TECHNICAL ARTICLE

Achieving World-Leading Load Lock Performance

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Faster cycle times boost throughput and profitability in load lock processes

Vacuum chambers are key components in a variety of industrial applications, from large-area coating for architectural or automotive glass to solar cell manufacturing and much more. In the field of coating technology, they are critical to physical vapor depositions (PVDs), chemical vapor depositions (CVDs/PECVDs), atomic layer depositions (ALDs) and other processes.

Although these systems can achieve very low suction pressures, it takes time to evacuate their large chambers, which can measure 60 m (196.85 ft) or more in length. As a result, it's not cost-effective to expose the process chamber to atmospheric pressure at the end of every cycle.

This limitation is commonly overcome using a secondary vacuum chamber called a load lock, which can be unloaded, reloaded and evacuated while the primary chamber is operating. Materials can then pass between the two chambers without the need to depressurize the primary module.

In this way, the overall productivity of the system is significantly increased. At the same time, however, the pump-down time and related possible cycle time of the load lock chamber can become the primary factors limiting throughput. Industry demand, therefore, is strong for backing pumps capable of delivering dramatically faster evacuation times down to deep vacuum levels with less power consumption — plus quieter, safer and cleaner operation in the smallest possible footprint.

Flowserve has developed a technology that not only answers all these requirements, but also delivers world-leading load lock performance. This game-changing innovation offers the potential to as much as double the output of load lock processes merely by upgrading the vacuum equipment.

The limitations of Roots-type blowers

Dry-screw and oil-sealed vacuum pumps are capable of compressing gas flows from atmospheric down to near-vacuum pressure. Since the volumetric performance of these pumps decreases as the suction pressure decreases, a single-stage pump would also require an extremely high power consumption for high vacuum requirements at low suction pressures. Multistage systems offer a more practical solution because they can achieve the necessary compression using significantly less energy.

Vacuum-coating processes have traditionally relied on just such a system: a combination of Roots-type blowers, also known as rotary lobe blowers, paired with oil-sealed or dry-backing pumps. Although standard for many years, this combination struggles to fulfill today's increasing demands for faster pump-down of load lock chambers.

Roots-type blowers are vacuum pumps designed to function as boosters in order to achieve high capacities at low pressures, typically below 10 mbar (0.15 psi). Their operation is limited, however, by the maximum difference allowed between their suction and discharge pressures. Since the full capacity of a Roots-type blower is only available at low pressure, the suction capacity of such a system declines significantly as the pressure rises, as shown in Figure 2. As a result, these pumps are not suitable for compression directly against atmospheric pressure.

Multistage system

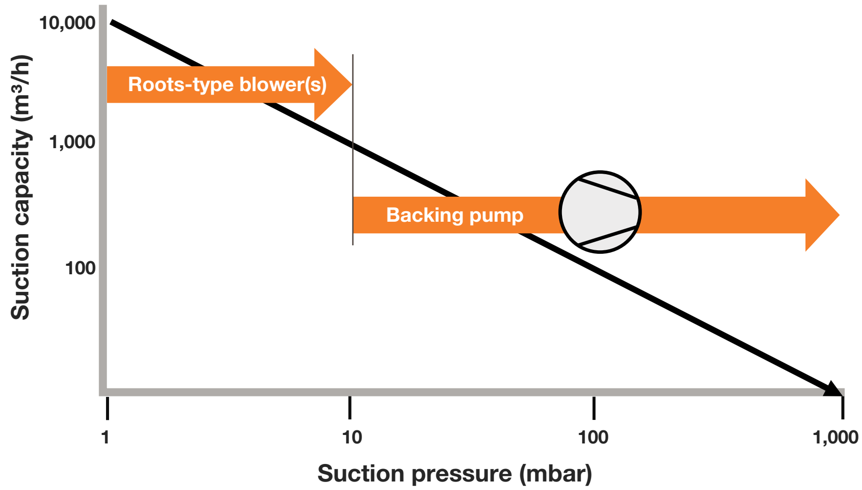


Figure 1: *A multistage system consisting of one or more Roots-type blowers and a backing pump offers compression with significantly lower electrical power consumption but fails to meet today's faster pump-down requirements.*

