Secondary Air Injection System Operation

When the engine is started, the engine control module checks the engine coolant temperature and if it is below 55° C, the ECM grounds the electrical connection to the coil of the secondary air injection (SAI) pump relay.

A 12V battery supply is fed to the inertia switch via fuse 13 in the engine compartment fusebox. When the inertia switch contacts are closed, the feed passes through the switch and is connected to the coil of the Main relay. An earth connection from the Main relay coil is connected to the ECM. When the ECM completes the earth path, the coil energises and closes the contacts of the Main relay.

The Main and Secondary Air Injection (SAI) pump relays are located in the engine compartment fusebox. When the contacts of the Main relay are closed, a 12V battery supply is fed to the coil of the SAI pump relay. An earth connection from the coil of the SAI pump relay is connected to the ECM. When the ECM completes the earth path, the coil energises and closes the contacts of the SAI pump relay to supply 12V to the SAI pump via fusible link 2 in the engine compartment fusebox. The SAI pump starts to operate, and will continue to do so until the ECM switches off the earth connection to the coil of the SAI pump relay.

The SAI pump remains operational for a period determined by the ECM and depends on the starting temperature of the engine, or for a maximum operation period determined by the ECM if the target engine coolant temperature has not been reached in the usual time.

When the contacts of the main relay are closed, a 12V battery supply is fed to the SAI solenoid valve via Fuse 2 in the engine compartment fusebox.

The ECM grounds the electrical connection to the SAI vacuum solenoid valve at the same time as it switches on the SAI pump motor. When the SAI vacuum solenoid valve is energised, a vacuum is provided to the operation control ports on both of the vacuum operated SAI control valves at the exhaust manifolds. The control vacuum is sourced from the intake manifold depression and routed to the SAI control valves via a vacuum reservoir and the SAI vacuum solenoid valve.

The vacuum reservoir is included in the vacuum supply circuit to prevent vacuum fluctuations caused by changes in the intake manifold depression affecting the operation of the SAI control valves.

When a vacuum is applied to the control ports of the SAI control valves, the valves open to allow pressurised air from the SAI pump to pass through to the exhaust ports in the cylinder heads for combustion.

When the ECM has determined that the SAI pump has operated for the desired duration, it switches off the earth paths to the SAI pump relay and the SAI vacuum solenoid valve. With the SAI vacuum solenoid valve de-energised, the valve closes, cutting off the vacuum supply to the SAI control valves. The SAI control valves close immediately and completely to prevent any further pressurised air from the SAI pump entering the exhaust manifolds.

The engine coolant temperature sensor incurs a time lag in respect of detecting a change in temperature and the SAI pump automatically enters a 'soak period' between operations to prevent the SAI pump overheating. The ECM also compares the switch off and start up temperatures, to determine whether it is necessary to operate the SAI pump. This prevents the pump running repeatedly and overheating on repeat starts.

Other factors which may prevent or stop SAI pump operation include the prevailing engine speed / load conditions.

SAI System Fault Finding and Check Malfunctions

The SAI system diagnostics monitor the whole SAI system for correct operation. Malfunction of any one of the SAI system components can cause fault codes to be stored in the ECM diagnostic memory.

Correct fault finding methods and investigation are essential to determine the root cause of the generated fault code(s) and prevent mis-diagnosis.

NOTE: TestBook/T4 must be used to perform active SAI diagnostics.

Fault Finding

In the event of SAI system malfunction and P Codes 1412 – 1417 being stored in the ECM diagnostic memory, the following information is designed to provide a logical checking process for investigation of the root cause(s) of the fault. This fault finding guide should be used in conjunction with the following 'Checking Malfunctions' procedure and other information contained in this Emissions section.

It is important that these procedures are performed to prevent the following:

- Excessive instances of No Fault Found (NFF) components in warranty returns
- Multiple repeat complaints from the customer before the cause of the fault is found.

