Differential expansion of steam turbine generators

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Turbine Supervisory Instrumentation

Modern vibration monitoring instrumentation systems are also specifically designed to perform critical measurements which are used in the control of large steam turbine generator trains. One of the most important measurements is that of differential expansion. This application note discusses the principles behind the differential expansion measurement itself.

Differential expansion

Differential expansion monitoring measures the change in axial clearances between the machine rotor and casing caused by thermal changes inherent in most machines. The primary purpose of a differential expansion monitor is to guard against axial rub between rotating and stationary parts. This measurement is typically performed on larger steam turbines. Excessive differential expansion can produce one of the most catastrophic failures of rotary machinery (resulting in very expensive repairs and possibly machine replacement).

The differential expansion measurement should not be confused with other axial position measurements such as rotor position and thrust position measurements. These measurements are designed to measure the axial position of the rotor within the machine train, with minimal or no effects from machine thermal changes. The parameters are equally important for proper machine protection. However, the location and application of these measurements are completely different than that of the differential expansion measurement. When discussing differential expansion, there are two basic machine conditions that can occur during machine operation:

- The rotor long condition
- The rotor short condition

Differential expansion – rotor long

When high temperature steam is applied to the machine (as during a machine startup), the rotor thermally expands at a faster rate than the machine casing because of its smaller mass and different metallurgy. When the rotor grows faster than the casing, the condition is referred to as a “rotor long” condition (the rotor is growing long with respect to the case). If the rate of rotor growth in relation to the rate of casing growth is not controlled, the moving and stationary parts of the machine come into contact. To control the system’s rate of expansion, steam temperatures and flows are controlled. Turbine soak periods further control the expansion process. “Soak period” is a term that describes the amount of time, and the machine speed, at which the machine is held to allow the machine’s casing to thermally expand and catch up to the rotor assembly. During these periods, steam temperatures and flows are...
strictly maintained to prevent diminishing the machine's internal clearances. Figure 1 represents a typical turbine double flow low pressure stage. As the rotor grows longer, clearances between the rotor mounted blade rows and the case mounted diaphragms diminish. Care should be taken to seal steam temperatures applied to the unit, as excessive seal steam temperatures have been known to cause excessive differential expansion values during machine startup procedures.

### Differential expansion – rotor short

The rotor short condition typically occurs during steady state operation. “Rotor short” describes the condition where the rotor shrinks with respect to the machine case. As with the rotor long condition, when the machine is subjected to a sudden temperature change the motor reacts first due to its smaller mass and differing metallurgical properties. To cause a rotor short condition, a cooling force must be applied to the rotor assembly.

This cooling effect is typically caused by a drastic reduction in steam temperature or flow within the machine and is normally referred to as “quenching the rotor”. Subjecting the rotor to this cooling effect causes the rotor to shrink with respect to the machine case, thus diminishing internal clearances in the rotor short direction. If this quenching action exceeds acceptable limits, the rotor short condition can occur very quickly. Acceptable limits in the rotor short direction are typically small when compared to those for the rotor long direction. The typical machine is designed to have larger internal clearances in the rotor long direction, as this condition is typical during the machine startup process. The rotor short condition however is designed to have smaller clearances to increase unit efficiency, as this condition typically should not occur during normal operation. Figure 2 represents a typical turbine double flow low pressure stage. As the rotor contracts, as in a short rotor condition, clearances between the rotor mounted blade rows and the case mounted diaphragms diminish.

### Understanding the machine

To accurately measure differential expansion, it is important to understand the machine's basic thermal characteristics. Without that, a full understanding the machine's characteristics, a full understanding of how to retrofit the unit or how to set up the differential expansion system cannot be achieved. Although each installation is configured slightly differently, understanding the machine and how it is designed to move puts you on the right track to a successful installation.

The first and most important thing to understand is that the metal alloys and castings used in the fabrication of turbine rotors and cases expand or grow as a temperature increase is applied to the material. Restricting the thermal growth of either the case or the rotor may cause internal damage to the turbine. To prevent an increase in stresses placed upon the turbine casings and rotor assemblies, all machines are designed to allow unrestricted growth of these parts.

### Rotor expansion

To allow unrestricted growth of the turbine rotor assembly, the machine rotor is restricted from axial movement within the machine case at one fixed point and allowed to move from that point. The point at which this attachment is made is at the machine's thrust bearing. Figure 3 and Figure 4 represent two examples of turbine generator machine trains.

In Figure 3, the thrust bearing is located in the machine's front standard or pedestal. The rotor assembly is restricted from movement at this point. In this example, all rotor expansion is toward the generator. Only one differential expansion measurement is required due to unidirectional growth of the entire rotor assembly.
In Figure 4, the thrust bearing is located at pedestal number two, between the low pressure and high pressure casings. The rotor assembly is restricted from movement at this point. Since the rotor assembly is restricted from movement at this point, the high pressure rotor grows or expands toward the governor end of the machine, while the low pressure rotor expands or grows toward the generator end of the machine from the thrust assembly.

Due to the bipolar growth of the rotor assembly, two differential expansion measurements are required.

One measuring high pressure rotor differential expansion and one measuring low pressure differential expansion.

The effect of casing and rotor expansion

In Figure 3 the high pressure case grows toward the governor as the rotor grows toward the generator (in response to an increasing temperature change). Under these conditions it would seem that the two machine components would quickly diminish internal clearances within the machine (as the growths occur in opposite directions). However, this is not the case, as the thrust assembly is located within, and physically attached, to the front pedestal.

This attachment of the thrust assembly to the pedestal is the key to maintaining machine clearances.

As the machine reacts to an increasing temperature change, the rotor reacts first, growing long toward the generator. To maintain internal clearances, the case expands toward the governor. Since the thrust assembly is attached to the case, the relative position of the rotor within the machine is physically changed by the case growth.

This design maintains clearances by changing the rotor’s axial position within the machine (for example, pulling the rotor toward the governor) as the rotor expands toward the generator.

In Figure 4 the machine configuration differs as the governor side half of the double flow low pressure section, the thrust bearing pedestal, the high pressure case, and the front pedestal are free to expand or grow toward the governor end of the machine. The generator half of the double flow low pressure section case is free to move toward the generator. Due to the location of the thrust assembly, both the high pressure case and rotor expand in the same direction in response to an increasing temperature change, thus maintaining internal clearances.

To maintain internal clearances of the governor side low pressure section, the case starts to expand toward the governor. Since the thrust assembly is attached to the case, the relative position of the rotor within the machine is physically changed by the case growth. Hence this design also maintains clearances by changing the axial position of the rotor within the machine (for example, pulling the rotor toward the governor) as the rotor expands toward the generator.
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