Innovative Solutions For The Steel Industry

Dry-compressing screw vacuum pumps as enabler for demanding steel degassing processes

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The demand for high-quality, refined steels has constantly increased in recent decades. In parallel to this, steelworks are under increasing pressure to make their processes more energy-efficient and to drastically reduce CO_2 emissions.

Steels of higher quality are mainly subjected to vacuum processes in order to create the required properties. Traditionally, the vacuum for steel degassing units was generated using so-called steam ejector systems. However, since these are extremely unfavorable from an energy usage point of view and the amounts of steam required for their operation often need to be generated in a CO_2-intensive way in gas- or oil-fired boilers, the steel industry is faced with the problem here as to how it can meet the increasing demand for higher-quality steels without increasing emissions and the amount of energy required.

Mechanical vacuum systems offer an efficient solution for this and have already been in use for more than 10 years. However, in practice there were major problems, since the types of pumps that were used initially had only a limited ability to cope with the tough conditions of use. They caused higher maintenance and servicing costs and could not fully assure reliable operation of the steel degassing system. Here the crucial breakthrough only came about through the use of modern, dry-compressing screw vacuum pumps.

The production process for high-quality steels

The primary metallurgy starts here with the blast furnace process (Fig. 1). In the first production step, liquid pig iron is driven out of the mixture of coke and iron ore that is used. Since this still has a very high concentration of carbon, the liquid pig iron has oxygen applied to it in a converter and the carbon is burnt up and carried away as a CO / CO_2 mixture. Alloying components are also added during the conversion process so as to maintain the desired steel quality.

The steel that has been produced in this way is adequate for most industrial requirements, but higher-quality steels such as are required by the automotive or aerospace industries, for example, require further treatment in the so-called secondary metallurgical processes.