The following table lists the P codes applicable to the SAI system and their meaning:

P-code	Description
P1412	Secondary Air Injection System – Malfunction Bank 1 LH (Insufficient SAI flow during passive test)
P1413	Secondary Air Injection System – Air control valve always open Bank 1 LH (Excessive SAI flow during active leak test)
P1414	Secondary Air Injection System – Malfunction Bank 1 LH (Insufficient SAI flow during passive test)
P1415	Secondary Air Injection System – Malfunction Bank 2 RH (Insufficient SAI flow during passive test)
P1416	Secondary Air Injection System – Ait control valve always open Bank 2 RH (Excessive SAI flow during active leak test)
P1417	Secondary Air Injection System – Low air flow Bank 2 RH (Insufficient SAI flow during active test)

Passive Test (P Codes 1412 and 1415)

During normal SAI operation the ECM uses HO2S sensor voltage output to determine if sufficient flow is being introduced into the exhaust system. Depending on which banks of the engine detect the fault, one or both P codes can be stored.

Active Tests

If the normal operation of the passive SAI diagnostics cannot be completed, (SAI operation being suspended by load/speed conditions, for instance) the ECM will attempt to perform an 'Active' test of the system when conditions allow. These conditions include, but are not limited to: 'Engine fully warm' and 'Engine at idle'. The active test comprises two parts; a 'Leak Test' followed by a 'Flow Test'.

Leak Test (P Codes P1413 and P1416)

The SAI pump is operated without opening the SAI control valves. In this condition no SAI flow should enter the exhaust system. By monitoring the HO2S sensor voltage output, the ECM determines if the system is functioning correctly. Depending on which bank of the engine detects the fault, one or both P codes can be stored.

Flow Test (P Codes P1414 and P1417)

When the Leak test has been passed successfully, the SAI control valves are then opened while the SAI pump is still operational. Flow should now begin to enter the exhaust system. By monitoring the HO2S sensor voltage output, the ECM determines if sufficient flow is being introduced into the exhaust system. Depending on which bank of the engine detects the fault, one or both P codes can be stored.

Fault Finding Methodology

Malfunctions can be broadly categorised into two different categories: Flow Faults or Leak Faults.

Additionally, they also differ depending if the corresponding P code exists for both cylinder banks simultaneously or is unique to one bank, for example:

P Code Type	One Bank Only	Both Banks
Flow	I	II
Leak	III	IV

Faults of each of the four basic types should be investigated in a different priority order, starting with the most logically plausible cause or component.

Fault Finding Flow Charts

The following flow charts show the order of investigation that should be performed depending on the type of fault present. These should be treated as guidelines to ensure that the most likely and plausible causes are addressed first.

However, the flow charts assume that no clear or obvious reason for failure exists. If the cause of the malfunction is immediately obvious, then the flow charts should not be followed.

Once a malfunction is identified, it should be rectified as necessary and the system checked as per the instructions in the following 'Checking Malfunctions' section.

NOTE: It is not necessary to follow the remainder of the flow chart once a potential root cause has been identified.

Flow Fault Finding chart

1 Fault codes P1412, P1414, P1415 or P1417 present
2 Insufficient flow detected
3 Is fault present on both cylinder banks?

If **'NO'** proceed to step 4

If **'YES'** proceed to step 8

4 Vacuum supply – Check for: blockage and/or vacuum line disconnected from SAI valve
5 SAI Valve – Check for: jam / diaphragm leak or blockage
6 Delivery Hoses to SAI Valve – Check for: blockage / leaks
7 SAI Pipes to Cylinder Head – Check for: blockage / leaks
8 Electrical Issue – Check for: Related P code (relay/fuse/solenoid), rectify as necessary and check connectors
9 Vacuum Supply – Check for: Blocked/leaking vacuum lines or correct solenoid operation (open/closed)
10 Delivery Hoses – Check for: Blocked/leaking hoses
11 SAI Pump – Check for: Correct operation using TestBook/T4 or pump blockage/failure
12 SAI Valves – Check for: Both SAI Valves jammed/blocked/leaking diaphragms

Leak Fault Finding Chart

1 Fault codes P1413 or P1416 present
2 SAI system leak detected
3 Is fault present on both cylinder banks?

If **'NO'** proceed to step 4

If **'YES'** proceed to step 5

4 SAI Valve – Check for: leakage
5 Vacuum supply – Check for: solenoid stuck open (mechanical failure) or stuck open (electrical failure)
6 SAI Valve – Check for: leakage from one or both valves

