

HP gas compressor PK-01A — Operating principles

Trainee document · BCL405 centrifugal compressor with variable-speed electric motor

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How to read this document

The simulator reproduces a high-pressure process gas centrifugal compressor: a barrel machine (BCL405) driven by an electric motor fed by a variable-frequency drive (VSDS) through a speed-up gearbox. Every number on the panel comes from a model solved at every scan: pressures, flows, temperatures, speed and vibration are not animations.

The document follows the machine systems, one per chapter. Each chapter says **why** the system exists, what it does, how it shows on the panel, which settings protect it and what the model simplifies compared with a real plant. Instrument tags (PIT-0102, SDV-0202/A, ASV-0201/A...) are written as they appear in the field and are never translated.

The ? buttons on the panel open a summary of the chapter related to that window. This document is the complete version.

1. The centrifugal compressor and its map

1.1 The gas path

Gas comes from the upstream condensate separator, whose pressure is measured by PIT-0102. It passes the suction isolation valve SDV-0202/A (with its bypass SDV-0406/A), crosses the suction scrubber V-01A, which holds back liquid droplets, and the flow element FIT-0201/A. It enters the BCL405 compressor, which raises its pressure, leaves hot and passes through the air cooler E-03A. After the discharge scrubber V-04A and the outlet valve SDV-0402/A, it crosses a check valve and reaches the discharge network, from which it is exported downstream.

Three branches complete the scheme:

- the **anti-surge recycle**: from the cooled discharge, through ASV-0201/A, back to suction (chapter 2);
- the **blowdown**: BDV-0403/A relieves the discharge into the HP flare header when the machine must be depressurized (chapter 8);
- the **relief valves**: one PSV on suction set at 35 barg and one on discharge set at 47 barg relieve to flare if the pressure exceeds them.

Why is the gas cooled after the compressor and not before? Compression heats the gas: at steady state the discharge is around 145 °C. Recycle gas, if it came back to suction hot, would raise the inlet temperature and with it the outlet temperature, in a self-feeding loop. That is why the recycle starts **downstream** of the cooler.

1.2 Why a centrifugal compressor has a map

A centrifugal compressor does not push a fixed volume at every turn, like a reciprocating one: it accelerates the gas with an impeller and turns that velocity into pressure. The head it can give depends on the rotating speed and on the flow through it. At constant speed, more flow means less head; less flow means more head, up to a limit.

The **map** is the chart that gathers these curves: one per speed, in the flow–pressure plane. The simulator uses nine of them, from 8113 to 13 105 rpm. The operating point is not decided by the compressor alone:

it lies where the curve of the current speed meets the head the plant requires, that is the ratio between discharge and suction pressure.

Head is computed in polytropic form: it depends on the compression ratio, on the suction temperature, on the molecular weight of the gas and on its compressibility factor. This is why, at the same speed and pressures, hotter suction gas moves the operating point.

1.3 Why surge exists

Reducing flow at constant speed, head rises up to a maximum. Beyond that point, if the flow keeps falling, the machine can no longer give the head the discharge asks for: flow separates from the blades, the discharge pressure pushes the gas **backwards** through the machine, the discharge empties, forward flow resumes, pressure rises again and the cycle restarts. This is **surge**: repeated flow reversals, hammering the impellers, the thrust bearing and the seals, and quickly heating the gas that recirculates inside the machine.

The locus of the points where this begins, for all speeds, is the **surge limit line (SLL)**. On the panel map it is the red line to the left of the speed curves.

1.4 Margin on the SLL

The margin shown in the header and in the anti-surge box is the **horizontal distance** between the operating point and the SLL, at the same head:

margin = (measured flow – surge flow) / surge flow

It is measured horizontally and not vertically because flow is the quantity being controlled: the anti-surge valve adds flow, it does not remove head.

Quantity	Reference value
Reference speed	12 481 rpm
Minimum operating speed (MOS)	65 % · 8113 rpm
Maximum speed	105 % · 13 105 rpm
Speed curves on the map	9, from 8113 to 13 105 rpm
Typical discharge pressure at steady state	about 43 barg
Typical flow at steady state	about 11 800 m ³ /h at suction

1.5 What the model simplifies

- Between two known speed curves, the map is interpolated in reduced coordinates (flow divided by speed, head divided by the square of speed), as the similarity laws suggest. There is no efficiency varying along the curve: polytropic efficiency is constant.
- Surge is represented as a flow-reversal cycle with a fixed period of about half a second, not as a computed fluid-dynamic phenomenon.
- The gas has constant properties (molecular weight, exponent, specific heat): there is no full equation of state.

