EFFECT OF DIFFERENTIAL PRESSURE SHORT STROKING ON THE COMPRESSOR DIVIDER BLOCK LUBRICATION SYSTEM

THE NEED FOR COMPRESSOR DIVIDER BLOCK LUBRICATION SYSTEM EQUALIZATION BEGINS AT 200 PSI

BY BILL TAYLOR

For decades, divider block manufacturers have recommended that all injection points of the divider block lubrication system should be equalized if the system's lube pressure is operating above 1000 psi (68.95 bar). New testing reveals that divider block systems operating with differential pressures more than 200 psi (13.7 bar) are compromised and do not dispense accurate quantities of oil designed to lubricate the compressor wear components. This article reports the effects of differential pressure short stroking (DPSS) on the compressor divider block lubrication system.

When the divider block system is operating with differential pressures of 200 psi or higher between cylinder and rod packing injection points, the quantity of oil designed to lubricate the cylinders and packing is greatly reduced to the highest pressure points (in some cases by as much as 50%), causing premature wear and failure of cylinder wear components.

Field and laboratory testing has shown the compromised output of the divider block system takes place much lower than 1000 psi and that DPSS is not isolated to one brand of block, one type of compressor, one pressure configuration, one pressure range, or one configuration or number of divider blocks. If the hydraulic circuit of the divider block assembly is working against a pressure differential, DPSS is occurring.

Noticeable output restriction caused by DPSS can occur with a differential as low as 100 psi (6.89 bar), and the full effects of DPSS can occur with a differential as low as 300 psi (20.68 bar), depending on the configuration of pressures. The only way to avoid DPSS is to equalize the pressures that are upsetting the hydraulic balance of the divider block assembly.

Consequences of differential pressure on divider blocks include the following:

• Divider blocks operating with differential pressures exceeding 200 psi can cause the internal pistons in the valve to hit the end plugs of the block, causing the pistons to bounce out of sync, locking up the divider block assembly.

• When the discharge pressures of divider block systems are not equalized within 200 psi, the slap action of the piston can also cause damage and spring failure in lube no-flow devices and proximity switches, which, in turn, will cause the compressor to shut down on lube no-flow.

Equalizing the working pressure of the divider block system allows the system to operate reliably and increases the longevity of the system components. Equalizing the working sections of all divider blocks ensures that the compressor rings, rods, packing, and cylinders receive the correct amount of oil.

Each reciprocating compressor manufacturer uses its own formula and variables to determine the oil injection rate for given compressor models, cylinders, and rod diameters. Although many original equipment manufacturers (OEMs) and system designers have not adhered to the divider block manufacturer's recommendation for today's lube system designs when the need for balancing valves is obvious, there are several companies that follow the divider block OEM's recommendation to include the installation of pressure-balancing valves on systems that operate above 1500 psi (103.42 bar).

DOCUMENTED FIELD ISSUES

Replacement of rod packing, piston rods, piston rings, and pistons during or before annual inspections (about 8500 operating hours) has been considered "normal" in numerous compressor applications for years. This "normal" maintenance repair is costly and can be improved.

The phenomenon of compromised cylinder lubrication is occurring on multistage reciprocating compressors of different makes and models operating with more than 200-psi divider block differential pressures. Gas compressors have various cylinder bore and piston rod diameters and an array of different manufacturer's divider block systems.

Therefore, it is conceivable that single-stage compressors will be adversely affected by compromised cylinder lubrication as well.

Reported operating conditions of speed, process gas pressures, temperatures, and gas analysis have little or negligible effect on affected component service life as DPSS and inadequate cylinder lubrication test data have shown.

The 3-stage compressor applications include wellhead compression, gas gathering, gas lift, and other common gas compression installations having inlet pressures of 20 to 100 psi (1.37 to 6.89 bar) and discharge pressures of 900 to 1350 psi (62 to 93 bar).

DEFINITION OF TERMS

Differential Pressure

Differential pressure is the difference between two pressures within a given system. Differential pressure within a given cylinder lube divider block system is the difference between the highest and lowest oil injection point pressures to which the given divider block assembly delivers oil.

