High-speed balancing

Dynamic balancing of rotating elements is an important aspect of the manufacture and the repair of any turbomachinery. A rotating element that is out of balance can cause major operational difficulties, which may prevent the timely start-up of a facility. Furthermore, the unbalanced element can cause internal damage that will rob a machine of its design efficiency, reduce machine reliability, and increase the costs of operation and maintenance, or worse.

1 A large steam turbine for a power generation facility undergoing a low-speed balance at the workshop. This low-speed balance stand has a capacity for rotating elements to 50 tons at 500 rpm.

All rotors are part of a machinery train, be it a generator, gearbox, compressor, or other mechanical assembly. The presence of an unbalance in any rotating component in the assembly may cause the entire train to vibrate. This induced vibration, in turn, may cause excessive wear in bearings, bushings, shafts, spindles, gears as well as the civil structures. The vibrations set up alternating stresses in structural supports and housings, which may eventually lead to total failure. Not surprisingly, the primary reason given by most of our clients for balancing a rotating element at the maximum running speed has little to do with the technical aspects of balancing or modal analysis. Rather, it is reliability, availability, profitability, and efficacy of the business unit that is weighed to reduce the overall risks inherent in the operation and maintenance of high-speed rotating equipment.

Low-cost insurance

An at-speed balance of the rotor, as a part of the overhaul, is considered low-cost insurance. Shop balancing, by contrast, is usually undertaken at low speed—generally below 1500 rpm—mostly due to the perceived initial cost and time advantages compared to the efforts required to balance a rotating element at high speeds. Low-speed balance stands come in a variety of types and sizes depending on the parts being handled and the measuring system being used. Most people are familiar with the balance machine used in a tire repair shop, where a lead weight is attached to the rim to compensate for an unbalance. A balanced tire gives the driver a comfortable ride on the road throughout the speed range of the vehicle. For most low-speed, rigid-shaft rotors with no adverse operational history, a low-speed balance in the workshop is usually sufficient 1. These rotors typically run at speeds that do not excite the first critical-speed band 2. Most of the rotors in this rigid class operate below the influence of the second critical-speed band, some-times called the first flexural mode, where the shaft takes the shape of a sinusoidal waveform, with identifiable nodal points outside of the radial journal bearing centerline, as is shown below 3.

Mandatory for high-speed rotors

At-speed balancing is necessary for some rotors running below the second critical-speed band and is considered mandatory for any rotor that operates within the influence of, or above, the second critical-speed band. Some of these high-speed rotors also require additional tuning of the low-speed residual unbalance to allow the rotor to come through the first critical-speed band without excessive deflection of the centerline. Excessive shaft deflections during the start-up and shutdown cycles will open up the clearances of the shaft seals, can damage the bearings, and may include severe rubbing of the rotating element surfaces to the stationary parts of the casing. While all of the original equipment machinery manufacturers have their own at-speed balancing facilities, they are dedicated to processing the new rotors for their various product lines and providing a small number of aftermarket services for clients. Very few of these specialized balancing bunkers are available to the independent repair market at a competitive price. With the order books for new equipment at historically high levels, it is now harder than ever to schedule an opening at the OEM balance facilities that coincides with the clients' overhaul cycle.

Extensive experience

Sulzer Turbo Services overhauls many rotating elements where the client has requested an at-speed balance as a part of the repair work scope or where the operational history suggests a benefit 4. It also engages in modernization work where seal and bearing design improvements can be demonstrated in the bunker before being placed into service. To better serve its clients, Sulzer Turbo Services operates two at-speed balancing facilities, including one of the largest and most advanced bunkers in the United States at its workshop near Houston 5, Texas, and a second facility in Winterthur, Switzerland. Both facilities undergo constant revisions and upgrades to keep their capabilities in step with advances in the industry. These two specialized balance bunkers provide reliable and timely service for all six of Sulzer Turbo Services' strategically placed regional repair facilities, as well as to other OEMs and customers directly. Both are equipped with advanced electronics and diagnostics to provide state-of-the-art troubleshooting capabilities.

Generator fields

One of the areas we have developed specifically for generator fields is a procedure that allows us to complete shorted-turn detection and analysis work using an air-gap flux probe that senses changes in the radial flux density as the rotor surfaces passes the probe. The resulting waveform highlights the presence of one or more shorted turns by amplifying the minute variations in the flux slopes testing at the operational speed of the field. For this procedure, the field is operated at its normal running speed with normal excitation. This procedure identifies problems that can affect the proper operation and the formation of hot spots in the generator field that normally would not be seen until the unit was taken into operation. In many cases, the discovery of these issues at the job site would require a forced outage to make the required corrections.

