STEAM TURBINE 101

Steam turbines for insurance professionals

An introduction and overview into Steam Turbine Power Generation Systems, their risk management and insurance considerations

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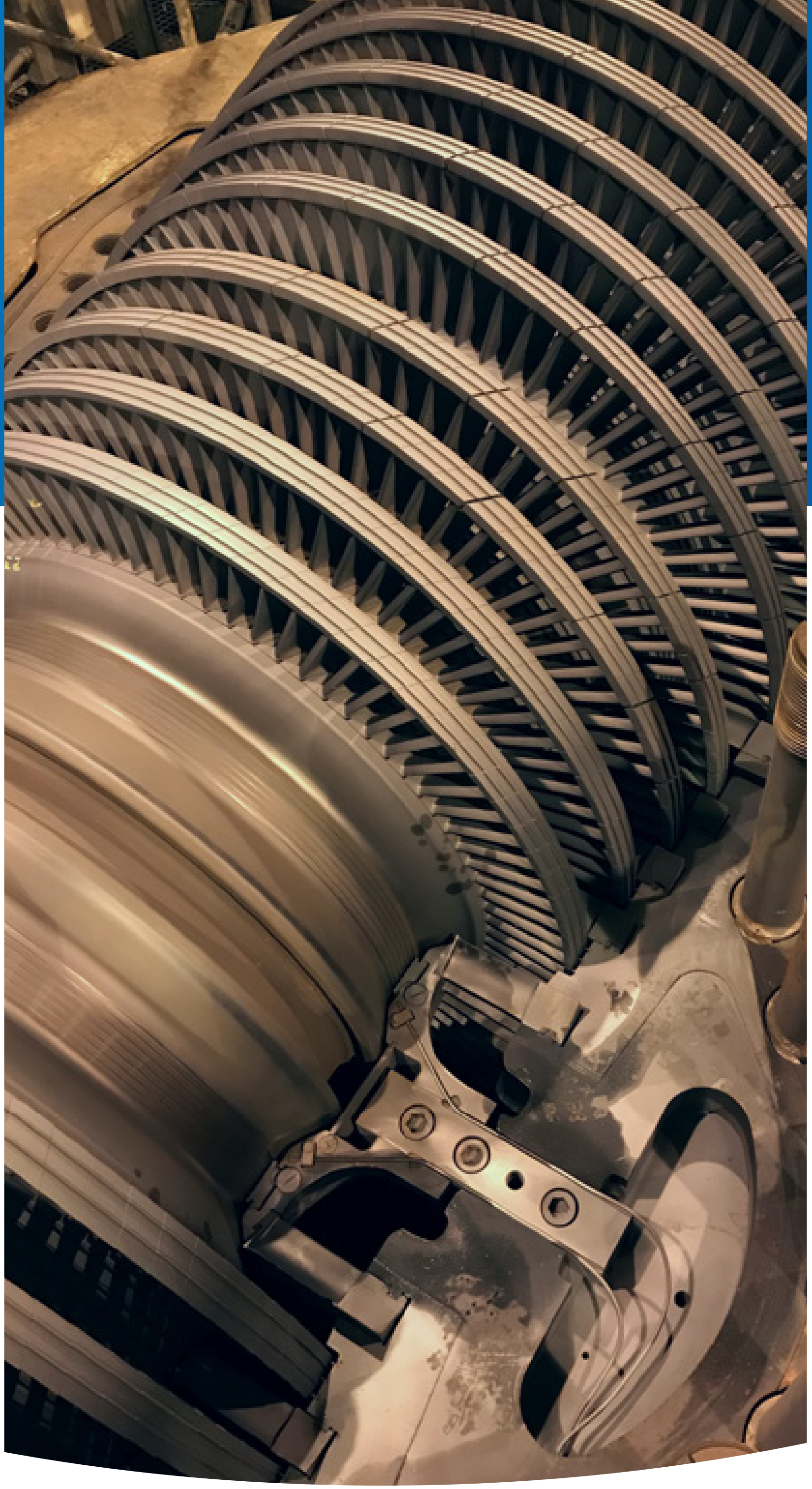
Principal author: Donald McNelly
donald.mcnelly@us.crawco.com

Contributor: Martin Dobson
martin.dobson@crawco.co.uk



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Introduction

No machine has powered humanity more than the steam turbine. To date, generators powered by steam turbine engines have produced far more gigawatt-hours than any other type of power plant. Steam turbines are a mature technology typically associated with coal, natural gas and nuclear power plants.