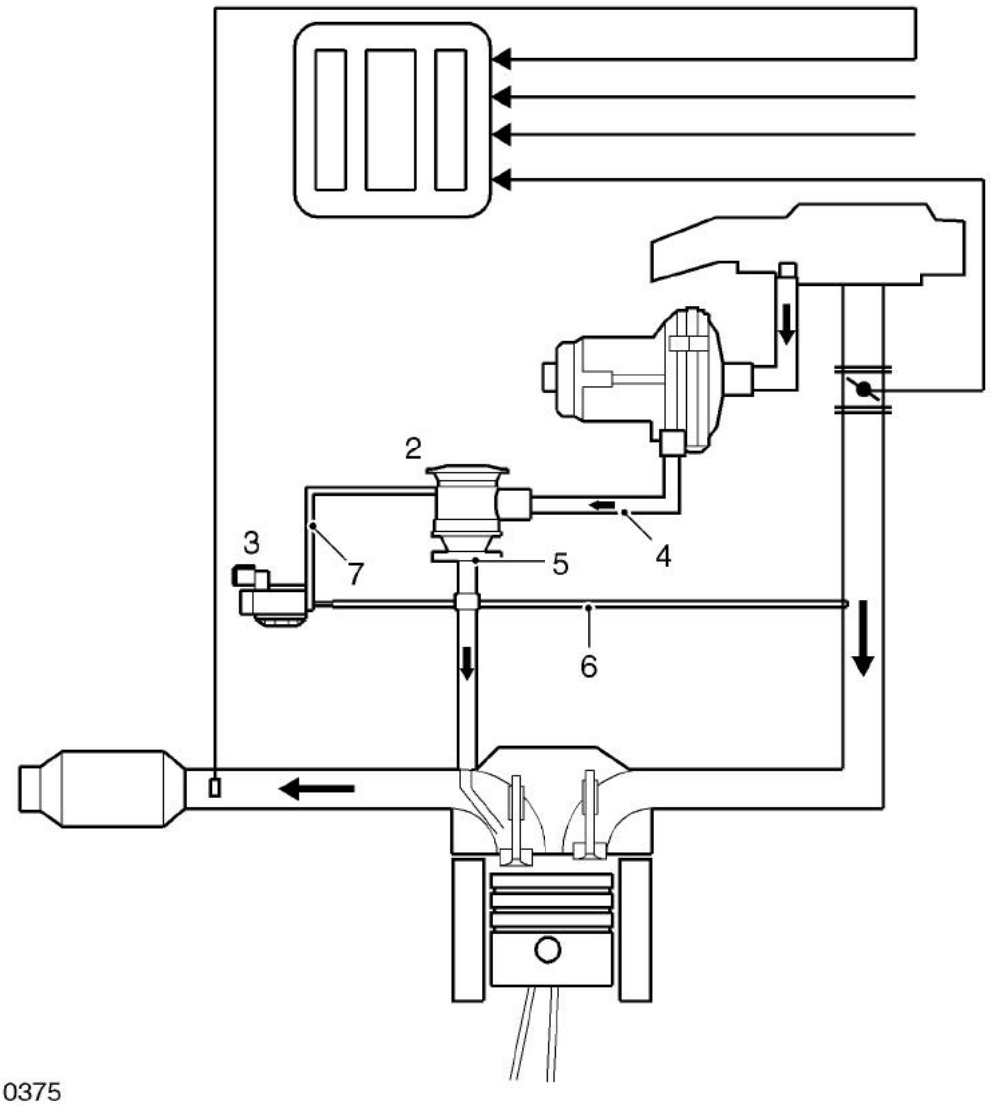
Checking Malfunctions

In the event of faults in the Secondary Air Injection system such as noticeable noise, scorching on the lines or fault indication P Codes, all components and the system must be tested for proper functioning on completion of repairs.

Long term malfunctions with some components can result in damage to other system components. This can result in excessive instances of No Fault Found (NFF) components in warranty returns and multiple repeat complaints from the customer before the fault is rectified.

