Understanding the Modern Automotive Air Conditioning System

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VARIABLE DISPLACEMENT COMPRESSORS

Manual/Pressure Sensing Type
VARIABLE DISPLACEMENT COMPRESSIONS
PRESSURE SENSING TYPE

THE BASIC SYSTEMS

Our most familiar system is the CCTXV (Cycling Clutch TX Valve) system where the TX Valve Controls flow in accordance with cabin heat loads. Under higher ambient / higher humidity conditions this system works fine – because there is sufficient flow requirements that the system needs to work “relatively hard”.

Under low heat loads however the TX Valve system is, from a purist standpoint, inefficient when comparing power consumption and net cooling efficiency.

When the TX Valve operates in cycling mode (low heat loads) the TX Valve closes down in response to superheat requirements. This drives the low side refrigerant pressures and temperatures down to an unacceptably low level (i.e. 100 kPa / 15 PSIG) to prevent evaporator icing. If we continued to run the system the evaporator would ice up, reducing vent airflows and increasing the risk of liquid flood back. The answer is to place a thermostat or a thermistor / amplifier into the circuit to establish a predetermined defrost cycle. From an efficiency standpoint this is a waste of energy.

EPR SYSTEMS

One solution to the cycling clutch problem is to use on EPR (Evaporator Pressure Regulator) or on STV (Suction Throttling Valve) into the system. This valve serves to hold evaporator pressures at a predetermined level to prevent the risk of icing. In controlling evaporator pressures the suction line pressures are reduced substantially, therefore the “work” the compressor has to do is significantly reduced.

EPR systems have been used, and are still used in the heavy vehicle sector where pressure drops become an issue with larger evaporators. Early GM (POAST and VIR) systems with the “throttling” valve being the POAST or VIR assembly. Toyota/Denso used EPR valves on some Australian released vehicles (i.e. MX83 Crassida).

Many people interpret this system as being wasteful because the compressor runs all the time but in fact it is a relatively efficient system with the pump going into a “semi idle” mode. It does however have the limitation that there is still energy required to drive the pump and the pistons / rotor vanes / scrolls still have to work against residual head pressures.
Service Tip:

When dealing with EPR/STV systems it is normal for heavy frosting/icing on the suction line and even the compressor. Many technicians misdiagnose this as a fault. This is effectively a “two zone” low side system with the evaporator pressure at 170 - 190 kPa (25 - 28 PSIG) and the suction pressure being so low that generates the frosting.

VARIABLE DISPLACEMENT PUMPS

Variable pumps are the most efficient of all systems. They work on a “destroking“ principle to control evaporator pressures to predetermined levels and the mechanical drive energy is also minimised. By controlling evaporator pressures to a predetermined level we can keep the evaporator out of the “chill zone” thereby eliminating the need for thermostats / thermistors plus by stabilising evaporator temperatures electronic control systems are stabilised in control (i.e. blend door actuators).

VARIABLE PUMPS – HOW DO THEY WORK

Early generation variable pumps used an internal bypass valve to control low side pressure. This was in principle on EPR Valve inside the pump. The Sanden TRV105 was an example of this type of pump.

Later generation pumps are true Capacity Control compressors. The most common of these is the Delphi (Harrison) V5/V7 fitted to VT/VX/VY Commodore, Barina and the CVC7 (VZ Commodore) etc. Sanden variable displacement compressors are the SDV Series, the most common being the SDV16 fitted to a wide range of European vehicles. It varies Displacement to control Capacity to meet A/C demand for all operating conditions. The demand verses capacity relationship must be fully understood for diagnosis. Failure to do this will result in misdiagnosis and unwarranted compressor replacement.

The design centres around a variable angle wobble plate in a five/seven cylinder axial piston.

Displacement (capacity) is controlled by a bellows operated control valve located in the rear cylinder head (Delphi) or in the dead centre of the pump Sanden). This valve senses and responds to the system suction pressure, which is proportional to the A/C system demand.

REDUCED SYSTEM DEMAND = TX CLOSING DOWN = REDUCED SUCTION PRESSURES.

There are 3 pressures internal of the compressor:

- Compressor Discharge Pressure
- Compressor Crankcase Pressure
- Suction pressure
The control valve works with these 3 pressures generally the compressor discharge pressure is much greater than the internal crankcase pressure which is greater than or equal to the compressor suction pressure.

