New concept lubrication system application on a HP reciprocating compressor

by:

Marco Sacco
CST S.r.l.
Package Engineering Leader
Florence, Italy
marco.sacco@cstfirenze.com

Pamela Tani
CST S.r.l.
Maintenance Consultancy Engineer
Florence, Italy
pamela.tani@cstfirenze.com

Massimo Maffeis
SIAD MI S.p.A.
Global Service Technical Director
Bergamo, Italy
massimo_maffeis@siad.eu

Alessio Scialpi
Eni Refinery
Reliability Leader
Taranto, Italy
alessio.scialpi@eni.com

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Abstract:

Among the most widespread lubrication systems on the market two types are most commonly used, the "pump to point" and "divider block" types, but further solutions can be developed according to the specific application and customized to fit the user's requirements.
This paper describes the solution applied to a critical application: retrofitting of the cylinder lubrication system of five hydrogen make-up reciprocating compressors operating in the ENI Refinery in Taranto.
The criticality of the application was due to the high discharge pressure of the final stage of the compressors (~200 bar-a) and the requirement to provide a fully redundant oil distribution system, retaining the existing lubricator as a stand-by system as well as in automatic combined operation with the new one.
The applied solution included flow and pressure instruments installed at strategic points of the system and management of the various signals to allow automatic switchover to the stand-by pump or to the old lubrication system, in case of major problems.
The few unexpected situations that occurred at the startup of the compressors are also examined, as well as the subsequent investigations that were performed using the supplied instrumentation, and the applied improvements that were the result of the lessons learned.
The experience showed how the presence of a redundant system and of adequate monitoring and diagnostics makes it possible to achieve high safety levels, high availability and optimized maintenance.

1 Introduction

Cylinder and packing lubrication system is one of the most critical item for the correct operation and reliability of a lubricated reciprocating compressor. What should be avoided is the poor lubrication and the consequent premature wear of piston rings and wear bands but, although maintaining proper lubrication is essential, it is not always technically simple and the injected oil quantity is very often higher than necessary, with side effects on process gas contamination, machine performance and operating costs. The two most commonly used lubrication systems currently on the market are [1]:

- the "pump to point" system,
- the "divider block" system,

each of which has pros and cons.

The pump to point mechanism consists of a lubricator system with a pump unit for every injection point; each pump has its own pressure rating and size, and a dedicated rocker arm system with a screw for adjusting the stroke. The oil delivery is adjusted individually and manually and can therefore be approximate (often resulting in over-lubrication) requiring technical time of setup and continuous inspection by the operator. Moreover, usually the only way to check and adjust the oil drip is by a sight glass, the reliability of which often proves to be a critical point in the system.

In the divider block (or divider valve) system, the lubricant is pumped into a single input of the "divider" and is spread volumetrically into a certain number of outputs through the progressive movement of the pistons in the elements arranged in sequence (see Figure 1) [2]:

