



Indirect Charge Air Cooler Performance Test

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. The purpose of this test is to evaluate, on engine, the air density recovery and heat rejection performance of an Indirect Charge Air Cooler (iCAC).

1.2 Applicability. This procedure is applicable to iCAC (i.e., air-to-liquid heat exchanger) for both gasoline and diesel applications. The iCAC is a device utilized to increase pressurized (e.g., turbocharge) air density and reduce temperature, as the air is delivered to the combustion system. An iCAC is typically mounted within the engine air delivery system, between the turbocharger and cylinder head.

This procedure may be applicable to any internal combustion engine type utilizing an iCAC.

1.3 Remarks. This standard is meant to evaluate iCAC performance as mounted in the engine design intent location and orientation, along with representative adjoining air flow componentry. This is in contrast to the supplier test which may only be performed within a uniform air flow box test bench, which may represent iCAC potential maximum or gross performance, and not necessarily net performance as utilized on engine.

This procedure may be adopted for iCAC component level bench testing, however it is advised that iCAC air side inlet and outlet housing geometries replicate the design intent as best as possible.

This procedure may additionally be adapted and utilized to evaluate the iCAC and related system's ability to produce condensate.

All pressure data units are in absolute scale, and not gage, unless stated otherwise.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

2.2 GM Standards/Specifications.

GMW16166

2.3 Additional References.

- Charge Air Cooler Data Standard (CDS)
- Sample preformatted data sheet, GM GPS Air Delivery PMT, GMD link:
<https://documents.naeng.gm.com/gdm3/drl/objectId/0b0163bd80ef0b6d>
- Statement of Requirements (SOR)
- Subsystem Technical Specification (SSTS)

3 Resources

3.1 Facilities.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

GM Confidential

© Copyright 2017 General Motors Company All Rights Reserved

November 2017

Page 1 of 16



Documents

Document Sharing Hub

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

Note: Bench testing may not be fully representative of the application, unless all related system hardware and engine inputs can be properly simulated.

3.2 Equipment.

3.2.1 Engine and Equipment.

The test engine shall have design representative (i.e., type, size, and construction) iCAC, and design intent pre and post iCAC air side plumbing and housings, and intake manifold assembly. This will ensure air flow is representative of the design intent hardware.

The engine dynamometer (dyno) test cell shall be capable of supplying coolant at a program defined volumetric flow rate (i.e., typically 10 L/minute to 25 L/minute per iCAC), and also at a coolant temperature range of 20 °C to 80 °C. Coolant type shall be standard per GMW16166.

The pre and post iCAC air flow path shall include the following test sensor hardware:

- Air temperature sensor (multiple for some applications)
- Air pressure sensor (pressure ring may be utilized to ensure proper pressure measurement, see Appendix A, Figure A5)

Note: The air temperature and pressure sensors may be in combination, for example as a TMAP sensor.

- Air flow meter (pre-iCAC), this may be part of engine dyno cell equipment, or instrumented system components.

The coolant side circuit shall include the following sensor hardware:

- Coolant temperature sensor, pre and post iCAC
- Coolant pressure sensor, pre and post iCAC
- Coolant flow meter, pre iCAC

The engine dyno test cell shall have a cooling stand which can provide coolant representing the low temperature radiator circuit to the iCAC, per the following parameters:

- Temperature range: 20 °C to 100 °C
- Flow rate: 0 L/minute to 100 L/minute, with capability to maintain constant flow at ± 1 L/minute throughout the testing

See Appendix A, Figure A1 for recommended sensor placement example, and Appendix A2, Figures A2, A3 and A4 for sample part examples. Some design configurations may require multiple placement of air temperature sensors to properly diagnose iCAC performance. Sensor placement shall be agreed upon by the applicable project Design Responsible/Release Engineer (DRE).

Note: If condensation production and collection is being performed, additional special equipment (e.g., catch can) for condensation collection within the air duct plumbing and/or intake manifold assembly may be further required. Additional equipment may be required to humidify the engine incoming air above standard test cell conditions.

3.2.2 Prop Shaft.

The prop shaft shall be suitably matched to inertia and torque output of the engine, the inertia of the dynamometer being used, and the maximum speed of the test.