**UNDER HIGH HEAT LOADS (HIGH DEMAND)**

The low side (suction pressure) is high, above 191 kPa (28 PSIG) – TX valve opens in accordance with high heat loads. This high pressure acts on the bellows to compress it. This in turn opens the suction crankcase valve to maintain a bleed between the compressor crankcase and suction pressure. Crankcase pressure and suction pressure are therefore equalised. The wobble plate angle is maximised under these conditions resulting in maximum piston displacement. This is the “full stroke” or %100 capacity position.

**UNDER LOW HEAT LOAD CONDITIONS (LOW DEMAND)**

As the TX Closes under reducing heat load conditions the low side pressure reduces to the control valve set point i.e. 191 kPa (28 PSIG). Under these conditions the control valve bellows expands. This effectively closes the crankcase to suction bleed valve and opens the discharge to crankcase valve to allow a bleed of discharge pressure into the crankcase. This effectively raises crankcase pressure to equalise piston force and move the wobble plate to a “de-stroked” position (with a reduced angle). In the period of de-stroking the displacement is infinitely variable between 5 and 100% of its maximum displacement.
The above diagram shows the control valve located in the rear of the compressor with a bellows controlling crankcase pressure via 2 valves. This effectively drops the crankcase to suction pressure or allows high discharge pressure to enter the crankcase.
Under high load conditions the TX opens resulting in a high suction pressure to close the control valve bellows to maximum stroke position.

Under low heat load conditions the TX Valve closes. This reduces the suction pressure, the bellows expand and the pump de-strokes by opening the discharge valve.
GAUGE RESPONSE

On initial start up the high side and low side pressures will be normal – In accordance with the system heat load. Dependent on this load (which includes both humidity and temperature) the TX Valve will begin to close down.

Under high constant loads the TX will stay open to maintain low side pressures above set point where the compressor operates at 100% and system pressures and evaluative procedures are unchanged from conventional systems.

Under lower heat loads the TX closes down with a subsequent reduction in suction pressure. At set point the low side stabilises off – it may “flutter” at this point – after which no reduction in low side pressures should occur. The point of stabilisation is controlled by the control valve setting of which there are numerous. Most systems use a control valve set at 150 to 200 kPa – dictated by system dynamics. Later model compressors de-stroke commonly at 190 - 200 kPa.

It is important to note that the suction pressure is controlled by the destroking of the compressor, not by an EPR (Evaporator Pressure Regulator) valve. With an EPR Valve the high side pressure remained at normal levels, with minor reductions only as a result of a reduced density of returning (suction) vapours.

Service Tip:

In variable compressor systems the high side (head) pressure reduces as the pump de-strokes. This often leads to a misdiagnosis of a failed compressor (Internal Bypass)

SYSTEM EVALUATION

To evaluate variable pump systems accurate testing must be done under high heat local conditions to check for adequate TX flow rates, compressor performance etc and under low heat load conditions (if possible) to check control valve operation, destroking and no evaporator icing.

SET UP CONDITIONS

All operational tests are conducted as for a normal system except where otherwise stated. This includes condenser fans operational (or a substituted airflow) 1500 – 2000 r/min and doors and windows shut, low fan speed selected for performance evaluation (vent checks). For condenser evaluation and / or maximum displacement testing high fan speed is selected with doors and windows open. It may be necessary to “preheat” the cabin (heater on) in low ambient conditions.
ADDITIONAL TESTS

COMPRESSOR DE-STROKE / NO STROKE TEST

This test is normally conducted to ensure the compressor can de-stroke. Remember it will only do this when the TX Valve shuts down to reduce suction pressures under low heat loads. Therefore a low heat load condition must be simulated. This is achieved by:

- Engine operating at 3000 r/min
- Maximum cold selected
- Doors / windows closed
- System stabilised to low cabin heat loads
  (in high temps / high ambients a simulated test may be required – see below)

Observe the low side gauge for a reduction to control valve set point and observe the suction pressure stabilisation – with a corresponding reduction in high side pressures. Providing the control valve set point is reached the compressor must de-stroke. A failure to de-stroke will result in a reduced low side pressure and a subsequent icing of the evaporator coil. **No additional de-icing control is used with variable pump systems.** They rely on the low side pressures being controlled to a sufficiently high pressure to prevent fin and tube temperatures dropping below 0°C. A compressor smoothness test should accompany this test.

DE-STROKE TEST
HIGH HEAT LOADS (SIMULATED TEST)

With systems having an accessible TX Valve the valve can be forced to close by the standard “TX Valve Closure Text” by spraying “spray freeze” or an alternative ozone safe/environmentally friendly substance onto the bulb. It is strongly recommended this is done “bit by bit” to observe the low side gauge characteristics.

Spraying the bulb will effectively reduce low side pressures to control valve set point, where the pump should de-stroke.