Declining suction capacity of Roots-type blower

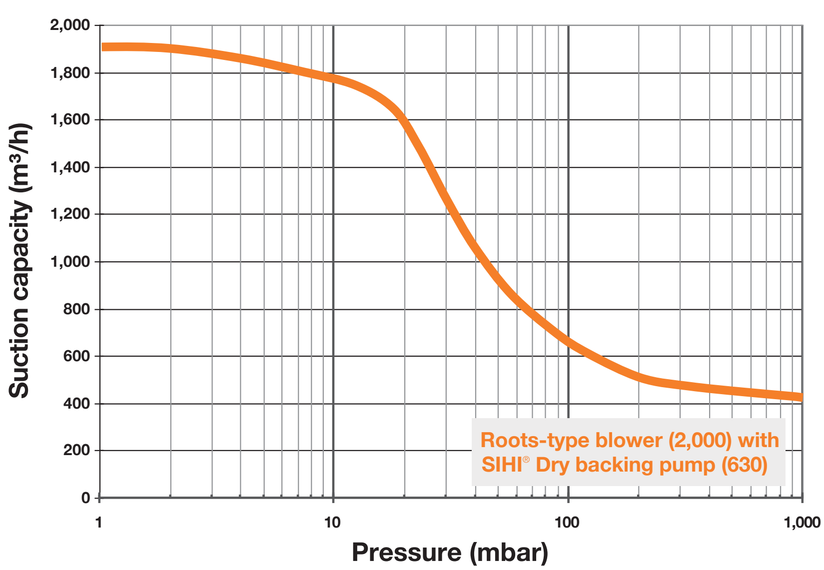


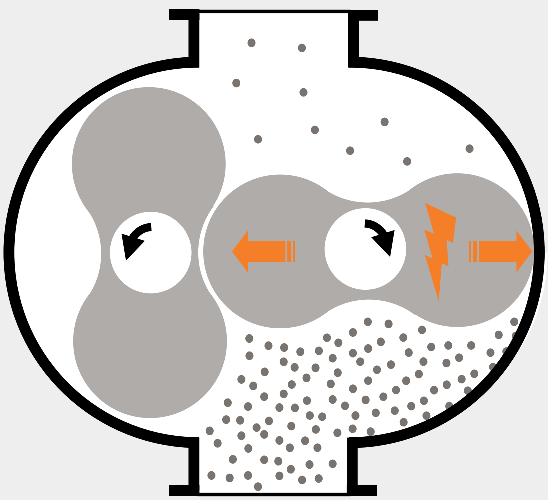
Figure 2: *Suction capacity of a Roots-type blower with SIHI Dry backing pump under increasing pressure*

The heat challenge

In addition to concerns about pressure, there's a linear relationship between the energy required to achieve greater pumping speeds and the buildup of heat in the pump. Greater power consumption leads to more thermal expansion of the pump's components, increasing the risk of contact between the rotors and the housing, which creates wear and eventually leads to breakdowns. Roots-type blowers have no internal compression. Therefore, their entire compression energy acts on the sealing gap of the rotary lobe when the individual chambers of the lobe are open.

The traditional solution to this problem is to add a bypass to the system, which recycles compressed gas back to the inlet when passing through the rough vacuum phase during pump-down cycles. Although this workaround solution protects the blower from overheating, it creates massive inefficiency in the system. As a result, the effective performance of the load lock is little more than the capacity of the backing pump during the rough vacuum phase. Furthermore, the only way to reduce the cycle time with a conventional Roots-type blower is to increase the capacity of the backing pump.

The risk from expansion



$$\text{Heat} = P_{compr} = \underbrace{\Delta P}_{(P_A - P_V)} \times \underbrace{S_{th}}_{V \times n}$$

Figure 3: *Energy consumption leads to thermal expansion and risk for contact between rotor and housing.*

A more efficient alternative: The SIHI Boost principle

Flowserve SIHI Boost dry-running vacuum pump systems, introduced in 2013, were developed specifically to meet the requirements of industrial applications in the medium and fine vacuum pressure ranges.

Even though SIHI Boost pumps have a much larger step-down ratio (up to 100:1) to the backing pump, the unit delivers significantly faster vessel evacuation than any other booster unit in the industry. Roots-type blowers are usually stepped to a maximum pumping speed ratio of 10:1 with the backing pump under ideal conditions. As a rule, however, the step-down ratio is no greater than 3:1 or perhaps 5:1 if a balance of performance at high and low pressures is to be ensured.

The unique design of SIHI Boost vacuum pumps allows them to harvest kinetic energy stored in the spindles, which can be exposed to atmospheric pressure at their full speed of 15,000 rpm — five times faster than traditional Roots-type machines — using less electricity. The unit's twin screws and symmetrical spindles produce an even distribution of forces, with compression to both ends of the booster.

