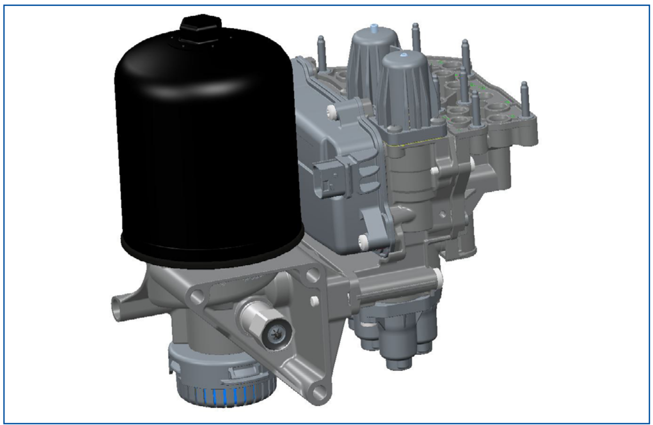
FuelGuard™ 932 510 200 0



1 Description

The E-APU (Electronic Air Processing Unit) is multifunctional, i. e. it is a combination of several types of equipment. It includes an air dryer with a purge valve and a safety valve. A multiple-circuit protection valve with two integrated pressure limiting valves and integrated check valves is flanged to the air dryer. The multi-circuit protection valve contains also four pressure sensors (for measuring the supply pressures in the service/parking brake circuits and in power train circuit) and two solenoids (for controlling compressor and air dryer regeneration). An ECU attached to the multi-circuit protection evaluates the signals of the pressure sensors and the vehicle data received via the CAN bus and controls the solenoids.

2 Purpose

The air dryer is used to dry and clean the compressed air delivered by the compressor. The flanged multiple-circuit protection valve is used to limit and guard the pressure in multiple-circuit braking systems as well as to establish a defined filling sequence. The signals of the four pressure sensors are sent to the CAN bus and the ECU controls the solenoids such that the compressor pumps preferentially in vehicle overrun and fuel is saved.

3 Operation

3.1 Filling the empty system

As the system is empty, the pressure sensors PS1, PS2, PS3 and PS6 show no pressure, so the ECU keeps the solenoids SVC and SVR de-energized. The ducts (r) and (d) are exhausted, which causes (via port 4) the compressor to pump and the purge valve PUV (controlled by duct (d)) to close. The compressed air supplied by the compressor flows via port 1.1 into chamber (a). Here the condensate caused by the reduction in temperature will collect at purge valve PUV.

After the compressed air is cleaned and dried in the desiccant cartridge ADC it reaches via duct (b) and check valve CVG duct (c) of the multi-circuit protection valve. The compressed air flows via duct (c) to overflow valve OV5, OV2 and OV1. And the compressed air flows via the open pressure limiting valve PL6 into duct (g) and to overflow valve OV6.

As all overflow valves are initially closed the pressure builds up and immediately the compressed air flows from duct (g) via the by-pass throttle BP6 into duct (q) and reaches overflow valve OV6 and port 26. The increasing pressure in duct (q) supports overflow valve OV6 to open in order to first of all supply the power train circuit connected to port 26 and to supply pressure sensor PS6