For example; a malfunction of the vacuum solenoid could result in uncontrolled opening of the SAI control valves. The could eventually lead to damage to the SAI valves and also the SAI pump. In this case, if only the pump was replaced, repeated failure may eventually occur over a period of time.

Necessary Tests



M17 0375

The following table shows the components itemised on the above illustration and the test applicable to each component.

Item No.	Component Description	Applicable Test
1	SAI Pump	Test 1 – Secondary Air Injection (SAI) Pump
2	SAI control valves (1 per engine bank)	Test 2 – Secondary Air Injection (SAI) Control Valves
3	Vacuum solenoid valve	Test 3 – Vacuum Solenoid Valve
4	Delivery hoses to SAI control valves	Test 4 – Delivery Hoses to Secondary air Injection (SAI) Control Valves
5	Connection to air manifold (SAI rail)	Test 5 – Connection to Air Manifold
6	Vacuum line (intake manifold to vacuum solenoid valve)	Test 6 – Vacuum Lines
7	Vacuum lines (vacuum solenoid valve to SAI control valves)	Test 6 – Vacuum Lines

Test 1– Secondary Air Injection (SAI) Pump
Power Supply and Relay

Check all wiring and connections.

Functional Check of SAI Pump

The ECM checks the engine coolant temperature when the engine is started in addition to checking the elapsed time since the last engine start. The engine coolant temperature must be below 55°C (131°F) and the ambient temperature above 8°C (46°F) for the SAI pump to run. Also, depending on the long term 'modelled' ambient temperature determined by the ECM, the minimum time elapsed required since the last engine start can be up to 8.25 hours. The period of time that the SAI pump runs for depends on the starting temperature of the engine and varies from approximately 95 seconds for a start at 8°C (46°F) to 30 seconds for a start at 55°C (131°F).

With a warm engine which is switched off and the SAI pump relay removed, the SAI pump can be supplied with power by bridging terminals 87 and 30 at the relay socket.

CAUTION: Ensure that terminals 87 and 87a are not connected or bridged in any way, a short circuit will occur.

NOTE: TestBook/T4 can also be used to force the SAI system to perform an SAI active diagnostic routine. During this routine the SAI pump will run for approximately 10 seconds.

When the terminals are bridged or the diagnostic routine initiated, the pump must run when requested which will be noticeable by the running noise of the pump. Only allow the SAI pump to run for a maximum of 90 seconds and allow sufficient time for the pump to cool down before running again.

If the SAI pump does not run or makes a scraping noise, it must be replaced. In this case, all other system components must also be checked.

Noise Complaints

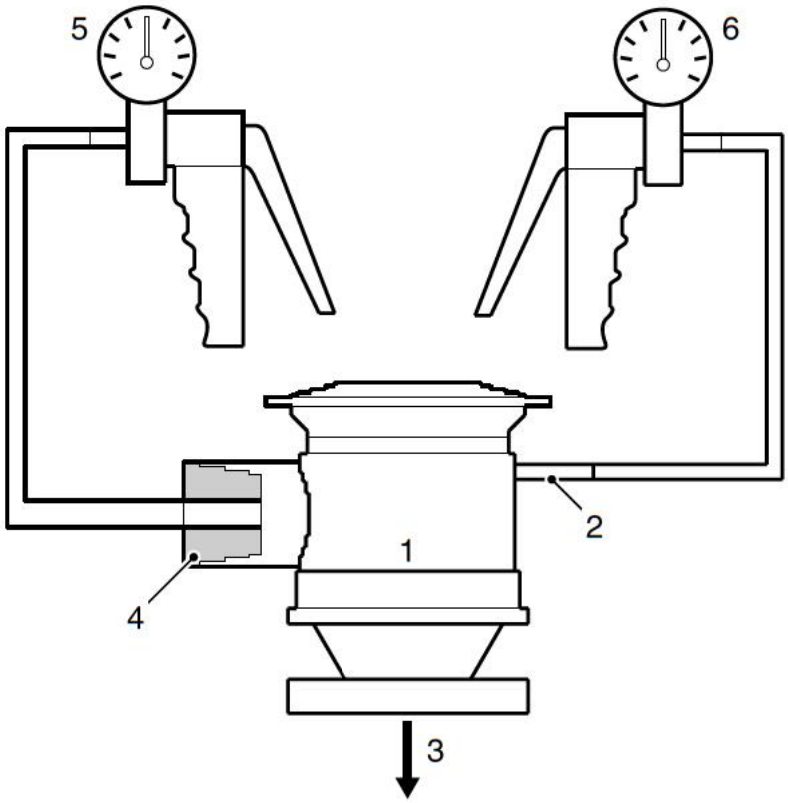
If the SAI pump runs but the operating noise is excessively loud, the external components of the pump, cable, hose line, and decoupling segments, must be checked. Check the decoupling segments and hose line for distortion and the cable and hose line for contact with the pump body.