Note: Improper shaft selection could lead to reduced shaft life and false failure modes caused by incorrect vibration conditions, e.g., elevated high-speed crankshaft torsional vibration or low speed prop shaft rattles.

3.2.3 Instrumentation.

Data acquisition equipment and sensors as needed to measure and collect the data parameters found in 5.1.

3.3 Test Vehicle/Test Piece.

The iCAC utilized for testing shall be representative of design intent, including proper air fin density and any coolant side tabulators. For application requiring any air bypass type sealing, a worse case air bypass built iCAC may be considering for testing to establish potential lower limits of performance.

GM Confidential

© Copyright 2017 General Motors Company All Rights Reserved

November 2017

Page 2 of 16

3.4 Test Time.

Calendar time:	3 days
Test time:	24 h
Coordination time:	24 h

Coordination hours are approximate and include time to instrument parts for this specific testing. Suggested times are on a per test sample piece basis, multiply test hours by number of samples. Time dependency will vary based upon test matrix size.

3.5 Test Required Information.

The program Subsystem Technical Specification (SSTS) information illustrating rated power operating conditions should be referred to in effort to include this engine operating point. The applicable iCAC supplier Charge Air Cooler Data Standard (CDS) sheet should be made available to not only contrast data, but also help diagnose any potential iCAC performance concerns.

The test cell shall have ability to output engine speed (rpm) and intake mass air-flow rate, to chart in correlation to the required test output data.

In an effort to properly calculate the iCAC outlet air density, the incoming air RH must be known.

3.6 Personnel/Skills.

The Development Test Engineering personnel shall be trained and capable to properly run and operate the engine in the dyno cell, while being able to help diagnose any incorrect operating performance or data, and also have capability to provide acquired data in a usable format (e.g., Microsoft Excel Spreadsheet).

4 Procedure

4.1 Preparation.

All applicable parts shall be instrumented to obtain the minimal required data. All part instrumentation and sensor placement shall be per applicable project DRE agreement.

For twin iCAC designs (e.g., V engines with left and right iCAC) near equal coolant flow must be maintained throughout all testing. Recommended maximum flow variance from left and right coolers is ± 1 L/minute.

Note: clarity must be obtained relative to whether specified flow rate is per system or per individual cooler.

Insure the coolant inlet plumbing is connected to the iCAC air outlet side (see Appendix A, Figure A6 example). The coolant inlet and outlet connection points should always be considered as in opposing direction to air flow inlet and outlet, unless otherwise specified by project DRE.

All air must be purged or vented from the iCAC(s) prior to engine operation. Typically the iCAC(s) will incorporate a service air bleed port, which can be utilized to relieve any residual air in the coolers. The dyno test cell iCAC cooling stand should additionally circulate coolant to ensure and air is forced out of the cooler.

4.2 Conditions.

4.2.1 Environmental Conditions.

Test environmental conditions shall be per GMW16166.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

Test ambient conditions shall be per GMW16166. Engine performance test conditions shall primarily be per the project Statement of Requirements (SOR) requirements, or secondarily the project SSTS requirements.

Run each engine speed (rpm) operating point per the following iCAC coolant inlet temperature (see Appendix A3): 20 °C, 25 °C, 40 °C, 60 °C, and 80 °C.

Note: Typically the engine dyno incoming air delivered to the engine has a relatively low dew point. However the Development Test Engineer must verify that the iCAC may not condense water, in order to ensure that all air mass delivered to the engine enters the cylinders (i.e., does not puddle and remain in air delivery system) for air density calculation purposes. See Appendix A, section A5 for simplified and more accurate dew point calculation formulas (if required for further scrutiny).

GM Confidential

© Copyright 2017 General Motors Company All Rights Reserved

November 2017

Page 3 of 16

Documents
Document Sharing Hub

Note: If test procedure is to be utilized for condensation evaluation, then the coolant temperature required to be below the dew point must be further determined.

Deviations from the requirements of this standard shall have been agreed upon by the project DRE. Such deviations shall be specified on the test report.

