

# Case Study

## An investment with good returns High-speed balancing

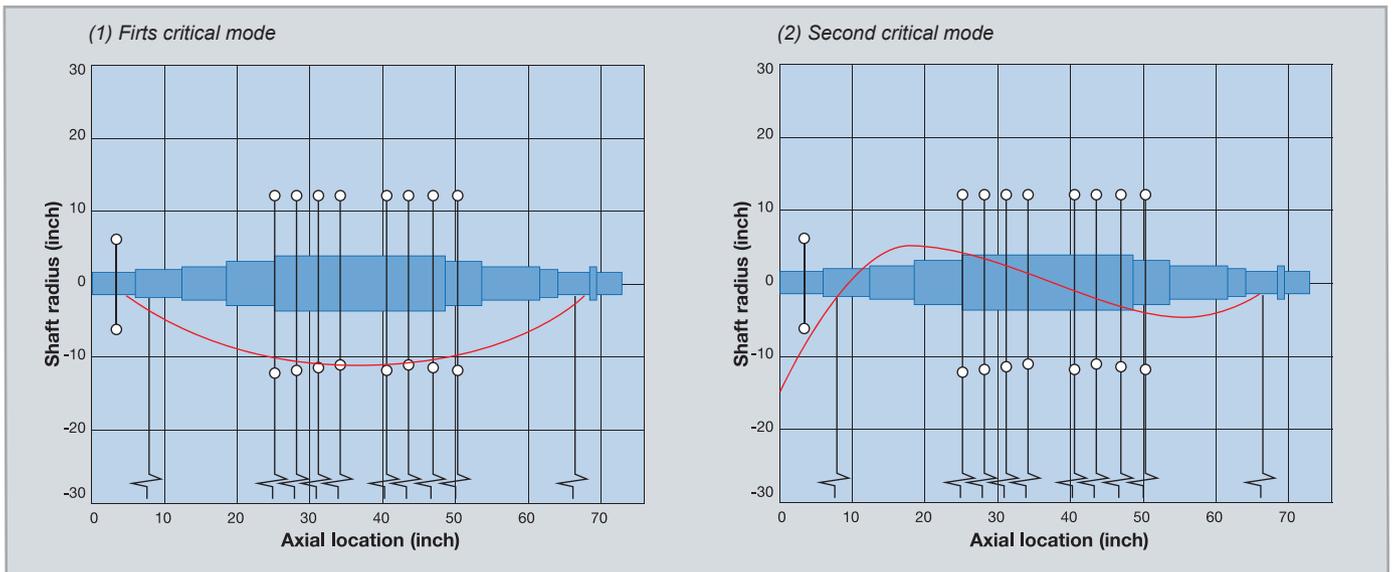
Dynamic balancing of rotating elements is an important aspect of the manufacture and the repair of any turbomachinery. A rotating element that is out of balance can cause major operational difficulties, which may prevent the timely start-up of

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.

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



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



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 a low-cost insurance. Shop balancing, by contrast, is usually undertaken at low speed – generally below 1500rpm – 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 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 normally sufficient. These rotors typically run at speeds that do not excite the first critical-speed band (1). Most of the rotors in this rigid class operate below the influence of the second critical-speed band, sometimes 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 above (2).

### 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 after-market services for clients. Very few of these specialized balancing bunkers are available to the independent repair market at a competitive price.



(3) High-speed steam turbine, typical of the type requiring high-speed balancing.

its workshop near Houston (4), Texas and a second facility in Birmingham, UK. 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 rotors

One of the areas we have developed specifically for generator rotors 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 surface 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 rotor. For this procedure, the rotor 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 rotor 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.

### 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 (3). 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

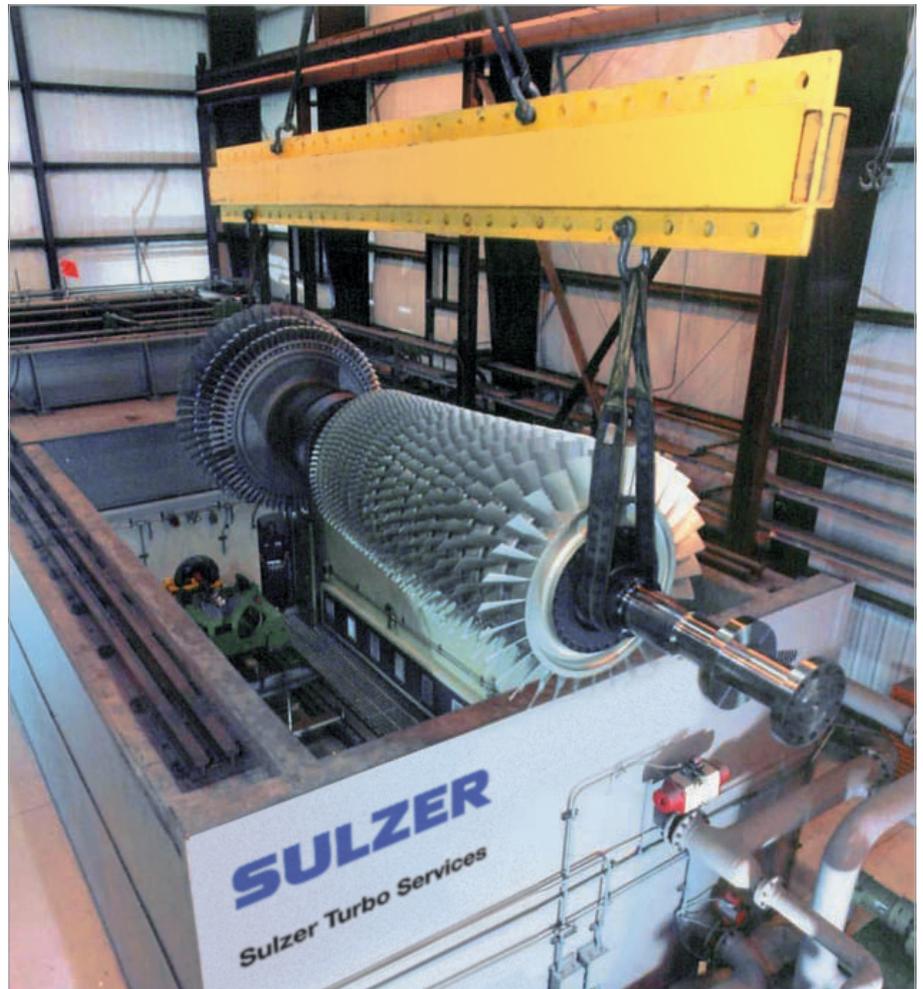
## Some elements that affect rotor balance

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:

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



## 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 speed 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 procedure.

### **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 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.

### **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 1mm / 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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