Steam turbines reached a plateau in efficiency and technology in the 1990s-2000s, and the development of new and more efficient steam turbines has stagnated. Some might suggest that the increasing buildout of renewable energy power stations may lead to a world where the steam turbine has less relevance. However, the steam turbine continues to be an effective device for converting thermal energy into electrical power and will likely always have a slice of the global energy pie.

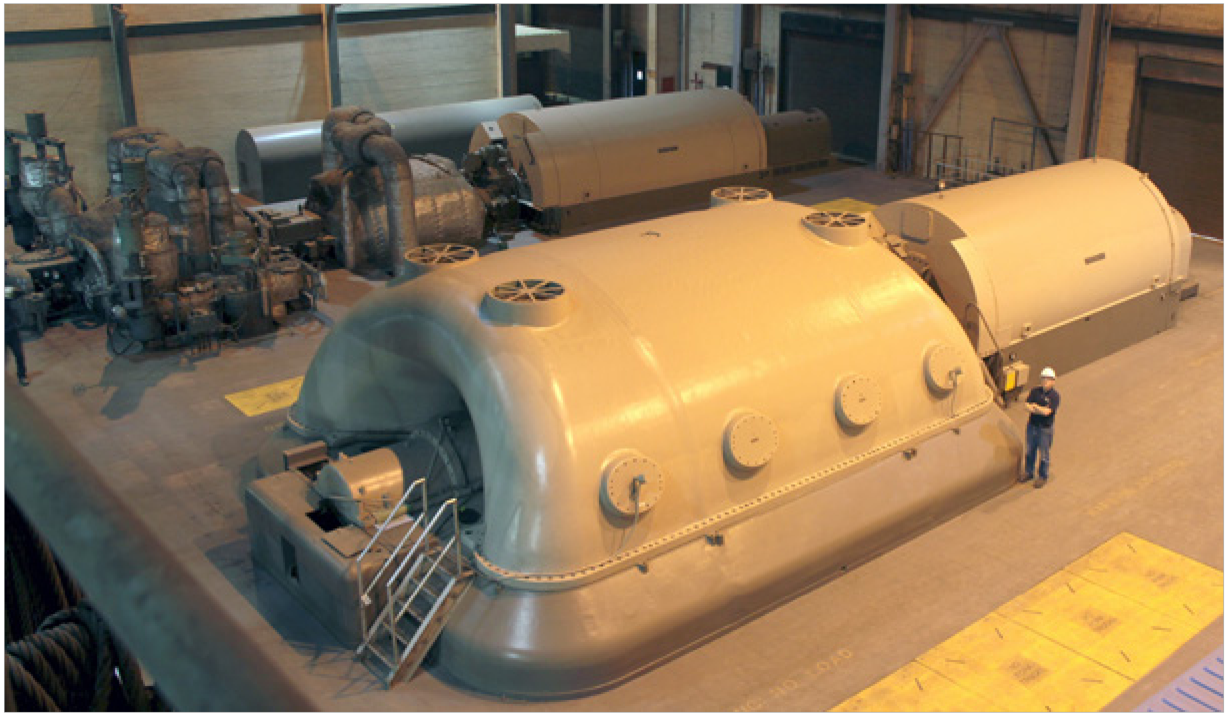

PHOTO: Steam turbine at coal power plant

Past and present

Indeed, steam turbines have already been replaced by other technologies in some applications. The first practical use of the steam turbine was achieved in the early 1900s and it was quickly employed to generate electricity on land and to propel ships on the seas. By the 1940s, the diesel engine became a more practical and economical means for mobile power generation and steamships became obsolete for several decades. However, steam turbines continue to have a place in the marine sector as engines for LNG carriers and on certain types of stationary and mobile oil production platforms.