If excessive noise still occurs, the SAI pump must be replaced.

NOTE: Before a new SAI pump is fitted, the SAI control valves must checked for correct function and tightness – Refer to Test 2 – Secondary Air Injection (SAI) Control Valves.

When fitting a new SAI pump, ensure that the hose lines, the cable and the decoupling segments are fitted without tension and contact with the pump body.

Test 2 – Secondary Air Injection (SAI) Control Valves



M17 0376

1 SAI control valve
2 Pressure connection
3 Outlet
4 Inlet connection stopper
5 Hand pressure pump
6 Hand vacuum pump

Visually inspect the SAI control valve for external damage.

Leak Test

Remove the line from the inlet connection and connect the hand pressure pump (5) using the inlet connection stopper (4). Using the hand pressure pump, pressurise the SAI control valve with 100 mBar (1.45 lbf/in^2) pressure. Maximum permissable pressure drop at the hand pressure pump gauge 10 mbar/minute (0.145 lbf/in^2/minute) with the outlet (3) open.

Valve Opening Test

Connect the hand vacuum pump (6) to the control pressure connection (2). Depressurise the pressure connection using the hand vacuum pump. When the vacuum reaches -300 mbar (-4.35 lbf/in^2), the SAI control valve (1) must open and the pressure on the hand pressure pump (5) gauge should drop suddenly.

Tightness of Diaphragms

The available pressure difference (vacuum) at the control pressure connection (2) must not drop over a period of time (Refer to Valve Opening Test).

NOTE: In the case of a leaking or incorrectly controlled SAI control valve, the inlet connection is usually heavily fouled and a condensate smell is noticeable on the hose line to the SAI pump.

If, after switching off the SAI pump, pulsation noise is still noticeable at the SAI pump, the SAI control valve and delivery hoses must be replaced before fitting a new SAI pump.

Test 3 – Vacuum Solenoid Valve

Function

The vacuum solenoid valve is energised for the duration of the secondary air injection. The valve is open when energised, the intake manifold vacuum acts on the diaphragm of the SAI control valve and the control valve opens. The solenoid valve is closed when de-energised.

Power Supply

Remove the harness connector from the vacuum solenoid valve and check the voltage between the connection terminals. No voltage must be present at the connector after switching off the SAI pump.

Opening/Tightness

Disconnect the vacuum line at one of the SAI control valves and connect a hand vacuum pump to the line. With the engine running at idle, a pressure difference of a minimum of 390 mbar (5.65 lbf/in^2) must measurable on the hand vacuum pump gauge with the vacuum solenoid valve energised.

The vacuum solenoid valve must be sealed when de-energised. If the Opening/tightness test fails, replace the vacuum solenoid valv.

Test 4 – Delivery Hoses to Secondary air Injection (SAI) Control Valves

Visually inspect the delivery hoses to the SAI control valves for damage or blockage. If damage, condensate or deposits are found the delivery hoses must be replaced. Check the hoses for correct connection and leaks.

Test 5 – Connection to Air Manifold

Check the connection for leaks visually or by using a leak detection spray. Reseal the connection if necessary.

Test 6 – Vacuum Lines

Visually inspect the vacuum lines for damage. Check each line for leaks or blockages using the vacuum hand pump. Check the lines for correct connection.