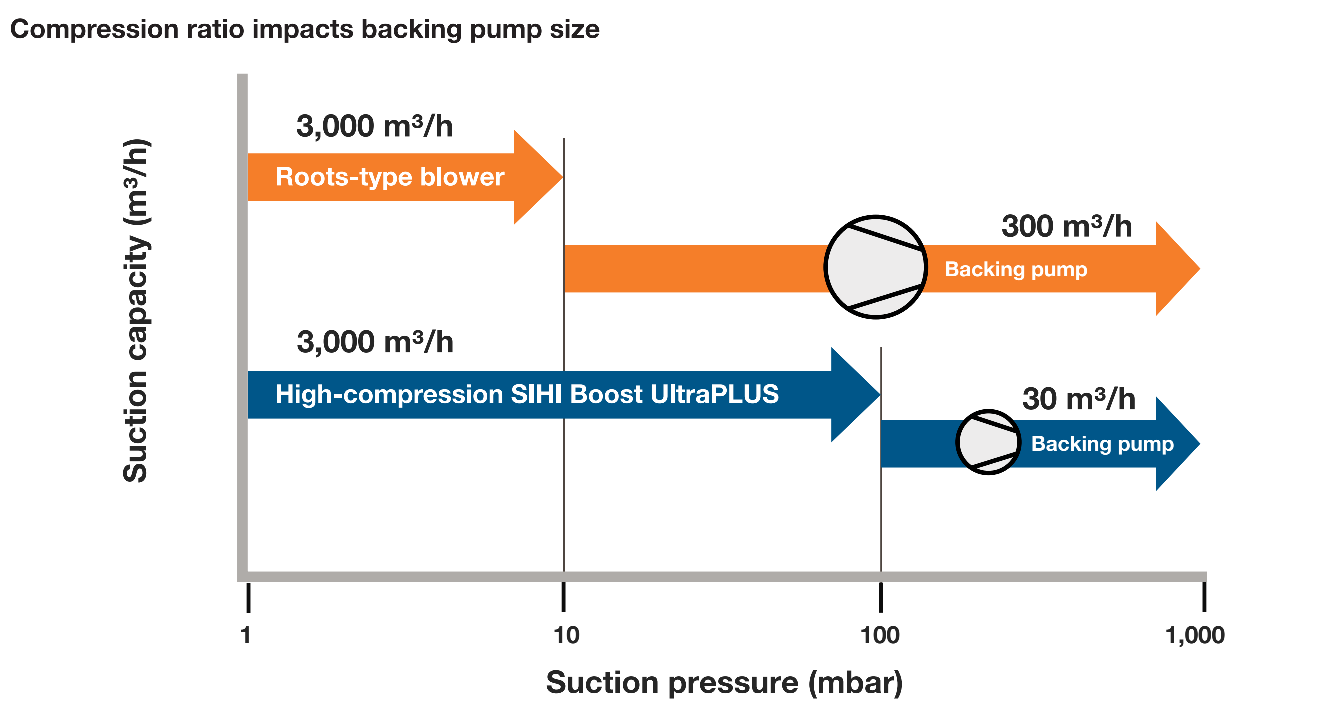


Figure 4: *Roots-type blowers were used because they allow the use of smaller backing pumps, which lowers power consumption. The higher compression ratio of the SIHI Boost pumps allows for even smaller backing pumps with lower power consumption.*

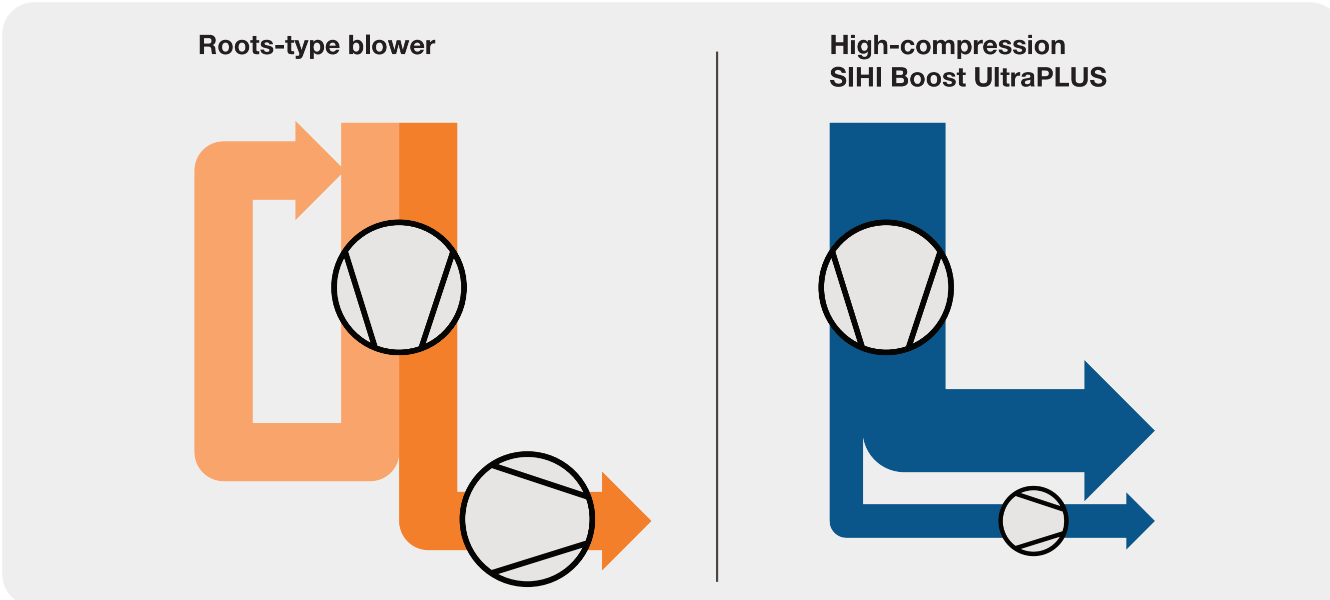


Figure 5: Greater efficiency reduces cycle times. *Roots-type blowers need to be bypassed at high pressure, creating a needless bottleneck in the process. SIHI Boost dry-running vacuum pumps offer full capacity from the moment the load lock valve opens, resulting in significantly faster pump-down and cycle times.*