Similarly, a significant buildup of electrical generation capacity occurred in the second half of the 20th century, primarily utilizing coal and nuclear fuel to generate steam. Technological advancement of the steam turbine was most significant during this period, with machines increasing in capacity from ~50MW in the 1950s to over 1300MW by the early 1980s when economic limits related to transportation and maintenance became apparent. In the 1980s, combustion turbines or gas turbines began taking over some of the market share of the steam turbine. Still, thermodynamic limitations of the gas turbine result in significant waste heat, which is most effectively utilized by a steam turbine in the “combined cycle” arrangement, which employs both types of machines within the same power plant. The steam turbine is also a key part of many cogeneration or combined heat and power schemes.

The rapid rise in renewable electricity production brings another potential competitor to the steam turbine, but the device’s flexibility will lead to continued use of steam turbines into the next century.

A variety of applications

Steam turbines are often employed in traditional power plants, which burn natural gas, coal, liquid hydrocarbons or uranium for fuel. However, other fuels can be burned and other heat sources can be utilized to generate steam. Steam generated from burning municipal trash, waste materials from oil refining and chemical processing, papermaking, lumber production, sugar cane and sugar beet processing, rum manufacturing and olive oil production are frequently used to drive steam turbines. Steam can even be generated by using mirrors or lenses to focus the sun or by drilling deep into high-temperature rock formations underground.

Steam turbines utilizing these alternative steam sources operate on the same principle as traditional power plants. However, the volume and properties of the steam produced using non-traditional sources differ significantly, which can reduce the turbine's reliability. In addition, the asset management and labour structure, the plant's size, the steam turbine's importance relative to other site activities and the type of installation have large effects on the potential risks of operating a steam turbine, which can be difficult to evaluate.

Design features of a steam turbine

The design of steam turbines varies greatly, but all follow the general principle of extracting thermal energy from pressurized steam and using it to do mechanical work on a rotating output shaft. To accomplish this, several components are required:

- Inlet piping, steam shutoff and steam control valves
- A rotating shaft fitted with one or more rows of blades
- Stationary elements consisting of one or more rows of nozzles or blades used to direct the steam onto the rotating blades
- Shaft bearings, generally of the pressurized-oil babbit design
- Shaft seals which prevent steam from escaping
- A casing which the above are installed within and attached to

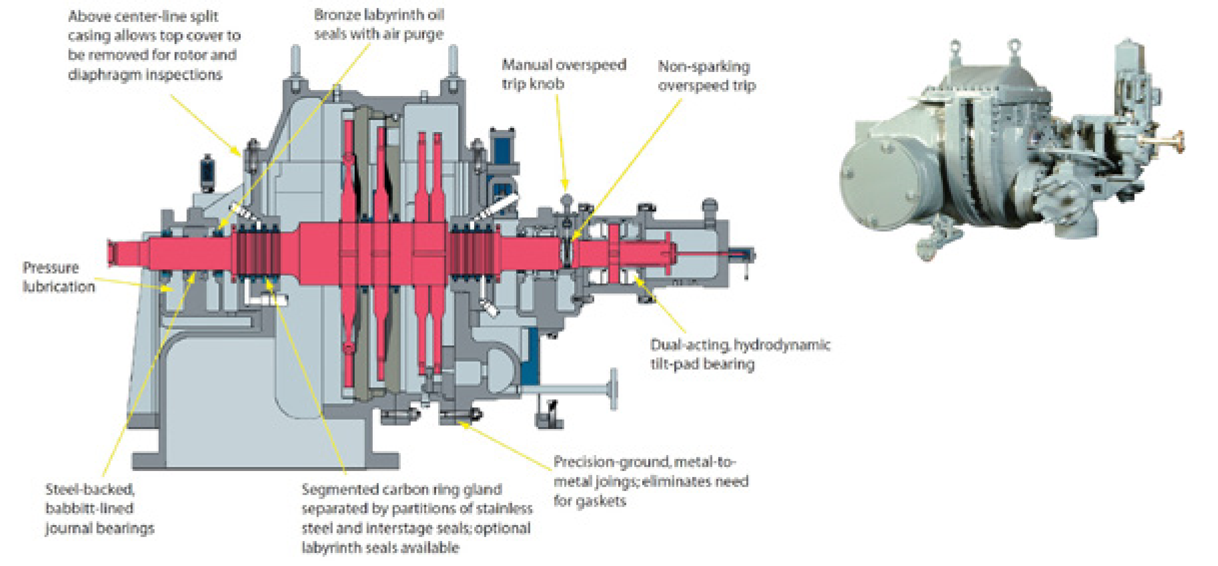

PHOTO: Diagram and photo of a small industrial-type turbine

Classification of steam turbines

Steam turbines can be broadly classified into four groups based on their physical design and application:

- **Nuclear** – Nuclear turbines are optimized to utilize steam produced by nuclear fission. These machines are physically the largest, have capacities between 300 and 1300MW and are operated exclusively by large, well-funded organizations. Nuclear steam is relatively low pressure and low temperature. Operating speeds are typically 1,500 or 1,800 RPM.
- **Fossil Fired** – Turbines are optimized for electrical generation using steam generated from coal, oil, natural gas, or in combined cycle arrangements. These typically have ratings between 100 and 600MW, but large coal power plants can have turbines that exceed 1000MW.

Steam produced for these machines is the highest pressure and temperature of all steam turbines. Depending on the grid frequency, these turbines are designed almost exclusively to operate at 3,000 RPM or 3,600 RPM.

PHOTO: Steam turbine used in a nuclear power plant

PHOTO: Steam turbine used in a conventional fossil fuel power plant

Classification of steam turbines (cont.)

Steam turbines can be broadly classified into four groups based on their physical design and application:

- **Industrial** – These turbines are physically smaller, ranging from sub-1MW to around 40MW. Industrial turbines utilize medium pressure and temperature steam and vary in operating speed depending on the design.
- **Geothermal** – Steam turbines utilizing geothermal energy vary depending on the steam available. Geothermal steam typically has low pressure and temperature, and machines tend to be physically large. Geothermal steam is usually contaminated with natural salts and other compounds that are difficult to remove altogether and turbines must be designed with this in mind.

PHOTO: Typical industrial-size steam turbine

PHOTO: Typical geothermal steam turbine rotor

Classification of steam turbines (cont.)

	Nuclear	Fossil	Industrial	Geothermal
Steam pressure	70 to 160 bar 1,000 to 2,400psi	80 to 220 bar 1,200 to 3,200psi	17 to 42 bar 250 to 600psi	7 to 35 bar 100 to 500psi
Steam temperature	250C to 300C 480°F To 575°F	425C to 593C 800°F to 1,100°F	120C to 315C 250°F to 600°F	7 to 35 bar 100 to 500psi
Physical size	Massive	Medium to Large	Small to Medium	Large
Power output	500 to 1,300 MW	100 to 1,000 MW	1 to 40MW	5 to 100MW
Rotational speed	1,500 or 1,800 RPM	1,500 to 3,600 RPM	3,000 to over 9,000 RPM	3,000 to 5,000 RPM
Common damage mechanisms	Water droplet erosion	Material degradation, steam erosion	Water droplet erosion, maloperation	Chemical attack, solid particle erosion, water droplet erosion
Typical applications	Nuclear power generation	Power generation, fueled by coal, oil, natural gas. Small numbers used in large-scale industrial schemes	Biomass, Solar thermal, Municipal waste, Papermaking, Petrochemical, Cogeneration and CHP, Other industrial processes	Geothermal power generation

Classification of steam turbines (cont.)

	Nuclear	Fossil	Industrial	Geothermal
Level of standardization	High	Common frame sizes but customized to most sites	Common frame sizes but customized to most sites	Low
Major maintenance interval	18 to 24 months	6 to 12 years	2 to 4 years	1 to 3 years depending on steam conditions
Typical major maintenance duration	14 to 90 days	28 to 42 days	14 to 28 days	14 to 42 days
Do operators hold capital spares?	Always	Almost never	Uncommon	Common
OEM availability of major components on short timescales	Generally available	Generally not available	Occasionally available for common models	Generally not available
Third party parts and service market	Limited to none	Healthy	Very healthy	Limited

Critical maintenance items

Regardless of the turbine design or application, care must be taken to maintain certain components. The most critical of these include:

- **Inlet steam stop and control valves and overspeed protection systems** – The ability to stop the turbine is essential. If the steam inlet valves are in poor condition, steam may leak past them. Poor valves or protection system conditions can allow the turbine to enter an overspeed condition, which causes severe damage and potentially a catastrophic failure.
- **Casing drain valves** – The turbine casing has drain valves that allow water to drain out. If these are obstructed, water may pool within the casing. This can result in uneven temperature distribution and cause the casing or rotor to be bent.

