Hofmann.
Intelligent Balancing Solutions

Balancing and over-speed testing of flexible rotors

Installations for low- and high-speed balancing and for over-speed testing HS 16 - HS 34

High-speed balancing installation HS 23 with vacuum proof safety containment to balance centrifugal compressors

Application

- Balancing of flexible rotors from turbo-machinery
  - Steam and gas turbines
  - Turbo generators
  - Axial- and centrifugal-com-pressors
- Balancing of flexible rotors at low- and high-speed
- Balancing of flexible rotors in their own bearings
- Spin-testing of the rotors at over-speed
- Special tests with rotors from electric machines
- Runout-measurement

Description

Many shafts from rotating machinery are being balanced applying the methods of rigid rotor balancing. Rigid rotors have the property that their unbalance state does not vary significantly with speed. However this is no longer valid with flexible rotors (rotors from turbomachinery, for example steam- and gas turbines, turbo generators and turbo compressors).

The operation of flexible rotors is being affected at least by one critical speed. Many (shaft-) flexible rotors even pass several critical speeds on their way to operational speed.

In the vicinity of a critical speed the rotors bend in a typical mode (eigen-mode). As a result new unbalances are being generated, which are depending on speed.

Among the unbalances due to the shaft flexibility unbalances may result from settings of rotor parts.

Because the unbalance state of flexible rotors is depending on speed, they require balancing up to maximum operational speed applying special methodes.

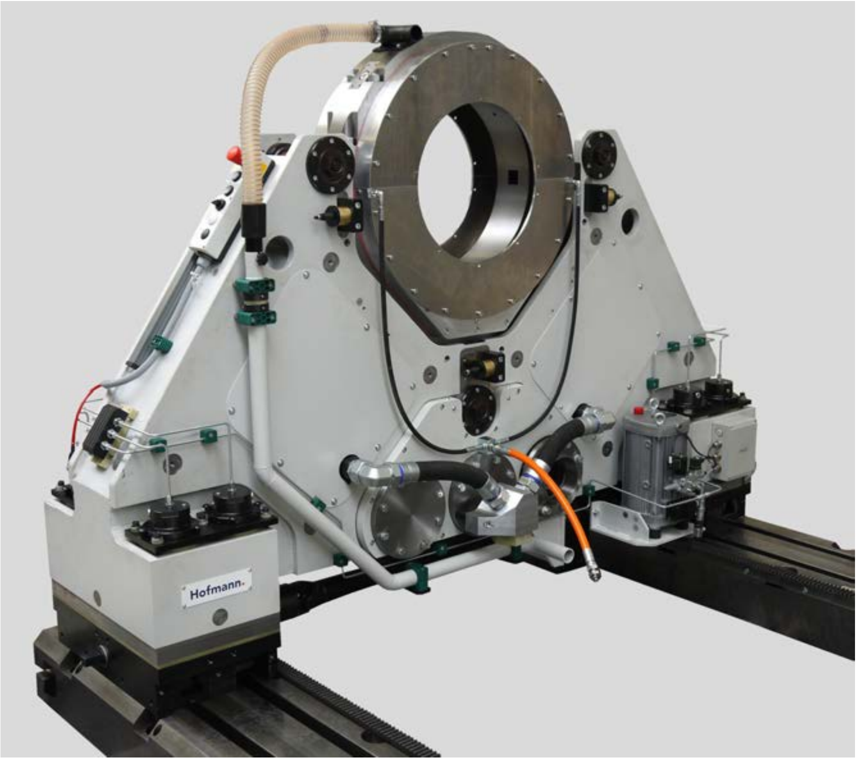
In addition it is many times of interest, whether a rotor can withstand the exposure at over-speed. In order to initiate settings or to check the strength flexible rotors must be accelerated to speeds substantially above the maximum operational speed.

To perform all those tasks the Hofmann installations HS 16 to HS 34 for low- and high-speed balancing and for testing at over-speed of flexible rotors are being applied. Those installations cover rotor weights from just a few kilograms up to 100 tons.

System Components

Bearing Pedestals

When balancing flexible rotors it is important, that the stiftnesses of the operational bearings and of the mounting for the bearing pedestals of the HS balancing installation are of similar size. Then the critical speeds and mainly the correspon-ding bending modes match the diffe-rent bearing conditions well. Thus those modal unbalances, that would excite rotor vibrations during oper-ation, will be exactly identified and corrected in the bearings of the balancing installations.