2. The anti-surge system

2.1 Why a dedicated system is needed

The load controller (chapter 3) moves the speed to hold the separator pressure. If the upstream plant sends less gas, the controller slows the machine down, but below a certain flow it can do nothing more: the lowest speed is MOS, and at MOS the machine still needs a minimum flow to stay away from the SLL.

The anti-surge system gives the machine the flow the plant does not give it: it opens ASV-0201/A and recirculates gas from discharge to suction. The machine sees more flow and moves away from the SLL; the plant does not notice, because that gas does not leave the unit. The price is energy: the recycled gas is compressed for nothing.

2.2 The surge control line (SCL)

The controller does not wait for the SLL: it works on a **surge control line (SCL)** shifted to the right of the SLL by an adjustable margin, parameter K on the panel (10 % baseline):

$$\text{control flow} = \text{surge flow} \times (1 + K)$$

As long as the measured flow is to the right of the SCL, the valve stays closed. When the operating point reaches it, the valve opens just enough to hold it there.

2.3 The three controller actions

1. **Proportional and integral**, with a 1.5 % dead band: they hold the operating point on the SCL during slow changes, such as a progressive load reduction.
2. **Rate-of-approach response**. If the margin is below 40 % and falling faster than 3 % per second, the controller opens the valve at once, by an amount that grows with the approach rate. **Why:** a load step takes the machine from the SCL to the SLL in a fraction of a second; a controller that waits to see the error is late.
3. **Safety opening (recycle trip)**. If the flow falls below one third of margin K beyond the SLL, or if surge is detected, the valve goes fully open and stays there for 3 seconds.

2.4 Why the valve opens on loss of command

ASV-0201/A is driven by a **reverse** signal: 4 mA means fully open. Solenoid ASY-0201/A, when de-energized, vents the actuator and the valve opens in less than one second. In any failure — loss of signal, of air, of the solenoid supply — the valve goes to the position that protects the machine, which is open. For the same reason:

- with the machine stopped and the controller disabled the valve is fully open;
- the start permissive requires the ASV open;
- every trip de-energizes the solenoid.

ASV-0201/A movement	Time
Opening commanded by the controller	≤ 2 s
Closing	≤ 10 s
Opening on ASY-0201/A de-energization	< 1 s

It closes slowly and opens fast: closing too fast would bring the machine back towards the SLL.

2.5 Automatic and manual

In **MANUAL** the controller output does not act: the valve goes where the operator puts it. It is meant for tests, not for operation. A running machine with the anti-surge in manual and the valve closed is not protected: a load reduction takes it into surge. The panel reports this in the window note.

Alarm or trip	Tag	Condition
Surge in progress	UA-0201	flow reversal
Recycle open while running	UA-0202	ASV above 5 % with machine running
Surge trip	USHH-0201	3 surges in 60 s (adjustable) or sustained surge beyond 8 s

2.6 What the model simplifies

- There is a single flow measurement (FIT-0201/A): no redundant measurements nor pressure and temperature compensation. The “FIT-0201/A drift” fault shows what happens when that single measurement is wrong: the controller believes it has margin and it does not.
- The SLL is derived from the map, not from pressure measurements as a real controller would do with a line expressed as a function of the compression ratio.

3. Load control

3.1 What it controls and why with speed

The compressor must take all the gas coming from the upstream separator, no more and no less. If it takes too little, the separator pressure rises; if it takes too much, it falls. Controller **PIC-0102** measures the separator pressure and holds it at setpoint by moving the machine speed: pressure above setpoint, the machine speeds up and draws more; below, it slows down.

Controlling with speed rather than with a suction valve is the efficient choice: the machine compresses only the gas that is needed, without throttling it first. The variable-frequency drive (VSDS) allows it between MOS (65 %) and 105 % of the reference speed.

