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Variable capacity control technology facilitates efficient operation for reciprocating compressors

Reciprocating compressors are used extensively in refinery and petrochemical operations to keep feedstocks and products moving through miles of piping. They also help balance loads and dispense those feedstocks into production processes at precise pressures and timings. Maximizing compressor efficiency and minimizing energy use are key concerns for process engineers.

This article details how a variable capacity control technology, such as a hydraulic variable volume clearance pocket (HVVCP), can quickly pay for itself with energy savings—sometimes in just months, depending on the application. It gives operators the ability to align compressor capacity with demand, while minimizing the recycling of compressed gases. Depending on the compressor's size and utility costs, HVVCP technology can save plant operators millions of dollars per year in those costs—and these savings can go straight to the company's bottom line.

Why capacity control of reciprocating compressors is important. Before getting into HVVCP technology, it helps to have some background on how capacity control has been managed in reciprocating compressors over time. First, most of these types of compressors are designed to produce more capacity than needed to give operators process control flexibility. The excess capacity is usually recycled to the inlet of the compressor via an external bypass (**FIG. 1**), but the energy required to recycle the excess capacity is wasted because the gas is being recompressed.

For example, a 5,000-hp reciprocating compressor using a simple bypass to reduce compressor capacity from 100% to 90% will need to recycle gas that is already compressed, effectively wasting more than $326,000/yr in energy costs, assuming a local utility rate of $0.10/kWh.

To help operators of reciprocating compressors gain greater control over their processes and energy costs, engineers have developed alternative capacity control technologies. One such alternative is pneumatically actuated inlet valve unloaders. These offer discrete capacity steps to provide greater efficiency and energy cost savings than using the simple external bypass previously described.

Typically, inlet valve unloaders are installed on both the outer end and the crank end of a reciprocating compressor's cylinder. One type of widely employed inlet valve unloader is the *finger unloader,* a pneumatically actuated on-off device. It uses small steel rods (i.e., fingers) to depress a compressor's valve elements to unload a cylinder end and to retract from the valve elements to load a cylinder end. Using air-to-unload logic, it is either in the activated position to unload a cylinder end or in the deactivated position to load a cylinder end. This is why finger unloaders can provide only discrete load steps of 0%, 50% or 100% on a single cylinder.

Due to the limitations of having only three load steps, a "stepless" loading technology was developed in the 1950s—called *infinite step control* (ISC)—that holds the compressor's suction valve open, providing variable end unloading. This is a hydraulically actuated finger unloader system that is usually installed on both the outer end and the crank end of a compressor cylinder.

While pneumatic finger unloaders remain stationary during a discrete load step, the ISC system's finger unloaders delay the closing of the inlet valve for a precisely timed portion of the discharge stroke of the compressor piston. In turn, this delays the beginning of the compression cycle in the cylinder, thereby reducing compressor capacity.

In addition, the ISC system's finger unloaders are timed to move with each compressor stroke, so they can operate synchronously with a compressor's speed. For example, if a compressor's motor speed is 300 rpm, the finger unloaders also move at 300 rpm, or 5 cycles/sec. The high cycle demands of an ISC unloader system require more rugged moving parts than

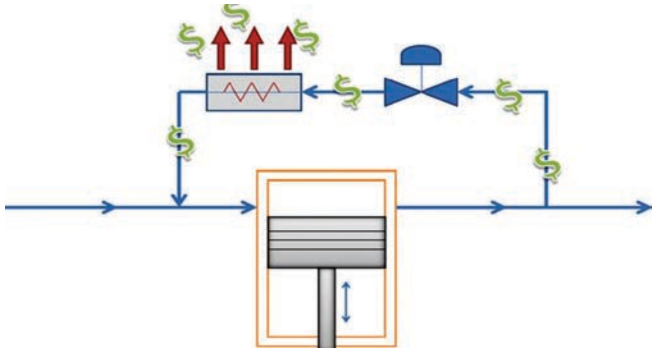

FIG. 1. Bypass valve around a reciprocating compressor that recycles excess capacity for simple but inefficient process control.