Be mindful that the highest and lowest lube oil injection pressures are different from the process suction and discharge gas operating pressures.

Differential Pressure Short Stroking

Differential pressure short stroking (DPSS) is the term used to describe the forceful, erratic, and often inconsistent movement of a given divider block spool moving within its body due to low and yet significantly different oil pressures applied to opposite ends of the given spool.

WHAT CAUSES DPSS?

Test data (both in-field testing and laboratory testing) show that all compressor divider block systems are not supplying the rings, rods, packing, and cylinders with the correct quantity of oil as designed, which has been causing premature wear and failure of compressor wear components.

The divider block assembly requires a minimum of three blocks for operation, as shown in Figure 1. Four, five, or six blocks may be used depending on the compressor frame model and cylinder bore diameters. A four-block assembly performs more efficiently. The use of primary and secondary block assemblies is beneficial for multistage compressors with multiple cylinders on large frames.

Smaller-sized divider blocks inject smaller amounts of oil per cycle. Injecting a smaller oil volume promotes more uniform lubrication throughout the cylinders than larger block sizes injecting a larger oil volume at longer frequencies.

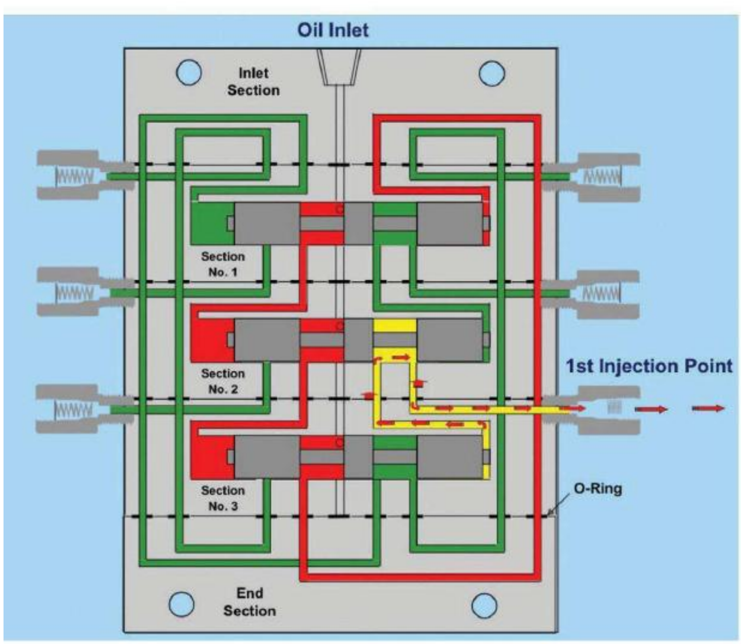

Figure 1. Divider Block Schematic And Operation

With the discovery of DPSS taking place in the divider block system, many instances of premature wear and failure of compressor cylinders, rings, packing, and rods can now be attributed to the reduced oil output of the divider block system when operating in differential pressure ranges above 200 psi. The lack of proper lubrication of compressor components causing premature wear and failure of compressor components can now be prevented or greatly reduced.

Lubrication of compressor cylinders is done by a hydraulic circuit sized for given compressor cylinders and piston rods.

Primary factors affecting divider block assembly performance include:

- Differential pressure ranges that the divider block assembly works against
- Position location of the block having the highest pressure on the block assembly
- Position location of the block operating against the second highest pressure

The relatively slow outward movement of the cycle indicator sleeve versus the sudden/rapid inward movement is indicative of DPSS. The divider block piston/spool slamming against its head end plug of the divider block results in damage to the divider block pistons and accessories installed on the divider block.

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Figure 2. The worn and "mushroomed" end of the divider block piston/spool caused by differential pressure short stroking (DPSS). Mushrooming damage on one end of the spool occurs when the spool is driven back against the end plug with high differential pressure on the ends of the spool.

FIELD INVESTIGATION, TROUBLESHOOTING, AND INSPECTION

The divider block sizing, outlet check valves, tube routing, termination point check valves, and cycle time lube injection rates for cylinders and rod packing cases have been confirmed correct according to the compressor and/or divider block manufacturer's specifications for the specific cylinder and rod diameters.