Bearing pedestal HS 26 with motorized moving gear and automatic clamping on the machine bed

Bearing pedestal HS 28 (top) and HS 23 (buttom)

High vibrations and high dynamic forces occur when passing through critical speeds. Some rotors may set at higher speeds and thereby get high unbalance. Therefore the bea-ring pedestals of a HS balancing ins-tallation have to be designed in such a way, that such possible critical con-ditions are well controlled.

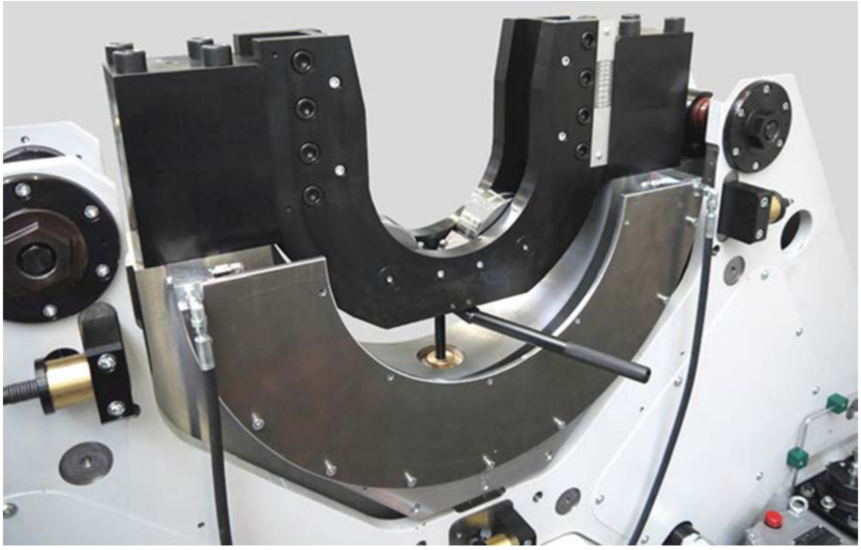
The necessary high stiffness of the HS bearing pedestals is achieved by applying the Hofmann force measu-ring principle. The force sensor, inte-grated into the force flow, is highly sensitive and has a high mechanical load capacity. Therefore it contributs to the stiffness of the bearing pedestal.

The support of the bearing head under 45° results in an isotropic stiff-ness. This avoids a splitting of the critical speeds and - as a conse-quence - an unnecessary increase of the complexity of the balancing proccedure.

The inclination of the bearing heads can be adapted to the static deflecti-on curve of a rotor to be balanced. Natural frequencies, based on the principle design of the HS bearing pedestals, are specifically damped. Thus they do not interfere balancing.

The bore of the bearing head has got a sufficient size to adapt tilting pad journal bearings with increased outer diameter as well. The same applies to the oil drain that can bear the clearly higher oil flow of tilting pad journal bearings in comparison to journal bearings with fixed lobes.

There are roller bearings available for Hofmann HS bearing pedestals. Hence a high-speed balancing installation may be used to balance rotors on openrollers at low speed. The elaborate installation of the rotor into journal bearings can be omitted.



Bearing pedestal HS 28 with roller bearing for low-speed balancing

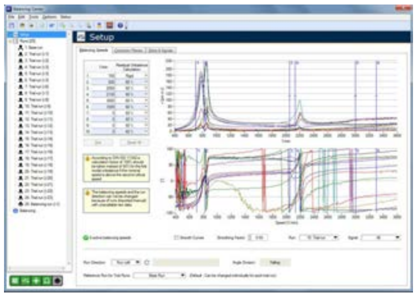
Measuring and Monitoring

Special balancing methods have to be applied, so that flexible rotors show a low vibration level over their entire speed range. Thereby the Hofmann unbalance measuring systems support modal balancing as well as the unbalance correction using Influence Coefficient method.

The operators of a HS installation shall fully concentrate on balancing and must not be surprised by unexpected events. Therefore the Hofmann HS installations are equipped with extensive safety and monitoring technique.

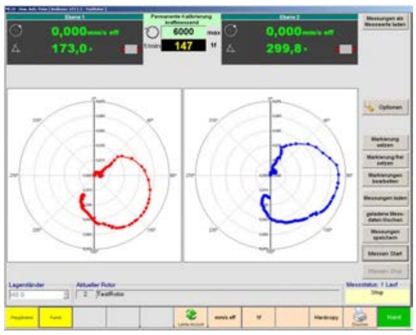
Among others the systems provide the following functions:

- Evaluation of the unbalance induced vibrations,
- evaluation of the vibrations at twice the rotor speed,
- presentation of the measuring values in terms of unbalance or vibration units,
- presentation of the measuring values in polar or x-y diagramm,
- prediction of the effect of an unbalance correction,
- processing of additional measuring values captured outside the bearing pedestals (e.g. relative journal vibration or shaft vibration at a rotor position of special interest).