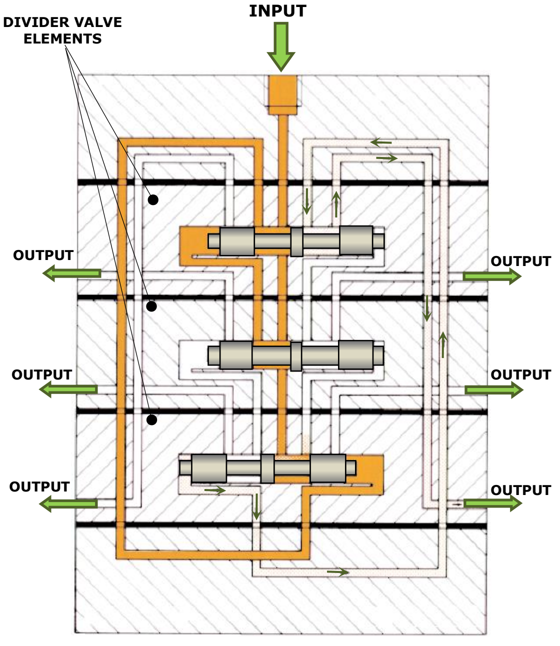

Figure 1: Divider valve section schematic

Each primary divider block outlet may lead to a secondary divider, usually one for cylinder and, from here, the oil flow is split again into smaller rates and sent to all the points on the compressor to be lubricated. The oil delivery is still adjusted by the pump, so this system does not allow any adjustment of the lubricant flow to the individual points either to the individual cylinders, unless the replacement of one or more elements respectively in a secondary or primary divider valve. As a matter of fact, the precision of the divider valve is entrusted to the dimensional tolerance with which each block is made and reliability cannot be guaranteed without an adequate control and maintenance of the quality of the oil and a system of properly designed alarms and trips. Moreover, obstruction of only one of the lubrication points can cause the whole system to shut down, also causing the machine to stop.

This paper describes the realization of a completely customized lubrication system aimed at overcoming the drawbacks of the two existing basic mechanisms. The adopted solution guarantees the intrinsic accuracy of the divider valves, dispensing with the approximate and inadequate adjustment of the drip rates; it also avoids the possibility of a compressor trip in the event of any critical issue, thanks to the provision of an optimized instrumentation and control system and of a redundant oil distribution arrangement, both perfectly manageable, even remotely.

The high pressure present on the last stage brought to light a further criticality of the divider block system; nonetheless, the intended instrumental equipment allowed the issue to be resolved, creating a lesson learned which must not be neglected in the future and emphasizing the importance of redundancy, of the proper instrumentation and of the monitoring system for the success of the project.

2 Project scenario

This paper concerns the installation and testing of a new lubrication system which was required for five hydrogen make-up three-stage reciprocating compressors, operating in the ENI Refinery in Taranto.

The existing reciprocating compressors were equipped with old pump-to-point systems, which were starting to present recurrent problems, mainly due to malfunctioning sight glasses: these elements were periodically and randomly losing their vacuum, with the result that the related pump units were not able to draw the oil from the tank; therefore the relevant injection points did not receive any oil, making the compressor run partially dry. Each time operators had to manually manage and force the relevant pump unit to try and restore the operating function. Finally, the end user decided to solve the problem with a definitive solution, substituting the existing lubrication system.

Besides solving the sight glasses issue, the new system was also required to assure continuity of lubrication and reliability, avoiding any unexpected shutdowns of the running compressor.

3 The new lubrication system in detail

3.1 Basic principle overview

The new cylinder lubrication system is based on a combination of the old pump to point conception, having more than one pump unit that allows us to adjust and optimize the oil flow to the single cylinder, and the divider block system, that has the capability of splitting the lubricating oil into precise fractions.

The oil pump is equipped with three pump units (see Figure 2), one for each cylinder of the compressor that needs to be lubricated.

