

Solutions Flash

Improve efficiency and reduce emissions with
abradable coatings for steam turbines

SF-0016.1 – October 2014



Today's situation

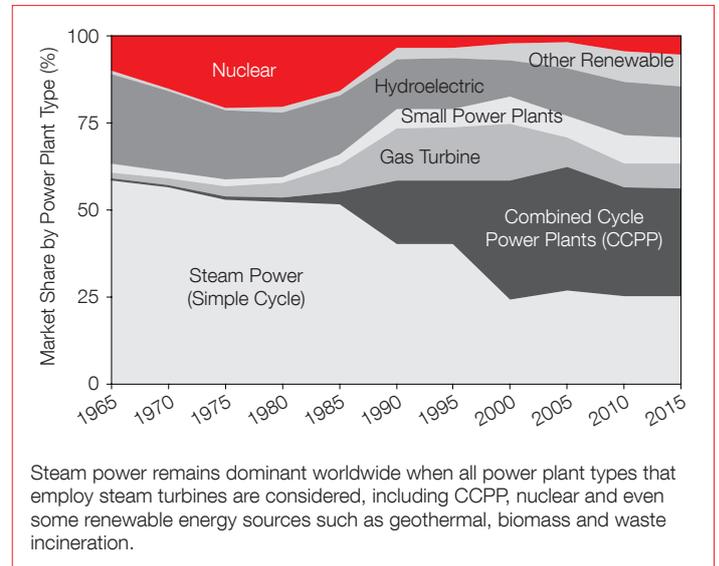
With steam turbines being the largest power generation type worldwide, both steam turbine designers and operators find they are under tremendous pressure to reduce emissions that contribute to global warming. This, combined with rising fuel prices and the need to deliver affordable power drives the on-going need for greater efficiency.

One area where such efficiency gains can be achieved is through reduction in the clearances between rotating components (such as blades and shafts) and stationary components through the introduction of abradable seals.

The steam turbine industry is in a process of adopting abradable sealing technology which has long been used in other turbomachinery applications, in particular aero and industrial gas turbine engines.

The weight and size of steam turbine components, particularly for the largest plants, precludes the possibility of transporting these components off-site for processing. Furthermore, extended overhaul outage time can cost millions of dollars per week in lost revenues. Therefore, the industry

needs services that can apply these sealing technologies at the manufacturing or final assembly site, or on-site during turbine overhaul.



The Oerlikon Metco solution

Oerlikon Metco, the leading supplier of abradable solutions for IGT and aero applications, has developed a portfolio of abradable materials for long term service in high pressure steam environments.

Applying abradable sealing technology to steam turbines results in increased power output and efficiency, or reduced fuel consumption. Both scenarios result in reduced CO₂ emissions, and in the case of coal-fired and oil-fired plants, reduced SO₂ emissions.

Just a 0.5% improvement in steam turbine efficiency is worth over US\$ 1 million per year for a 1000 MW unit. Within a typical 5-year overhaul period, the investment in steam turbine abradables pays back 13 times. When all relevant

sections of the steam turbine are fitted with Oerlikon Metco's abradable technologies, efficiency gains of up to 1% can be achieved.

In addition, Oerlikon Metco Coating Services have developed specialty skills to apply abradable seals to very large steam turbine components as large as 2 m (6 ft) in diameter and 4.5 m (15 ft) in length and weighing more than 10 tons. And these coatings can be applied either in their spray shops or at the site of final turbine assembly or overhaul to ease logistics and reduce outage time.