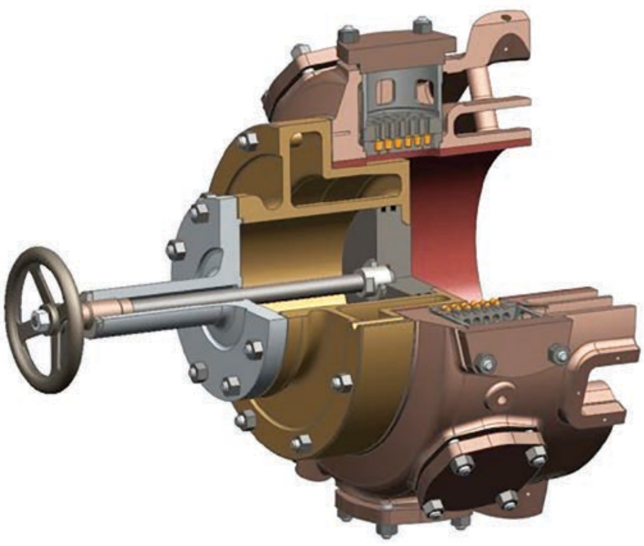

FIG. 2. Cutaway view of an MVVCP. Operators use the wheel to adjust the volume—for safety reasons, only when the compressor is shut down.

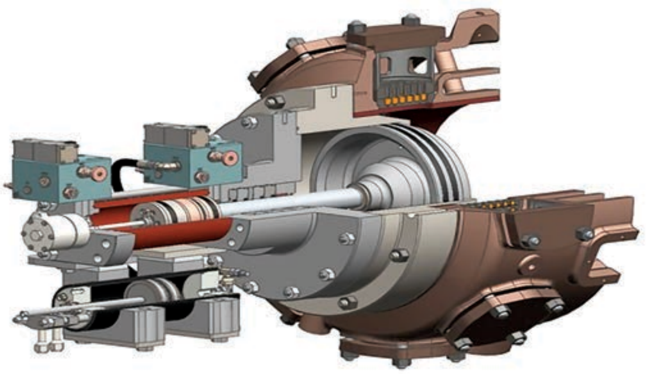

FIG. 3. Cutaway view of an HVVCP that can adjust compressor capacity without shutting down the compressor.

traditional finger unloaders, which are primarily static devices.

ISC inlet valve unloaders enable operators to control reciprocating compressors across a wide capacity range, from 30% to 100%. This wide operating range would seem to be ideal for process control, but it comes with some operational overhead in the form of relative complexity (compared with HVVCP) and associated maintenance. For example, an ISC system requires finger unloaders to be installed on all inlet valves in all cylinders. If the reciprocating compressor is a four- or six-cylinder model, then an ISC system can involve a lot of equipment.

How HVVCP technology works. In contrast to an ISC system, HVVCP technology takes a simpler, less complicated approach. It is a self-contained system that bolts onto the outer end of a cylinder in a reciprocating compressor. It does not require an external hydraulic power supply, as ISC systems do, and it also does not get in the way of a compressor's valve maintenance. Operators can choose to add an HVVCP system to one or more (or even all) cylinders, depending on their requirements.

To understand the workings of an HVVCP capacity control system, it helps to know about a manually operated predecessor technology called the *manual variable volume clearance pocket* (MVVCP). This technology is installed on the outer head of the compressor cylinder, allowing a precise amount of clearance volume to be added to a reciprocating compressor cylinder's outer head.

The variable positions of the clearance pocket piston determine compressor capacity. Moving the clearance pocket piston toward the compressor piston increases capacity, as shown in **FIG. 2.** Moving the clearance pocket piston away from the compressor piston decreases capacity.

Most MVVCP applications are found on high-speed, natural gas reciprocating compressors, such as those operating at 900 rpm–1,800 rpm. Since many of these compressors must operate over a wide range of pressures, temperatures and compressor speeds, they are designed for a wide capacity range. Although the MVVCP is the simplest and most economical way to accomplish this, it has a significant shortcoming: for safety reasons, an MVVCP should only be operated when the compressor is shut down. This precaution can interrupt process workflows, along with the utilization of a plant's assets.

Like MVVCP technology, an HVVCP capacity control system is installed on the outer head of a compressor cylinder (**FIG. 3**). Instead of being manually operated, it is a remotely controlled, hydraulically activated clearance pocket that can be applied to virtually any reciprocating compressor and any process gas (including sour gas) without any modification to the compressor cylinder.