Past theory claims that the typical pressure in which oil was injected into the respective stage packing case assembly and its related cylinder was the average of the stage inlet and discharge pressures. This theory depends on numerous assumptions and variables of component geometry, design, and material of rod packing and piston rings, sealing effectiveness, component wear, gas system pressure losses, etc.

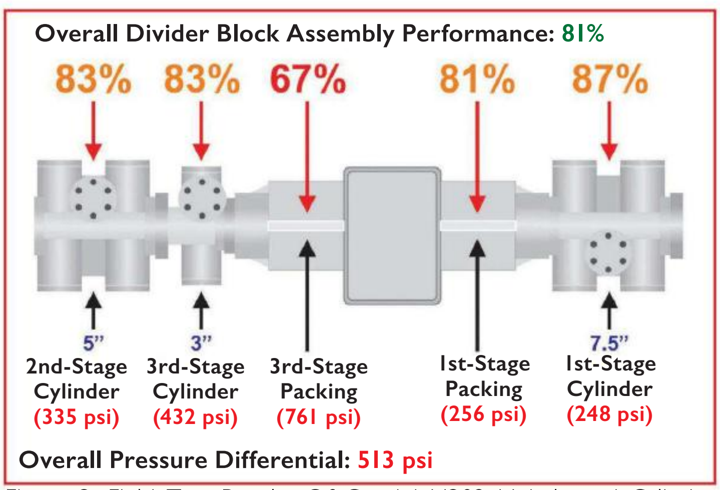

Figure 3. Field Test Results Of Gemini H302 Unbalanced Cylinder Lube Pressures

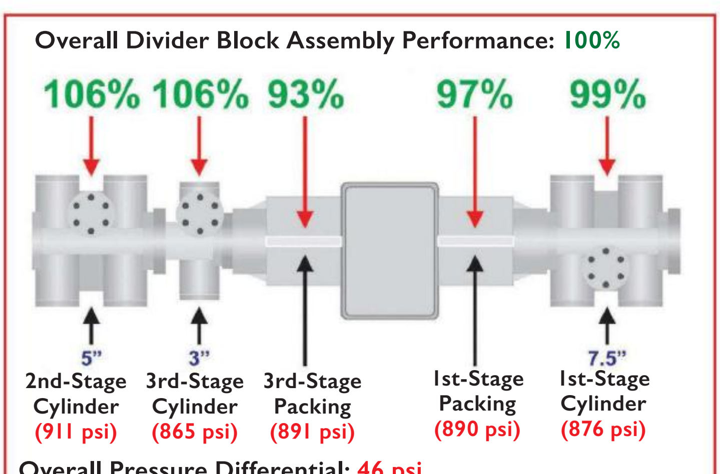

Figure 4. The Same Gemini H302 After Equalizing Pressures

A single viscosity SAE 40 weight oil, supplied to the cylinder lube pump from the compressor crankcase lubrication system, is the common lubricant for piston rod packing and cylinders. It has been discovered that by reducing the supplied oil pressure from the typical compressor crankcase bearing oil pressure of 40 to 65 psi (2.76 to 4.48 bar) to 15 to 20 psi (1.03 to 1.37 bar), oil slippage by the injection pump plunger is reduced and pump life is increased.

Pressure transducers with an accuracy of 1% were installed in the divider block oil outlet delivery lines to the cylinders and rod packing cases of compressors in the field. Actual oil delivery pressures were recorded during compressor operation under stabilized operating conditions.

Performance scores in Figures 3, 4, 7, and 8 reflect the amount of oil being delivered vs. the amount expected from each block's output at the cycle time recorded during the test. A score of 100% would indicate uncompromised lube oil delivery. Pressures were measured upstream of each injection point with the unit operating at full speed and loaded. Components of this divider block system were properly installed.

FIELD TEST RESULTS OF ARIEL JGK-4 LEFT BANK STAGES 2 AND 3 UNBALANCED CYLINDER LUBE PRESSURES

The significant wear and heat discoloration in Figure 5 is attributed to insufficient lubrication quantity evidenced by lack of oil found and dryness of packing, packing cases, and piston rods.