The system benefits from the mass inertia of the spindles' rotating weight when passing through the rough vacuum phase during pump-down cycles. At that time, the installed motor power is much lower than the compression energy demand and the machine starts to slow down. Since it takes more time for the heavy screws to reduce speed than is required for the pump-down of the load lock chamber, this mass inertia enables the system to offer significantly higher volumetric flow. After achieving the low vacuum pressure level, the installed motor power is higher than the compression energy demand and can be used to bring the spindles back up to the desired rotating speed, ready for the next pump-down cycle.

In addition, an integrated pressure-relief system allows SIHI Boost units to be used with smaller backing pumps while still achieving rapid pump-down times, further reducing energy consumption.

Deep process pressure and load lock applications can be realized with almost any roughing pump technology, including liquid-ring, rotary-piston and dry-screw vacuum pumps.

In this way, SIHI Boost units offer full capacity from the moment the load lock valve opens, as well as significantly faster cycle times with smaller backing pumps.

Electronically synchronized spindles eliminate noise, vibration and oil

Unlike Roots-type blowers, which use oil-lubricated gearboxes to achieve synchronization, the spindles in SIHI Boost pumps are electronically synchronized. This innovative design enables quiet, vibration-free operation of the vacuum system while eliminating the needs for oil lubrication and costly mechanical seals. Contact-free operation extends component life and allows wider tolerances, significantly reducing the chance of shutdowns caused by liquid or particulate carryover. By making the gearbox obsolete, SIHI Boost pumps also eliminate the costs and labor required to maintain and change gear oil.

All of these innovations combine to produce a booster that provides dramatically faster evacuation down to deep vacuum levels with less power, a smaller footprint, plus quieter, safer and cleaner operation. A single unit can easily replace two or three Roots-type blowers — plus any interstage cooling units they might require — and deliver superior performance, even when paired with smaller backing pumps.

Using an old idea in a new way

Combining a SIHI Boost pump with a liquid-ring vacuum pump (LRVP) — the most rugged backing pump the process industry has known for 100 years — eliminates the risk of process buildup. Particles from process carryover are washed out in the LRVP, which acts like a scrubber to provide a pre-cleaned discharge flow. Particles either get solubilized, dissolved or suspended.

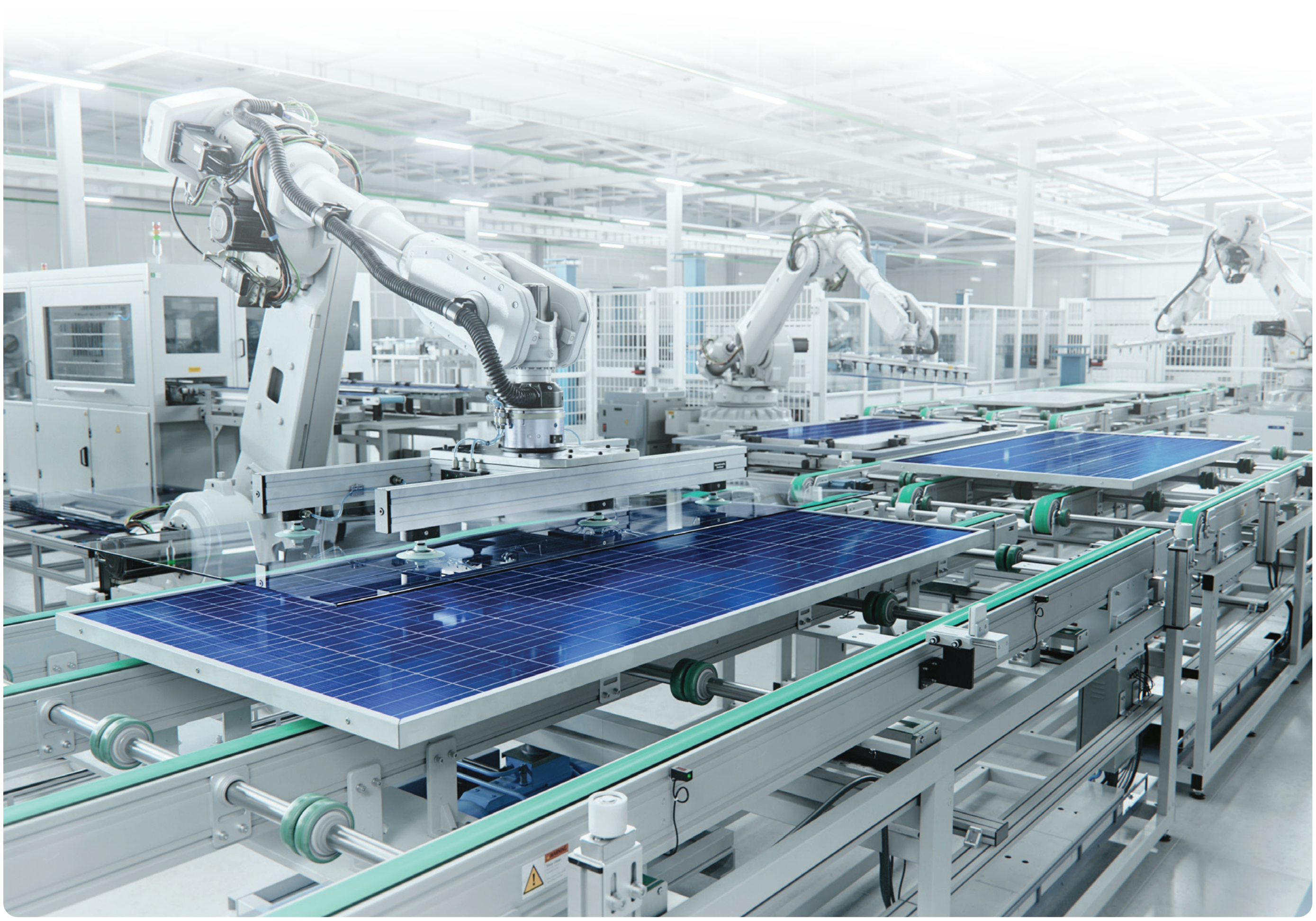
This dual-stage system solution offers the following unique features:

