What other practices are used during turbine startup to prevent excessive rotor vibration?

i) ______________________________

____

ii) ______________________________

____

iii) ______________________________

____

c) One other operating practice that can prevent excessive rotor vibra-

tion during all turbine operating conditions is ______________

____

9\. a) Suppose that a high bearing vibration alarm was received during normal turbine operation, but the vibration level is below the trip setpoint. If you were the operator, what would you do to ensure adequate turbine generator protection?

i) ______________________________

____

____

ii) ______________________________

____

____

b) If a similar situation occurred during manual turbine startup, what action would you take to minimize the vibration?

____

____

c) In either case, if the vibration were rising and its indication were legitimate (no instrument malfunction), what will you eventually do for turbine generator protection?

____

10\. In most cases, accelerated wear and eventually failure of turbine generator bearings are caused by:

a) ______________________________

____

b) ______________________________

____

c) ______________________________

____

11. Bearing overheating can damage the bearing in the following ways:

a) ______________________________

b) ______________________________

c) ______________________________

12. a) When turbine speed increases, the bearing metal temperature (decreases / increases) because ______________________________

____

b) When bearing load increases, the bearing metal temperature (decreases / increases) because ______________________________

____

c) When bearing inlet oil pressure drops, the bearing metal temperature (decreases / increases) because ______________________________

____

____

d) A significant deterioration of bearing surface condition can result in abnormally high bearing temperatures because ______________________________

____

____

____

____

____

____

____

____

____

13. Two operational factors affecting the bearing load are:

 a) ______________________________

 b) ______________________________

14. If you were the operator, what actions would you take in response to a high bearing metal temperature alarm?

 a) ______________________________

 b) ______________________________

 c) ______________________________

15. Operational experience shows that a bearing metal temperature spike detected during turbine runup or rundown can indicate early bearing deterioration:

 a) Why can bearing deterioration produce such temperature spikes?

 ____

 b) Why are such spikes much less likely to occur during normal turbine operation?

 ____

c) Why is monitoring for such temperature spikes particularly important during turbine rundown?

i) ______________________________

____

____

ii) ______________________________

____

____

16\. a) What is the other way in which monitoring bearing metal temperature can early warn about bearing deterioration?

____

____

b) How can we improve chances of noticing this indication?

____

____

17\. a) The most common causes of blade failures are:

i) ______________________________

ii) ______________________________

b) Consequences of blade failure on turbine operation can be as follows:

i) In the worst case, ie. breaking off of a long moving blade in an LP turbine: ______________________________

____

ii) In the case of failure of a smaller blade or its part: ______

____

____

____

____

____

iii) In the case of loss of a small part of a blade (such as ______):

______

______

______

______

______

18. a) Steam flow can induce blade vibration in the following ways:

i) ______

Description:

______

______

______

______

______

ii) ______

Description:

______

______

______

______

______

______

b) Another stimulus of blade vibration is ______

c) Fatigue failure of a turbine blade can be accelerated by:

i) ______

ii) ______

d) Blade fatigue failures are prevented by the following general operating practices:

i) ______

ii) ______

19. a) The major hazard of underfrequency operation is that it can damage the turbine generator due to resonant vibration of the rotor. (False / true)

    b) Underfrequency/overfrequency operation can easily result in resonant vibration of some turbine blades. (False / true)

    c) Overfrequency operation is dangerous mainly because of excessive centrifugal stresses in the rotor. (False / true)

20. A relatively small change in turbine speed can result in increased levels of blade vibration because:

    a) ____

    ____

    b) ____

    ____

21. a) Turbine operation is limited by underfrequency/overfrequency conditions as follows:

    i) Δf up to 1% – ____________________

    ii) 1% < Δf ≤ 4% – ____________________

    iii) Δf above 4% – ____________________

    where Δf is the frequency deviation from the normal 60 Hz.

    b) These limits:

    i) Apply to operation at full power. (False / true)

    ii) Apply to turbine runup, rundown and actual overspeed testing. (False / true)

    iii) (Are / Are not) affected by the past incidents of underfrequency/overfrequency operation of the turbine because

    ____

To complete this last module, **review the objectives** and make sure that you can meet their requirements.

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