  In addition, water is significantly denser than steam and rotating blades that strike pooled water can be severely damaged.
- **Shaft alignment** – Turbines operate at high speeds and the clearances between the rotor and stationary elements are often as small as 0.38mm (0.015”), or approximately the thickness of four sheets of copy paper. Contact between these components can cause severe vibration and damage. Even slight settlement of the foundation can cause the turbine to become misaligned, so confirming alignment at every maintenance interval is strongly recommended.

PHOTO: Result of a catastrophic overspeed

PHOTO: Damage to turbine blade tips due to severe misalignment and rubbing

Critical maintenance items (cont.)

Regardless of the turbine design or application, care must be taken to maintain certain components. The most critical of these include:

- **Blade integrity** – High-speed rotating blades are subjected to enormous mechanical stresses and design margins are relatively small. Blades are also subjected to erosion by water droplets and solid particles within the steam, corrosion from chemical attack and material degradation due to long-term exposure to high temperatures. The blades must be regularly assessed to confirm their suitability for operation.
- **Oil systems** – Steam turbines employ one or more oil systems to lubricate the bearings and provide hydraulic power for operating the control valves. Failure of these systems can cause catastrophic damage.

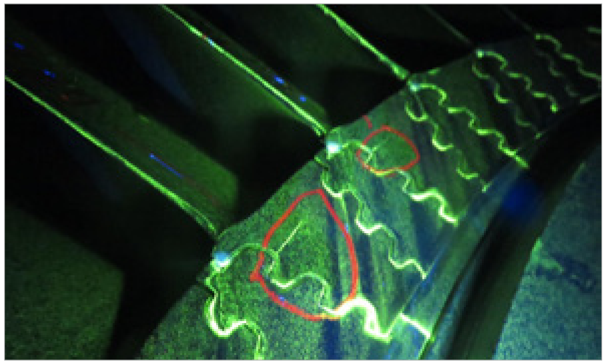

PHOTO: Cracking of blade roots due to high stress and chemical corrosion pitting

PHOTO: Severe damage to turbine shaft caused by lube oil system failure

Application-specific concerns

Steam turbines are employed in a variety of different industries, which present their own unique challenges.

BIOMASS, WASTE FUELS AND HEAT

Steam turbines installed at sites utilizing waste materials for fuel, such as biomass, chemical processing, papermaking, or the processing of other goods are almost exclusively part of the "industrial" category of steam turbine design. These machines are typically more tolerant of rough operation but more likely to experience it.

Steam turbines at industrial facilities are often neglected.

Steam turbines utilizing steam derived from waste products are typically secondary to the site's primary purpose. Owners primarily focused on other industrial activities often view power generated from the steam turbine as a "bonus" revenue stream and not a core part of their business. As a result, owners are less likely to prioritize steam turbine expertise when making hiring decisions and less likely to prioritize the steam turbine when preparing maintenance budgets. In addition, steam turbines generally require lengthier maintenance windows than other types of equipment, which often conflicts with the owner's other maintenance plans. It is, therefore, not surprising that operators of these sites are generally less knowledgeable than their counterparts in more traditional power plants and maintenance of steam turbines at these sites is often deferred well beyond OEM recommendations.

The operating arrangement matters.

The way a steam turbine is integrated into a larger site varies. At some facilities, the steam turbine is an integral part of the process and is required to be online for the facility to function. These facilities tend to prioritize turbine maintenance since a fault would result in not only the loss of revenue from the sale of electricity but also the loss of production of other industrial activities.

At other sites, the steam turbine may be integrated into the main process, but production of the primary product could continue if the steam turbine were offline. However, under such schemes, the loss of the steam turbine can still have significant impacts. Depending on the type of site, auxiliary boilers may need to be operated to satisfy process requirements; unused steam may need to be disposed of inefficiently or vented to the atmosphere, or waste materials may need to be burned less efficiently or with higher emissions of pollutants. In some cases, the facility may technically be operable but unable to continue production due to environmental regulations, accelerated wear on other equipment or other factors. This level of integration is typical for steam turbines used in processes that require

Application-specific concerns (cont.)

steam to refine raw materials or produce goods.

Some sites employ steam turbines purely to make use of a waste material and the steam generated by burning it is used only for electricity production. A turbine outage may have limited effects on other site processes at such sites. However, if the waste material cannot be burned, the stockpiling or disposal of this material may become an issue during extended outages.