- The ability to handle gases, condensable vapors and/or solid carryover
- Optimization of process and load lock applications
- Entirely oil-free operation
- Easy maintenance
- High reliability
- Low noise and vibration

Since the achievable vacuum of LRVPs is limited to a pressure level above 100 mbar abs (1.45 psi abs), combining them with Roots-type blowers is not an option in coating applications.

The SIHI Boost design remains unique in the industry, delivering significant competitive advantages traditional Roots-type blowers simply can't provide. SIHI Boost pumps can compress easily to a pressure level of 100 mbar abs (1.45 psi abs), ideally to combine it with LRVPs.

Now Flowserve is taking the LRVP technology to an even higher level with the SIHI Boost UltraPLUS dry-running vacuum pump, which more than doubles the evacuation speed of the pump — without increasing the unit's footprint.



More power enables the world's fastest evacuation speed

The SIHI Boost UltraPLUS vacuum pump was developed with the goal of dramatically increasing the continuous output of the original SIHI Boost units, which were limited to 12.5 kW to protect the machine from overheating and thermal expansion of key components. Every change necessary to achieve this outcome required more power, including gap optimization, temperature distribution and adaptation of the integrated motors.

Several measurements were required to qualify the new product for different volumes and combinations of backing pumps. Improvements in thermal utilization were only possible with the use of simulation and, above all, measurements of asymmetrical gap distribution options during operation. Through this combination of simulation and testing, a very precise understanding of the thermal deformations that can result during operation was obtained. This led to three key solutions: optimized cooling, changing the material used for specific components to enable them to withstand the highest load scenarios, and modifying the pump's gap distribution strategy.

With a power limit more than double that of SIHI Boost vacuum pumps, SIHI Boost UltraPLUS pumps can reduce pump-down times of existing systems by as much as 20% while reducing cycle times and energy consumption by up to 50%.

Together, these improvements dramatically increased the machine's performance, enabling the original SIHI Boost vacuum pump's continuous power limit of 12.5 kW to be more than doubled to 28 kW in SIHI Boost UltraPLUS pumps, as shown in Figure 6. All this was realized without changing the size of the casing or modifying the drive electronics.