3.2 Three controllers, one speed

Three controllers each propose a speed, and the **lowest** wins (low select):

Controller	Quantity	In command when
PIC-0102	upstream separator pressure	normal operation
Discharge override (PIC-0405)	discharge network pressure	approaching 44 barg, one bar below alarm PAH-0405
Current limiter (JIC)	motor current	approaching 780 A, the rated current

Why low select: the two limiting controllers must never speed the machine up, only stop it from going further. The panel shows which controller is selected in the “Load sharing” field.

Why tracking: the non-selected controllers have an integral that, left free, would keep growing (windup) and on return would give a speed bump. The PIC-0102 integral, when not selected, tracks the actual output: on return it restarts from where the machine is.

3.3 PIC-0102 tuning

The controller is in industrial form:

$$\text{output} = K \cdot (e + 1/T_i \cdot \int e \, dt + T_d \cdot de/dt)$$

with the error normalized on the transmitter span (0–20 barg). The three parameters are changed online from the window. The **Test step** button raises the setpoint by 0.5 barg for about 90 s and brings it back by itself: it is used to see the response on the trend.

Parameter	Baseline	Effect if increased
K	1.5	faster response, up to oscillation
T _i	1.7 s	residual error removed more slowly
T _d	0 s	anticipates changes, but amplifies measurement noise

A very long T_i leaves the pressure far from setpoint for a long time: the panel reports it. A very high K drives the speed against its limits.

3.4 Automatic and manual

In **MANUAL** the operator sets the speed between 65 and 105 %. On return to automatic the PIC-0102 integral restarts from the current speed, without bumps.

3.5 The process network

The “Process network” window is not a machine system: it sets the **boundary conditions**. The flow arriving from the separator and the downstream network pressure are decided by the plant, not by the compressor.

- **Flow from the separator.** Reducing it is how a turndown is done: the controller slows the machine down to MOS and beyond that point the anti-surge works.
- **Downstream network pressure.** It decides the head the machine must give. Raising it moves the operating point up and towards the SLL; above 44 barg the discharge override steps in.

Why the downstream pressure matters so much: the check valve prevents the network from flowing back into the machine, but the machine, to push gas into the network, must exceed its pressure. A higher network asks for more head, hence more speed, hence more power.

3.6 What the model simplifies

- The VSDS is a speed ramp (520 rpm/s), with no electrical dynamics.
- Motor current is proportional to the absorbed power.
- There is no second machine in parallel nor load sharing between two trains: the “Load sharing” field only says which controller is selected.

4. Process valves

4.1 Why purge and pressurization

Before a start, the stopped machine and piping may contain air. Putting process gas into a volume that contains air means creating a flammable mixture. **Purging** pushes the air towards the flare with the gas itself, at low flow. Then **pressurization** slowly brings the machine to suction pressure, without steps that stress seals and bearings.

These operations are manual: the control system only checks that the valves are in the right position.

4.2 The valves and the two line-ups

Valve	Service	Stroke
SDV-0202/A	suction isolation	6 s
SDV-0406/A	loading bypass, in parallel with SDV-0202/A	5 s
SDV-0402/A	discharge gas outlet	6 s
BDV-0403/A	blowdown to the HP flare	4 s
SDV-0101/A	V-01A scrubber drain	4 s
SDV-0401/A	V-04A scrubber drain	4 s

Line-up	SDV-0202/A	SDV-0406/A	SDV-0402/A	BDV-0403/A
Purge	closed	open	open	open
Running	open	closed	open	closed

Why the SDV-0406/A bypass: it is small. Gas enters from the bypass line at limited flow, sweeps the machine and leaves to flare through BDV-0403/A. Closing BDV-0403/A, the same limited flow pressurizes the machine gradually. Only when upstream and downstream are equalized is SDV-0202/A, which is large, opened: opening it with the full pressure difference across it would be a shock.

The sequence on the panel is: purge line-up, wait, close BDV-0403/A, pressurize above a few barg, open SDV-0202/A, close SDV-0406/A. The note under the table always says which valve is out of position.

4.3 Drains

Scrubbers V-01A and V-04A collect the liquid carried by the gas. The level rises slowly in operation, faster with the “liquid carry-over” fault. Drains SDV-0101/A and SDV-0401/A empty it. **Why it matters:** liquid reaching the impeller damages it; that is why the high level (LAH-0102, LAH-0402, at 62 %) is an alarm not to be ignored.