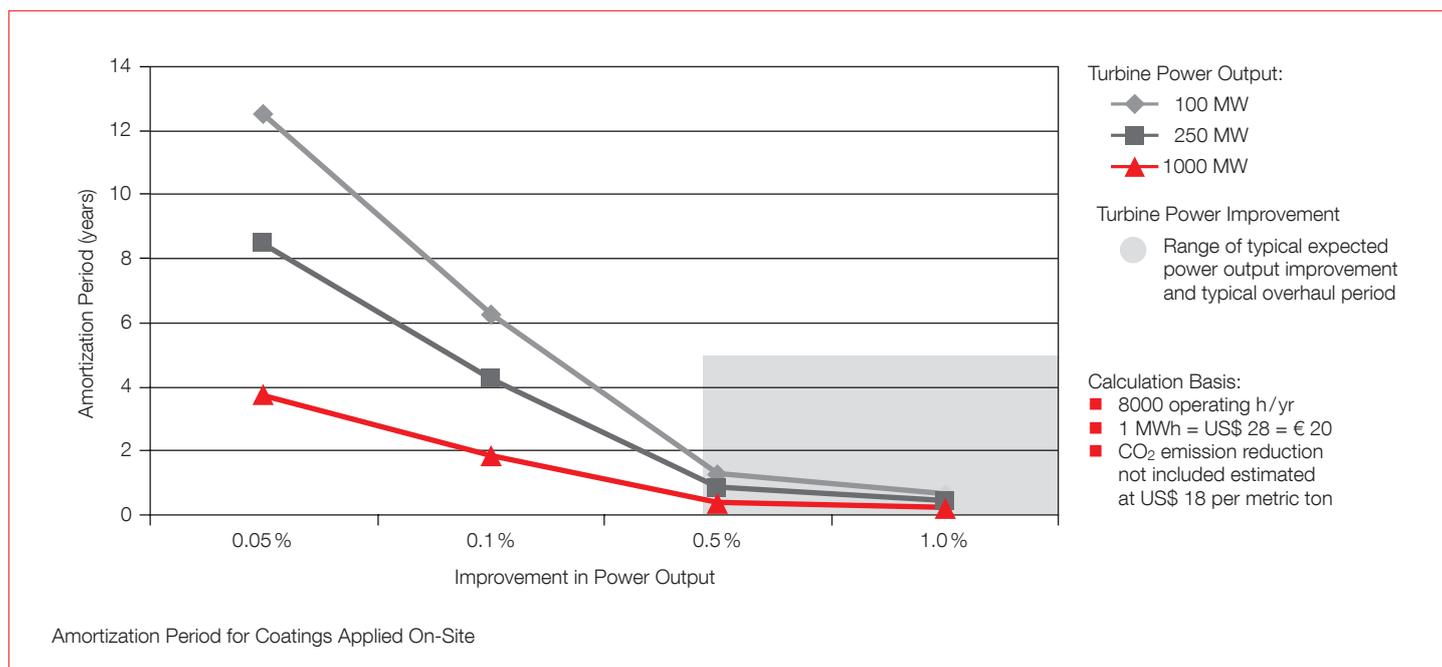
Leading turbine OEM's have already incorporated Oerlikon Metco's abradable technology with very successful results.

Solution description and validation

Rapid return on investment

When abrasible coatings are applied to all applicable areas (yielding a 0.5% – 1.0% power output improvement), the cost to apply the coatings is very economical, even for on-site service. The amortization time for steam turbines with output ratings > 250 MW is only a fraction of the overhaul cycle. For the largest units with outputs ≥ 1000 MW, the investment pay back is only a matter of weeks.

When this rapid pay back period is combined with the additional benefit of reduced CO₂ emissions, Oerlikon Metco's abrasible sealing technologies becomes a very attractive solution. Furthermore, when the coatings are applied on-site, the additional assembly or overhaul time is minimized and the logistics and risks associated with off-site service eliminated.



Example value proposition for steam turbine abrasible coating services

The following example reflects calculated data generated with on-site coatings on a 1000 MW steam turbine:

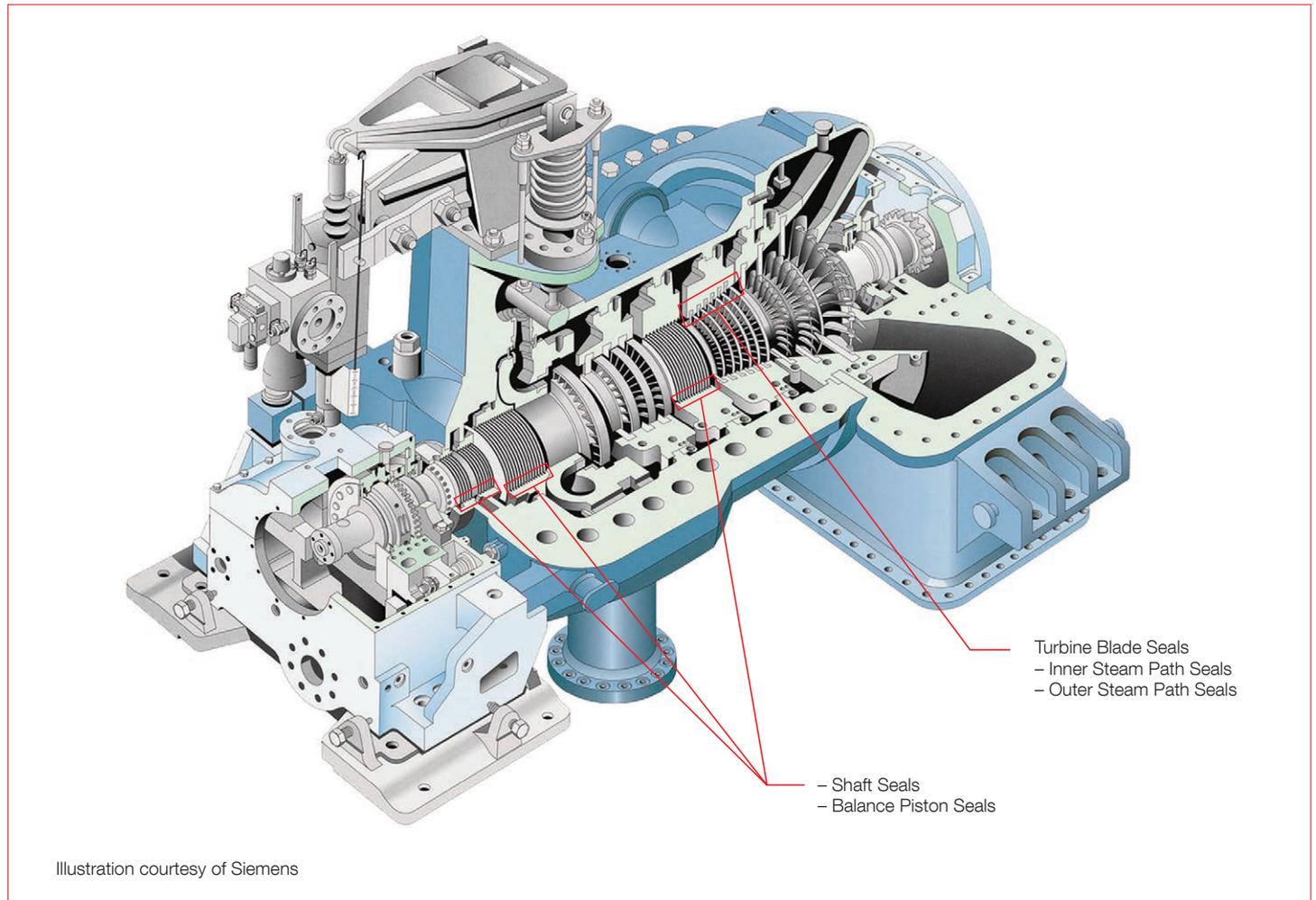
	OEM efficiency focus	OEM environmental focus
Issue	Sub-optimal turbine efficiencies	High cost of excessive CO ₂ emissions
Oerlikon Metco Solution	Full steam path sealing	Full steam path sealing
Benefit	Up to 1% efficiency gain; valued at US\$ 2.2M/yr/unit sold	Approx. 73,600 metric tons/yr/unit CO ₂ emission reduction
Payback Time	0.2 yr	0.35 yr ^a
Financial Return (NPV)	US\$ 7.8M	US\$ 4.7M

^a Cost of CO₂ emission valued at US\$ 18/metric ton

Note: M = 1 million

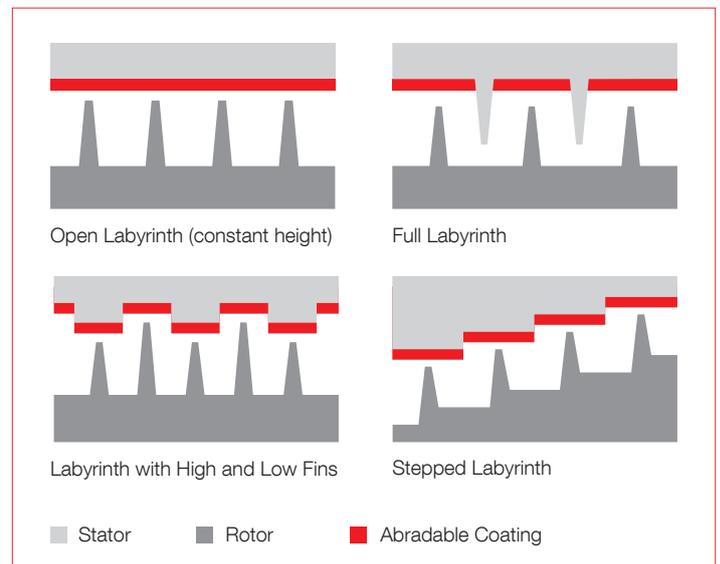
Abradable coating applications for steam turbines

In steam turbines, abradable coatings should be applied to shaft seals, balance piston seals and seals over shrouded blades. Application to all of these areas ensures a complete solution that will maximize efficiency gains by reducing leakage flows through labyrinths.



Function of abradable coatings on labyrinth seals

The coating process is very flexible and can be applied to the stator of a labyrinth seal system of any configuration. Coating thickness can be adapted to provide ideal clearances between rotating seal fins and the stationary component. In addition, a variety of material choices are available for different seal applications that can be sprayed consistently with coating properties that minimize or eliminate seal fin damage in the event of a rub.