FULL STROKE TEST

The full stroke test is conducted at high heat loads and is based on existing test parameters. The compressor should be on full stroke when the system is out of the ‘control valve zone’ (shown over).
PERFORMANCE TESTING

Performance testing should be based on manufacturers recommendation taking into consideration both Ambient Temperature and Humidity. An alternative to manufacturers recommendations is to conduct Psychometric Performance Testing.

**IMPORTANT NOTE:**

It is of paramount importance that testing is conducted in accordance with recommended procedures. A failure to do so will result in a misdiagnosis of lack of performance.

GAUGE ANALYSIS

A compressor that fails to exhibit pressures as for a normal system, in the full stroke test, is possibly in the de-stroke or partial de-stroke condition. This will give the same indicators as a conventional pump that has an internal bypass. (High low side / low high side.) Always ensure the variable pump is not operating in conditions that would de-stroke it at the time of testing. (Shown as the control valve zone on the diagram over.)

Ensure the following conditions exist when conducting full stroke tests.

- Engine at 1000 – 1500 r/min
- Adequate condenser airflow (fans operational)
- A/C not operated for 30 minutes in ambients below 25°C. Alternatively the heater can be selected to raise heat loads to acceptable levels prior to testing – then select A/C
- Doors / Windows open
- High fan speed
- Maximum Cold Selected
An alternative to the graph above is to use a Psychometric Chart for full humidity versus performance evaluation.
FAULT DIAGNOSIS TIPS
VARIABLE PUMPS

A variable pump may fail to de-stroke if the following conditions exits

- High ambient / humidity loads
- Overcharge
- Poor condensing
- TX Valve jammed open
- Control Valve Malfunction

A variable pump may fail to 100% stroke if

- System is undercharged
- TX Valve closed / restricted
- Heat loads are low
- Low side blockage
- High side blockage
- Control Valve Malfunction

COMPRESSOR NOISE DIAGNOSIS

Normal tests are to be conducted

- Bearings / Idlers
- Mount Bolts
- Belt Damage / Dance

In the event of a hydraulic knock charge rates must be evaluated (verify no overcharge exists) and TX Valve stuck open tests must be conducted.

Note – Minor liquid slugging may occur in variable pumps in low ambient conditions (i.e. overnight). This is due to the condensing of suction vapours at higher pressures as ambients drop. This is a normal condition (providing it clears in less than 30 seconds and it cannot be attributed to an overcharge or TX Valve malfunction). TX Valve malfunctions or overcharges normally result in regular liquid slugging – not intermittent.

TX VALVE SELECTION

TX Valve Selection is critical. Variable pump systems use a specially designed “low flow calibrated” TX Valve. Only genuine valves or a guaranteed direct replacement must be used in these systems.
SERVICE TIPS

VARIABLE DISPLACEMENT COMPRESSORS
DIAGNOSIS OF OPERATING MODES

The key to diagnosing variable pumps is to firstly identify whether they should be in full stroke mode or de-stroke mode.

This is determined by the heat load that is on the system.

Heat loads are the TOTAL of:

- The ambient temperature of the air
- The latent heat that is in the humidity that is in the air
- The volume of air being pumped over the evaporator

The ambient temperature of the air is an obvious heat load and the one we immediately relate to. We know that on hot days the TX valve opens, the low side pressure rises and “chill levels” of the air are reduced.

The volume or air is also a commonly recognised factor. High fan speeds result in the TX valve opening due to higher heat loads. Generally speaking above 25°C (cabin air temperature) there is enough heat load to keep the pump in full stroke mode on full fan speed.

The humidity is the hidden factor most people do not think about. Water vapour in the air (humidity) must have had heat added to turn it into a vapour. The evaporator must take that heat out to condense it back into a liquid. This is effectively a very high heat load on the system. Generally speaking above 15°C cabin air with 80% RH on high fan speed the pump should be in full stroke mode.

There are three ways to determine whether or not the pump should be in de-stroke mode with respect to total heat loads.

Method 1

Using the manufacturers low side pressure analysis graph (for various humidities) determine whether you are in the control valve zone (as shown on the graph), or if the control valve zone is not shown whether or not your low side is down to set point.

If it is down to set point it may be still on full stroke mode, but it may be de-stroking by anything up to 95%. Low side pressure will stabilize at set point through the full de-stroke range.
The key now is to look at the high side pressure to determine if condensing pressures are normal, (use the doubling rule or the +30° rule).

If high side pressures are normal you are on the verge of de-stroking, but not yet in the de-stroke mode. Continued operation or dropping down the blower speed will reduce heat loads even further and the high side pressure should “wash off”.