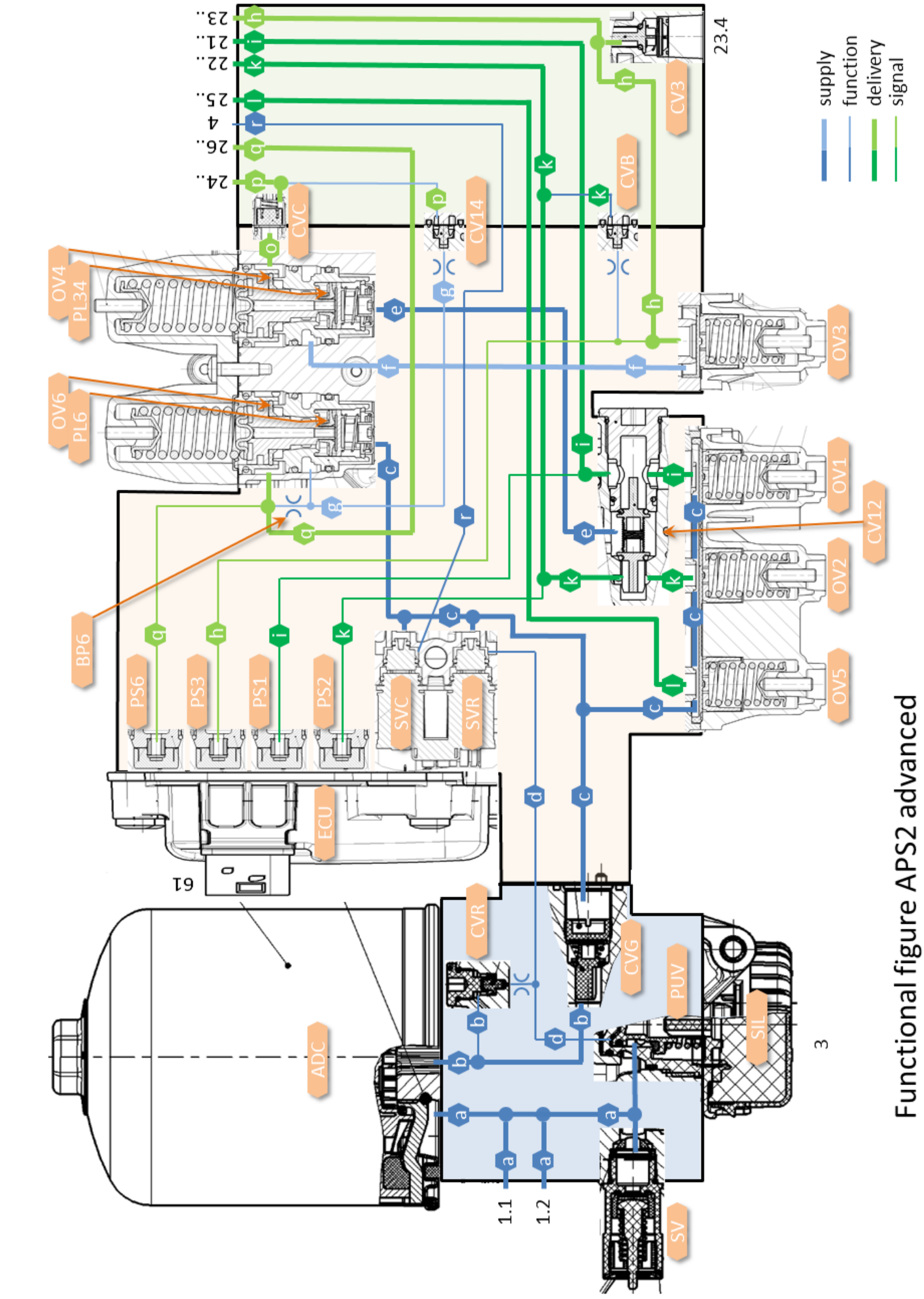
At the same time compressed air also flows from duct (g) through throttled check valve CV14 into duct (p) and to port 24 in order to restrictively supply the auxiliary circuit right from the beginning. As check valve CVC is closed the compressed air does not reach duct (o) and overflow valve OV4.

The pressure in duct (c) rises further until the pressure has reached a level where – depending on the tolerances for the opening pressures - overflow valve OV1 and/or overflow valve OV2 open. Compressed air flows into duct (i) and/or duct (k) and simultaneously into service brake circuit 21 and/or 22 and into pressure sensor PS1 and/or PS2. Double check valve CV12 opens as well allowing duct (e) to be pressurized by duct (i) and/or duct (k). The compressed air flows via duct (e) and the open pressure limiting valve PL34 into duct (f) and to overflow valve OV4, which is still closed. Via duct (f) the compressed air reaches also overflow valve OV3.

Depending on the - compared to overflow valves OV4 and OV5 - lower setting of the opening pressure, overflow valve OV3 opens next, pressurizing now via duct (h) pressure sensor PS3 and the trailer circuit connected to port 23. Branching-off from duct (h) compressed air flows via check valve CV3, which opens, and via port 23.4 to the parking brake circuit.

As the compressed air delivered by the compressor continues to fill the open circuits, overflow valve OV1 or OV2 will - in case not opened already - open now and the corresponding circuit is filled.

While the pressure rises further overflow valve OV5



Functional figure APS2 advanced

opens and air flows from duct (c) via duct (l) and port 25 to the air suspension circuit. Overflow valve OV4 opens as well, so that the auxiliary circuit is now fully supplied from duct (f) via OV4, duct (o), the opening check valve CVC, duct (p) and port 24.