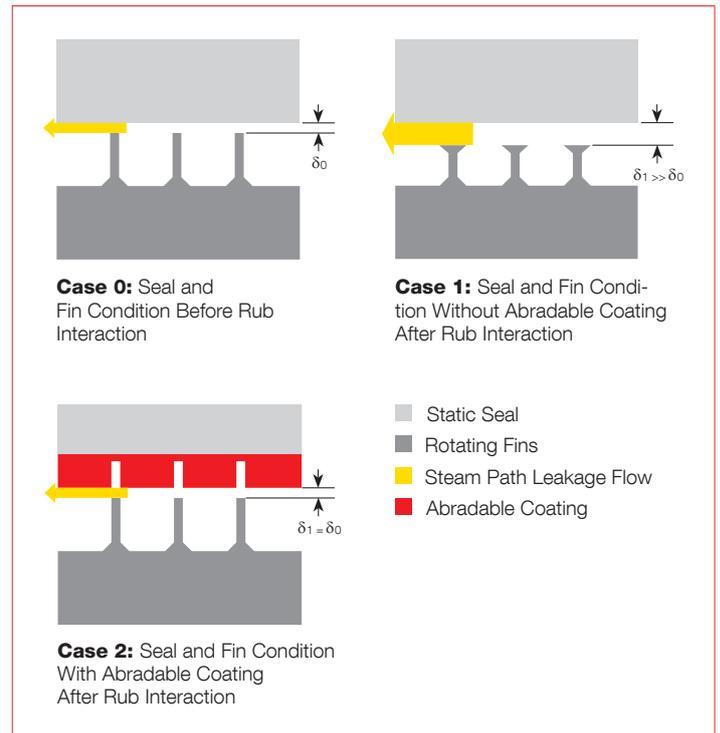
Labyrinth seal rub event

Ideal abrasability is schematically depicted below for a hypothetical labyrinth seal system. Upon displacement, the rotor can come into contact with and rub against the casing.

Without an abrasable coating, as shown in Case 1, the rotor fins are worn and reduced in length, which gives rise to an increased clearance of δ_1 that is much larger in size than the initial design clearance of δ_0 around the entire circumference. This results in deterioration of labyrinth seal efficiency.

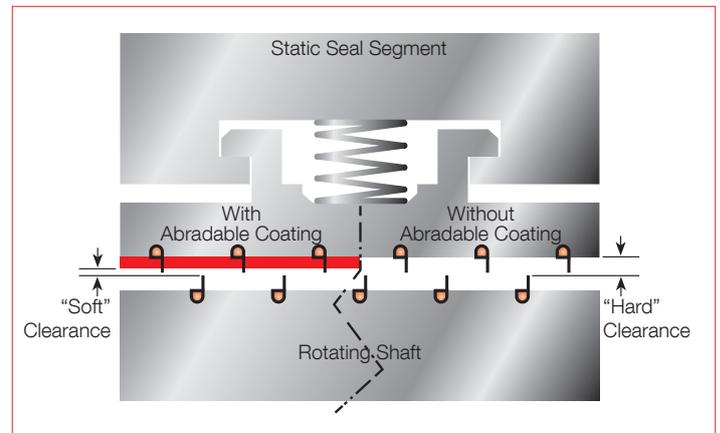
When an ideal abrasable coating is used, as shown in Case 2, the fins on the rotor can cut cleanly into the stator without any reduction in rotor diameter or fin height. Upon returning to the initial position, the design tip clearance of δ_0 is maintained around the circumference.

Both cases are boundary scenarios. In practice, mixed forms with some seal and some fin wear will usually be observed. In general, fin wear up to 5% of the total geometric overlap of the rotor and stator, i.e., the total incursion depth, is acceptable.



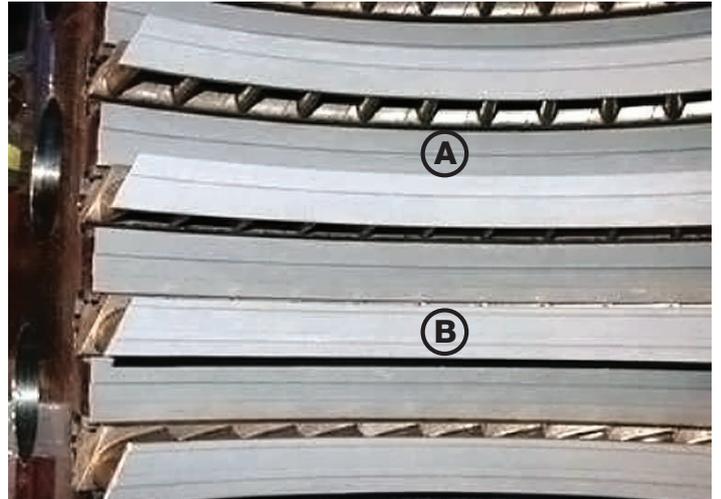
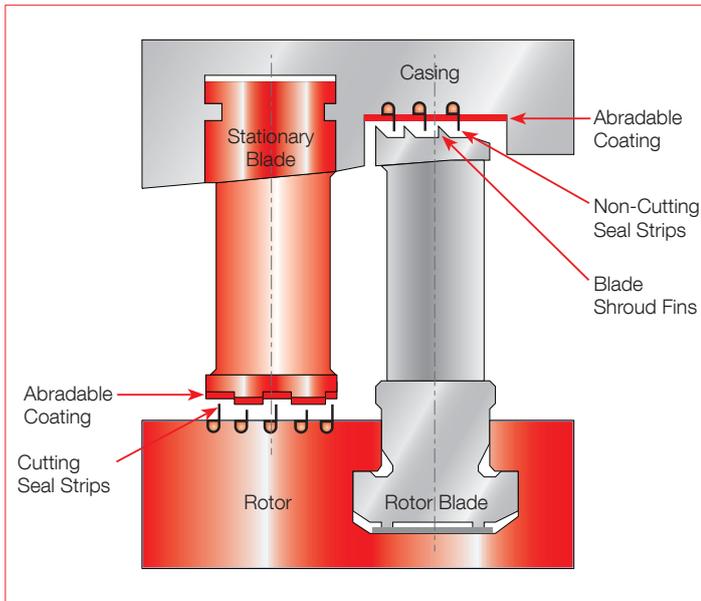
Function of abrasable coatings on shaft and balance piston seals