In operation, an HVVCP system can be controlled by a programmable logic controller (PLC) connected to a plant's distributed control system (DCS) and provide infinite step capacity adjustments within the limits of the clearance pocket volume and the stage ratio of compression (**FIG. 4**). Importantly, it allows for safe and reliable capacity adjustments while the compressor is running under full load.

As shown in **FIG. 5,** an HVVCP operates via a self-contained hydraulic actuator assembly that is connected to a clearance piston riding inside of a clearance pocket. However, the HVVCP unit's actuator is operated remotely for safety, and offers the flexibility of accurately positioning the clearance pocket piston in any capacity step between 55% and 100%.

The HVVCP consists of the following: a custom-designed hydraulic cylinder, an accumulator, a clearance pocket piston that attaches to the hydraulic cylinder piston, and hydraulic manifold blocks. Since the hydraulic system is self-contained, it requires no external hydraulic reservoir or power supply, uses standard hydraulic components and is virtually maintenance free. As such, it provides maintenance and operational cost savings—the latter via reduced horsepower consumption and energy costs.

Each of the two manifold blocks features a set of solenoid valves and check valves that facilitate the flow of hydraulic fluid in a closed circuit (**FIG. 6**). A common misperception of the HVVCP is that it uses an external pump to move the clearance pocket piston. The HVVCP uses alternating pressure in the compressor cylinder as the force to move the clearance pocket piston. The hydraulic cylinder and its circuitry operate as a brake when the clearance pocket is at rest.

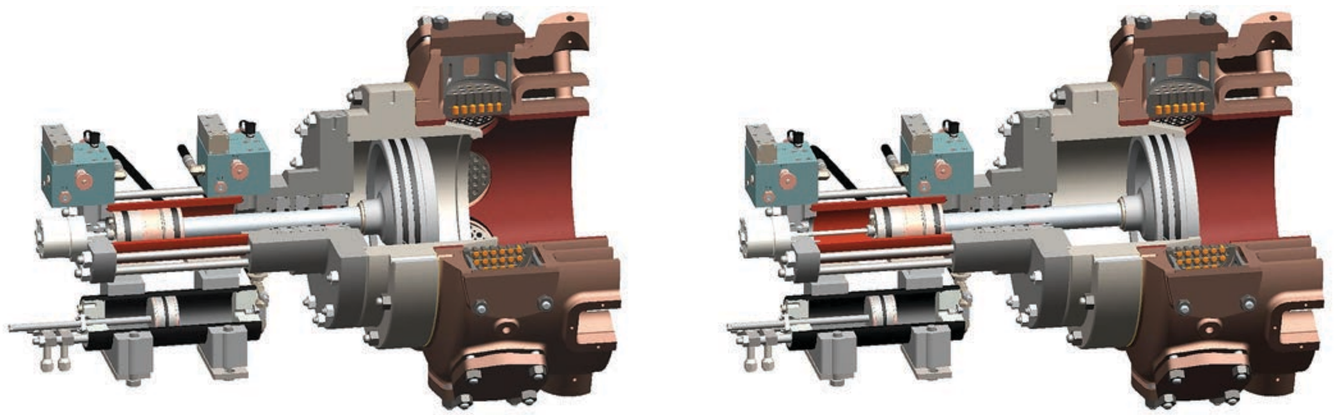

FIG. 4. Cutaway view of an HVVCP showing the HVVCP piston retracted (left) and extended (right). It is capable of remote control and, if connected to a PLC, automated control.

An air-operated solenoid valve is mounted on each of the two manifold blocks attached to the inner and outer ends of the hydraulic cylinder. When both solenoid valves are closed, no hydraulic fluid flows and the HVVCP stays in a fixed position.

However, when the outer solenoid valve is opened, hydraulic fluid flows from the outer end of the hydraulic cylinder to the inner end via a check valve located in the inner manifold block. Because the fluid flows only during the discharge stroke of the compressor piston, it provides the needed pressure to move the clearance pocket piston toward the outer end.

This piston action increases the pocket's clearance volume, which reduces compressor capacity. The check valve in the inner manifold prevents the hydraulic fluid from flowing on the intake stroke of the compressor piston, so the clearance pocket piston cannot move during this portion of the compressor cycle.

