The GE Frame 5 combustion turbine is operating in power generation and other plants worldwide. Many of these turbines are aging, however, and require repairs and refurbishments. Identifying components that need replacement requires an effective diagnostic process.

This article suggests best practice for conducting such diagnostics, while identifying many of the common components that should be carefully examined within the scope of a typical unit refurbishment. In addition, certain advanced tools, such as vibration analysis, are described that shed light on conditions internal to the turbine (Figure 4).

The marriage bolts, from the compressor to the turbine and the first stage wheel to second stage wheel, are particularly challenging to diagnose because conventional methods involve disassembling the unit’s rotor for examination. Early diagnosis of a unit requires advanced multi-plane orbital analysis software, historical data, and intermittent data.

**Guidelines for operators**

One power producer, delivering electricity to around 3.3 million customers in the Northeastern U.S. called on HPI in Houston to help diagnose the cause of abnormal vibrations affecting a backup GE Frame 5 gas turbine (Model J, 15 MW) for emergency power in one of its facilities. The system is a “black start” generator used to restart this particular power station in the event of a power outage.

After performing a thorough inspection, it was determined that the root cause of the problem was deterioration of turbine wheel marriage bolts. With these bolts compromised, the turbine became misbalanced and the rotor was no longer rigid.

The Frame 5 had been installed in 1969 and refurbished in 1991, according to plant representatives. For the most part, refurbishments on the Frame typically involve repairing the compressor and marriage bolts or placing new blades on the wheel, but few include inspecting the marriage coupling on the first stage wheel.

The initial borescope investigation revealed that the 1st stage rotating buckets were missing trailing edges. Large amounts of metal were missing.

The actual reason for the vibration was the missing pieces of the marriage bolt locking segments. Two bolts rarely break at once but that had apparently occurred. It was hypothesized that the turbine wheel marriage bolts had cracked some time ago and the cracks had propagated under persistent stress.

Most likely, when the marriage bolts failed, the locking segments broke immediately thereafter. As shown in Figure 1, the two pieces were each about 1.5 X 2.0 X 4.5 inches. This imbalance induced abnormal vibration in the rotor, which caused the 1st stage bucket tips to contact the shroud and break off (Figures 2, 3). Because the blades were old and hardened, they broke easily. Fortunately, the locking segment and turbine wheel marriage bolts did not go into the rotating equipment but hit stationary pieces, otherwise the damage to the turbine could have been catastrophic.

Several key discoveries from the aforementioned incident provide guidance to other operators of old GE Frame 5 turbine systems. They are given below. Once the turbine is open for refurbishment, the shop inspection process must determine if the turbine wheel marriage bolts are mechanically sound. To do this, they must be examined and tested thoroughly.

Torquing the bolts could reveal significant cracks in the bolts, but will not necessarily identify minor cracks. The marriage bolts should at least be removed and carefully examined to assess for stress cracks. Preferably, at that point the bolts would be replaced, but knowing the condition of the bolts may provide insight into other aspects of turbine operation.

The condition of the marriage bolts reflect other aspects of the turbine, such as turbine wheel health, alignment of rotor, and the health of bearings, seals and so on. If predominant cracks are found in many of the turbine wheel marriage bolts, other turbines placed in operation around the same time may have similar cracks. Alternately, it may reduce cost and avoid risk to take the turbine down for refurbishment based on total hours of operation alone to conduct preventive maintenance, rather than conducting maintenance when problems are identified.

**Preventive diagnostics**

Clearly, the industry needs better methods and tools to diagnose mechanical conditions of turbine components, which can save time and avoid lost production. Advanced vibration analysis, which tracks changes in vibration patterns over time, may be one such method.

Vibration may not change significantly while the phase angle will change to a greater extent. When the turbine marriage bolts begin to crack, the torque on the bolts will drop, relaxing the marriage joint. This relaxation, in turn, will affect changes in the phase angle. Other factors, of course, also affect changes in phase...
angle vibration, such as loss of a blade, but sudden, pronounced changes are more easily identified by observation and conventional means.

While instantaneous vibration analysis, as a current snapshot, has been employed for years as a diagnostic tool, more advanced tools are needed to reliably detect rotational anomalies. The new gas turbines are being equipped with seismic systems to detect warping in shaft rotation.

If the turbine is younger, for instance, multi-plane vibration analysis may reveal cracking in the marriage bolts, among other internal conditions, that are otherwise difficult to assess and diagnose. A phase angle vibration system with a seismic or proximity probe, which monitors distance between the probe pick-up and rotor, could be captured on regular time intervals and monitored over time for phase angle changes. Standard process monitoring systems, equipped with a robust process historian, could be used to historize, chart and display the value of phase angle versus time.

**Focus on marriage bolts**

While the case study mentioned is a single instance, it serves to highlight that turbine wheel marriage bolts on older GE Frame 5 turbine systems are subject to cracking and should be examined during overhaul. Even though gaining access to the turbine marriage bolts is labor-intensive, substantial risk may exist for the overall integrity of the turbine when even two of these bolts fail. Advanced diagnostic tools based on vibration analysis and changes to the phase angle can indicate possible bolt cracking.

**Author**

Jim Vines heads the Mechanical Group at HPI (www.hpi-llc.com), which provides turbine solutions including retrofit control, mechanical inspection, overhaul, turnkey engineering, and construction of power plants. Vines has worked with turbine systems for over 40 years and has extensive experience on Westinghouse, GE, Pratt and Whitney and other gas turbines.