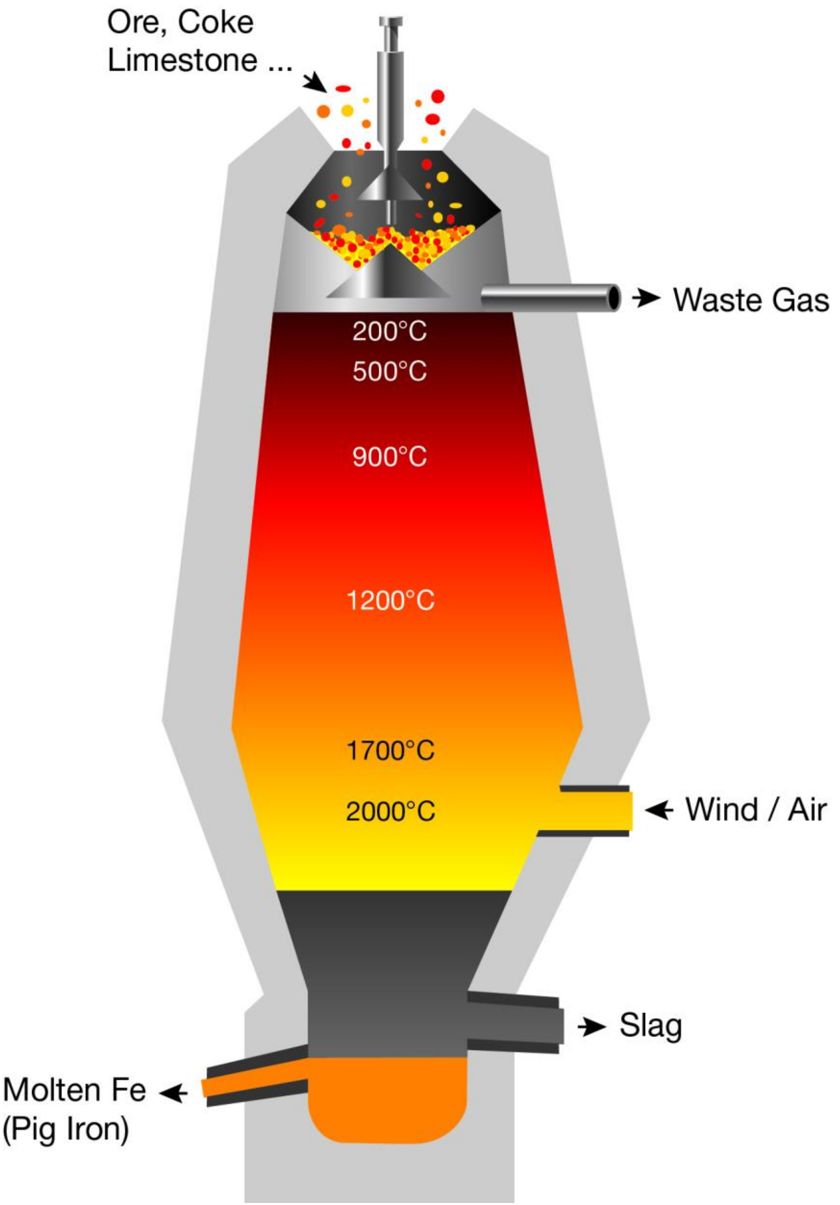


Fig. 1: The blast furnace process, works graphic Oerlikon Leybold Vacuum

Tough requirements

Steels for these industries have special requirements such as for strength, toughness, ductility, ability to be shaped and resistance to corrosion and wear.

In order to achieve these special properties, degassing procedures such as VD (Vacuum Degassing), VOD (Vacuum Oxygen Decarburization) or the RH (Ruhrstahl-Heraeus) process are used, among others.

Through these vacuum processes the amount of gases dissolved in the metal and of elements such as carbon or phosphorous can be reduced further, since they affect the quality and properties of the steel to be produced.

The VD and VOD processes are carried out in tank degassers (see Fig. 2). The steel that had been produced in the converter is filled into ladles holding around 20 - 200 tons which are then put into a vacuum tank. In the VD procedure the pressure within the tank is typically reduced to < 1 hPa after closing and sealing and held at that level for 10-20 minutes. Due to the reduced pressure, the dissolved gases are released at the surface of the metal and are drawn off by a vacuum system.
In the more demanding VOD procedure the pressure is initially reduced to a range of 200-50 hPa. Pure oxygen is blown onto the surface of the steel for around 10 to 40 minutes at this pressure. The oxygen thus burns off the excess carbon or phosphorous components, which are drawn off in gaseous form as oxides. Following the oxygen blowing process, a degassing process (VD) at < 1 hPa is always done as well.

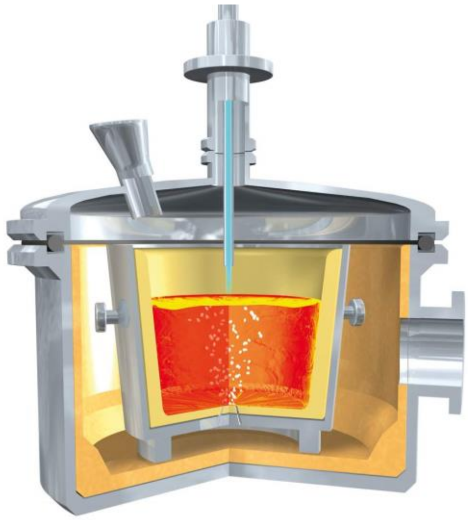


Fig. 2: VD/VOD tank degasser, works graphic Oerlikon Leybold Vacuum

The RH treatment was named after the company that had developed this process at the end of the 1950s. The RH vacuum treatment procedure is also called “stream-degassing”. It is especially suitable for very large tonnages but is relatively complicated. In view of the large tonnages, the ladle is not put into a (then very large) tank, but instead the vacuum chamber is inserted into the ladle via two snorkels (Fig. 3). Due to the vacuum, the steel is drawn up into the degassing chamber where then the oxygen blowing process and/or a degassing process (as with VD/VOD) can be carried out.