When the outer solenoid valve is open, the clearance pocket piston moves outward during each discharge stroke until the desired clearance pocket setting is reached, at which point the outer solenoid is closed. A position transducer inside the hydraulic cylinder records the pocket position and provides feedback to the client's control system, which keeps the outer solenoid open until enough clearance is added to obtain the required capacity turndown.

When the inner solenoid is opened, the clearance pocket piston moves inward on the intake stroke because the inlet pressure force on the clearance pocket piston is less than the pressure force acting on the opposite side of the pocket piston during this part of the compressor cycle.

In this case, the hydraulic fluid moves from the inner end of the hydraulic cylinder to the outer end. This results in decreased clearance volume in the pocket, which increases compressor capacity. The check valve in the outer manifold block disallows hydraulic fluid from flowing during the discharge stroke, so the clearance pocket piston ratchets inward during each intake stroke until the desired reduction in cylinder clearance is obtained, at which point the inner solenoid valve is closed.

Since the diameter of the HVVCP piston is normally a large fraction of the compressor cylinder bore, no pressure or horsepower losses are associated with the movement of gas in and out of the clearance pocket. The clearance pocket is wide open to the cylinder bore throughout the compressor cycle, which

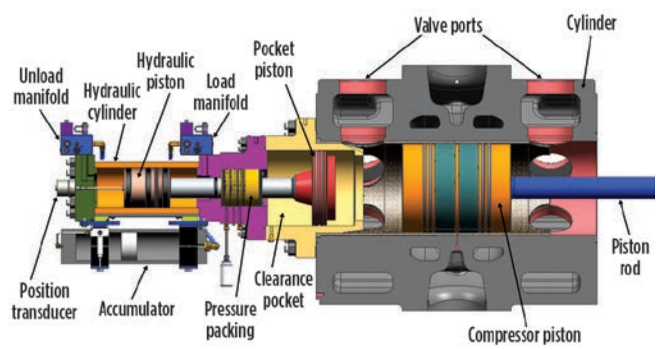

FIG. 5. An HVVCP assembly with a pressure transmitter.

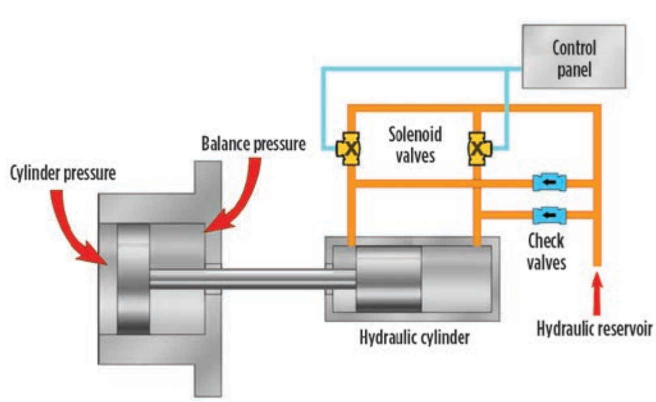

FIG. 6. Schematic showing the HVVCP concept.

makes the HVVCP the most efficient capacity control device. This should be considered when calculating the overall compressor power savings that the HVVCP can provide, particularly in relation to the inherent power loss associated with an ISC during its unloading cycle.

One tradeoff from the greater simplicity, efficiency and lower cost of HVVCP systems compared to ISC systems is that HVVCP systems provide variable control of reciprocating compressor recycling across a range of 55%–100%—a smaller range than with ISC systems, as shown in **FIG. 7.** However, in most applications, the capacity range offered by an HVVCP system is

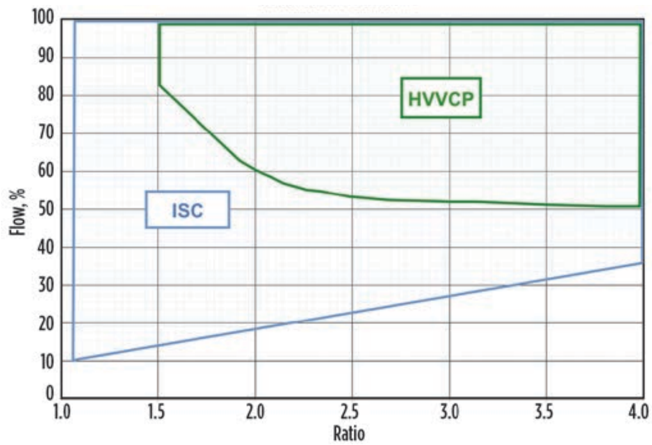

FIG. 7. Reciprocating compressor turndown chart comparing ISC and HVVCP turndown ranges.