During reassembly, the dimensional measurements of piston rods, packing cases, and cylinder bores, in addition to operating clearances of consumables — packing rings and piston rings — were confirmed to be within the manufacturer's specifications. New, reconditioned, or reusable parts were used during field reassembly. This gives a baseline for evaluating service life and component wear rates.

Two-throw, 3-stage compressors typically have one double-acting, 1st-stage cylinder opposed by a tandem

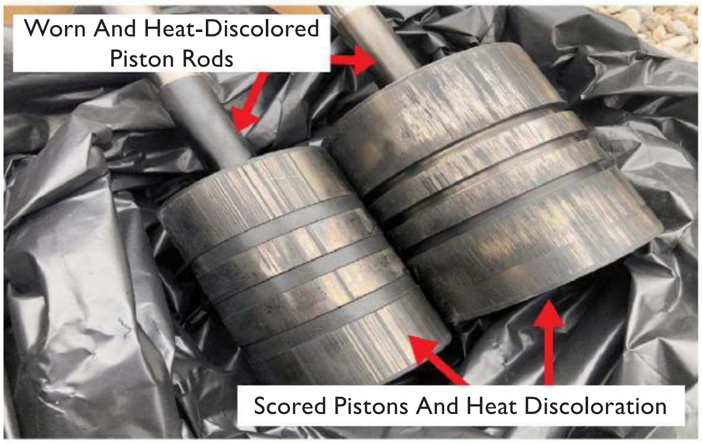

Figure 5. Scored Pistons, Worn Rods, Heat Discoloration On Rods

cylinder. The tandem cylinder usually has a head end 2nd-stage cylinder and a smaller-diameter crank end 3rd-stage cylinder. In most industry-accepted divider block system designs, a "T" divider block is used to provide lube oil to the piston rods of the same diameter. Using a "T" block is not optimum due to the operating gas pressures of 50, 195, 549, and 1250 psi (3.44, 13.44, 37.85, and 86.18 bar). The expected differential pressure between the 1st- and 3rd-stage rod packing cases is 500 psi (34.47 bar). The differential gas pressures of the cylinders also affect the differential pressures needed to inject oil in the rod packing and cylinder lubrication points.

A 4-throw, 3-stage compressor typically has two double-acting 1st-stage cylinders mounted side by side. One

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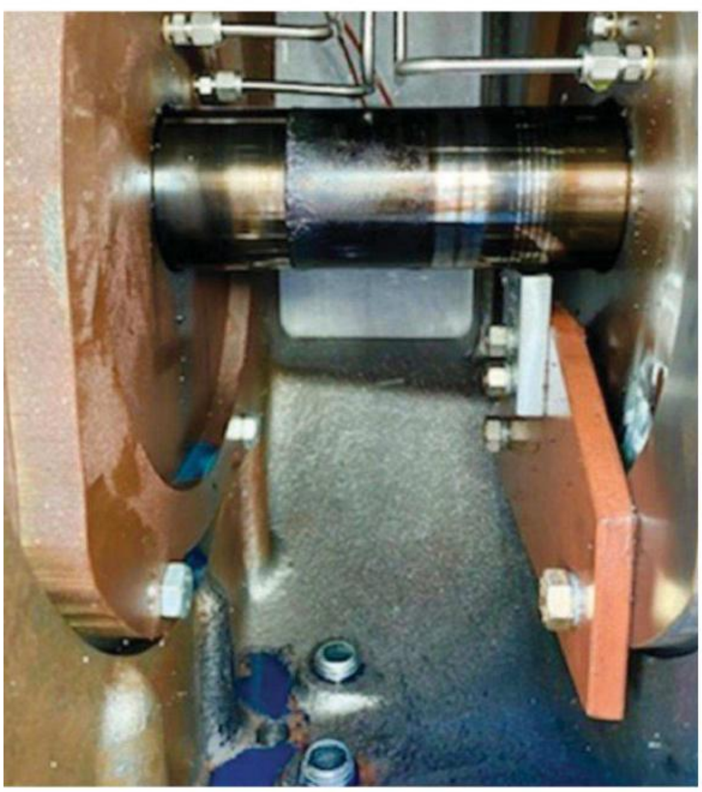
Figure 6. Compressor rod discoloration (turning blue) is a symptom of differential pressure short stroking (DPSS). The lubricant output of the divider block system to the rod packing has been reduced.