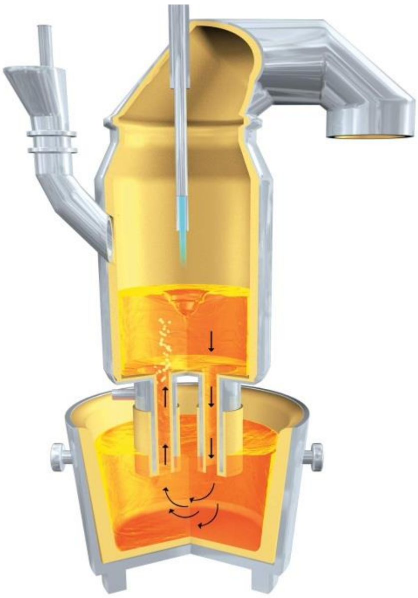


Fig. 3: Ruhrstahl-Heraeus (RH) steel degasser, works graphic Oerlikon Leybold Vacuum

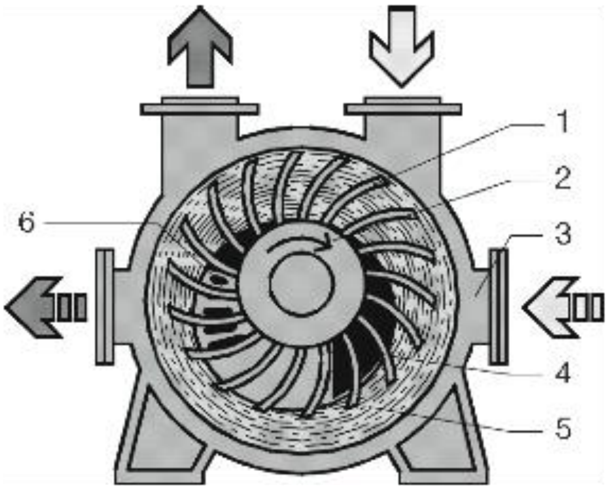
One important factor during steel degassing procedures is that the evacuation process must be done as quickly as possible because the melt cools down continuously. This also leads to extremely short evacuation times of typically only 3-7 minutes.
Due to the very large volumes that are possible and the very large amounts to be degassed in the case of large tonnages, the required vacuum systems are often very large. The required exhaustion rate here for a design pressure of 0.67 hPa is thus around 30,000 m³/h for a small VD unit up to >1,000,000 m³/h for a large RH unit.

Insensitivity to dust required

Not only the soluble gases are expelled at the typical degassing processes of < 1 hPa, but also metal components evaporate from the melt that is at a temperature of >1500°C. During the oxygen blowing process large amounts of metal oxides are produced as well. The metal and metal oxide vapours cool down on their way out and condense out in the form of large amounts of very fine dust. This is extracted by the vacuum system, which must be able to cope with the dust that is created. However, depending on the type of vacuum system, the sensitivity to dust varies very greatly.

The established standard vacuum solutions for steel degassers are steam ejector systems, and in practice these are often combined with liquid ring vacuum pumps (Fig. 4). The advantages of these vacuum systems are the relatively low investment costs and the fact that it involves a well-known technology which ensures reliable operation. However, these positive properties are obtained at the price of a whole series of disadvantages. By comparison with mechanical vacuum systems, the biggest drawback here is the very large amount of energy that is required, and consequently the very negative CO_2 balance.

Purely as a practical consideration, the long start-up times of a steam ejector unit and steam generation for at least 1-2 hours need to be mentioned. A system of this kind cannot be switched on at short notice when it is required, but it practice it is run continuously in standby mode.
In addition, it is not possible to adequate regulate the pressure, and in view of the layers of dust that settle out within the ejector system mean that regular mechanical cleaning and maintenance of the ejector systems is required.
A further disadvantage of steam ejector systems is the "wet" separation of the transported dust within the condensers and liquid ring pumps. This results in waste water that is heavily contaminated with dust and which requires expensive treatment. The operating costs of such a water circuit are also under-estimated in many cases. In practice, alone the circulating water pump required for a steam ejector system already consumes more power than the complete alternative mechanical vacuum system that can replace the entire steam ejector system.
Moreover, the deposition of dust means that the liquid ring pumps, which are used frequently, "clog up" and likewise need regular maintenance.