Application of an abrasable coating to shaft and balance piston seal segments reduces the effective clearance between members of the seal system, thereby creating a “soft clearance”. Without the abrasable coating, the effect is an increased “hard clearance” between the components. continuously automated applications.



Function of abradable seals on shrouded rotor and stationary blades

Abradable coatings are also applied in the labyrinths that seal the steam path over shrouded blades. The abradable is applied to both the turbine casing to provide sealing of the rotor blades and to the shroud tips of the stationary blades to provide sealing against the rotor.

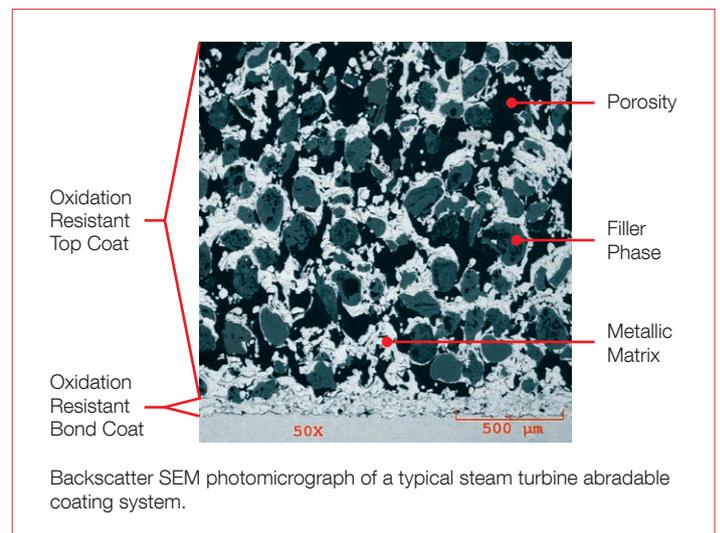


A) Abradable coating applied to the outer steam path seals on the casing.
B) Abradable coating applied to the inner steam path seals on the shrouds of the stationary blades.

Abradable materials technology

Coatings applied in steam turbine sealing applications are deposited as a coating system consisting of an oxidation-resistant bond coat and an abradable top coat. In order to function properly in a high pressure steam environment, both coatings need to resist steam oxidation for extended periods of time.