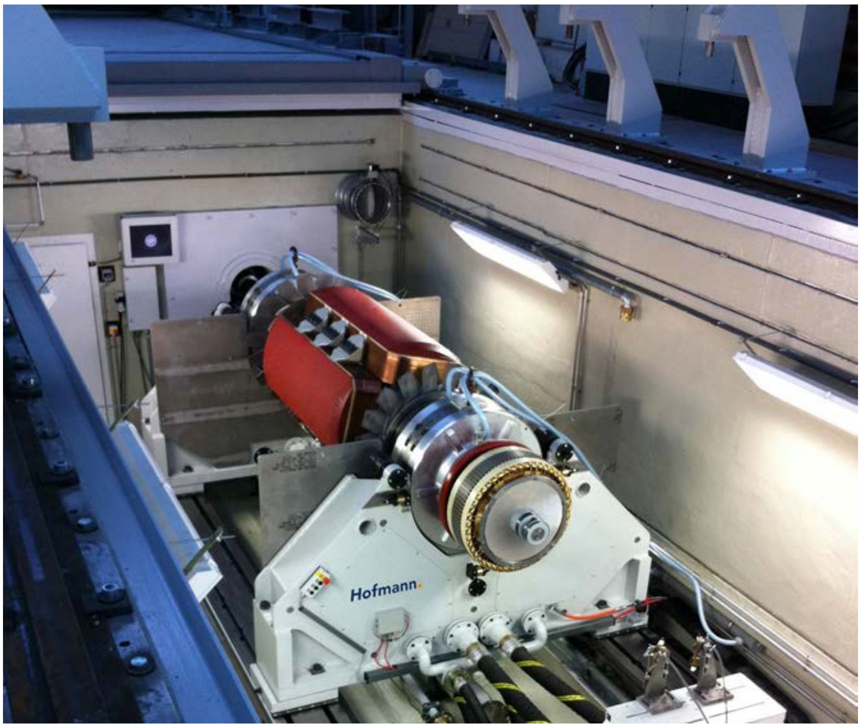


Balancing applying influence coefficient method

Control room of a high-speed balancing and over-speed testing installation



MC 10 HS for balancing flexible rotors applying modal methods



HS 28 für Turbogeneratoren ausgeführt als Grube mit verfahrbarem Deckel.

Drive System

The drive system of a HS installation must be capable to quickly and safely accelerate the rotors up to the required speeds. Given measurement speeds must then be held constant and critical speed ranges have to be rapidly passed.

Depending on the existing rotor range a gearbox will be used to best adapt the power of the electric drive motor to a rotor's moment of inertia, its friction losses and its max. speed.

If necessary, an intermediate shaft will be required. That shaft has to bear high axial loads caused by the rotor and allows the integration of a vacuum seal.

A well constructed, high-precision drive shaft forms the connection to the rotor. In case of high speeds special high-speed Hofmann membrane joint shafts are being used.

Containment

While balancing and over-speed testing parts may get detached from the rotors or even the rotors may burst. Therefore the space around the rotor must be designed as a safety containment.

For small rotors that containment is being constructed with a movable steel enclosure. In closed position that enclosure is being moved against a stationary bulkhead.
For rotors from 6 to 8 tons the containment is being constructed from concrete with rebar. Those containments with rectangular or circular cross-section are accessible.

A special transport system will be used to move a rotor into a containment erected on floor level having a movable door at one face end. Hence the rotors will already be installed on the pedestals outside of the containment. The construction as a pit with a movable cover makes it possible to load the rotor into the pedestals using a crane.

Bladed rotors or rotors with impellers create high ventilation losses when revolving in normal air. Therefore the containments will be constructed as vacuum containers for balancing and over-speed testing of turbines and compressors. Special vacuum pumping stations achieve an absolute pressure of appr. 1 mbar. The size of such vacuum pumping stations is determined by the volume of the containment to be evacuated and the required evacuation time.

Oil System

High-reliable oil stations are provided for the supply of the rotor's journal bearings and the supply of the bearings and gears of the drive system (drive motor, gearbox, intermediate shaft). In case of larger rotor weights the journals are lifted by use of a jacking oil station. Then the rotors can be brought up to speed literally without friction or wear.

