Plant Services

COMPRESSED AIR IS FOR PUSHING, NOT PULLING

Improve energy efficiency by restructuring vacuum generators

By Dan Bott

Vacuum generators powered by compressed air represent one of the most inefficient uses of that valuable utility. Behind every quiet, vibration-free, low-cost, environmentally friendly venturi vacuum pump is an expensive, energy-consuming, large-footprint air compressor. In many applications, electric motor-driven vacuum pumps can achieve the same performance as vacuum generators while using one-fourth to one-tenth the energy. In fact, replacing compressed air vacuum generators might be one of the last methods remaining for increasing production energy efficiency and taking overworked air compressors off-line.

The simple mechanism

Venturi-style vacuum pumps, also called vacuum generators or compressed air ejectors, produce vacuum by passing high-velocity compressed air through a venturi or nozzle. Performance depends on the nozzle's shape and size, compressed air pressure and flow, and the desired vacuum level. The greater the vacuum being maintained, the lower the flow of induced air. Other motive fluids include steam, vapor, water and other liquids.

Compressed air vacuum generators are common in industry. Palletizers, material-handling systems, pick-and-place operations, drum-type vacuum cleaners and packaging applications are just a few examples. Each generator is mounted in close proximity to the point of use, with supply tubing connecting the vacuum device to a central compressed air system.

Vacuum generators are reliable, compact, lightweight and quiet. They have no moving parts and can be mounted directly on production machinery. Their maintenance requirements are minimal. They're available in aluminum, plastic and corrosion-resistant construction for harsh applications. Replacement or repair is simple and requires no special tools or training.

Air versus electricity

A vacuum generator, by itself, is equivalent to an engineless automobile. Neither makes any noise nor requires maintenance. Neither has an operating cost. The drawback, of course, is that neither does any useful work. Without an air compressor "engine" operating under the equipment room "hood," the vacuum generator can do no work. One can't evaluate a vacuum generator without accounting for the air compressor in the calculation. An objective evaluation compares the relative efficiencies of electric-driven vacuum pumps and vacuum generator-compressor combinations.

Vacuum generator literature uses two key terms: induced airflow and air consumption. Induced airflow is the air being evacuated from inside the vacuum system. Air consumption refers to the compressed air the vacuum generator requires. These flows combine and discharge through an exhaust port.

A vacuum pump driven by an electric motor, on the other hand, uses a varying rotational swept volume to produce a suction that induces flow from inside the vacuum system. The rotor compresses the induced flow and discharges it to an exhaust port. Motor-driven vacuum pumps consume no compressed air.

Analyzing the question

Production demands dictate vacuum pump size and serve as the basis for evaluation. Continuous vacuum applications seek to maintain a fixed vacuum level. In cyclic applications, on the other hand, a chamber at atmospheric pressure is evacuated to a target vacuum level for a period of time and then vented. Given the two application types and the two vacuum technologies, which pairing is most energy efficient?

The answer lies first in determining the cost of compressed air and how much induced flow a vacuum generator develops. Table 1 illustrates a representative continuous application with 20 vacuum generators. The values represent the average performance of typical industrial units. Each generator requires 20 scfm of motive air to induce a vacuum flow that is a function of vacuum level.

Nearly every vacuum generator application uses 100-plus psig air from the central compressed-air system and regulates it down to the recommended 30 psig to 90 psig for the venturi. Rarely is low-pressure air generated specifically for these applications. This regulation in itself is a major source of inefficiency.

A typical compressed-air system produces no more than 4 scfm output for every input horsepower. While a standalone air compressor is more efficient, losses through ancillary equipment, headers and the partial loading of compressors reduce overall system efficiency. So, we need nearly 100 compressor horsepower to drive the 20 vacuum generators.

Table 2 highlights typical performance ratings for an electric motor-driven vacuum pump that is equivalent to the 20 vacuum generators. Rotary lobe blowers are for vacuum levels below 15 in. HgV, and rotary vane vacuum pumps are used for higher vacuum levels.

The data in the tables reveal that the vacuum generator system requires nearly 100 compressor horsepower while the motor-driven vacuum pump system needs 15 hp. For any level of vacuum, an electric motor-driven vacuum pump is at least 6.5 times more efficient than a compressed-air vacuum generator.

The real kicker is that, in many cases, pressurized air flows through the vacuum generator even when no vacuum is needed. Most vacuum generator installations have built-in shutoff valves to avoid this situation, but bypassed or defective valves add significant waste.

Up and down repeatedly

Vacuum generator specifications typically include a table showing pumpdown time needed to achieve a targeted vacuum in a volume of 1 cu. ft. This pump selection information is used for applications requiring vacuum pickup or parts movement in production machinery. Locating the vacuum generator close to the point of use reduces the volume of piping to be evacuated. Smaller chamber volumes result in faster cycling.

The next example highlights a cyclic application with 20 use points, each consuming 30 scfm of compressed air. The total air demand is 600 scfm, which represents about 150 compressor horsepower. Figure 1 shows the horsepower required to pumpdown a volume of 20 cu. ft. Pumpdown times range from fractions of a second for 5 in. HgV to more than 20 seconds for 27 in. HgV. Many production applications require shorter pumpdown times, but this chart is intended to illustrate the relative efficiencies of each vacuum pump technology over a wide range of conditions.