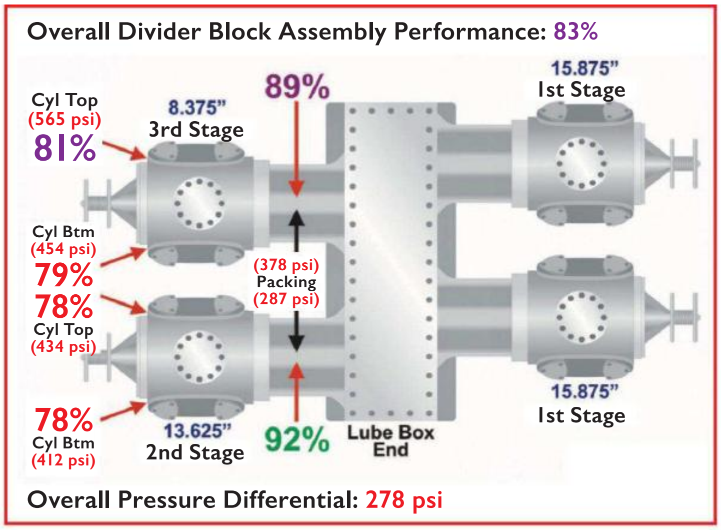

Figure 7. Field Test Results Of Ariel JGK-4 Left Bank – Unbalanced (The right bank is a single-stage with low pressure. Differential pressure short stroking [DPSS] is minimal.)

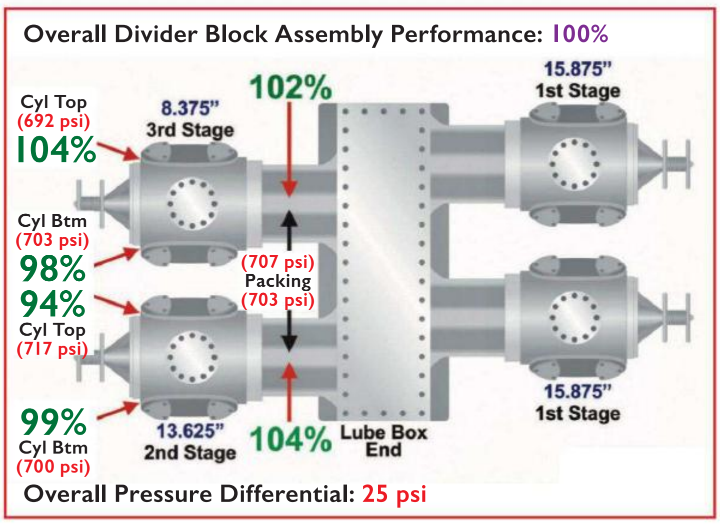

Figure 8. The Same Ariel JGK-4 Left Bank After Equalizing Pressures

1st-stage cylinder opposes a smaller-diameter, 2nd-stage cylinder. An even smaller-diameter, 3rd-stage cylinder opposes the remaining 1st-stage cylinder. An appropriately sized "T" divider block is commonly used to provide lube oil to the piston rods of the same diameter. Using a "T" block is not optimum for rod packing cases due to the different operating gas pressures of 18, 104, 306, and 1180 psi (1.24, 7.17, 21.1, and 81.36 bar). The expected differential pressure between the 1st- and 3rd-stage and the 2nd- and 3rd-stage rod packing case has a differential pressure exceeding 300 psi (20.68 bar). The differential cylinder pressures affect pressure the divider block must build to inject oil in the rod packing and cylinder lubrication points. The differential pressure creates DPSS in the system.

METHODOLOGY

An electrically driven test bench simulated actual performance of cylinder lubrication divider block systems and components. New cylinder lubrication pumps, divider blocks, check valves, and related components were used on the test bench. The three or four blocks of single, twin, or a combination of single and twin outlets were mounted to the baseplate positioned vertically as on most compressor applications.