4.4 After a trip

A trip closes SDV-0202/A, SDV-0402/A and SDV-0406/A. After the reset **the valves stay closed:** they must be lined up by hand in the running line-up before restarting. This is intended: a reset must not put gas back into a machine nobody has checked.

4.5 What the model simplifies

- Valves are fully open/fully closed with a linear stroke; there are no failed limit switches.
- Gas composition does not change during purge: the model does not compute the oxygen content, it only checks the line-up.

5. Start-up and shutdown sequences

5.1 Why permissives

A compressor started without oil, without seal gas or with the wrong valves is damaged in a few seconds. **Permissives** are the conditions that must all be true together for the START button to be accepted. The note under the machine commands always shows the first one missing.

Permissive	Condition
No active trip	trips reset
Lubrication	one oil pump running, header above 1.8 barg
Mist extraction	one fan running
Run-down tank	full above 60 %
Oil temperature	above 25 °C after the cooler
Separation nitrogen	above 3.2 barg
Seal gas	above 110 °C
Balance line	above 0.2 barg (machine pressurized)
Anti-surge valve	ASV-0201/A fully open
Motor	ready
Process valves	in the running line-up

5.2 Start-up

Step	What happens
Start	solenoid ASY-0201/A is energized, the motor starts; vibration and axial displacement settings are multiplied by 3 until 10 s after half speed is passed
To MOS Enable	speed rises to 65 % with the ASV fully open after 12 s at MOS anti-surge and load control are enabled
Running	the ASV closes, the machine takes load and PIC-0102 brings the separator to setpoint

Why the settings are multiplied: crossing the rotor critical speeds, vibration rises for a few seconds. With normal settings the machine would trip at every start without anything being broken.

Why the start is made with the ASV open: at low speed the machine gives little head; with the discharge closed towards the network it would go straight to the SLL. The open valve gives it a closed loop to run on until it is at MOS.

5.3 Normal stop

The normal stop is a sequence, not a switch-off:

1. load control is disabled; speed falls towards MOS in 25 s while the ASV ramps open in the same time;
2. the anti-surge **stays in service** throughout the run-down;
3. with the ASV fully open and the machine at MOS, the motor stops, the solenoid is de-energized and SDV-0202/A, SDV-0402/A and SDV-0406/A close;
4. with the machine stopped the 300 s **post-lubrication** starts; at the end the auxiliaries may be stopped.

BDV-0403/A stays closed: the unit stops **pressurized**.

Why the anti-surge stays in service: as speed falls the machine loses head much faster than the network loses pressure. If the ASV were still closed, the machine would end up on the SLL during the stop.

Why post-lubrication: with the machine stopped the bearings are still hot. Oil that keeps circulating carries that heat away; without it, the white metal overheats precisely when the machine is stopped.

5.4 What the model simplifies

- Critical speeds are not represented as vibration peaks: the setting multiplier exists, but vibration grows with speed smoothly.
- The motor has no sequence of its own (excitation, drive precharge): it is always ready.

6. Lube oil

6.1 Why lubrication is critical

The bearings of a machine running above 12 000 rpm work on an oil film a few hundredths of a millimetre thick. If the film is missing, metal on metal, the bearing is destroyed in a few seconds. The oil also carries away the heat generated in the bearings.

6.2 The oil path

From the reservoir, one of the two pumps PM-51A/B drives the oil through the cooler and the filters to the bearing header of compressor, gearbox and motor, then back to the reservoir. An elevated **run-down tank** fills during operation and, if the pumps stop, feeds the bearings by gravity during the coast-down.

6.3 Pump redundancy

One pump is enough. The other is on standby and starts by itself, with the machine running or in post-lubrication, if the header pressure falls below 1.8 barg or the pump discharge below 2.3 barg.

Why the automatic standby: between a pressure drop and the trip only a few seconds pass. An operator would not make it; the logic does.

6.4 Filters, mist fans, heater

- **Filters.** As they clog, the pressure drop grows and takes pressure away from the header. Above 1 bar ΔP (PDSH-1641) the standby filter must be switched in. The standby pump does not help: the problem is downstream of both.
- **Mist fans KM-51A/B.** They keep the reservoir under slight vacuum and extract oil vapours. If the reservoir ΔP rises above 0.30 bar (PDSH-1642) the standby fan starts.
- **Heater H-51.** In automatic it switches on below 30 °C and off above 45 °C. It is locked out if the reservoir level falls below 40 %: an uncovered element would burn the oil.