Now all circuits are filled simultaneously until the pressure in the circuits 23, 24 and 26 reach 8,5 bar. Then the pressure limiting valves PL34 and PL6 close, so that the pressure in these circuits does not increase any longer.

The pressure in the circuits 21, 22 and 25 still rises. When the pressure at the pressure sensors PS1 and PS2 reaches the cut-out pressure the ECU energizes solenoid SVC, which opens, and via duct (r) and port 4 the control line to the compressor is pressurized. This causes the compressor to stop pumping (off-load).

3.2 Air sharing

All overflow valves are fully open. So the compressed air freely can be shared between the circuits 21, 22 and 25. Similarly the compressed air can be shared from circuit 23 to circuit 24, however any return flow of the pressure from circuit 24 to circuit 23 is prevented by check valve CVC. Also a restricted sharing takes place from circuit 26 to circuit 24 via throttled check valve CV14.

Air consumption in the circuits 23, 24 and 26 is compensated from the compressed air in the circuits 21, 22 and 25 via the pressure limiting valves PL34 and PL6, which open for the time the compensation takes place.

3.3 Intelligent Pressure Regulation

If, due to air consumption, the supply pressure in the system and at the pressure sensors PS1 and PS2 falls to a value below cut-in pressure, the ECU de-energizes solenoid SVC, which closes and via duct (r) and port 4 the control line to the compressor is exhausted. This causes the compressor to start pumping (cut-in).

Cut-out and cut-in of the compressor are varied according to vehicle conditions. CAN data are used to determine the vehicle load condition. The system preferentially pumps when the vehicle engine is not fueled, to utilize the kinetic energy of the vehicle.

The intelligent pressure regulation band is smaller than (and shifts within) the traditional operating range between maximum cut-out and minimum cut-in pressure. The “low pressure band” sticks to the minimum cut-in and the “high pressure band” sticks to the maximum cut-out pressure. Which band is active depends on the vehicle state, see list of vehicle states.

List of vehicle states:

“Engine stopped”: Bad time to pump with switched off engine, regeneration could be started.

“Engine idle”: In stand-still bad time to pump with low engine speed, regeneration could be started

“Static Braking”: bad time to pump with activated brake in stand-still and low engine speed, regeneration is not preferred in standstill because of noise reduction

“Driving”: bad time to pump because in driving engine load is high and engine power will not be used to pumping, driving time is good time to regenerate

“Overrun”: Good time to pump because kinetic energy shall be used, regeneration could be started to use high pressure level for drying and to use a long overrun phase for refilling after regeneration

“Neutral throttle”: In stand-still good time to pump because engine speed is high and driver wants high pressure, regeneration could be started

“Pump up”: In stand-still good time to pump because engine speed is very high and driver wants high pressure, regeneration is suppressed

3.4 Intelligent Regeneration

During pumping the ECU calculates the air volume pumped through the desiccant (IDU = Integrated Desiccant Use) using the engine speed data (from CAN), the engine compressor gear ratio and also the compressor performance data. After each cut-out the decision is taken, if a regeneration of the desiccant is needed or not. This decision is based on the IDU calculated compared with the current regeneration threshold. Which threshold is active depends on the actual vehicle state, see list of vehicle states.

With setting of regeneration threshold depending on vehicle state it is possible to postpone regeneration from a vehicle state with priority on pumping like vehicle state “Overrun” to other vehicle state.

If, after cut-out, regeneration is needed, the ECU energizes solenoid SVR, which opens, and pressurizes duct (d). This causes purge valve PUV to open. The air, the condensate plus any impurities and oil carbon from chamber (a) will be emitted via silencer SIL to atmosphere at vent 3.

Due to the drop in pressure in chamber (a) and via desiccant cartridge also in duct (b), the check valve CVG closes. The air for regeneration is now taken from the air reservoirs connected to port 21, port 22 and, if existing, also to port 25. As the overflow valves 21, 22 and 25 are open the air flows from the ducts (i), (k) and (l) into the duct (c) and further via the open solenoid SCR into duct (d). Branching-off from duct (d) compressed air flows via throttled check valve CVR, which opens, to duct (b). As it passes through the desiccant cartridge ADC in the reverse direction, the humidity in the desiccant is taken up by the air and emitted to atmosphere at port 3 after passing duct (a), the open purge valve PUV and silencer SIL.