Divider block sizes were identical to those supplied by the compressor manufacturer/packager. Graduated cylinder beakers were used to simultaneously, yet separately, capture and measure the oil output volume from each divider block outlet during test run time periods.

Variables of inlet oil pressure, lubricator pump box input shaft speed, pump plunger diameter, effective plunger stroke length, divider block sizing, injection tube routing, and operating process gas pressures were verified correct on the operating field compressors.

Adjustable backpressure regulators (ABPRs) were installed on the divider block oil outlet lines of the test stand equipment to simulate actual pressures needed to inject oil into the compressor cylinder and rod packing lubrication points. Each ABPR was adjusted to the applicable pressure recorded during the previously described field testing.

Divider block sizes are selected in relation to the cylinder and piston rod diameters. It is seldom that all lubrication points will receive 100% of the calculated oil volume. Therefore, it has been determined that the optimum oil delivery volume is between 95% and 105% of the calculated oil volume.

Prudent care was taken in all test setups to ensure air was thoroughly purged from the system.

A series of test stand runs were made using four of the same-sized (6S, 9S, 12S, 15S, 18S, 21S, 24S, or 30S) single outlet blocks.

The ABPRs were adjusted to 850 psi (58.60 bar) for the top block and 350 psi (24.13 bar) for the lower three blocks of the same size. This arrangement provided a 500-psi differential pressure across the divider block system.

In eight test runs with the higher pressure at 850 psi, results revealed that the top block had an output volume as low as 51% to 75% of expected/required oil volume. Further, the output volume of the second block down from the top, operating at the 350-psi pressure, was adversely affected, producing 72% to 89% of the expected/required oil volume. The blocks at lower elevation delivered 95% to 119% and 86% to 112%, respectively, of the expected/required oil volume.

TEST RESULTS*

Top Block Value Comparison – Assembly Output Analysis Results

In a separate study, 12 tests were set up using four blocks of the same size (6S, 9S, 12S, 15S, 18S, 21S, 24S, and 30S) on a common base block. ABPRs were placed on the outlet of each divider block. The ABPR for the top block was set at 850 psi. ABPRs for the lower three blocks were set to 350 psi. This was a 500-psi differential pressure across the divider blocks.

**Additional test data are available from Patton Divider Block Systems. Data requests for field and/or lab testing should be sent to charlie@pattonlube.com.*


Figure 9. Dispensed Oil Volume Differences

All testing was done using multiple pressure ranges, different arrangements of pressures, different combinations of block values, higher and lower differentials, and varied cycle times. Tests proved that divider block systems installed on compressors that require more than 200-psi differential pressure between each point to force oil into the lubrication points will become compromised. Accurate, required quantities of lubricant will not be dispensed to lubricate the wear components correctly.

The four graduated beakers in Figure 9 show the oil individually dispensed from each of the four divider blocks during testing. These results were from four identical blocks on the same assembly, cycling at the same speed, which should have resulted in identical amounts of oil in the four beakers. This test run applied the elevated pressure to only the top block of a four-section assembly, with the lower three pressures balanced with one another. The output of the top block is the beaker farthest left, with the second block down being the second beaker from left and so on. These are disturbing results for identically valued blocks.

Test results consistently revealed unsatisfactory performance. The top blocks, operating against 850 psi pressure, had output volumes of 59% to 75% of required oil volume. The second block down, operating against 350 psi, was adversely affected as its measured output volume ranged from 71% to 105% of required oil volume. Interestingly, the output volume of the bottom two blocks, also operating against 350 psi, had measured output volumes of 86% to 119% of required oil volume.

The next test setup involved four blocks, from top to bottom of 24S, 18S, 12S, and 9S. Outlet pressures were adjusted to 850 psi on the top block and 350 psi on the bottom three blocks down. This arrangement maintained a 500-psi differential pressure.

Test results proved unsatisfactory and the following output oil volumes were measured in descending, top-to-bottom order: 72%, 85%, 107%, and 100%.

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Top Block Combos — Assembly Output Analysis Results

Outlet pressures were adjusted to 450 psi (31.03 bar) on the top 9S block and 350 psi on the three lower blocks. This arrangement maintained a 100-psi differential pressure.