Why the oil must be warm before starting: cold oil is too viscous, it does not build the film at the right speed and the measured pressure is misleading. The permissive asks for at least 25 °C.

Setting	Tag	Value	Action
Header pressure low	PSL-1622	1.8 barg	alarm, standby pump start
Header pressure very low	PSLL-1623 · 2003	1.2 barg	pressurized trip
Pump discharge low	PSL-1621	2.3 barg	alarm
Filters ΔP high	PDSH-1641	1.0 bar	alarm, switch filter
Reservoir ΔP high	PDSH-1642	0.30 bar	standby fan start
Run-down tank low	LAL-1622	60 %	alarm and permissive

6.5 What the model simplifies

- Trip PSLL-1623 is labelled 2003 but is computed on a single pressure value: there are no three independent transmitters that can fail one at a time.
- Pressures are tuned on typical values, not computed from pump curves and pressure drops.
- Bearing temperatures depend on speed and faults, not on a heat balance on the oil.

7. Tandem dry gas seals

7.1 Why gas seals are needed

Where the shaft leaves the casing, the high-pressure gas would try to escape. A **dry seal** is made of two rings, one rotating and one stationary, separated by a gas film a few microns thick: very little gas crosses it, and it is collected and sent to flare. In the **tandem** arrangement there are two seals in series: the primary holds the pressure, the secondary is the backup if the primary fails.

7.2 Why the seal gas must be filtered and hot

The gas film between the rings is so thin that any droplet or particle breaks it. Process gas, expanding through the seal, cools down: if it were close to its dew point it would condense right there. That is why the seal gas is filtered and **heated** by H-54 and H-55 before injection.

Heaters	Seal gas temperature
H-54 in service	about 130 °C
H-55 only	about 112 °C
none	ambient temperature

Below 110 °C (TAL-1633) machine pressurization is inhibited.

7.3 Where the seal gas comes from

- **External source** through XV-1652, when available at high pressure (PIT-1635 above 40 barg) and the machine is at least at MOS.
- **Booster KM-52**, which takes gas from the machine itself and pushes it to the seals. It starts automatically at pressurized standstill, while running if the external source is missing, and after every trip. **It does not start if neither heater is in service:** pumping cold gas to the seals would be worse than not pumping it.

7.4 Separation nitrogen and vents

- **Separation nitrogen** (PIT-1628/1629, about 4 barg) is a barrier between seal and bearings: it keeps oil from reaching the seal and gas from reaching the bearings.

- **Primary vents** (PIT-1626/1627) measure the gas crossing the primary seal. They rise if the seal degrades; they fall almost to zero if the seal receives no gas.

Setting	Tag	Value	Action
Cold seal gas	TAL-1633	110 °C	alarm, pressurization inhibited
Primary vent high	PAH-1626/1627	1.2 barg	alarm — primary ring degraded
Primary vent very high	PAHH-1626/1627 · 2003	2.0 barg	depressurized trip
Primary vent very low	PALL-1626/1627 · 2003	0.05 barg for 5 min	depressurized trip
Seal gas very cold	TSLL-1671 · 2003	below 60 °C for 5 min, without external source	depressurized trip
Nitrogen low	PSL-1628	3.2 barg	alarm and permissive
Nitrogen very low	PSLL-1629 · 2003	2.4 barg	pressurized trip
Booster ΔP low	PDSL-1644	0.1 bar	alarm

Why seal trips are depressurized: if the primary seal is broken, keeping the machine full of gas means pushing gas on the secondary, which is not made to hold it for long. Emptying the machine removes the cause.

7.5 What the model simplifies

- Seal flows and pressures are tuned, not computed from the face geometry.
- The secondary seal does not fail: the “primary ring degraded” fault acts only on the primary.

8. Protections

8.1 Alarm and trip

Every critical quantity has two settings: the **alarm** warns the operator that there is time to act; the **trip** stops the machine because that time is over. The trip setting must always lie beyond the alarm, in the direction in which the quantity gets worse. The panel allows changing settings online and **realigns them by itself** if an edit would invert the order.