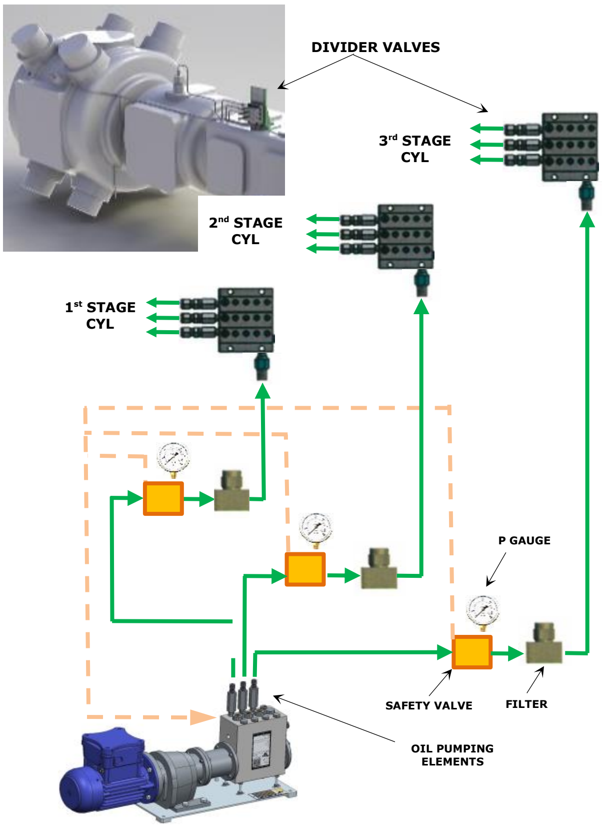

Figure 2: New lubrication system principle schematic

Each pump element is connected to a divider valve that splits the incoming flow into fractions and each of them is injected into the relevant injection point.

In some applications the outlet flow of a single pump is too high of a single cylinder therefore an additional line is provided to release the exceeding flow.

An accessory assembly, consisting essentially of a 10µm filter, a pressure gauge and a pressure relief valve, located between each pump element and the related divider block, protects the divider block from any impurities in the oil.

The hydraulic pump is a piston type and, according to the particular requirements of the application, it is designed for a relatively high operating pressure (550bar). It is suitable for a wide range of viscosity oils (10 cSt ÷ 460 cSt at 40°C) and it has high reliability, requiring minimal maintenance.

3.2 Functional mechanical description

The new lubrication unit, installed on an independent rack near the compressor (Figure 3), is composed of the following main items:

- Oil tank;
- 2 hydraulic pumps: one in operation and one on stand-by; each driven by an electric motor and fed by a line from the oil tank. The feed line of each pump is equipped with a 150µm filter, to prevent solid particles from entering the pump and compromising the proper functioning;
- accessory assemblies: one downstream of each pump unit; they are clamped over the tank and each equipped with a filter (10µm cartridge rating) and a pressure gauge / transmitter;
- local control panel, with main warning lamps and start/stop commands, installed on the rack;
- divider blocks, downstream of each accessory assembly and clamped on the compressor; each block is equipped with an overpressure visual indicator on every outlet, a visual flow indicator and a flow transmitter.

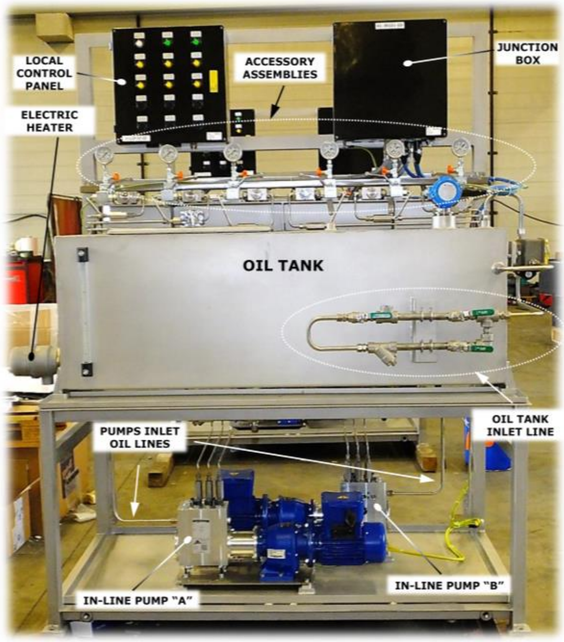

Figure 3: New divider valves lubrication rack

The compressor is equipped with three divider valves, one for each cylinder, that work at the pressure value corresponding to the stage. Each valve has as many outputs as the injection points of that stage.

When the pressure difference between the output lines of the same divider valve exceeds a certain value (typical prescription is DP > 70bar [3]), it is advisable to install a balance valve on the lower pressure lines in order to balance all output pressures and to ensure accurate dispensing of the lubricant volume. In this case recycle lines were provided on both 2nd and 3rd stage divider valves and, being the relevant outlet lines at rather high pressure (120bar-g and 215bar-g respectively), balancing valves were necessary on the tank "recycling" lines with a set value according to the differential pressure to be faced.