In case rotors are being balanced under vacuum condition, the supply of a rotor's journal bearings will be provided by a special vacuum oil station. The jacking oil station will then be included in the vacuum oil circulation.

Emergency Supply

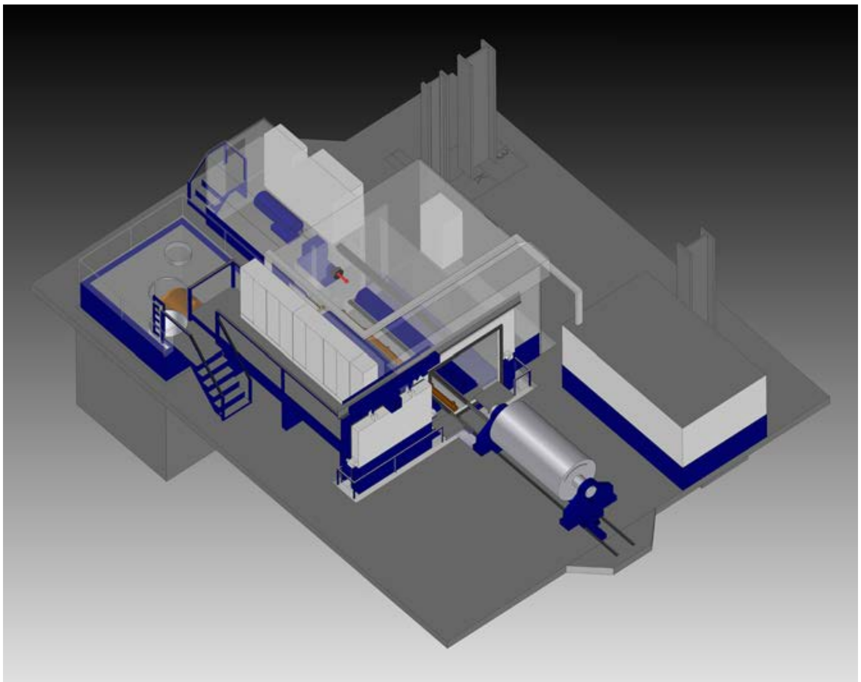
The rotors which are balanced and/or tested at over-speed in a HS installation are quite valuable. They must not be damaged under any circumstances. This is also valid in case of a power failure.

Therefore the Hofmann HS installations are designed to safely bring back a rotor to zero speed even in case of electrical power outage. For that purpose it is necessary to keep up the supply of lubricating oil for the rotor bearings and specific drive components.

With small HS installations this is being realized by the application of uninterrupted power supplies (UPS), which provide sufficient battery capacity. With larger installations the UPS overtakes the supply instantly after the power failure. Then an emergency power unit will start, which can also supply pumps with high power request.

Drive system with motor, gear box, intermediate shaft and moving device

Vacuum oil station, installed underneath vacuum oil tank, and vacuum oil distribution with filtering, flow monitors and pressure control



Layout of a high-speed balancing and over-speed testing installation HS 25
with accessible containment made from reinforced concrete

Realisation

The Hofmann scope of supply depends on the strategy of our customers. It may range from the core balancing components of a HS installation to the responsibility for constructing and delivering a complete installation.

Part of the Hofmann scope of supply is engineering work. That covers the design of the installation area, the evaluation and design of the containment including foundation, the evaluation and design of the necessary oil and vacuum pumping stations and of the electric control as well as the adaption to the existing infrastructure.

Technical Data

Type of installation	HS 16	HS 18	HS 19	HS 22	HS 23	HS 24
Max. rotor weight [kg]	150	300	700	1,500	3,000	5,500
Max. rotor diameter [mm]	1,260	1,260	1,260	1,260	1,260	1,600
Max. speed [1/min]	> 50,000	32,000	30,000	22,500	20,000	18,000
Typical driving power [kW]	160	200	250	250	315	315

Type of installation	HS 25	HS 26	HS 27	HS 28	HS 29	HS 34
Max. rotor weight [kg]	8,000	12,500	20,000	32,000	50,000	100,000
Max. rotor diameter [mm]	2,000	2,250	2,500	3,000	3,200	4,000
Max. speed [1/min]	15,000	12,000	10,000	8,000	6,000	4,500
Typical driving power [kW]	500	500	500	1,000	2,000	4,000

Modifications are possible. To cover a wider weight- and/or speed-range within one installation two or more pairs of pedestals with different sizes are being applied.

All information without obligation, subject to change without notice!

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