Test results proved to be satisfactory as the following output oil volumes were measured in descending order from top to bottom: 106%, 98%, 107%, and 100%.

The next test setup involved four 9S blocks. Outlet pressures were adjusted to 850 psi on the top block, 350 psi on the second and third blocks down, and 600 psi (41.37 bar) on the bottom block. This arrangement maintained a 500-psi differential pressure.

Test results proved unsatisfactory as the following output oil volumes were measured in descending, top-to-bottom order: 72%, 89%, 105%, and 97%.

Outlet pressures were then adjusted to 850 psi on the top and bottom 9S blocks and 350 psi on the second and third blocks down. This arrangement maintained a 500-psi differential pressure.

Test results proved to be satisfactory as the following output oil volumes were measured in descending, top-to-bottom order: 99%, 95%, 104%, and 97%.

The next test setup decreased the outlet pressure of the top 9S block to 450 psi and kept the lower three block pressures at 350 psi. This arrangement provided a 100-psi differential pressure.

Test results proved to be satisfactory as the following output oil volumes were measured in descending, top-to-bottom order: 106%, 98%, 107%, and 100%.

The next test setup increased the outlet pressure of the top 9S block to 1350 psi and kept the lower three block pressures at 350 psi. This arrangement provided a 1000-psi differential pressure.

Test results proved to be unsatisfactory as the following output oil volumes were measured in descending, top-to-bottom order: 62%, 78%, 102%, and 99%.

The next test setup decreased the outlet pressure of the top 9S block to 1100 psi (68.95 bar) and kept the lower three block pressures at 350 psi. This arrangement provided a 750-psi (51.71-bar) differential pressure.

Test results proved to be unsatisfactory as the following output oil volumes were measured in descending, top-to-bottom order: 61%, 72%, 110%, and 103%.

Additional testing of different block sizes was performed as described above. The results were remarkably similar, showing less-than-required oil injection volumes when divider blocks operate against differential pressures exceeding 100 psi.

Testing of three divider block assembly systems in lieu of four block assembly systems provided similar oil volume delivery variances.

Seldom would a multistage reciprocating compressor cylinder divider block lube system be set up with identically sized divider blocks for all lube points; however, testing and data obtained show three factors adversely affecting cylinder and rod packing service life:

- The top-to-bottom placement orientation of the higher-pressure delivery point adversely affects the oil delivery volume of all divider blocks on a given divider block assembly.
- Operating differential pressures and location placement of the divider blocks on the baseplate assembly adversely affects oil volume delivery regardless of divider block size.
- Oil delivery volume is much more evenly distributed to all lubrication points when the differential pressure is less than 100 psi across the divider block assembly.

REMEDIAL ACTION

An end-user client has installed a multipoint remote monitoring system to report an array of operating parameters, including a proximity switch to monitor divider block operation and lubricant output, on several compressors packages.

This monitoring system was installed on 2-throw, 3-stage field compressors before the cylinder lube oil pressure ABPRs were installed.

ABPRs, all adjusted to the highest measured injection pressure, were installed on one compressor.

The results demonstrated significant improvements of frequency, stability, and uniformity of divider block operation, correcting oil delivery to cylinder and packing lubrication points. Therefore, extended service life of affected components is certainly expected when all other factors remain unchanged.

Figure 10 shows the divider block performance before and after installation of the pressure balance regulators (Equalizer).

Divider block spool action (units in seconds) as monitored by a proximity switch is on the Y-axis. The time and monthly date are shown on the X-axis. The significant cycle time variances occurred between September 15 and September 22, 2021 — before pressure balance valve installation.

The week following the installation of ABPRs, from September 22 through September 28, the compressor and monitoring system experienced a variety of operational changes affecting divider block system cycle times and lubricant output to each point as the system was adjusted for optimal performance.