3.3 Instrumentation and control logic

The system is provided with the following instrumentation:

- Electric heater, with a thermostat, on the oil tank, with high temperature alarm and heater exclusion;
- Level switch on the oil tank, with permissive signals to the pumps to start, low level alarm and heater switch off;
- Pressure transmitters with high and very high alarms upstream of the filter on the accessory assembly to indicate the obstruction of the filter when it needs to be replaced. In case the measured pressure is lower than the expected, the running pump automatically switches to the stand-by one.
- PSV upstream of each 10µm filter with a set value slightly higher than the average pressure of the line to be protected; it deviates the flow towards the oil tank. The safety valve opens in the event of overpressure or blockage of the divider block: in this case, after a period of time (5 minutes) the pumps are switched over. If the problem persists the pumps switch again and if it still does not work, the new lubricator switches off while the pump to point lubricator starts working.
- A pop-up indicator is provided on each element outlet of the divider block in the event of overpressure: if a divider block piston stops, arresting the whole valve, a visual indicator signals that the line needs to be reset.
- A proximity switch with a low flow alarm is provided on the divider block; if flow is very low, the running pump automatically switches to the stand-by one. If the problem persists even with the other pump, the pumps switch again and if it still does not work, the lubricator goes off while the pump to point lubricator starts working.

In the event that both pumps are not allowed to run, the existing lubricator is put in service.

The system supplied provides for the presence of two reciprocally redundant divider block type systems, plus the original pump to point system ready to go into operation if the first two have problems; this solution ensures delivery of lubricant at every injection point, ensuring complete reliability of the entire system and the machine (see Figure 4)

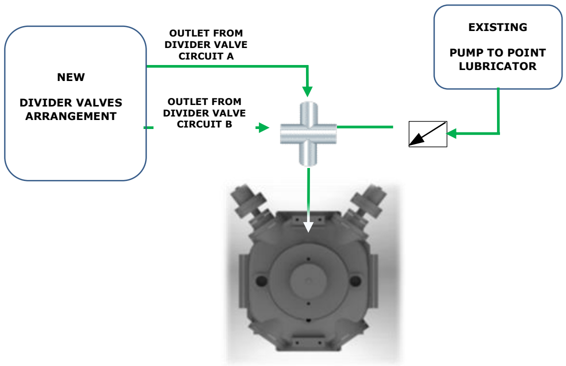

Figure 4: Lubrication supply redundancy

4 Start up

The first control units to start operating were those on the A, D and E machines, while machines B and C were to start only at a later time.

The commissioning and setting up of the lubrication system and the instrumentation was rather quick and did not present any particular problems. The control units had already been tested in the workshop by means of the pressure test, but what represented the unknown was the software part that was to integrate the system only during installation in the field. The software configuration took its time, but proved to be successful for the management of the signals and the logic.

4.1 Issues

An unexpected situation occurred at the start-up of the compressors: blockage of the high pressure line (3rd stage) of the new lubricator.

At the first start-up step, corresponding to a counter-pressure of 20 bar-g at each injection point, there was a blockage of a 1st stage divider (on one machine) and of a 2nd stage divider (on another machine) but it was immediate to realize that the cause was located in the check valves of the injection quills installed on the cylinders, which were obstructed. Once the injection quills had been replaced the system started working but, when the running conditions were reached, the 3rd stage divider blocks always appeared as if they were obstructed.

The same situation occurred on intial startup of all three compressors A, D, and E, therefore it was believed to be due not to a random malfunction of a divider block or an accessory but to the design of the high pressure line.

The hypothesis by which the problem was due to a high differential pressure between the injection lines downstream of the divider valve was soon deleted, since this phenomenon cannot cause complete blockage of the divider but only affect the quantity of injected oil due to a leakage of lubricant inside the divider valve, from the high to low pressure points [4].

The cause of this issue was investigated using, at first, a series of pressure gauges installed at the oil injection points, and it was verified that the counter pressure values had been evaluated correctly, therefore the cause of the issue had to be found elsewhere.