SOLAR THERMAL

Solar thermal power plants, which focus the energy of the sun in order to heat a fluid, typically employ steam turbines as the prime mover. The turbines used at these sites are generally of an industrial design and face similar challenges as those of other sites with this type of machine. One key difference is that turbines used in these installations are started and stopped daily, which is not the case for most other industrial type turbines. This can accelerate wear and tear on the machine, especially if there is excessive moisture in the startup process.

GEOTHERMAL

Geothermal steam is generally nasty.

Geothermal steam is generated by tapping into an underground thermal resource. Boreholes are drilled to great depths, typically with one borehole for extracting the steam and one or more boreholes to inject water, which then migrates through permeable rock to the extraction hole. The steam generated within the porous rocks of these underground formations is exposed to mineral salts and can include mercury, arsenic, silica, chloride, sodium, potassium, calcium and hydrogen sulfide. These elements and compounds are challenging to remove entirely from the steam. As a result, geothermal steam turbines are often exposed to highly acidic and saline steam containing solid particles and heavy metals. This combination is hugely damaging compared to the steam used by all other steam turbines.

Turbine maintenance must therefore be conducted more regularly at geothermal sites. The heavy metals present a contamination issue when maintenance is performed and must be cleaned in a safe manner and disposed of properly.

Geothermal steam turbines employ exotic materials.

As a result of the severe operating environment, geothermal steam turbines frequently employ materials not used in turbines used in other sectors. Geothermal steam turbines often include one or more rows of titanium rotating blades

Application-specific concerns (cont.)

and use stainless steels of higher chromium and nickel content than other turbines. It is common for the shaft seal areas to be clad or sleeved with superalloys such as Inconel 718 or 625 or coated with cemented carbide protective layers. Blades near the turbine exhaust are more likely to be fitted with erosion strips made of stellite, a cobalt-based alloy. These materials must be repaired or reapplied periodically and the use of these materials reduces the number of qualified vendors who can affect repairs. The result is that repairs to geothermal turbines take longer to perform and are more expensive compared to other types.

Geothermal sites prioritize short outage windows.

While all power plants are under pressure to maintain high operational uptime, geothermal power plants are especially incentivized. Once drilling operations have been completed, the incremental costs of the "fuel" are extremely low, and the majority of site expenses are related to equipment maintenance, labour and the costs of financing the project. Operators of geothermal power plants are therefore more likely to carry spare components to maximize uptime. However, specific components within geothermal steam turbines, such as the turbine casing, are not easily exchanged. Casing repairs can take significantly longer than the planned outage window for a rotor swap and are often deferred or only partially repaired as a result.

PHOTO: A geothermal power plant.

Insurance considerations

Insurers can take steps to guide operators of steam turbines towards safer practices. Specific terms and conditions are frequently included within policies covering steam turbines.

VIBRATION MONITORING

Vibration monitoring systems are commonly supplied with most steam turbines. Vibration monitoring can warn of internal damage or misalignment and can avert catastrophic incidents before they occur. In addition, vibration data is critical when determining the cause of a loss, should an incident occur. We consider a steam turbine operating without such a system to be "flying blind" as there is limited or no insight into the internal condition or health of the machine. Some policies covering high-speed rotating equipment require the operator to maintain a functioning vibration monitoring system. We have been involved with several incidents where the vibration monitoring system could have prevented the incident but was nonfunctional at the time of the loss.

TESTING AND OVERLOADING

Steam turbines' safety and protection systems should be checked regularly according to OEM guidelines. Depending on the design, checks of the overspeed trip mechanism can involve tests which manipulate digital or analogue signals within the control system, bench testing of the governor assembly, or intentionally raising the machine speed above 100% of the rated speed. The equipment is generally designed to withstand such testing, but actual overspeed tests do introduce a risk of equipment in marginal condition failing.

Operators should be encouraged to assess their systems without requiring the machine to exceed 100% of the rated speed. However, this is not possible for some designs and due to the importance of the overspeed mechanisms, simply skipping this testing is not recommended.

Testing of the steam valves is critical to ensure that they are able to stop the flow of steam when required. Steam turbines do not have brakes; a leaking valve can result in uncontrollable acceleration and a catastrophic failure is almost certain in such cases. Valve tests should include confirmation that the valves move when commanded by the control system and that the valves do not allow steam to pass when in the closed position.