While regeneration, the counter of air volume pumped through cartridge (IDU) will be decreased. When the IDU is recovered, the ECU de-energizes solenoid SVR, which closes. So the regeneration flow is stopped and duct (d) is exhausted. Thus check valve CVR closes as well as purge valve PUV. Depending on the type of compressor it may happen, that some compressed air is still entering via port 1.1 chamber (a), desiccant cartridge ADC and duct (b) and is building up some pressure. This situation persists until, due to air consumption, the supply pressure in the system falls to a value below the intelligent pressure regulation band. Then the ECU de-energizes solenoid SVC and the compressor starts pumping again.

If a planned regeneration could not performed completely due to high air consumption or detection of overrun phase the current IDU value is still stored and will be used as base for the next pumping phase. Amount of regenerations and regeneration length is optimized to minimize fuel consumption and to ensure dry air delivery.

3.5 CAN Communication

The ECU exchanges data with other ECU’s on the CAN bus according to SAE J1939. Transmitted are pressures of circuit 21, 22 and 23 as well as the system pressure. If both pressure values are valid the maximum value of pressure 21 and 22 will be used as system pressure. If one of the pressure values is invalid the valid pressure valid will be used to generate the system pressure.

In addition to the pressures figures other messages are sent, as for example:

- Air compressor torque
- Air in volume flow
- Filling up the time
- Leckage information
- Air consumption information
- Cartridge exchange information
- Fan request
- Power Manager request

The diagnostic system operates according to UDS standard providing the functions error memory interrogation, manual operation of solenoid valves, real-time reading of all sensors and other inputs and setting of system parameters

3.6 Cold Operation

The cold operation mode is entered when the ambient temperature value via CAN indicates that the temperature is close to freezing and at the same time the air consumption from the system is low. Then the system will cause the compressor to operate in a different off-load mode.

WARM-UP

As above described at cut-out normally solenoid SVC is energized. In cold operation mode however solenoid SVR is energized instead. Like with the regeneration - SVR opens and pressurizes duct (d). This causes the purge valve PUV to open and the air from chamber (a) will be emitted via silencer SIL to atmosphere at vent 3 and the unit is regenerating. As solenoid SVC is still energized the unloader of the compressor is in the position that the compressor further pumps hot air to the E-APU port 1.1 and via duct (a) and silencer SIL to the atmosphere.

The hot air heats the discharge line between compressor and port 1.1 as well as the chamber (a) and purge valve PUV. This is in addition to the heating coming from the pumping events. Thus the freezing of discharge line and purge valve PUV is prevented. This mode is kept active as long as the ambient temperature value and the air consumption from the system allow cold mode to be switched off.

3.7 Power-Down Regeneration

In order to further support the prevention of freezing the E-APU control software initiates a regeneration event whenever the engine is stopped. So any liquid water, which could freeze during standstill, is emptied from chamber (a) and purge valve PUV and the desiccant is regenerated for some time (up to 60s). After power down completion the ECU will be switched off.

3.8 Engine Cranking Unloading

If the ignition is switched on and the engine is not started, E-APU is in Power up mode. The compressor is unloaded (subject to available air pressure and battery voltage) to reduce the load for the engine during cranking. Therefore the ECU energizes solenoid SVC and via duct (r) the control line to the compressor is pressurized. So the compressor is unloaded until the engine is running or the vehicle is moving.

3.9 “bleed-back” function

A throttled check valve CVB located between circuit 22 and circuit 23 assures, that, once applied, the spring brakes must not release unless there is sufficient pressure in the service braking system to at least provide the prescribed residual braking performance of the laden vehicle by application of the service braking control.

If (for example due to leakage overnight) the pressure in circuit 22 and also in duct (k) falls below the pressure in duct (h), throttled check valve CVB opens and air flows from duct (h) into duct (k). Therewith the pressure in circuit 23 falls simultaneously with the pressure in circuit 22, so that the spring brakes cannot be released without sufficient service brake performance.

3.10 Reactions in case of circuit break

3.10.1 Reactions in case circuit 21 fails

If circuit 21 fails, overflow valve OV1 closes. This will initially cause via duct (c) the pressure in circuits 22, 25 and - as PL6 opens - also 26 to fall below the opening pressure. Although the check valve CV12 closes immediately, when the pressure in duct (i) and (k) is lower than in duct (e), the pressure in circuit 23 falls also slowly, as some compressed air flows from duct (h) via throttled check valve CVB into duct (k). Only the pressure in port 23.4 of circuit 23 is not affected, as check valve CV3 closes immediately. Also circuit 24 keeps the pressure since the check valves CVC and CV14 close.