At this point a test bench was set up for the 3rd stage divider block to replicate the same behaviour that occurred in the field and better evaluate the phenomenon.

5 Testing

5.1 Bench preparation

The test bench (see Figure 5) was used to simulate the third stage behavior providing a counter-pressure of 100bar on all the injection points. In particular, the test conditions were the following:

Cylinder injection point:	**100**bar
Cylinder packing injection point I:	**100**bar
Cylinder packing injection point II:	**100**bar
Balancing valve set setpoint	**80**bar
Oil viscosity:	ISO VG **32** and ISO VG **150**

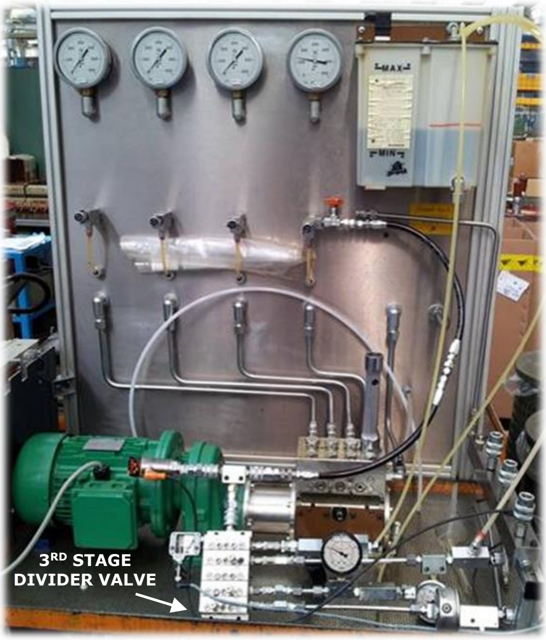

Figure 5: Test bench

The same problem that occurred in the field was experienced after about 3 minutes of operation, applying the above conditions and using both types of oil reported above.

The registered pressure trend was the same as that registered by the DCS in Taranto, shown in following Figure 6.

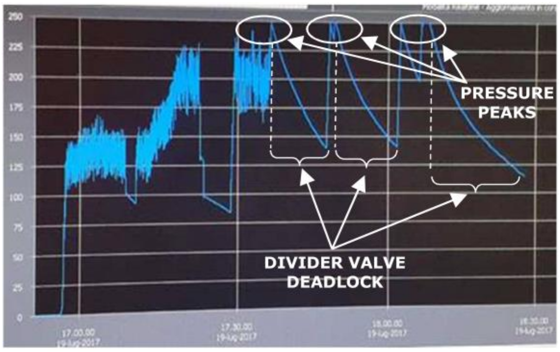

Figure 6: DCS pressure trend registration

The anomaly manifested by the pressure trend consisted in a divider block stall and a subsequent pressure increase, beyond the expected operating values, reaching 250/270 bar. Actually, the divider block ran at first for a few minutes until it reached the expected values of 130/150 bar and then stopped and restarted cyclically; subsequently, on reaching pressures above 250/270 bar, the divider block stalled and it was necessary to reset the inlet pressure and restart the pump to restart the system.

Since the test facility replicated the same issues experienced in the field, an accurate investigation and measurement campaign made it possible to understand the causes of the recurring issue and to implement the corrective actions listed below.

5.2 Testing and solution of the first issue: divider block stall

The divider block is normally supplied with a single check valve at each outlet but, in this case, a double check valve had been required by the customer due to the high pressure. However, instead of having a double check valve, two valves were arranged in series (see Figure 7).