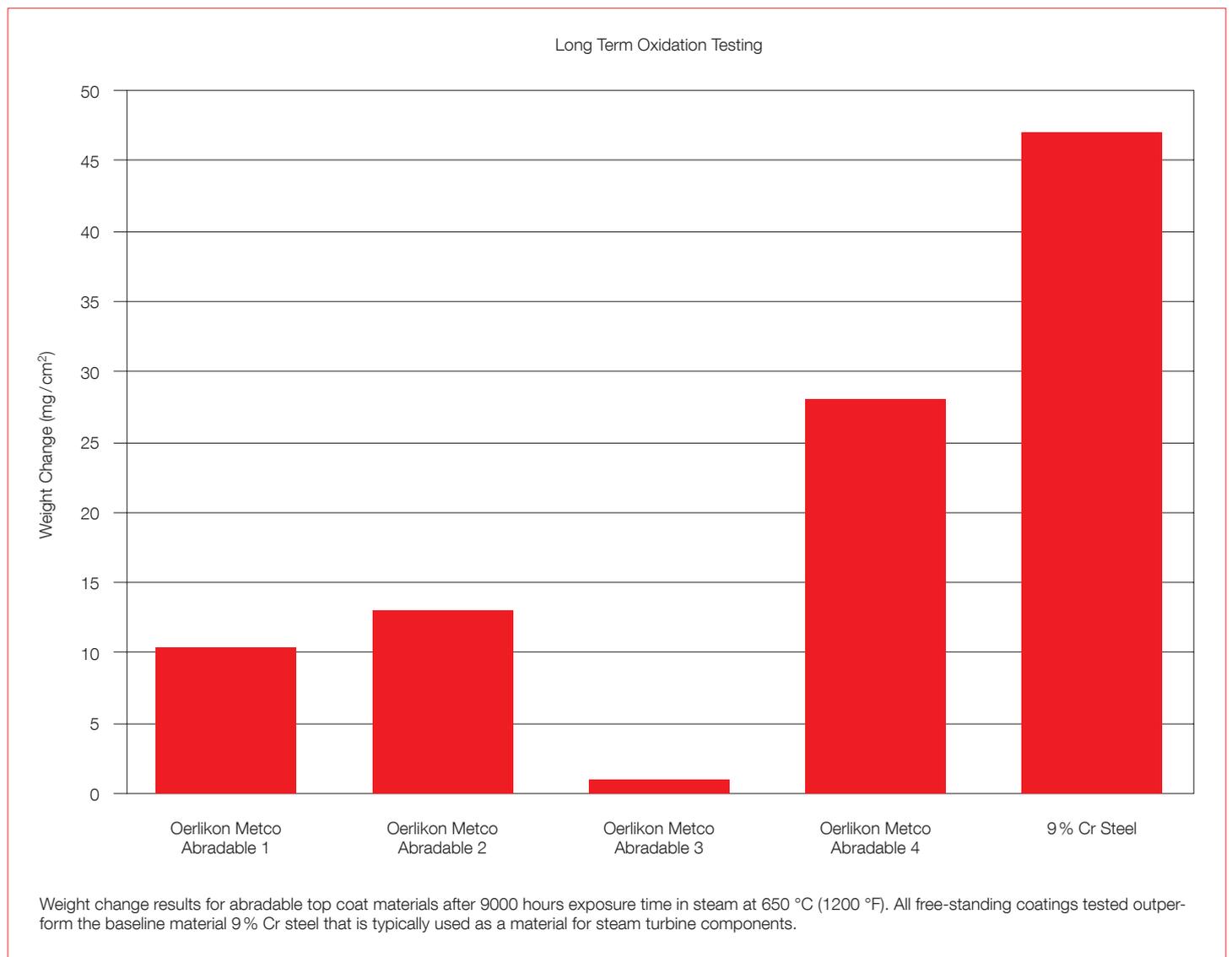
Oerlikon Metco has developed a portfolio of coating systems that resist steam oxidation well while maintaining their ability to be cut by seal strips and fins. Bond and top coats, as well as complete coating solutions, have been subjected to extensive testing for suitability in steam environments.



Backscatter SEM photomicrograph of a typical steam turbine abradable coating system.

The bond coat is carefully chosen to minimize thermal expansion mismatch between the abradable top coat and the base material while enhancing coating bond strength. It also acts as an oxidation resistant barrier layer. Within the abradable top coat, the metallic matrix phase provides structural integrity while the filler phase enhances abrasability. Controlled porosity levels within the top coat also serve to enhance abrasability and can be adjusted for differences in application.

Oerlikon Metco abradable systems are optimized to accommodate a variety of rub variables that include operating temperature, rotational speed, incursion rate and the material the abradable system will rub against.



Performance testing

Integration of abradable seal coatings into steam turbines requires an appropriate design approach that should be supported by performance testing to validate the selected seal design. Relevant performance tests include particle erosion and abradability testing using seal strips, fins or knife edges of various designs and materials. Oerlikon Metco has developed unique specialty testing capabilities that closely match actual operating conditions to qualify steam abradable seals for specific applications.



Abradable test facility



Stemming seal strips into the rotor

Component testing of the abradable system using the Oerlikon high temperature abradability test rig

Using our component testing facility, Oerlikon Metco can generate wear maps that validate the correct abradability over a range of test conditions. These include seal strip circumferential velocity, radial and axial incursion rate and test temperature. The test rig consists of a rotor disc that holds several seal strips and a stationary test shroud segment coated with the abradable system. For each coating, the rub mechanism is evaluated and a wear map generated.