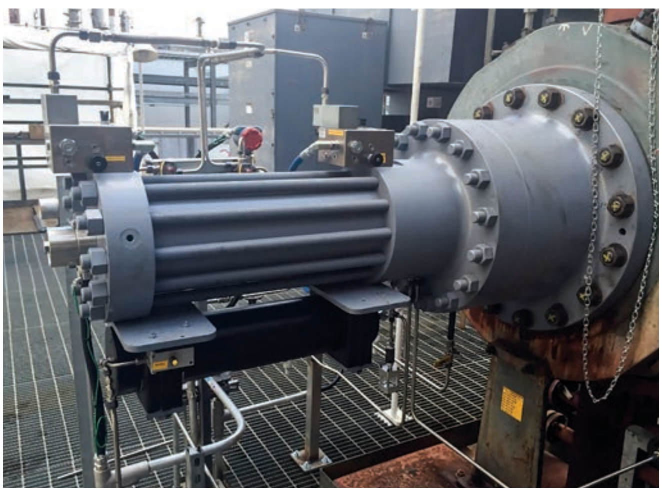

FIG. 8. An HVVCP unit installed on the outer end of a compressor cylinder used for hydrogen service.

more than enough and, therefore, makes better economic sense.

Use cases and cost savings. In a typical load-balancing use case, a major U.S. gas plant deployed HVVCP technology on a new, proprietary reciprocating compressor[a] to reap the benefits of variable control with each stage of compression. The HVVCP capacity control technology enables the operator to shift the load from its smaller, older compressors to the newer and larger proprietary compressor, so as not to overload the other units. This provides significant savings in energy and related costs, without needing to replace the older installed compressors.

Due to their relative simplicity, high reliability and adequate turndown capacity control range, HVVCP technology is also being used by vendors who supply hydrogen for various processes at oil refineries to maintain sufficient reserves. Traditionally, this was done by running the compressors at full load and recycling large amounts of hydrogen back to the compressor inlet, so the hydrogen is always available. However, this recycling wastes energy by recompressing already-compressed hydrogen

TABLE 1. Comparative annual energy cost savings, depending on compressor size, percentage of capacity turndown (i.e., % recycling) and utility rates

Electricity cost, $/kWh		0.05	0.1	0.15
	$/hp/yr	$327	$653	$980
Compressor power, hp	Recycle, %	Savings/yr	Savings/yr	Savings/yr
10,000	10	$326,617	$653,233	$979,850
5,000	10	$163,308	$326,617	$489,925
1,000	10	$32,662	$65,323	$97,985
500	10	$16,331	$32,662	$48,992
10,000	15	$489,925	$979,850	$1,469,775
5,000	15	$244,962	$489,925	$734,887
1,000	15	$48,992	$97,985	$146,977
500	15	$24,496	$48,992	$73,489
10,000	20	$653,233	$1,306,466	$1,959,700
5,000	20	$326,617	$653,233	$979,850
1,000	20	$65,323	$130,647	$195,970
500	20	$32,662	$65,323	$97,985

gas. By deploying stepless capacity control systems, such as HVVCP, hydrogen vendors can produce the precise amount of hydrogen needed.

For these vendors, HVVCP technology ensures that the right amount of hydrogen is produced for their customers' processes, while also helping those plants realize substantial energy cost savings (**FIG. 8**). **TABLE 1** shows the savings that HVVCP technology can provide, depending on compressor size, percentage of capacity turndown (i.e., % recycling) and utility rates. Savings of nearly $2 MM/yr can result from a 10,000-hp reciprocating compressor, using HVVCP technology to turn down compressor capacity (and gas recycling) by 20% at an electricity cost of $0.15/kWh.

These substantial energy cost savings provide a compelling business case for adding bolt-on HVVCP technology to outer cylinder heads of virtually any brand of reciprocating compressor. The larger the compressor, the greater the potential savings. Installation of an HVVCP system is straightforward, maintenance costs are minimal and payback can be measured in months, not years. HP

NOTES

[a] Siemens HHE-VL reciprocating process compressor

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