Dry mechanical vacuum pumps for vacuum degassing

Large Roots-style mechanical vacuum booster pumps, designed for high dust tolerance and backed by rugged, dry, mechanical vacuum pumps are superior to steam ejectors in terms of dust handling, pumping speed in the crucial processing pressure zones and significantly reduce environmental impact and operating cost.

AUTHOR: Vic Cheetham
BOC Edwards

Investment in steel vacuum degassing processes is continuing as steel companies see the opportunity to add value to their products by improving quality and supplying more speciality-grade steels. In ladle refining, recent advances in degassing processes using dry mechanical vacuum systems in place of fluid-sealed water ring and/or steam ejector systems, offer significant savings of as much as 90% in running and maintenance costs as well as improvements in increased speed, flexibility and overall productivity for steel degassing operations.

Vacuum degassing (VD) and vacuum oxygen decarburising (VOD) generate large volumes of dissolved metallurgical gases, metallic fines and oxide dust, requiring high-capacity, robust vacuum pumping equipment. Large Roots-style mechanical vacuum booster pumps, designed for high dust tolerance, are the major component of today's 'dry' vacuum degassing systems and, backed by rugged, dry, mechanical vacuum pumps, form today's advanced dry pump systems. These are superior to previously used steam ejectors in that they enable better dust handling, increased pumping speed in the crucial processing pressure zones, and significantly reduced environmental impact.

BACKGROUND

Dry running mechanical vacuum pumps are not new, they have been used in the metallurgical industry for degassing since the 1920s, but it is only recently that reduced manufacturing costs and the invention of suitably large dry running backing pumps (claw, lobe and screw) has realised the potential for completely dry vacuum pumping systems with sufficient capacity for modern steel degassing facilities.

PUMPING PERFORMANCE REQUIREMENTS

The basic performance parameters of a typical steel degassing pump system are shown in *Table 1*. It is essential that the system specification is accurate and realistic; note that specifications of legacy steam ejector systems often include excessive margins to allow for ▷

Parameter	Value
Heat mass (capacity)	Tonnes of liquid metal
System volume	2–3m^3 per tonne (typical)
System air leakage	Target <= 1kg/h (air@20°C) per 10 tonnes
Initial pump down time to VD	7–10 mins
VD process pressure	1mbar to <0.67mbar (0.5torr)
VD suction capacity	1.0–1.2kg/h/tonne (air@20°C) or 1,250–1,500m^3/h/tonne
VD line diameter	800–1,000mm
VD gas dust load to pump system	Low
VD gas temperature at pump system inlet	Should be <= 60°C
VOD process pressure	80–200mbar (60–150torr)
VOD suction capacity	Variable, typically: 20–30kg/h/tonne (air@20°C) or 75–150m^3/h/tonne
VOD line diameter	800–1,000mm
VOD gas dust load at pump system inlet	Can be high if filtration is poor
VOD gas temperature to pump system inlet	Should be <= 60°C (gas coolers typically required)

Table 1 The basic performance parameters of a typical steel degassing pump system for VD and VOD

Fig.1
40 ton steel degassing system – first stage dry mechanical booster pumps

ejector degradation and air leaks. Significant air leaks must be properly addressed by suitable maintenance, otherwise unwarranted extra pumping capacity will have to be installed.

To meet the high speeds required, systems should use an adequate number of large high vacuum mechanical booster pumps, staged correctly to achieve sufficient pumping speed while maintaining a satisfactory pressure ratio across each stage. These should be backed by primary pumps of sufficient capacity.

LIMITATIONS OF WET VACUUM PUMPING

Steam ejectors Steam jet ejectors are popular for industrial vacuum pumping systems because of their low initial cost and apparent maintenance-free operation. Compression ratios as high as 30 to 40 can be obtained in a single-stage ejector, but efficiency at these high compression ratios is poor, therefore single ejector stages are generally limited to a compression ratio of around 10. Typically, multiple ejector stages must be used for practical degassing systems, and a four-stage system is typical of steel degassing installations where final vacuum levels of 0.67mbar (0.5torr) are required. Importantly, the steam ejector system installed needs to have sufficient excess capacity to handle the process loads, steam pressure variations, and the inevitable loss in performance which will result from nozzle wear and diffuser contamination from the large amounts of dust. This contamination has the unfortunate characteristic of forming a hard aggregate inside the ejector, which must be regularly mechanically removed.