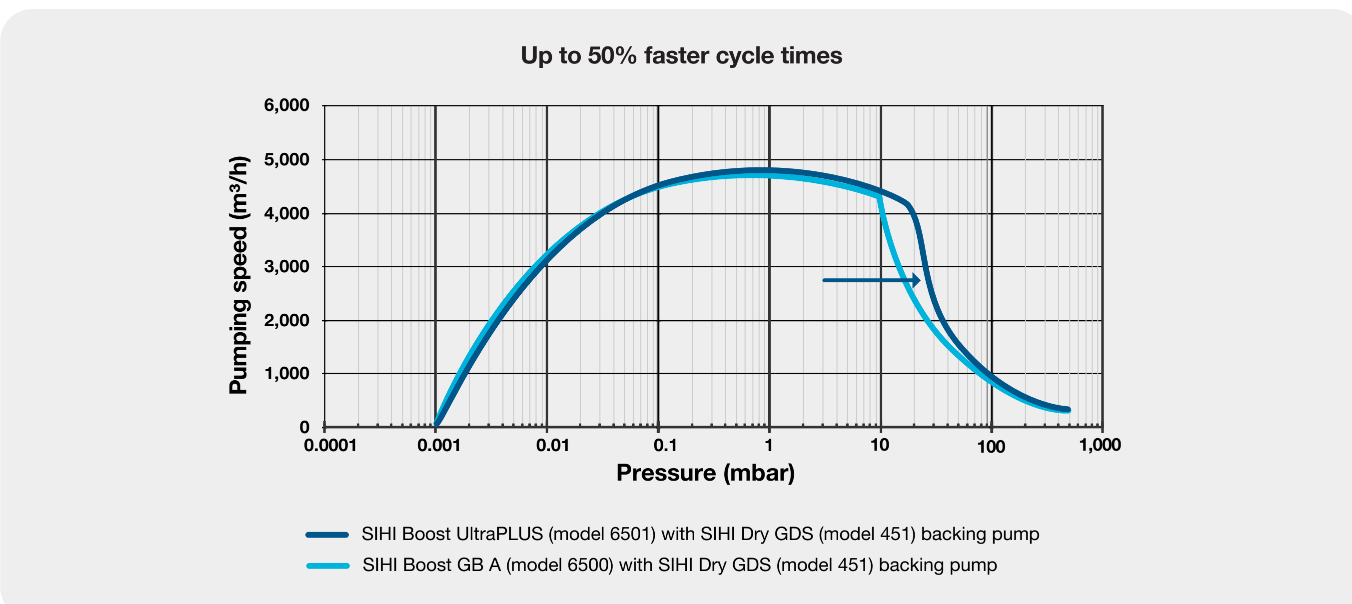
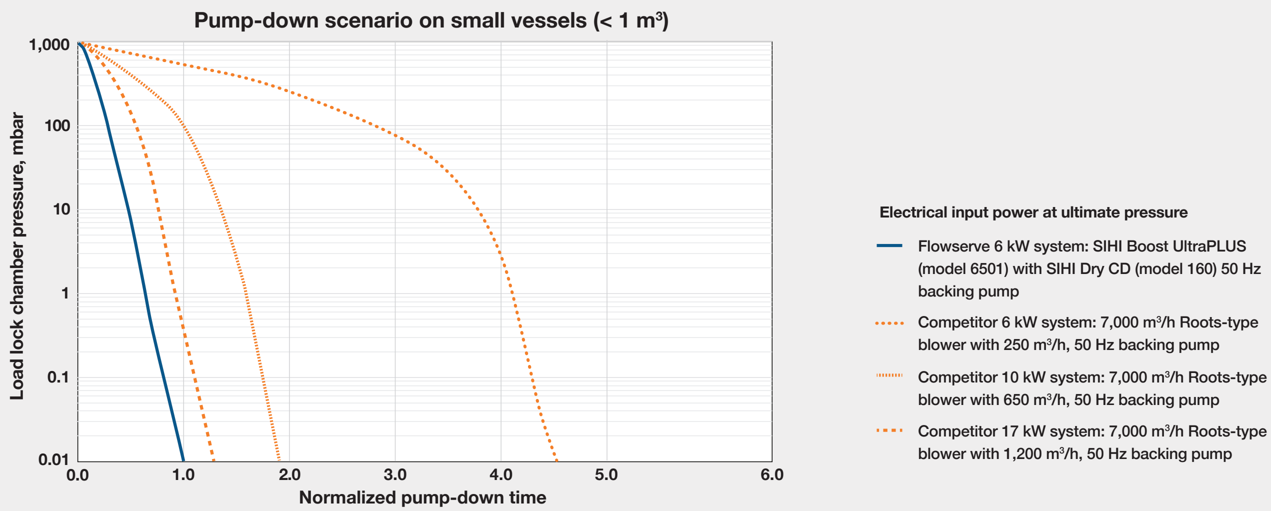


Figure 6: *Comparing the static pumping capacity of SIHI Boost GB A pumps and SIHI Boost UltraPLUS pumps. The performance improvements of the SIHI Boost UltraPLUS pump more than double the speed of a technology that was already unrivaled in the industry.*

The business case is clear

SIHI Boost UltraPLUS dry-running vacuum pumps offer significant opportunities for vacuum coating and other load lock processes to increase the throughput of existing production tools and reduce production costs per item. Flowserve focused the development of SIHI Boost pumps precisely to meet these market demands. As a result, replacing existing Roots-type blower systems with SIHI Boost UltraPLUS units can enable existing production equipment to achieve 20% shorter pump-down times while requiring only half of the backing pump capacity of the original SIHI Boost pumps. This can result in 50% faster cycle times and 50% less energy consumption compared to standard vacuum systems.