1 Rotor
2 Rotor shaft
3 Housing
4 Intake duct
5 Liquid ring
6 Flexible discharge duct

Fig. 4: Liquid ring vacuum pump, works graphic Oerlikon Leybold Vacuum

Another negative factor is that the pressure that can be attained with such vacuum systems depends on the temperature of the cooling water. If the same system is used, for example, in a hot country such as India where the cooling water circulated through cooling towers can easily reach temperatures of >35°C, then other qualities of steel are produced than in "cold" Germany, where the cooling tower water seldom reaches a temperature of >20°C even in summer.

Mechanical vacuum systems

It is precisely in comparison with steam ejector systems and liquid ring pumps that innovative mechanical pumps provide a practicable, reliable and powerful vacuum supply for steel degassing, offering a stable vacuum that is not dependent on external influences such as the temperature of the water, for example. This is especially important against the background of increasingly tough requirements for operating costs and CO_2 emissions.

Roots pumps

Roots pumps (Fig. 5) were used in all kinds of mechanical vacuum systems and displayed good performance right from the beginning: Adhering dust particles do not form hard layers on the inner walls of the pumps but instead are blown out again by the process gases.

In Roots pumps of modern design details such as the build-in motor (no need for shaft seals), hermetically sealed rotors and the intelligent use of sealing gas facilities considerably reduce further the stress caused by the dust that is brought in and so making this type of pump even more robust.

Operation via exactly parameterised frequency converters allows the use of the maximum exhaustion rate over the entire pressure range of the steel degasser.

Fig. 5: Exploded view of a Roots pump of modern design¸ copyright Oerlikon Leybold Vacuum

It is necessary to combine Roots pumps with suitable pre-vacuum pumps to achieve the required exhaustion rate. Nowadays the best optimised compromise for economic and energy considerations is usually provided by using three-stage vacuum systems (Fig. 6).