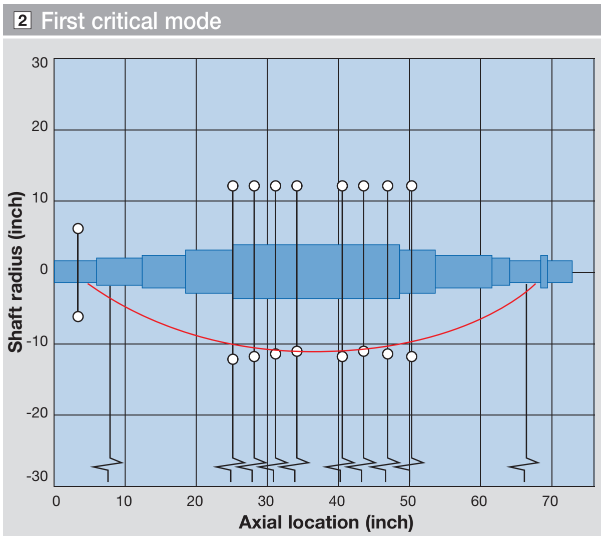
Research and development platform

Because of the unique nature of the facilities, the bunkers are also utilized by our research and development departments of Sulzer Turbo Services, Sulzer Metco Surface Coatings, and our independent research arm Sulzer Innotec to develop and operationally test various sealing system configuration designs. Tests include measurements of the durability of various abradable coating systems applied to segmented seal rings for use in the next generation of steam turbines and industrial gas turbine engines.

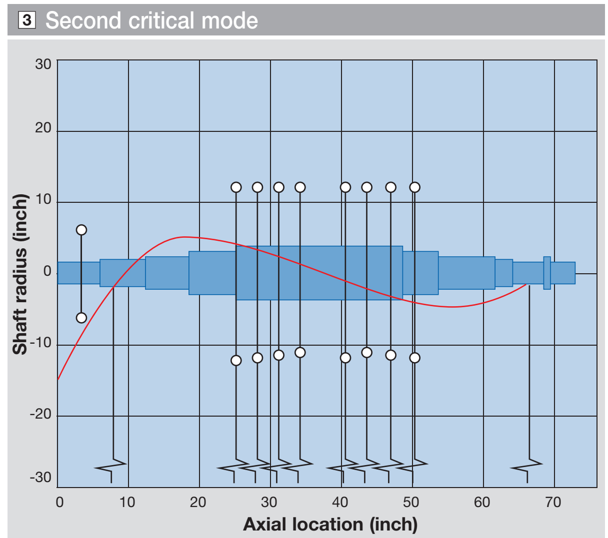
Some elements that affect rotor balance

Rotors are built up in a variety of ways to accommodate the process gas or fluid, the stress levels acting on the parts, and the materials available for construction. Some examples are listed below:

2 First critical mode



3 Second critical mode



- Solid forgings for steam turbines and hot gas expanders
- Forged shafts with shrunk-on disks, or impellers, only
- Forged shafts with all of the sleeves, disks, and other trim parts shrunk on
- Forged disks or packs of disks bolted together with one central or many peripheral tie bolts using a Hirth or Curvic type clutch fit to transmit torque between disks and to the shaft stub ends
- Welded cylindrical assemblies—these are usually found in very large steam turbines or high-speed axial-compressor rotors where the shaft body is made of hollow cylinders seam welded together by lasers to reduce the weight of the rotor assembly
- Lastly, a mix of any of the methods above

The excitation of vibration modes is then further complicated by differences in materials, material quality, rotor size, and stiffness. Any unbalance located along the rotor that coincides with deflection in the mode shape will amplify the deflection at those positions. Unless corrected, the unbalance creates a vibrating force on the bearings. The movement of individual disks or groups of disks, along the shaft or off centerline during the operation cycle of the machine can become problematic, especially if the shift of the mass encroaches on an area where the deflection is amplified.

4 High-speed steam turbine, typical of the type requiring high-speed balancing.

Quality assurance process

When a new rotor is manufactured, the OEM often balances the rotor at speed as part of the quality assurance process. The initial balance work provides the owner with a benchmark rotor signature to compare with any subsequent inspections. It is also important to consider items attached to the shaft, such as coupling hubs and thrust disks, as they can affect the balance and the response of the rotor. Progressive stacking and balancing of a rotor can provide a reasonable level of low-speed balance, and it is an important tool to ensure that the rotor is built with a low level of vibration. This method has been used by Sulzer Turbo Services many times to fix a rotor with a poor vibration history. Progressive stacking and balancing does not assure a smoothly running, completely assembled rotor because it does not account for the vibrations caused by system excitations as it is accelerated through the critical speed bands and up to its operating speed.

During the service inspection of a rotor, it is always worthwhile to check the weights added to correct the rotor's inherent unbalance. The objective of any balance process should be to use the minimal number of weights to correct any unbalances in the rotor.

Running above the first critical speed

Many high-speed flexible rotors run above the first critical speed. With such rotors, it is also important to correct the unbalance response at the first critical speed for two reasons:

- The unbalance forces and resulting shaft deflections may be so violent that the rotor will not pass the first critical speed, or it may do so only after wiping out the shaft seals. Even minimal contact between the shaft and the seals will open the seal clearance values and decrease the efficiency of the unit. This also creates localized heating of the shaft, which can amplify the deflection at the first critical speed and may result in a permanent shaft bend.

- A rotor could do well at the first critical for too long a time during start-up and shutdown events—even when controlled acceleration and deceleration rates are employed—causing extensive damage to the unit.