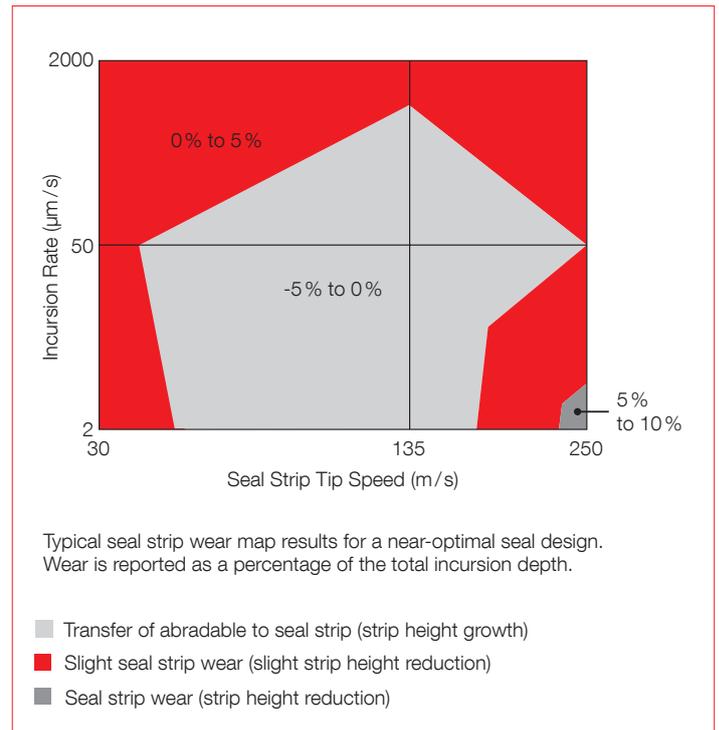
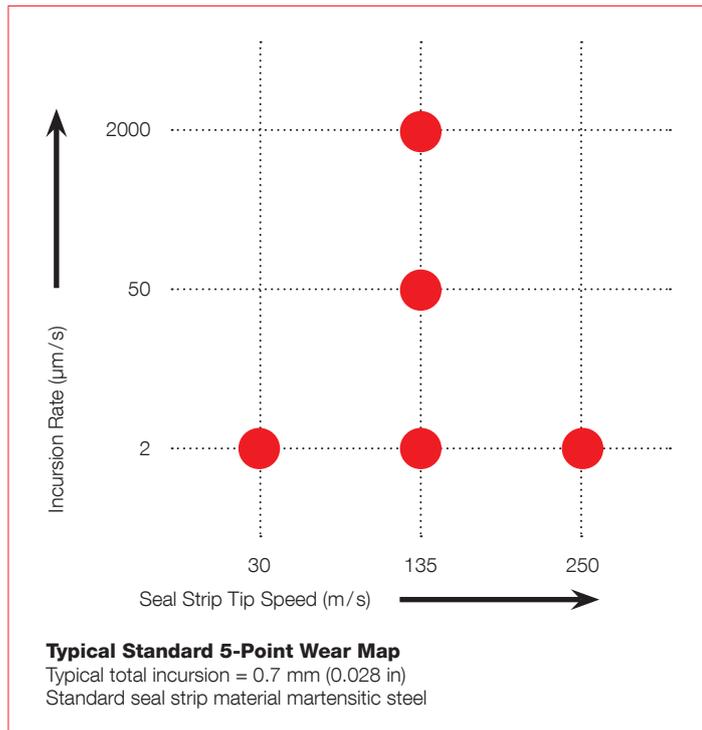
Rub scars from two labyrinth seal strips in a steam turbine abradable as generated using the Oerlikon testing facility. Test conditions used a combined radial and axial incursion rate of $50 \mu\text{m/s}$ ($1968 \mu\text{in/s}$) each and a strip circumferential speed of 90 m/s (295 ft/s) at a test temperature of $500 \text{ }^\circ\text{C}$ ($930 \text{ }^\circ\text{F}$).

Abradable test rig parameter range:

Seal strip circumferential velocity (max)	300 m/s	985 ft/s
Seal strip thickness (max)	1 mm	0.040 in
Incursion rate	1 to 2000 $\mu\text{m/s}$	39 to 78740 $\mu\text{in/s}$
Shroud temperature	20 to 700 $^\circ\text{C}$	70 to 1300 $^\circ\text{F}$

Wear map generation

A general screening test makes use of a standard wear map consisting of five different tip speed/incursion rate pairings. When combined with various coating microstructures, the results from these wear maps are a powerful tool for determining ideal abrasability of the seal coating to meet the specific design requirements.

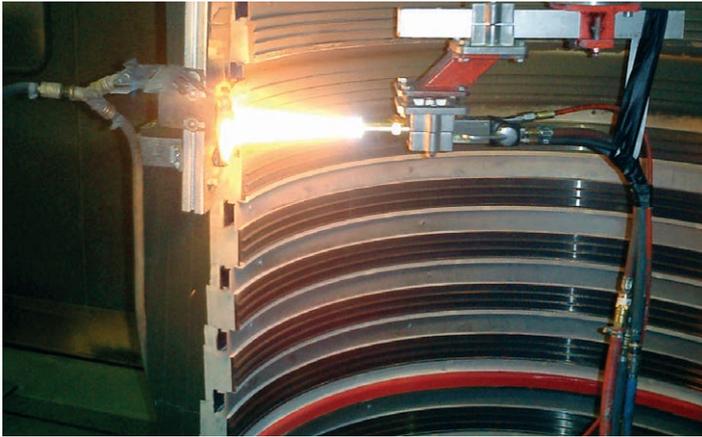


Make or buy – it's your decision

As the worldwide leader in thermal spray technologies, Oerlikon Metco offers customers flexibility for their coating implementation. Oerlikon Metco can provide the abrasable materials, or a complete coating facility solution that consists of the abrasable materials, state-of-the-art efficient spray systems custom-designed for the components to be sprayed and technology transfer that includes training and support for optimal and consistent processing results. However, not all customers desire such a solution. We therefore offer expert coating application services through our network of worldwide service centers that can provide both in-shop or on-site. These service centers are well-respected for their attention to detail and quality of production. Whatever your decision, Oerlikon Metco is there to ensure that your abrasable coating solution meets your expectations.