Due to the fall in pressure at pressure sensors PS1 and PS2, the ECU de-energizes the solenoids and the compressor will switch to delivery, continuing to feed the intact circuits 22, 25 and 26 up to the opening pressure of circuit 21. If the pressure at port 1.1 exceeds the opening pressure of overflow valve OV1, the higher pressure will escape at the defective point of circuit 21. This ensures that the intact circuits 22, 25 and 26 continue to receive compressed air.

If the consumers connected to circuits 23 and 24 use up compressed air, the pressure in duct (e) will fall. If the pressure in duct (e) is lower than in duct (k), check valve CV12 will open and supply compressed air for the consumers connected to circuits 23 and 24 until the opening pressure of the defective circuit 21 has been reached.

3.10.2 Reactions in case circuit 22 fails

If circuit 22 fails, overflow valve OV2 closes. The supply of the compressed air to the intact circuits now becomes effective for circuits 21, 25 and 26, similar as described under “Reactions in case circuit 21 fails”. Circuits 23 and 24 are supplied with compressed air via the open check valve CV12 from duct (i).

Some air from circuit 23 escapes via the throttled check valve CVB at the defective point in circuit 22. However, as this is much less than the compressor delivers, the supply of the sound circuits is still ensured.

3.10.3 Reactions in case circuit 23 fails

If circuit 23 fails, the pressure in circuits 23 decreases. Port 23.4 is not affected as check valve CV3 closes. The pressure in circuit 23 continues to fall until overflow valve OV3 closes at a pressure below the opening pressure. This is followed by the sound circuits 21, 22, 24, 25 and 26 being supplied with compressed air by the compressor which is has been switched to delivery, until the opening pressure of the defective circuit 23 has been reached (like described under “Reactions in case circuit 21 fails”).

Sometimes the overflow valve OV3 opens again, so that the reaction process starts again. Then the system pressure is alternating between the dynamic closing pressure and the opening pressure of circuit 23. However, as check valves CVC and CV14 are closed, circuit 24 is not affected as long as there is no consumption in circuit 24.

3.10.4 Reactions in case circuit 24 fails

If circuit 24 fails, overflow valve OV4 closes. The supply of compressed air to the sound circuits becomes effective like described under “Reactions in case circuit 21 fails”. Depending on tolerances the opening pressure of circuit 24 can be higher than 8,5 bar. In this case the pressure in circuit 23 and 26 is limited to 8,5 bar.

Some air escapes via the throttled check valve CV14 at the defective point in circuit 24. However, as this is much less than the compressor delivers, the supply of the sound circuits is still ensured.

3.10.5 Reactions in case circuit 25 fails

If circuit 25 fails, overflow valve OV5 closes. The supply of compressed air to the sound circuits becomes effective like described under “Reactions in case circuit 21 fails”. Depending on tolerances the opening pressure of circuit 25 can be higher than 8,5 bar. In this case the pressure in circuit 23, 24 and 26 is limited to 8,5 bar.

3.10.6 Reactions in case circuit 26 fails

If circuit 26 fails, overflow valve OV6 closes. The supply of compressed air to the sound circuits becomes effective like described under “Reactions in case circuit 21 fails”. Depending on tolerances the opening pressure of circuit 26 can be higher than 8,5 bar. In this case the pressure in circuit 23 and 24 is limited to 8,5 bar.

Some air escapes via the by-pass throttle BP6 at the defective point in circuit 26. However, as this is much less than the compressor delivers, the supply of the sound circuits is still ensured.

3.11 Plausibility checks

Plausibility checks with respect to the behavior of the system pressure during pumping and regeneration are implemented:

- Not possible to stop the compressor.
- No pressure drop while regeneration.
- Sensor signal stuck (frozen).

3.12 Operation modes

3.12.1 Normal mode

The energy saving mode (Normal mode) is active if following mandatory CAN signals are valid: Engine Speed, Vehicle Speed, Percent Load at current speed and Service brake. If the Normal mode is active the ECU is working with the intelligent pressure regulation band, which is described before.

3.12.2 Bus mode

Via a parameter the Bus mode can be enabled for busses and other vehicles with short driving periods followed by stops (stop and go) with a high air consumption. The ECU monitors maximum IDU and compressor duty. If one of these exceeds a pre-configured threshold, the Bus mode becomes active. It prefers pumping during driving (with high engine speed) and regeneration in standstill (with low engine speed). If the thresholds are not reached, the vehicle continues to perform pumping and regeneration similar to normal mode.