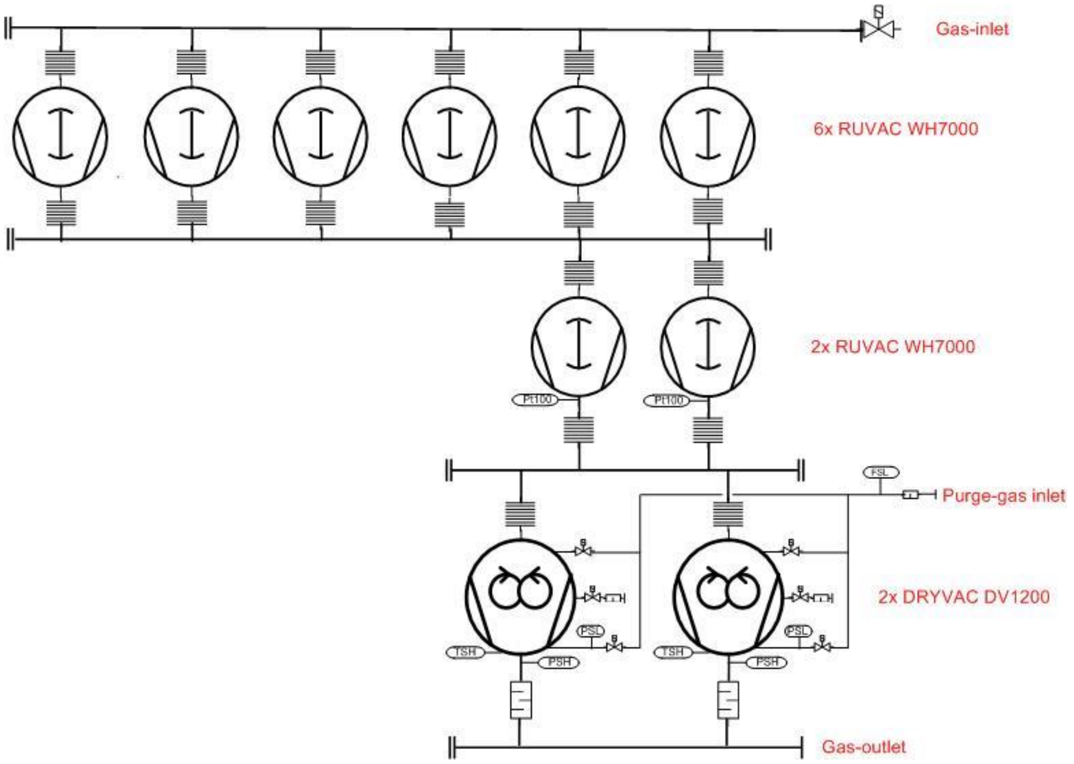


Fig. 6: Three-stage vacuum system. Ideal for use in steel degassing systems, copyright Oerlikon Leybold Vacuum

While Roots pumps could always be used without any problems in steel degassing systems, the fore-vacuum pumps that were required posed more of a problem here:

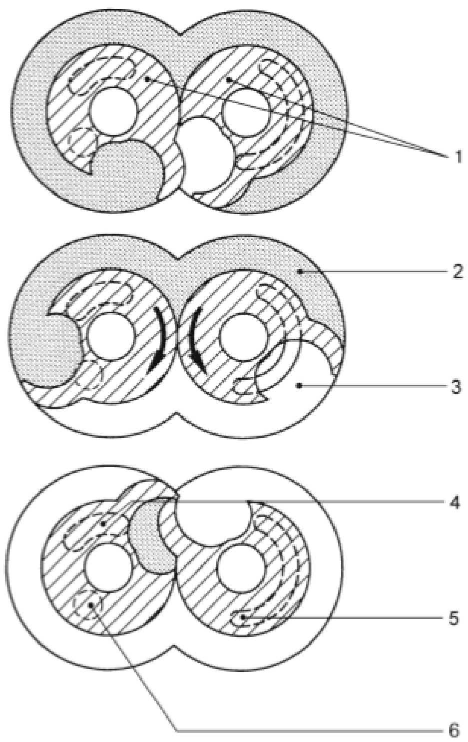
Oil-sealed rotary vane or rotary piston vacuum pumps

Oil-sealed pre-vacuum pumps were frequently used in the smaller vacuum degassers of the first generation. They turned out to have the disadvantage above all that the dust that got into the pump was washed out by the sealing oil that was used and became bound up in the inside of the pump. This particular circumstance caused problems in view of the sensitivity of pumps of this type to dust because the oil that was laden with dust acted like a grinding paste and led to damage to the interior of the pump. In order to effectively prevent damage of this type, this type of pump requires extremely efficient dust-filtering systems and oil changes and maintenance and servicing overhaul work at very short intervals. Weekly oil changes and annual overhauls of the pumps are not unusual here.

Especially when using them with degassing systems with oxygen blowing processes (such as VOD), it is necessary to note in addition that the vacuum needs to convey gas mixtures with high concentrations of oxygen for short periods. Since normal pump oils are not resistant to oxygen, special pump oils must be found, such as the extremely expensive PFPE oil to prevent the oil from being burned away. A cheaper alternative to this is also the use of special synthetic ester oils. However, if these are used the inspection intervals must be very short so as to ensure the oxygen resistance of the oil.

Dry-compressing claw vacuum pumps

Claw vacuum pumps (Fig. 7) were used as the first generation of dry-compressing pre-vacuum pumps. The idea was that, in view of the absence of oil in the suction chamber, any dust particles that were brought in could be simply discharged at the outlet in the same way as with Roots pumps.