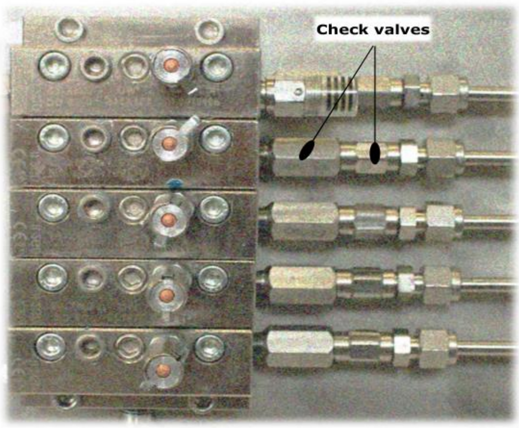

Figure 7: Divider output check valves

Before carrying out the tests, as a first step, it was decided to fit only a single check valve at each outlet on the test bench assembly, in order to reduce the variables to be examined.

The new series of tests and a careful analysis of the phenomenon revealed that the particular arrangement of the divider valve elements, combined with low flow rates (3÷4 cycles per minute) and a back pressure of 100 bar, caused the systematic fail of the 0.04 cm^3 element, that integrated the Namur sensor. To confirm this, at higher flow rates (~25 cycles per minute) the problem did not occur.

It is to be considered that the pistons in a divider valve normally have different diameters, being sized according to the quantity of oil to be dispensed at each lubrication point. The Namur is a 2-wire proximity sensor that transmits a signal every time the divider valve has completed a lubrication cycle, therefore it is used to measure the quantity of injected oil to monitor the condition of the divider valve. From a functional perspective, the Namur can be mounted on any divider valve piston and the position is normally determined by ease of assembly and minimum overall dimensions.

The displacement of the piston generated by the passage of the lubricant inside the block is detected by a proximity sensor through a dipstick with a very thin diameter. Moreover, the piston of the element on which the Namur is mounted has a particular shape, the dipstick being an integral part of the piston.

The explanation of the stall issue is related to the dimensions of the internal pistons used in the divider block element and the Namur sensor. The internal piston of the 0.04 cm^3 element has a 3mm diameter and the shaft connected to the Namur sensor has a 1.6mm diameter (see Figure 8) with the result that the surface on which the oil pressure acts is a ring given by the difference between the piston diameter and the dipstick diameter; at low flow rates the piston needed a much higher pressure in order to be moved with the same translation force, because of the small section differences.

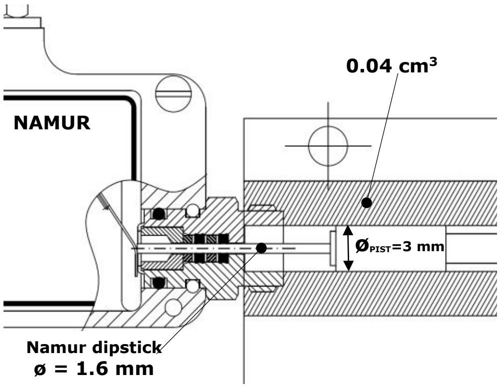

Figure 8: Namur to 0.04 cm^3 element connection detail

The force acting on the circular area was not sufficient to move the piston, which remained blocked despite the pressure rising, until the divider block was blocked: this explains the very high pressures read by the field pressure sensors.

By modifying the position of the Namur sensor (see Figure 9) and moving it to the 0.16 cm^3 block (taking advantage of the divider block modularity) which had an internal diameter of 5mm, the phenomenon no longer occurred and the operating pressures drastically reduced to values congruent with expected values: the new measured values were, in fact, between 130 and 150 bar (100 bar counter-pressure + 20 bar divider block pressure drop + 10/15 bar of pressure drop on the check valves).

5.3 Testing and solution of the second issue: pressure peaks

Once the first problem was solved, the additional check valves were installed on the test bench divider block (Figure 9), to exactly replicate the configuration of the divider blocks present in the field.

The test bench was finally left in operation for a few hours, and the stall phenomenon no longer appeared.

Nevertheless, pressure peaks of around 190 bar were noted over time.

It was found that with the installation of two identical check valves of the original type with the same masses and opening pressures, the pressure peaks no longer occurred.