3.12.3 Clutch mode

Vehicles equipped with a compressor clutch may run in a special mode. Then every time the compressor is switched off a regeneration takes place. This ensures that the discharge line is always exhausted in compressor off-load, which supports the proper function of the clutch.

3.12.4 Hybrid mode

With hybrid vehicles, which can be driven purely electrically, it has to be ensured, that during this time enough compressed air is available (to be generated by the combustion engine driven compressor), Therefor the ECU communicated via CAN bus with the power management of the vehicle. The power management promotes pumping before an electrical drive, so that the reservoirs are filled maximum. During electrical drive the power management triggers the ECU to avoid pumping. If however the system pressure is below the minimum cut-in, or if in cold mode warm air is needed, the ECU requests the power management to start the combustion engine, in order to switch on the compressor.

3.13 Degraded modes

3.13.1 Mechanical mode

If for any reason mandatory CAN information becomes unavailable or a memory error was noticed or the mechanical mode was activated on purpose via parameter, the system will operate in a mode analogous to a traditional mechanically controlled air dryer system. Having started, pumping will continue until the cut-out pressure is reached.

The compressor is switched on, if due to consumption from the circuits the system pressure falls below cut-in pressure, and will again stop pumping, if the cut-out pressure is reached. After each cut-out the desiccant cartridge ADC is regenerated until the pressure has dropped a predefined percentage of the operating range (typically 50%).

3.13.2 Alternate unloading

In case of a detected fault on solenoid SVC, which normally controls the compressor, or in case it is not possible to stop the compressor pumping, the ECU controls solenoid SVR such, that the system pressure still is regulated like in normal mode. However, as the compressor cannot be switched off, during off-load the full air flow from the compressor is exhausted via the open purge valve PUV and silencer SIL to atmosphere. In addition the unit is regenerating in the entire off-load time.

3.13.3 Over-pressure dump

Should the system become over-pressurized, for example due to a faulty compressor installation, air is exhausted through the regeneration orifice until the system pressure is within normal range. The compressor is unloaded during this period.

3.13.4 Safety valve / limp home

In case of certain electrical failures (for example loss of electrical power or pressure sensors of circuit 1 and 2 are faulty) both solenoids SVC and SVR are de-energized and thereby closed. The ducts (r) and (d) are exhausted, which causes the purge valve PUV (controlled by duct (d)) to close and (via port 4) the compressor to pump. Compressed air flows to circuits 21, 22 and 25 increasing the pressure there. As there is no electronic control the pressure rises above the cut-out pressure. When the pressure in chamber (a) exceeds the opening pressure of safety valve SV, the higher pressure will escape via safety valve SV to atmosphere. This stops the pressure from rising further.

The vehicle is supplied with compressed air and is able to limp home. As the compressor is continuously pumping, no regeneration takes place, so that after some time wet air and condensed water enter the unit and the circuits.

3.13.5 Insufficient Pressure level

If, for example because of high air consumption or a big leakage in the circuits or poor air delivery from the compressor, the ECU detects that for a longer period the pressure cannot be pumped up to the normal operating range, it sends the information „high or critical air consumption“ via Air Pressure Information on CAN bus to inform the driver of this situation.

The insufficient pressure goes along with insufficient regeneration of the desiccant.

That means the IDU is above the critical threshold.

3.13.6 Pressure limiting failure

Should the pressure in circuits 23/24 or circuit 26 become over-pressurized, for example due to filling from external sources or due to failure in pressure limiter valve PL34 or PL6, air is exhausted through the regeneration orifice until the system pressure is below the pressure limiting pressure (8,5 bar). Then the compressor is regulated such, that the pressure is in a small band below 8.5 bar, similar to mechanical mode without fuel saving strategy.

3.13.7 Low voltage protection

Below the normal voltage working range the fault detections are disabled. Apart from that the system behaves normal as long as the voltage is sufficient to activate the solenoids. At very low voltages (<13V) the system will stop the controlling of pressure and regeneration and the transmission of pressures via CAN.

3.13.8 High voltage operation

When supply voltage exceeds the normal operating band, the ECU protects the solenoids, and ensures continued safe operation by limiting the solenoid current using pulse-width modulation.