Steam ejectors have served the steel industry well over the years, but the issues that are increasingly making users consider dry alternatives can be summarised as:

- Cost of the energy required
- Cost of maintenance
- Cost of waste water disposal
- Environmental impact

Liquid ring pumps (LRPs) Large LRPs (or WRPs – water ring pumps) are a very reliable way to generate fast roughing and high-capacity backing for large sets of steam ejectors or dry mechanical boosters. They are well accepted in the steel industry as simple, reliable pumps for initial 'hogging' and also to run higher pressure processes such as VOD. LRPs are inherently quite tolerant of process dust and dirt since these are largely absorbed and flushed out with the contact seal water, creating an effluent. However, they are power hungry and demand more power as vacuum increases. The practical limitations associated with the use of water sealed LRPs for steel degassing are:

Seal water consumption A typical 4,200m^3/h LRP might consume up to 10m^3/h water in standard operation (50% recycled) or 20m^3/h water in 'once-through' mode, which is recommended for VOD processes to minimise abrasion inside the pump. The incoming seal water must be clean and the contaminated effluent must be properly disposed of.

Seal water temperature Seal water temperature is critical

Fig.2 **40 ton steel degassing system – inter stage dry mechanical booster pumps with heat exchangers**

Fig.3 **40 ton steel degassing system – dry claw primary pumps**

to LRP performance. This is of special concern for VD backing where the LRP must achieve a good ultimate vacuum to avoid presenting the preceding pumping stages with an excessive pressure ratio. LRP manufacturers' specifications are usually based on 15°C seal water temperature and care must be taken to establish the expected performance with the actual water temperature. As the seal water temperature increases so does its vapour pressure which impairs the LRP's vacuum pumping speed and also begins to cause cavitation within the pump as the inlet pressure drops towards ultimate. Although many manufacturers incorporate anti-cavitation devices, the net result can be loss of pumping speed and cavitation noise and vibration which can cause damage. Where this has an impact on VD performance it must be dealt with by:

- Use of once-through water (a likely requirement anyway)
- Chilling the seal water (high plant and energy cost – might not be economic)
- Adding an air ejector stage in front of the LRP
- Use an additional booster stage in front of the LRP (adds cost and complexity)

DRY MECHANICAL VACUUM PUMPS

Dry mechanical boosters The modern, large mechanical booster is a highly cost-effective way of providing large pumping capacity at low pressures, especially suited to VD processes (see *Figure 1*). The Roots mechanism, mounted for vertical gas flow, is inherently effective at sweeping larger entrained particulates straight through, while finer dust accumulation can be minimised using appropriate design features. These include adequate shaft seals, which avoid any lubricating oil seepage from the gears and drive, pressure balancing of the gearbox and drive ends to avoid excessive pressure differential across the seals, and low flow purging to prevent dust penetration through the pressure balancing lines. The use of frequency converters to control booster motor speeds and power delivery gives flexibility for starting at higher pressures to provide faster pump down times.

The mechanical vacuum booster is not a true compressor; it always needs a final primary vacuum pump (backing stage) with true compression to vent to atmosphere. For a typical VD system two or three stages of mechanical boosters might be used (see *Figure 2*), backed by a suitable primary pump. For VOD at higher pressures only the final booster stage of this system might be needed, backed by the primary pump(s).