1 Rotors
2 Compression chamber
3 Intake area
4 Discharge slot
5 Intake slot

Fig. 7: Compression process in a claw pump, works graphic Oerlikon Leybold Vacuum

However, in practice the convoluted conveying path in claw pumps led to part of the dust

settling out within the gas path. Attempts to remove the accumulations of dust by blowing them out with sudden blasts of gas did not lead to satisfactory results. Depending on the sealing concept, sealing oils are also brought into the suction chamber, and these form abrasive coatings in combination with the dust. Since the clearances below the claws are reduced when the pump cools down after switching off (resulting in any accumulations of dust being squeezed between the housing and the claw), it turned out to be a typical problem of this type of pump that it was difficult to start them up again if there were any dust accumulations inside them.
A further disadvantage is the typically very high noise level of claw vacuum pumps.

Suitable vacuum systems for metallurgy: dry screw vacuum pumps
The breakthrough concerning the process suitability of mechanical vacuum systems was provided by the development of modern dry-compressing screw vacuum pumps (Fig. 8).

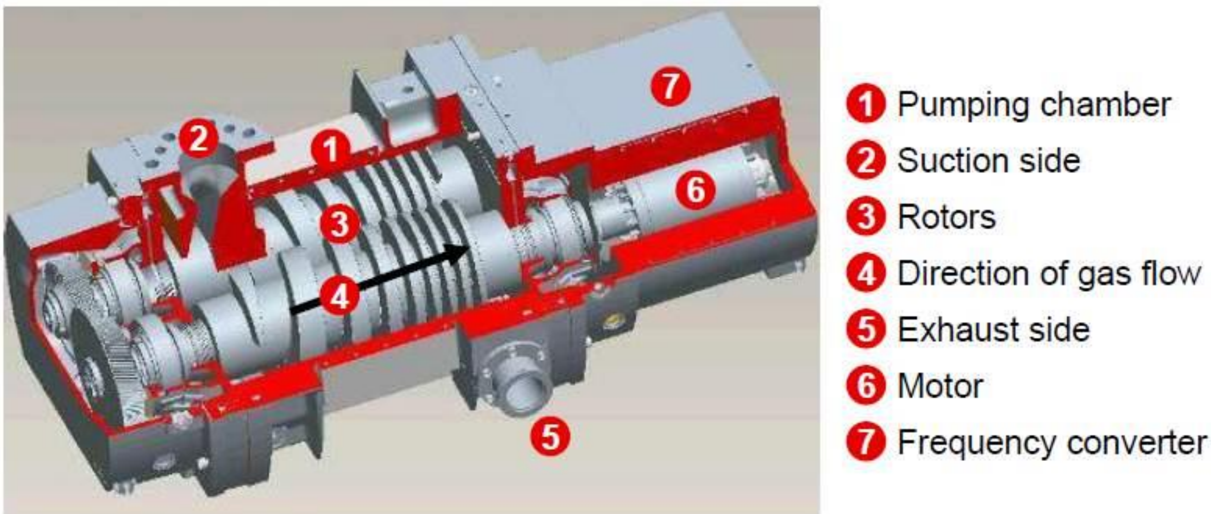


Fig. 8: Dry-compressing screw vacuum pump of the latest construction (DRYVAC), copyright Oerlikon Leybold Vacuum

These provide convincing results in demanding metallurgical processes through their simple design and robustness in operation. With these properties they guarantee a maximum degree of functionality and reliability, because screw pumps work even under very difficult conditions without any problems. In the same way as Roots pumps, screw vacuum pumps of the latest designs have design details such as a build-in motor that makes parts unnecessary that are subject to wear such as shaft seals, and also use intelligent sealing gas systems that prevent the entry of dust into the sealing systems, motor and bearing areas. Here, too, operation with optimally parameterized frequency converters leads to a maximized exhaustion rate over the entire working range. The intelligent electronics within the frequency converter are used in addition to monitor vital pump functions, and BUS communication to a higher-level controller is possible.

But the main advantage of screw vacuum pumps for these processes is primarily their insensitivity to the dry dust that occurs (Fig. 9). The direct gas path reduces to a very large extent the accumulation of particles that have been carried over into the process area. However, accumulations of dust are not a problem as long as the particle size is not greater than the gap between the rotor and the housing. Excessively thick accumulations of dust are simply pushed out in the direction of the outlet. Since the clearances between the rotor and the housing increase when the pump cools down, it is also possible to start the pump up again without any problems.