When the pump is in full de-stroke mode, which normally only occurs with continued operation or on highway cycle the high side pressure will decrease to near ambient temperature. i.e. the condensing temperature will be near ambient.

LOW SIDE (SUCTION PRESSURE) EVALUATION

**Method 2**

Method 2 is to refer to the performance evaluation chart. The purpose of the variable pump is to unload when heat loads have reduced to a level where icing becomes a problem. Instead of cutting the system out (via a thermostat or thermistor) the pump de-strokes to effectively prevent the evaporator pressure (and corresponding temperature) being pulled any lower.
So, from the performance evaluation chart, once again it may show the de-stroke zone (that corresponds to certain pressures and temperatures) but if it does not show it we simply need to evaluate when the evaporator is down to 0°C (usually 2-5°C at the vent), or when the graph ‘flattens out’ at its minimum.

Once this is determined we then look at the low side gauge for set point, and the high side gauge for de-stroke, indicated by a wash off of high side pressure below normal levels.

**PERFORMANCE EVALUATION**

![Performance Evaluation Chart]

An alternative to the graph above is to use a Psychometric Chart for full humidity verses performance evaluation (Method 3).

**Method 3**

The third, and by far the most accurate method of determining de-stroke is to use the psychometric chart that has been used by professionals for system analysis for a number of years.

The key to using the psychometric chart is to realise that it is the only true measurement of expected performance of systems, because it is the only method that accurately takes into account total heat loads. *Total heat load is humidity plus temperature.*
It is only when an accurate analysis of total heat load is done that we know for sure whether the pump should be on full stroke or de-stroke mode. Using this method is the professional technicians preferred, because if we know the absolute de-stroke point we can accurately determine whether or not other faults are driving the pump into de-stroke or the pump is stuck in de-stroke. Feeding the suction with a pressure above set point will quickly determine whether or not the pump is capable of going into full stroke mode.

**DETERMINING HUMIDITY**

There are two methods of determining humidity in the air:

- The first is to use an electronic humidity probe to give accurate, fast humidity readings.
- The second is to use wet bulb and dry bulb thermometers then using a psychometric chart (Chart 1) to determine humidity

Once humidity is determined the performance chart (chart 2) can be used to determine how much heat can be taken out of the air by the evaporator.

**EVAPORATOR PERFORMANCE**

The first thing to appreciate about evaporator performance is that is actually has two roles to perform.

It must:

- **Dehumidify the air**

Then it can:

- **Cool the air.**

The amount of cooling that can be achieved is directly controlled by the humidity in the air. Cooling is a direct factor of how much work is “left over” after the dehumidification is completed.

It is therefore critical humidity is accurately determined to then enable evaporator performance to be calculated.
DETERMINING HUMIDITY USING WET AND DRY BULB THERMOMETERS (PSYCHROMETER)

Step 1

With the wet bulb saturated place the psychrometer over the re-circulate door with “Recirc” selected and the fan on High.

Diagram reproduced courtesy of DENSO. For training purposes only.

Step 2.

With the wet and dry bulb thermometer readings taken refer to the psychometric graph over.

- Identify the dry bulb temperature on the bottom line and draw a vertical from it.

- Identify the wet bulb temperature ‘going up the hill’ (the 100% humidity line). Draw a line down from that temperature at a ‘4 o’clock’ angle.

- Where the 2 lines intersect identifies the relative humidity.
CALCULATING PERFORMANCE

With the humidity calculated it is now time to go to the second graph, the evaporator performance graph. (Shown over)

The vertical axis of this graph is the temperature between the air onto the evaporator and the air off. In real terms it is the amount of heat the evaporator can ‘suck out of the air’.

By looking at the graph you can see that the heat removed by the evaporator with dry air is between 25 and 30°C yet at 80% relative humidity it is down to 12 - 14°C. All the ‘extra work’ has been used to dry the air.

Simply go along the horizontal axis until you find the predetermined humidity (previously calculated). Draw a vertical line from this point up to the specified ‘performance band’. Note the bottom and top performance limits.

With a dry bulb thermometer (normal thermometer) placed in the outlet vent compare the readings of the inlet air (the air read on the dry bulb of the psychrometer) and the outlet air.
Example:

Dry bulb on psychrometer reads 30°C
Vent air temperature reads 8°C
Air removed by evaporator = 22°C

From here you can allow 2 - 5° duct reheating. In real terms if the vent temperature was 8°C the evaporator itself would have an ‘air off’ of 3 - 6°C.