If cleaning does become necessary, the unit's simple design allows it to be easily serviced by on-site maintenance personnel; there's no need to contact the manufacturer.



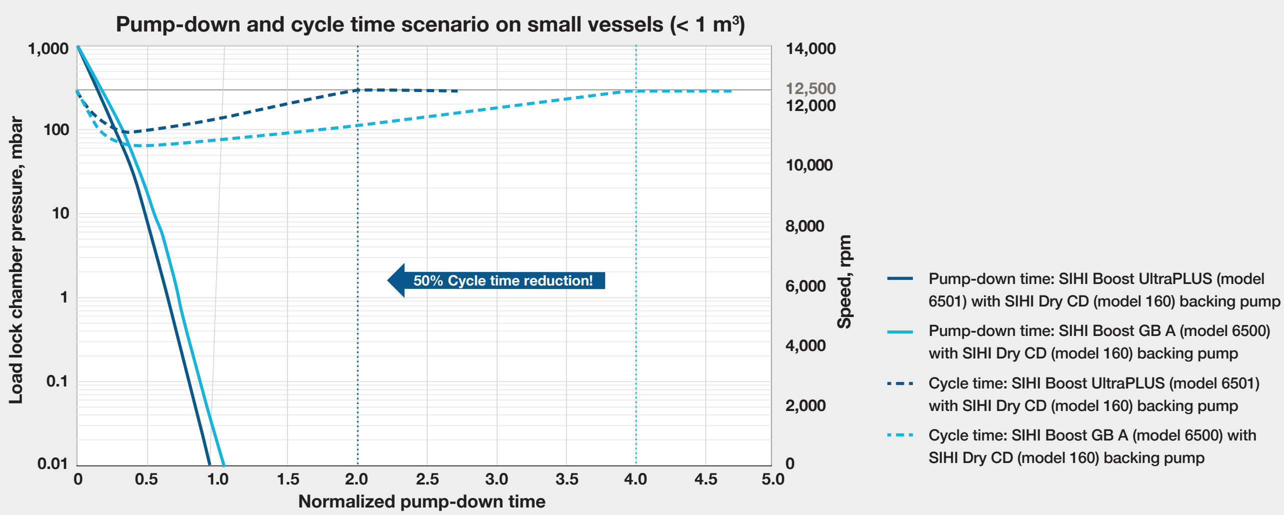


Figure 7: SIHI Boost UltraPLUS system offers lowest pump-down time. *These charts illustrate the difference in performance among a Flowserve SIHI S160 screw vacuum pump with a SIHI Boost UltraPLUS unit and several common alternatives offered by competitors, using small vessels (< 1 m³ [35 ft³]) as the benchmark. In this example, the pump-down time of the SIHI Boost UltraPLUS system is the lowest with a pumping system that requires only 6 kW of power at ultimate pressure. In the same scenario, the competitor's equal power solution takes more than four times longer. For a comparable pump-down time, the competitor's solution requires more than twice the power and greater backing pump capacity (measured at ultimate pressure).*

As previously discussed, the limitations of Roots-type blowers make them impractical for shortening cycle times. The energy wasted to ensure their safe operation doesn't contribute to cycle time improvement if the chamber pressure exceeds 80 Torr (0.11 bar). Even below this limit, shortening the cycle time with conventional blowers creates the need for larger or additional backing pumps. This reduces energy efficiency and increases maintenance costs, while requiring a larger footprint for the equipment. Downtime over the equipment life is also extended, increasing operational costs.

Unlike Roots-type blowers, SIHI Boost UltraPLUS vacuum pumps only require backing pumps to achieve the high vacuum pressure range. This means the backing pump capacity can be up to 10 times smaller than using standard Roots-type vacuum pump sets.

Pump design reduces maintenance, shutdowns and other costs

SIHI Boost UltraPLUS vacuum pumps also offer maintenance advantages that minimize costs and downtime. Utilizing an LRVP minimizes the need for cleaning while enabling safe handling of solid carryover. The LRVP acts like a discharge scrubber, which allows abatement systems for cleaning the downstream discharge to be downsized significantly. Thus, in addition to providing a more powerful and efficient vacuum system, the unit optimizes the entire gas handling vacuum train, further reducing costs.

Minimize downtime with built-in predictive maintenance capability

RedRaven is a predictive maintenance service from Flowserve that improves plant performance by detecting anomalies in pumps, valves and seals, enabling you to predict why your critical assets may experience issues and take preventive action.