Table 1: Pulling a load

Vacuum (in. Hg)	Air consumption (scfm)	Induced flow (scfm)	Induced flow (acfm)
5	400	540	648
10	400	220	330
15	400	140	280
20	400	60	180
25	400	20	120

System of 20 typical venturi vacuum pumps; acfm = scfm * P_1/P_2 (absolute)

Table 2: Electricity doing the work

Vacuum (in. Hg)	Approx hp req'd	Induced flow (scfm)	Induced flow (acfm)
5	10	540	648
10	10	220	330
15	15	140	280
20	10	60	180
25	7.5	20	120

Typical rotary vacuum pump efficiencies; acfm = scfm * P_1/P_2

The disparity between vacuum generator and electric motor-driven pumps energy efficiency in cyclic applications is quite remarkable. A closer look at cyclic applications reveals that during an average evacuate/hold/release cycle, compressed air might be used only one-third of the time. In the absence of functional shutoff valves, compressed air flows needlessly during two-thirds of the cycle.

Even with shutoff valves in place, energy comparisons between motor-driven vacuum pumps and vacuum generators are still valid. Motor-driven vacuum pumps can be downsized to meet the actual application requirement. Figure 1 illustrates the apples-to-apples comparison when both technologies are operating at full load.

> **What at first appears to be a winning way to produce vacuum turns out to be a technology with inadequate performance.**

The differences in efficiency are alarming for both continuous flow and closed applications. In addition, the efficiency gap widens as the required vacuum level increases. The bottom line is that from an energy perspective, compressed-air vacuum generators are not environmentally friendly.

Restructure it

Vacuum generator popularity is derived from its low capital cost. OEMs favor first cost over operating cost. Regardless, retrofitting each venturi vacuum pump with a dedicated electric motor-driven vacuum pump would be cumbersome.

The alternative is a central vacuum system. Like compressed air, vacuum can be generated at a central location and distributed through a network of headers and drops. Unlike compressed air, vacuum supply piping can be made of light, flexible, inexpensive and easy-to-install plastic.

Installing a duplex vacuum pumping station to provide 100% backup can put reliability issues to rest. If the lead pump needs servicing, the backup pump takes over automatically. Duplex vacuum pump packages with alarms, automatic sequencing, PLC interfacing and manual overrides are standard products. They can be installed in the same location as the existing "extra" air compressor.

A central vacuum system retains the advantages of individual compressed-air vacuum generators. There's no pump or motor noise at the point of use. Vacuum tubing takes up about the same space as compressed-air supply tubing. There are no heat problems or oil mist. The servicing schedule for an electric motor-driven vacuum pump is usually identical to that of an air compressor.

Heed the numbers

Economic evaluation is straightforward. First, determine the cost of compressed air and the total air consumption for the vacuum generators. Amortize the cost of maintenance, floor space, repairs and the like, and add it to the base electric cost. In addition, determining the total air leakage in the compressed air system is sometimes sufficient to initiate a leak repair program for the entire site.

No more imput than necessary

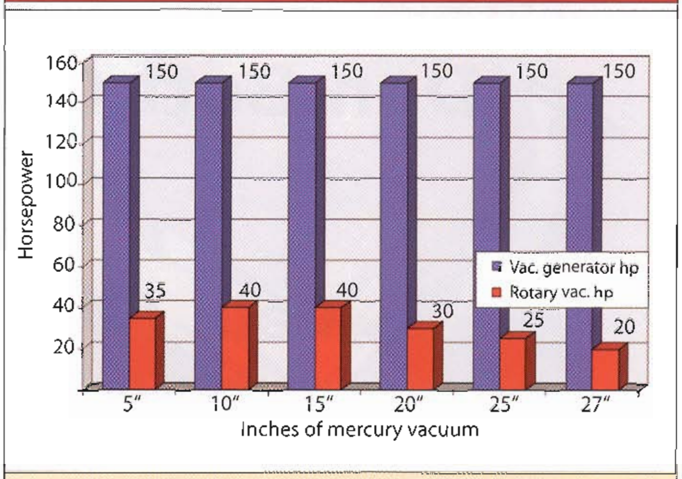

Figure 1. Closed-system pumpdown energy requirements to evacuate 20 cu. ft.

With current costs identified, evaluate proposed costs to determine if switching to vacuum pump technology is justified. Don't forget inlet filtration for those rotary vacuum pump technologies that require it. Life expectancy for some rotary technologies is closely related to the efficiency and care of the inlet filtration system.

Focus on the system with the lowest energy and maintenance cost for the required production throughput. Compute the payback period if a new vacuum pump is involved. The annual cost for a 100-hp air compressor, including costs for cooling, air treatment, maintenance, depreciation and the like, exceeds $50,000 at $0.06/kWh. A typical 15-hp electric motor-driven vacuum pump, on the other hand, has an annual operating cost of $7,700.

Many applications use hundreds of compressor horsepower to generate vacuum. Replacing these systems with dedicated electric vacuum pumps can save thousands of dollars annually. How vacuum is generated is irrelevant to the production process, as long as vacuum is at the required level when needed.

Not every application is a candidate for electric vacuum pump replacement. But, if demands on the compressed-air system are suggesting the need for an additional compressor, it's worthwhile to investigate alternate vacuum technology. The effort can result in significant cost and energy reductions. ⊗

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