Primary vacuum pumping The oil-sealed rotary piston pump has proved itself a good enough primary vacuum pump to become the metallurgical industry standard for induction melting, precision casting and thermal processing. These processes generate metallic and ceramic dusts which can accumulate in the pump sealing oil, causing wear and performance degradation. While the maintenance implications are acceptable for these applications, they cannot be justified for steel degassing where dust levels are higher and product values relatively low. Dry vacuum pumps present opportunities for efficiency improvements and cost savings. ▷

Fig.4 **BOC Edwards' IDX1000 dry screw pump**

The ideal primary pumping mechanism for backing steel degassing vacuum systems is a dry one, in which process dust can be swept through continually without causing any significant damage. There are three major types of dry pump that can be considered: claw, screw and lobe.

Dry claw mechanism Dry claw pumps have the advantage of generating very high internal turbulence, high internal temperatures and good compression in the gas passing through (see *Figure 3*). This is ideal for handling most types of potential contamination and is particularly useful for applications which tend to produce metallic dusts and fines. BOC Edwards has considerable experience with this technology, not only in metallurgy but in other highly dusty and corrosive processes such as semiconductor processing. Good experience in steel degassing installations has been achieved which demonstrates simplicity of operation and good reliability. Power consumption is also comparatively low towards the ultimate pressures maintained during VD processing, as is the consumption of other utilities.

Dry screw mechanism Dry screw pumps have the capacity to generate high internal temperatures and good compression, and are useful where entrained liquids or corrosives might be occasionally encountered. The latest third generation machines have been designed to handle high dust load applications by eliminating compression plates where dust could accumulate, and like dry claw pumps, power consumption is comparatively low (see *Figure 4*).

Dry lobe mechanism Dry lobe pumps are, in effect, multi-stage Roots mechanisms and therefore have the advantage of being able to pass much contamination straight through. Compression is achieved through the staging (a typical pump has three reducing stages on a common shaft, with intercooling). The turbulence generated deals with most metallic dusts and fines. Much experience has been gained on dirty and corrosive processes with these pumps. Power consumption is typically higher towards the ultimate pressures maintained during VD processing.

LARGE DRY EXHAUSTERS

An exhauster is a large mechanical Roots-type booster modified for direct venting to atmosphere as a primary pump. It differs from a convention mechanical booster in that it has a stronger construction, built-in gas cooling devices, and a more powerful motor. These machines are effectively dry alternatives to the LRP, and they can provide big roughing capacity at proportionately lower cost than sets of other dry primary pumps. As single units, exhausters usually have a much poorer ultimate vacuum than LRPs, typically limited to 100mbar (75torr), which may still be useful for VOD applications. However, for VD duties, two-stage exhauster sets are needed. The ultimate designs of these two-stage sets are typically better than those of LRPs. The big advantages of dry exhausters compared to LRPs are:

- Minimal water consumption (only small quantities needed for indirect cooling)
- No waste water disposal problem
- No performance dependence on water temperature
- A good, reliable ultimate pressure

The only drawbacks associated with the use of dry exhausters for steel degassing are that they are comparatively more expensive, generate high noise levels and their power consumption is higher than LRPs.

SUMMARY

Based on BOC Edwards customers' experience over the past five years, the use of mechanical vacuum pumps to replace steam ejectors is a viable option and offers some significant advantages. The biggest of these is the saving in power and operating costs. More than 90% of the operating costs can be saved by using mechanical pumps in place of steam ejectors. Using entirely dry running pumps has further advantages with regard to the amount of wet effluent generated, and this brings additional environmental benefits.

While the initial capital cost of mechanical pumps can be about double the cost of a new steam ejector system and boiler, the payback even on moderate steel production volumes can readily be justified, particularly when typical 10 year life cycles are considered for VD/VOD installations. This consideration excludes the hidden costs of routine boiler certification and maintenance, and the need to retain qualified boiler operators in some regions. Reliability has also been effectively demonstrated, and optimised designs for gas path and pump purging have ensured dust does not cause problems. Any residual dust collecting in the pipe work is easily removed with a vacuum cleaner through the access ports placed at appropriate points. By contrast, the dust accumulation in steam ejector pipe work (where dust combines with water to form a cement-like deposit) always requires significant effort to clean. MS

Vic Cheetham is with BOC Edwards

CONTACT: info@bocedwards.com