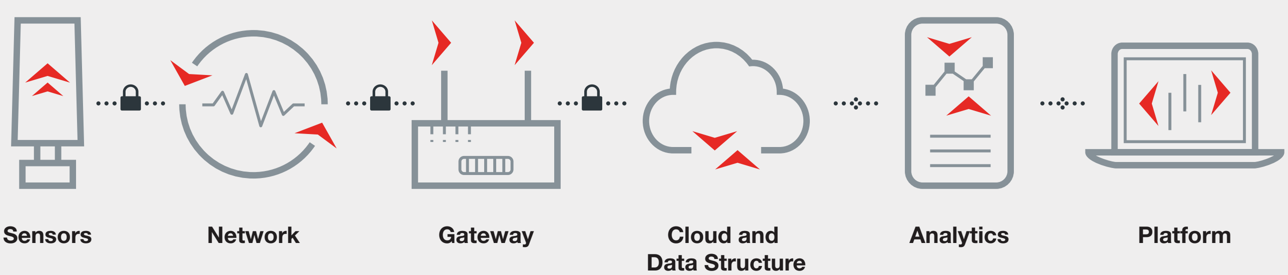
The SIHI Boost UltraPLUS vacuum pump is RedRaven Ready. It has been designed and built with all the hardware needed to take full advantage of RedRaven capabilities and benefits. No additional sensors or other devices are required.

RedRaven enables SIHI Boost UltraPLUS vacuum pumps to provide clear insights that improve your plant's efficiency, productivity and reliability with a secure IoT platform that includes hazardous area-certified equipment sensors, secure communication, performance analytics and reporting tools — all tailored to your specifications. Options include:

- **Condition monitoring:** Enables you to capture asset performance data for analysis
- **Predictive analytics:** Helps you identify and diagnose equipment problems before they fail

With access to advanced analytics and trends, you can often detect even the slightest changes in your equipment's performance — variations that can indicate a problem is looming. You won't just receive data, you'll get real insights needed to make more informed decisions for improving your plant's efficiency, productivity and bottom line.

For more information on RedRaven, contact your Flowserve representative or visit https://www.flowserve.com/redraven



Benefits of the SIHI Boost UltraPLUS pump in key applications

PECVD processes

Today's PECVD processes typically rely on Roots-type blowers in combination with dry-screw or claw-backing pumps. These backing pumps are predominantly for processing non-reactive, particle-free gas loads with low amounts of dust particles carried over in CVD plasma processes. By contrast, many gases commonly used in PECVD plasma operations create layers of deposits within the pump during compression to atmospheric pressure. The many resulting technical challenges can lead to major maintenance and downtime issues. Mechanical damage typically cannot be repaired by on-site maintenance personnel.

Flowserve SIHI Boost UltraPLUS vacuum pumps offer features ideally suited to deal with process issues, even in tough PECVD applications. By allowing much higher compression ratios, they create the opportunity to use SIHI liquid-ring vacuum backing pumps, which eliminate the risk of process buildup by allowing particles to be solubilized, dissolved or suspended. SIHI Boost UltraPLUS pumps can therefore handle plasma process gas mixtures without the creation of buildup in the vacuum pumps.

Titanium fabrication

Original SIHI Boost vacuum pumps are used successfully in many process applications. Initial experience in the titanium fabrication market, however, has demonstrated a need for these pumps to handle more demanding, dusty application environments. This market also has placed a high priority on the challenge of evacuating medium-sized volumes in significantly shorter times. Both of these considerations became core requirements for the pump-down time and thus for the installed power and motor torque of Flowserve SIHI Boost UltraPLUS vacuum pumps.

Vacuum coating

The Roots-type blower systems commonly used in vacuum coating processes struggle to fulfill the growing demand for reliable handling of plasma process gas mixtures that can cause buildup in oil-sealed or dry-vacuum pumps. By contrast, SIHI Boost UltraPLUS vacuum pumps are specifically designed for a much higher compression ratio, which utilizes LRVPs for vacuum-coating applications.

Other applications

SIHI Boost UltraPLUS dry-running vacuum pumps are also ideal for the following applications:

- Vacuum chamber evacuation
- Solar panel manufacturing
- Freeze drying
- Sterilization
- Thin film technology
- Metallurgy
- Leak detection
- Food and beverage
- Packaging

Conclusion

The innovative design of SIHI Boost UltraPLUS dry-running vacuum pumps literally doubles the value of a technology that was already unrivaled in the industry. The new pump design retains all the advantages of the original SIHI Boost pumps, including oil-free operation and full electronic synchronization, while cutting re-acceleration time up to 50% or more — without increasing the footprint of the unit. Simply by replacing the obsolete technology of Roots-type blowers, SIHI Boost UltraPLUS pumps can enable existing equipment to achieve the industry's fastest load lock cycle times to date.

About the author

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In his role, Stefan develops strategic and operational plans for vacuum pumps, liquid-ring compressors and related systems. These include the analysis of the liquid-ring and dry-vacuum pump markets, as well as forecasting and creating product marketing plans for individual product groups. In addition to evaluating market opportunities for new product ideas, he is involved in the product development process, solving technical problems as a team member.

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