Actually, the check valves added at a later time required a different (greater) opening force but, although the overall losses remained negligible since the operating pressure was high, the interaction between the different stiffnesses and the particular combination of the low flow rate and the high pressure impeded the lubricant flow, occasionally increasing the upstream pressure.

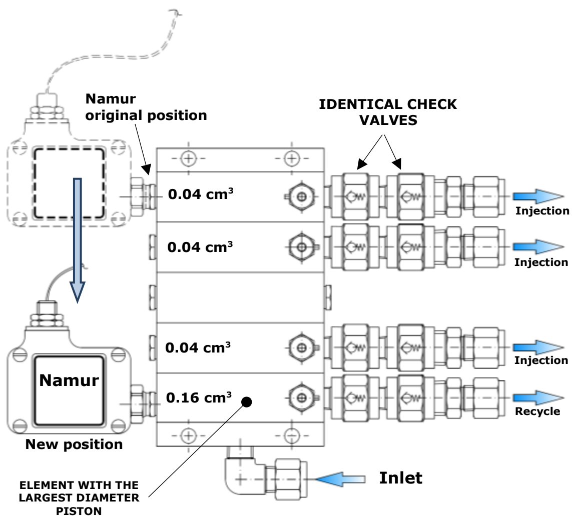

Figure 9: Divider block final configuration

Finally, the test bench was left in operation for 8 hours, monitoring and recording the pressure values and the Namur sensor signal.

None of the above phenomena occurred again, therefore the divider valve was considered to be operating correctly and reliably and the systems installed in the field were modified accordingly.

After units A, D and E, also those mounted on the last two machines B and C were rearranged in the same way and, to date, all five compressors and lubrication units have been running for more than six months and none of the above mentioned phenomena has recurred, to the complete satisfaction of the customer.

6 Lesson learned

Although progressive systems are now widely applied, there are still some critical applications, like the one mentioned in this paper, that can present problems and issues on system start-up for which there is no apparent immediate solution.

The experience that was gained using a test bench has taught that the two following actions are necessary to avoid inconvenient stalling of the divider valve and undesired pressure irregularities:

- installation of the position sensor on the larger diameter element;
- if two check valves are installed on each divider outlet, it should be ensured that they are identical and have the same opening force; if possible, use one double type check valve.

For accessibility and maintainability, the Namur sensor is generally applied in line with the piston at the opposite side to the inlet oil on the divider valve, but experience shows that it is appropriate to revise this philosophy, taking into consideration the dimensions of the element on which it is applied.

The reported case suggests that both the above two counter-measures should always be adopted, even under normal pressure conditions and with greater oil flowrates.

7 Conclusion

Basically, the progressive system technology is quite simple, therefore making it suitable for a large amount of applications. In this case, the equipment redundancy, the provision of an adequate instrumentation and control system and the combination with the existing PTP lubrication unit, made the system perfectly versatile, functionally valid and reliable, suitable even for the strict regulations generally applied in refinery and petrochemical sectors.

Nevertheless, when new solutions are needed due to the criticality of the application, unforeseen issues can still arise: in the case described above particular operating conditions, such as the high operating pressures and the low lubricant flow rates required, revealed intrinsic problems of the system that do not emerge in the majority of applications. Nonetheless, the presence of a measurement and monitoring system has also been a very useful tool for the evaluation and detection of unexpected problems and made it possible to identify the nature of the possible causes, finally leading to the solution.

Moreover, the redundancy of the system, not only applied to each single piece of equipment but also to the whole architecture, allowed the customer to continue production even during the testing. In fact, adopting a particular tubing and check valve arrangement enabled lubrication to be remotely switched from the old PTP to the new progressive system. The switch-over is also performed automatically in the event of malfunctioning of one of the systems.

With the modifications that were carried out, the system can be considered completely reliable and the proposed solution could represent a valid and innovative update to be evaluated both for newly developed lubrication systems and for existing lubricated compressors which have been running for a long time and which have the old pump to point type of lubrication or other poor lubrication system, in order to improve the lubrication performance and also the reliability of the machine as a whole.

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