The evaporator is therefore ‘sucking out’ 24 to 27°C. This is acceptable for dry air and above specification for air with 20% humidity or greater.
PRESSURE CONTROLLED VARIABLE DISPLACEMENT COMPRESSORS

DELPHI (CALSONIC) CVC-7 COMPRESSOR AS USED ON VZ COMMODORE

Whilst this pump is still a pressure sensing type it has one very important variation:

The ‘biasing spring’ is located on the opposite side of the wobble plate.

Therefore.....

The static position (the rest position) for this pump is the “no stroke” position.

The previous model Delphi V5 had a rest position of Full Stroke, and when set point was reached it de-stroked. This pump is opposite.

OPERATION - CVC 7

When the vehicle is started the spring on the back of the swash plate/wobble plate ‘flattens’ out the swash plate. This is assisted by high pressure under the pistons in rest position also ‘flattening out’ the swash plate.

When the vehicle is started the pressure on top of the pistons (in the cylinders) forces the swash plate onto an angle. For this to occur we have to ‘bleed crankcase pressure off’. If there is still full crankcase pressure the swash plate cannot move to its ‘angle position’ (full stroke), because the pressure under the pistons will be forcing the pistons to TDC.

So.....

When the vehicle is started under full heat load the pressure in the crankcase is ‘bled off’ and the compressor goes to its full stroke position.

Then....

With continued running (especially on low heat load/low fan speed)....

Pressure is bled to back into the crankcase to work underneath the pistons to force the swash plate/wobble plate to flatten out, thereby de-stroking the pump.
CUSTOMER COMPLAINT:

“The air conditioner takes too long to get cold”

From the first air conditioning engagement the customer will not feel cold air through the face vent until between 5 to 20 minutes has elapsed.

When a customer experiences this issue they may ring to ask if they can bring the vehicle in for a quick check of the air conditioning performance.

When you check the face vent temperature by hand, you will find that the air conditioner is cold, once the vehicle has warmed up. This will be the case if the customer has driven the vehicle in to you.

This issue only seems to appear when the vehicle is in a cold engine state (coolant and ambient temperature similar). Once the engine is warmed up and the engine bay is hot, the compressor body and plumbing warms up, then the compressor starts to work (Refrigerant thermal expansion).

You will notice the following when carrying out your “slow air conditioning ramp up” testing.
The cooling fan takes a long time to activate. The cooling fan is engaged at 1500 kPa (high side pressure).

After the air conditioning switch is operated there is a 12 second delay which is the PCM delay to air conditioner relay. Your stopwatch should be started once the air conditioner clutch is in engaged, not when the air conditioner is operated.

If the compressor is faulty the high side pressure will take a long time to get to 1000 kPa but once at 1000 kPa will go faster up to 1500 kPa (engine fan engagement). At that stage the air conditioner should start to feel cold.

**SLOW A/C RAMP UP TESTING**

Vehicle set up for testing. Connect pressure gauge set to the a/c system, insert a digital thermometer into the face vent and have a stop watch at the ready to record time taken.

Engine coolant and ambient temperature MUST be the same or within 5 degrees of each other. The ideal test set up is to leave the vehicle overnight for a next morning test.

Ignition Off. A/c system high and low pressures MUST be equalised and be within specification depending on ambient temperature between 475 - 900 kPa.

If your static pressures are not equal, below or above the specification for the ambient this will indicate that the coolant temperature has not reached ambient, blockage in the a/c system, TXV fault or low/high refrigerant charge. Investigate and rectify the issue before continuing.

Start engine, engage the air conditioner. Start your stopwatch as soon as the compressor clutch engages (visual).

Record the time until the low side pressure reaches the compressor control valve set point of 200 kPa. At set point the low side tube from the TXV will be cold and the face vent temperature will also be cold.

If the recorded time is greater than 3 minutes the compressor is faulty. Replace the compressor through your normal warranty procedure.
ROOT CAUSE OF THE ‘SLOW A/C RAMP UP’ ISSUE

The established root cause for this issue is that the compressor rear head casting partially covers a cylinder bleed port. This cylinder port is the bleed off for the internal crankcase pressure (opposing force behind the pistons).

A crankcase pressure reduction is required via the bleed to allow the crankcase pressure to decrease and the swash plate to increase its angle which then increases the compressor output.

BREAK POINT ESTABLISHED

This fault existed on compressors manufactured in 2006. If you look on the Delphi ID Plate it will have a Serial Number that starts with 06 on the third line of the ID place. This is an eight digit serial number just above the word “Caution”.

\[
\text{Red = Suction Reed} \\
\text{Blue = Valve Plate} \\
\text{Green = Cylinder}
\]