Note the frequency, stability, and uniformity of the recorded lube times of 30 to about 37 seconds with the pressure-equalized divider block system from September

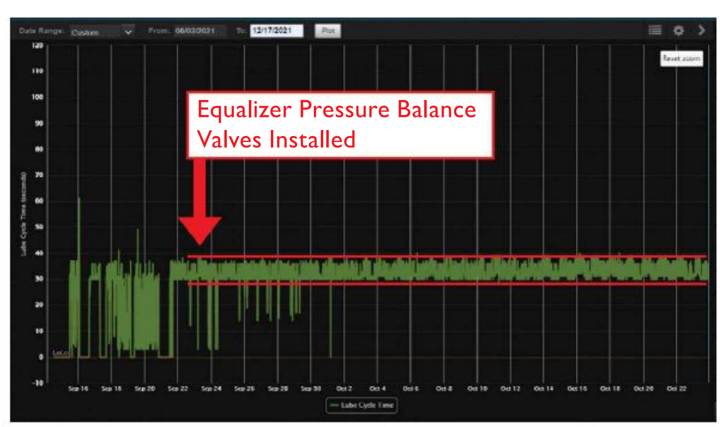

Figure 10. Unit 1 Prior To And After Pressure Equalizing

29 through October 22. Only one shutdown occurred following the equalized pressure system. No shutdowns were attributed to the cylinder lubrication system following pressure balancing.

Note the high and irregular time variances of the lube system without pressure balancing.

FIELD OR SHOP INSTALLATION UPGRADES FOR DIVIDER BLOCK SYSTEMS

Upgrades involve evaluation of existing equipment, operating conditions, review of operating history and maintenance/repair records, and verification of the cylinder lube pump camshaft operating speed.

All upgrades to the divider block system provide lubrication much more precisely delivered to the rod packing cases and cylinders.

Cylinder lubrication system upgrades may be made in the field or during shop overhaul before recommissioning the compressor in a field application.

Applicable upgrades to ensure that the divider block system will operate efficiently and increase longevity include installation of the following:

- A 15-psi, low-cracking pressure check valve at the oil supply source.
- An appropriately sized, low-pressure inline oil filter between the compressor oil system supply and cylinder lube supply oil pressure regulator. This will filter oil before entering the lube pump.
- An oil pressure regulator limiting the oil pressure to the lubrication pump to no more than 15 to 20 psi.
- A new lube injection pump of correct diameter pump plunger for the application.
- An inline 10-micron stainless steel (SS) filter with pleated SS washable element.
- New divider blocks correctly sized for gas stream, maximum discharge pressure, compressor cylinder sizes, and rod diameters.
- New cycle indicator to monitor actual divider block movement.
- Overpressure indicators on divider blocks for future troubleshooting.
- Resettable overpressure relief valve to protect the system from overpressure.
- No-flow switch compatible with control panel logic and applicable codes.
- Check valves on each divider block outlet port.
- Pressure equalizers installed in the tubing lines of all divider block outlets to equalize the operating pressure of each divider block. Note the tamper-proof seals or lock-wire seals on each equalizer divider block outlet.
- Pressure gauges on each divider block inlet to monitor system pressure.
- New termination check valves installed to aid oil sealing and to eliminate gas migrating into the system.
- New 1/4-in. (6.35-mm) seamless SS tubing with a minimum 0.035-in. (0.889-mm) wall thickness. Seamless SS tube wall thickness of 0.049 in. (1.245 mm) is suggested for pressures above 2000 psi (137.9 bar).

CONCLUSION

When divider block systems are installed on compressors that require more than 200-psi differential between each lubrication point, the divider blocks do not dispense accurate quantities of lubricant needed to lubricate the wear components correctly.

Installation of pressure-balancing valves to equalize cylinder lubrication systems ensures correct lubrication is supplied to wear components. Profitability for contract compression companies and owner/operators increases exponentially due to extended service life of the affected components.

ABOUT THE AUTHOR

Bill Taylor is an independent compression consultant with more than 40 years of reciprocating compressor experience. He has worked in domestic and foreign locations for Energy Industries Inc., Weatherford Global Compression, and Universal Compression, before retiring from GE Oil & Gas in 2016. Areas of responsibility included technical support to internal and external users of reciprocating compressors, domestic and international site supervision of fabrication and compressor package assembly, compressor assembly, troubleshooting, quality control inspection, electronic engine/compressor performance testing, and vibration analysis. He has a Bachelor of Science degree in mechanical engineering technology from Le Tourneau College.