Service	Alarm	Trip	Minimum margin
Lube oil header (PSL-1622 / PSLL-1623)	1.8 barg	1.2 barg	0.2 bar
Radial vibration (XA / XSHH-162x)	65 μm	95 μm	5 μm
Axial displacement (ZA / ZSHH-1632)	0.35 mm	0.50 mm	0.05 mm
Thrust bearing metal (TAH / TSHH-166x)	100 °C	115 °C	5 °C
Discharge temperature (TAH / TSHH-0204)	163 °C	178 °C	5 °C
Discharge pressure (PAH / PSHH-0405)	45.0 barg	46.5 barg	1 bar
Primary vent (PAH / PAHH-1626/1627)	1.2 barg	2.0 barg	0.2 bar
Separation nitrogen (PSL-1628 / PSLL-1629)	3.2 barg	2.4 barg	0.2 bar

Why a trip setting out of range is a hidden fault: if it is moved beyond the value the quantity can reach, the protection exists only on paper. A protection is proven, not declared.

8.2 Voting

The most important measurements have several sensors, and the trip fires when a given number of them exceeds the setting. The vibration monitoring system votes as follows:

Chain	Probes	Voting
Electric motor	4 radial probes	2oo4
Gearbox	4 radial probes	2oo4
Compressor	4 radial probes	2oo4
Axial displacement	ZT-1632/A/B	2oo2
Thrust bearing metal	TE-166x	1oo2

Why not 1 out of N for all: a single failed sensor would stop the machine for nothing. **Why not N out of N:** a single failed sensor would prevent the trip when needed. 2oo4 is the compromise: it tolerates one failed sensor in both directions. The thrust bearing votes 1oo2 because its failure is fast and costly, and there one extra trip is the lesser evil.

An excursion on a single probe gives the chain alarm, not the trip. During start-up, until 10 s after half speed is passed, vibration and axial displacement settings are multiplied by 3 (chapter 5).

8.3 Pressurized and depressurized trip

Trip	What it does	Causes
Pressurized	stops the motor, de-energizes ASY-0201/A, closes SDV-0202/A, SDV-0402/A, SDV-0406/A; BDV-0403/A stays closed	oil, vibration, axial, thrust bearing, nitrogen, surge, discharge pressure and temperature, XS-0107A
Depressurized	as the pressurized one, and also opens BDV-0403/A to flare	primary vent high or low, cold seal gas, XS-0108A

Why two kinds of trip: for most faults a stopped machine full of gas is safe and restarts quickly. When the hazard is the gas itself — a leaking seal — it must be emptied.

The two buttons of the Emergency window command the two manual trips, XS-0107A and XS-0108A. The **reset** clears the causes that are no longer present; it does not reopen the valves (chapter 4).

8.4 The alarm list

The list follows the ISA-18.2 standard.

State	Meaning
ACT	active, not acknowledged: the condition is present and nobody has seen it
ACK	acknowledged: the condition is still present, the operator has seen it
RTN	returned to normal, not acknowledged: the condition has cleared, but nobody has seen it

An acknowledged alarm that returns to normal disappears from the list. A returned alarm is removed by acknowledging it. There are three priorities (Critical, High, Low): trips are critical. The **FO** (first-out) mark shows the cause that came first when several trip causes fire together.

Why first-out: in a trip, after the first event many others follow as its consequence. Knowing which came first is the most valuable information to understand what happened.

Why acknowledge and reset are two different gestures: acknowledging says “I have seen it”; resetting says “the machine may restart”. Confusing them leads to restarting without having understood.

Trip	Tag	Setting
Repeated surge	USHH-0201	3 events in 60 s or sustained surge beyond 8 s
Discharge pressure	PSHH-0405	46.5 barg
Discharge temperature	TSHH-0204	178 °C
Oil	PSLL-1623 · 2003	1.2 barg
Nitrogen	PSLL-1629 · 2003	2.4 barg

8.5 What the model simplifies

- Voting counts values over the setting; probes do not fail and there is no “not valid” state that degrades the voting.
- The motor trip (XS-0143) is in the list but no condition of the model fires it.
- The vibration of the three chains depends on the same speed and the same faults, with small fixed differences between probes.