Fig. 9: Dry-compressing screw pumps can convey dry dust, works picture Oerlikon Leybold Vacuum

Intelligent pump drive units with frequency converters and a BUS interface are becoming increasingly important. This statement can be seen on the one hand from the point of view of the process control technology. There is the option to integrate the pump in such a way that it is actively involved in the implementation of the process requirements. However, on the other hand the use of integrated frequency converters also optimizes the power drawn by the pumps. In addition the amount of power that is required in any case is further reduced in modern screw vacuum pumps through the variable pitch of the screw rotors which ensures a continuous compression over the complete screw length.

Process advantages of mechanical vacuum systems

During the rapid evacuation of steel degassing systems it can happen within certain pressure ranges that the slag floating on the melt suddenly starts to foam. If countermeasures are not taken the metal melt can spill over the edge of the ladle. In practice, in such case nowadays the vacuum that has been generated with a steam ejector system is interrupted by admitting nitrogen or argon and the evacuation process is started again. When using mechanical vacuum systems with vacuum pumps that are controlled by frequency converters, the speed of evacuation can be regulated in advance in such a way that the pumps can "creep through" this critical range. This reliably prevents the slag from foaming over.

Summary

The increasing demand for higher-quality steels emphasises the necessity for an innovative and efficient form of steel degassing. The steam ejector systems that have been used traditionally have a number of disadvantages such as high energy consumption and massive emissions of CO_2. In addition, the metallurgical processes are made more expensive by the elaborate treatment that is required for the waste water and the steam that needs to be generated as required. Modern. mechanical vacuum systems (Fig. 10) offer a genuine alternative in functional and economic terms.

The use of modern, robust, dry-compressing screw vacuum pumps and Roots pumps means that such systems can be used today, even in the most demanding degassing processes.

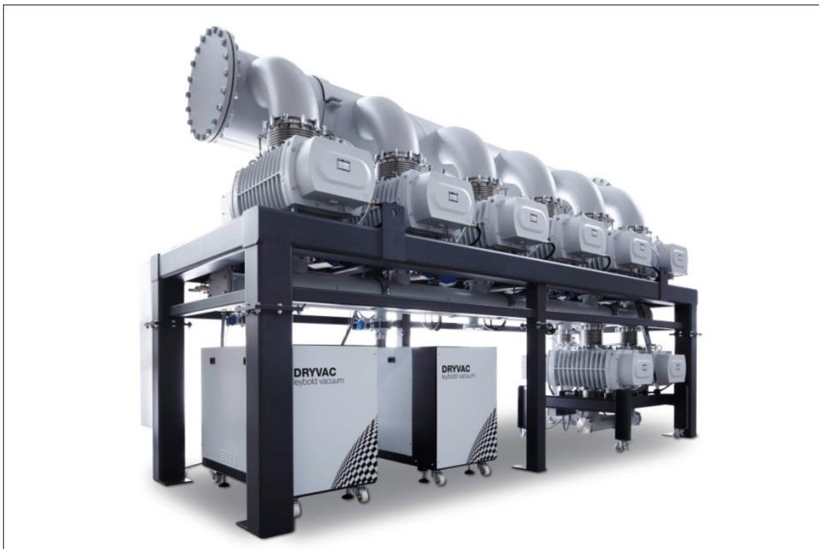


Fig. 10: Three-stage vacuum system, optimized for steel degassing processes, works picture Oerlikon Leybold Vacuum

The vacuum pump technology that is available today which is robust and optimised in energy terms could support the operators of steelworks still using older forms of vacuum technology in their efforts to reduce operating costs pollution of the environment to a minimum - both of these circumstances have gained in importance in recent years. The market potential of modern mechanical pump systems is correspondingly high. It can therefore be foreseen that the demand for mechanical vacuum systems in steel degassing will continue to increase in the near future. In view of the advantages stated above mechanical vacuum pump systems will take over from existing installed steam ejector systems in the medium term.