Coating Services for large components:

To provide sealing over shrouded rotor blades, the abradable coating system must be deposited directly onto the inner diameter of the casing. Turbine modules with large and heavy casings require specialized set-up facilities and procedures for application of the bond and top coats. Oerlikon Metco Coating Services has developed sophisticated skills to provide abradable coatings on these large components at our facilities.



Application of an abradable coating system to the upper half of a large steam turbine high pressure (HP) split casing at Oerlikon Metco Coating Services.

On-site coating application:

For extremely large or heavy casing components or when maintaining, repairing and overhauling large steam turbine units, the risk, cost and time to transport these components for processing by a dedicated coating shop may be unfeasible. In these situations, Oerlikon Metco offers a team of skilled operators and engineers to provide on-site application of the abradable coating systems. Moreover, Oerlikon Metco is highly experienced in proper project and process flow planning and coordination with the maintenance teams at the turbine site to ensure efficient and safe on-site processing.

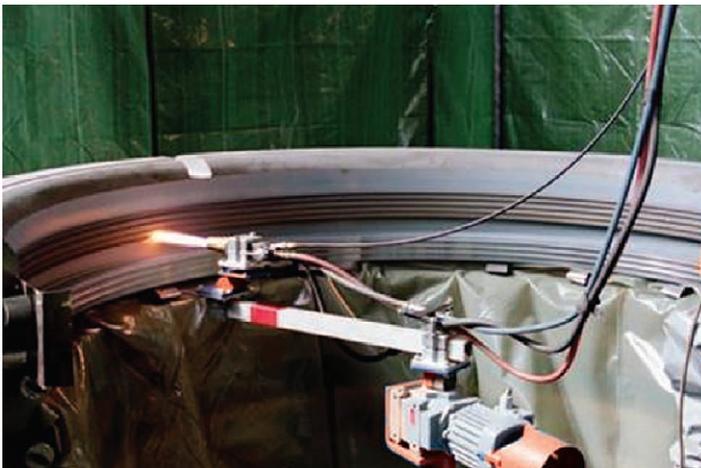
Preparation prior to on-site application:

- Seal system (bond and top coat) material selection
- Seal design and rig performance testing of selected design
- Sprayability demonstration and process qualification using the equipment to be used on-site
- Manufacturing Processing Plan (MPP) provided
- Quality Plan provided

On-site application:

- Surface preparation to provide optimal coating bonding
- Spray processing of the abradable coating systems
- Coating thickness measurement and documentation
- Coating surface roughness and optical appearance evaluation
- Simultaneous spray of witness samples representative of the coatings applied to the various stages. These samples are used for subsequent laboratory evaluation as agreed to in the Quality Plan, such as:
 - Coating macrohardness
 - Coating structure (metallic content, porosity)
 - Coating erosion resistance
 - Maintenance of historic quality control samples

Additional coating quality testing, such as coating tensile strength and abradability on witness samples can be performed if required for an additional fee.



Application of an abradable system to the intermediate pressure (IP) casing of a 900 MW steam turbine unit. Top image: pre-coating preparation; middle and bottom images: thermal spray coating application.

Customer benefits

Environmentally friendly

- Significantly reduces steam turbine CO₂ emissions and, where applicable, SO₂ emissions.

Effective

- Abradable coating systems are proven technologies that effectively reduce clearances and maintain efficiency between overhauls, even after rub interactions.
- Abradable coating system bond coats and top coats are oxidation resistant and designed to withstand the steam path environment.
- A portfolio of Oerlikon Metco materials combined with flexible, reproducible coating parameters allows the design of a coating system with optimized abrasability that meets specific operating requirements.
- State-of-the-art materials technology for coatings that results in very minimal seal wear during rub interactions and maintains steam path design clearances.

Efficient

- Can increase overall steam turbine power output by 0.5 % to 1 % when applied to all applicable areas of the turbine.
- Ideal abrasability confirmed using Oerlikon Metco's advanced rig that can test under a variety of conditions.
- Customers have the option of purchasing coating equipment and materials to apply the abrasable systems in-house, or procuring coating services.
- If desired, Oerlikon Metco Coating Services are available for coating application at our facilities or on-site.

Economical

- Economical process with a rapid return on investment.
- Minimal seal wear can extend life of turbine seals.
- On-site coating services reduces costs, saves time and eliminates the risk associated with the transport of large, heavy components.