Testing of other equipment can also influence the turbine. Hydrostatic boiler testing can introduce large quantities of water into the steam piping, which must be completely drained before starting the turbine. Other commissioning activities include

Insurance considerations (cont.)

'steam blows' of the boiler, during which the turbine is bypassed and steam vented to the atmosphere. Following such testing, care must be taken to restore all pipework and instrumentation to the correct operating arrangement.

Many policies incorporate language similar to the following:

> **Testing and Overloading**
>
> Damage or Mechanical and Electrical Breakdown to plant or machinery caused by or occurring during testing, experiment or intentional overloading except for Damage or Mechanical and Electrical Breakdown caused by and occurring during the checking of the correct operation of the plant or machinery or of safety installations in connection therewith or if carried out with the approval of the manufacturer or in accordance with normal good industry practice, but this Exclusion shall not apply to resultant Damage caused or contributed to by a peril not otherwise excluded.

Insurers should accept that certain types of testing and overloading are recommended by the manufacturer or required to complete commissioning. Certain types of testing are even legally required in some jurisdictions. It is therefore not possible to avoid such testing altogether.

PHOTO: Valve cartridge for a steam turbine shutoff valve

Insurance considerations (cont.)

FOUNDATION SETTLEMENT

Due to the requirement for precise alignment within the turbine, even small amounts of foundation movement can affect the turbine. Installations where the steam turbine, electrical generator and/or gearbox are installed on separate foundations are more likely to be affected. Instances of foundation settlement resulting from proximity to the sea, significant rain events, flooding and earthquakes have been known to cause steam turbine misalignment and forced downtime.

Turbine vibration and misalignment caused by foundation settlement can be more difficult to diagnose since the settlement may not occur linearly and personnel are less likely to have direct experience with this issue. Some sites perform periodic foundation surveys to assess any movement that may have occurred.

These can be critical to confirming a root cause of foundation settlement since a foundation survey is only useful if it can be compared to a previous survey.

Many policies include an exclusion similar to the following:

> **Settling, expansion or cracking (Inherent Vice)**
>
> Wear and tear, gradual deterioration, inherent vice, latent defects, cracking, shrinkage, settlement, bulging or expansion of foundation, walls, ceilings, floors, roofs, roads or pavements. However, this exclusion shall not apply when such loss or damage is caused by a peril which is not otherwise excluded, or to loss or damage resulting there from.

Since foundations under steam turbines are generally very robust and unlikely to experience direct damage from settlement, underwriters may feel that foundation settlement is unlikely to result in a significant claim. However, consequential damage to the steam turbine itself is not excluded from many policies and repair costs related to misalignment can be substantial.

OEM recommendations vs. industry practice

In some cases, a turbine OEM will identify an issue and recommend inspections or repairs which are exceedingly difficult to perform, unreasonably uneconomical or excessively conservative.
In such cases, it is not uncommon for the industry to defer the specific recommendation indefinitely or perform alternative but less adequate inspections. It has even been the case that a turbine OEM operating under a long-term service agreement has disregarded its own inspection recommendations. These situations can lead to very complex claims should an incident occur.

IN COMPARISON TO OTHER ROTATING EQUIPMENT

Steam turbines are a subset of high-speed rotating equipment, including pumps, compressors and combustion turbines. Steam turbines are significantly less numerous than these other types of rotating equipment. In addition, steam turbine maintenance is performed at longer intervals between outages compared to other rotating equipment. As a result, generalist rotating equipment engineers employed by project owners are usually less familiar with steam turbines and less likely to have direct experience. This is mirrored in the service provider networks; the number of vendors repairing steam turbines is far lower than the number of companies that service combustion turbines and compressors.

Conclusion

Steam turbines will remain a core part of electrical generation for decades. Insurance professionals should be aware that many machinery breakdown risks depend on the application, how the turbine is integrated within the overall project and the knowledge and experience of the operator. This type of machinery requires regular testing of the valves and shutdown mechanisms, as the consequences of failure can be catastrophic. In addition, maintaining a vibration monitoring system is critical to preventing incidents and determining the root cause when they do occur.

PHOTO: A geothermal power plant.

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