Field balancing vs. at-speed balancing

A rotor can be balanced successfully in the field within its own casing and bearing system. However, access to balance planes can be a limiting factor. Some machines accommodate this requirement by adding a single access hole or a series of access points at each of the two end planes, thus eliminating the need to remove the entire upper casing half. However, if the location of the unbalance is not in an accessible plane, the correction at the end planes is only a compromise. When there is no access provision, then the whole upper casing—or parts of it—must be removed and replaced after each balancing run. A minimum of five runs is typically needed.

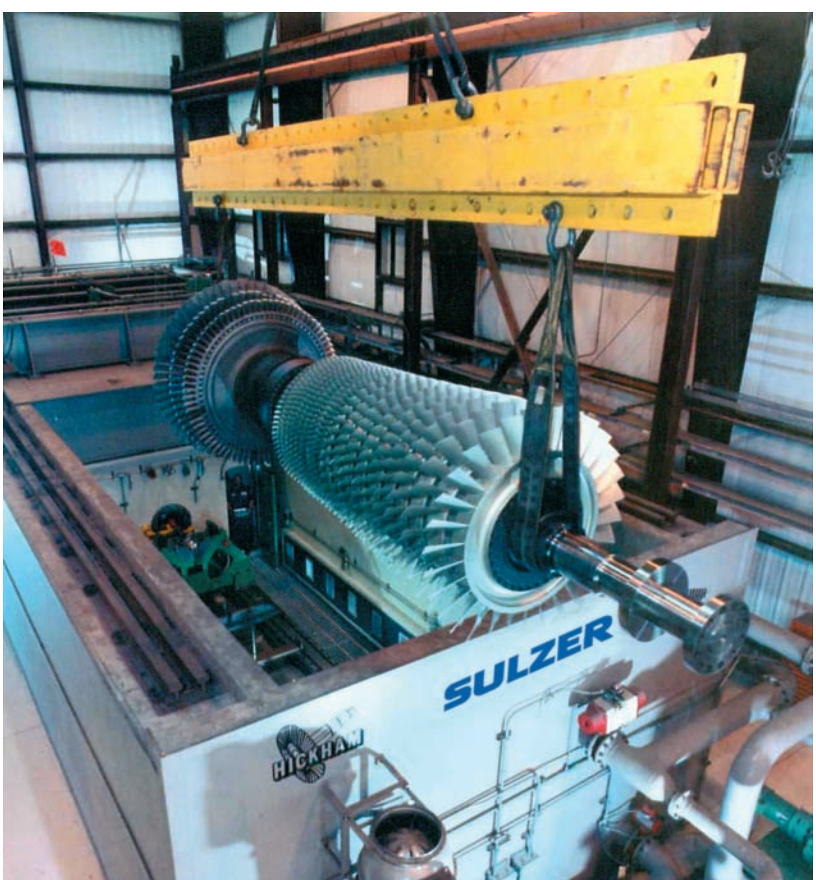
Balancing on the half shell

In some very extreme instances Sulzer Turbo Services has field balanced the rotor on the half shell, meaning that the upper half of the casing is left off, the lower half seal rings are removed, then the bearings are assembled and fitted. For a steam turbine rotor, an external fluid, usually dry air ported through a nozzle, is used to spin the rotor to the desired speed where readings will be taken. In the case of a large, motor-driven turbomachine, the drive motor is used to operate the machine to obtain the desired readings; this type is limited by the number of permissible motor starts per day. As you might imagine, this is a time-consuming prospect.

Rotating element in the field

There are significant risks and costs associated with balancing a rotating element in the field. Every time a casing is opened, there is a chance to introduce foreign objects into the flow path or to damage a component. As most machines are part of a process, the process has to be started and stopped many times to achieve the proper balance level. Imagine having to ask the operator of a nuclear facility run the fuel rods in and out a half dozen times or so over the course of four or five days so that you could accomplish something that should have been done off site, in a controlled setting, with proper equipment, during the outage cycle. To make the situation a little more uncomfortable, field balancing forces the user to adjust the rotor response to correct the combined effect of all the non-rotating items (such as misalignment, foundation resonances, piping resonances). If a rotor runs in its casing with undesirable vibration levels after being balanced at-speed it is probably not a rotor issue. A system issue will require further investigation and correction.

5 Gas turbine rotor assembly being loaded into the bunker. The compressor and turbine sections being bolted together.



Acceptable levels of unbalance

Zero unbalance would always be preferred and many engineers will discuss the acceptable level for hours, given that zero is seldom economically achievable, a common level is chosen using industry standards for various types of machinery. For at-speed balancing, the American Petroleum Institute (API) requires vibration levels less than the greater of 1 mm/sec, or 7400 rpm.

An investment that pays well

There is rarely a more uncomfortable time in the professional life of a rotating equipment engineer, maintenance manager, or operations manager than when a critical part of their process fails to start on time, will not run, or becomes unreliable between maintenance cycles. The costs of trying to correct the issues, while accounting for lost production, can be quite staggering. Sulzer's dynamic field-balancing methods save both time and money over conventional site methods.

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