4.3 Instructions.

4.3.1 Engine Operating Procedure.

The engine operating procedure shall be per GMW16166 WOT1, and specifically 4.3 and 4.3.1 (of this GMW) (i.e., to include peak power and peak torque operating points).

Prior to recording data at each engine speed (rpm) operating point, the engine should dwell long enough to establish that the turbo outlet temperature has established relative steady state.

4.3.2 Record Data.

The following data shall be recorded into correlated table format per each engine operating point (see example Appendix A, A3):

- a. Charge Air Inlet Temperature
- b. Charge Air Outlet Temperature
- c. Coolant Inlet Temperature
- d. Coolant Outlet Temperature
- e. Charge Air Inlet Pressure
- f. Charge Air Outlet Pressure
- g. Coolant Inlet Pressure
- h. Coolant Outlet Pressure
- i. Mass Air Flow Rate
- j. Coolant Volumetric Flow Rate
- k. Engine Speed (rpm)
- l. Engine Dynamometer (Dyno) Cell Air Inlet Temperature, Pressure, and Humidity
- m. TMAP (in intake) Temperature Data (optional, to insure reading of bulk temperature)
- n. Air Temperature at Intake Runners or Cylinder Head Port Entry (optional per design architecture)

4.3.3 Condensation Production and Collection – Optional.

Condensation production and collection may be optionally and additionally performed, in effort to evaluate the specific system's ability to produce condensate. Condensate may be produced when the system internal air temperature, pressure, and humidity are such that the dew point is exceeded, and water droplet may form from the charge air. These conditions may be encountered as the charge air crossing the iCAC, when the iCAC internal coolant is circulated at low temperatures.

When condensation production and collection is being considered, the Development Test Engineer should help formulate appropriate conditions in which condensate may be produced based upon potential vehicle and engine operating conditions, and collective input from the Air Delivery Technical Specialist, Program DRE, and the Engine Program Team.

For condensation collection, the following should be implemented to avoid potential contamination of condensation specimen samples:

- PET (polyethylene terephthalate) or stainless steel containers should be utilized to collect the samples. Glass containers may influence the condensate composition. The closed container should have a minimum vent hole to allow fluid flow, while helping reduce any contamination from potential external debris.
- Stainless steel adaptor fittings should be utilized for required connections, as aluminum fitting may react with the condensate potentially increasing the pH level.
- PE (polyethylene) or PTFE (Polytetrafluoroethylene) tubing should be utilized, in effort to further avoid contamination of the condensate specimen samples.

GM Confidential

© Copyright 2017 General Motors Company All Rights Reserved

November 2017

Page 4 of 16

AVA Documents
Document Sharing Hub

5 Data

5.1 Calculations.

The required calculation to determine iCAC physical performance are defined in the following subsections.

5.1.1 Effectivity.

Effectivity is the ratio of actual and maximum possible heat transfer rates, as follows:

$$\varepsilon = \frac{q}{q_{max}}$$

iCAC effectivity as a function of temperature delta ratio can be calculated as follows:

$$\varepsilon [\%] = 100 * \frac{(T_{Air_{in}} - T_{Air_{out}})}{(T_{Air_{in}} - T_{Cool_{in}})}$$

Where:

$T_{Air_{in}}$ is the temperature of the air entering the iCAC [°C]

$T_{Air_{out}}$ is the temperature of the air exiting the iCAC [°C]

$T_{Cool_{in}}$ is the temperature of the coolant entering the iCAC [°C]

Effectivity may typically range between 85% and 95%, and should never result as 100% or more.

The effectivity calculation shall be added to the resulting data spreadsheet correlated to the required data output per 5.3.

5.1.2 Pressure Drop.

$$\text{iCAC air pressure drop: } P_{Air_{\Delta}} = P_{Air_{in}} - P_{Air_{out}} \text{ [kPa]}$$

$$\text{iCAC coolant pressure drop: } P_{Cool_{\Delta}} = P_{Cool_{in}} - P_{Cool_{out}} \text{ [kPa]}$$

These previous pressure calculations shall be added to the resulting data spreadsheet correlated to the required data output per 5.3.

5.1.3 Air Density.

iCAC air output density (i.e., air density recovery), as a function of humidity and as an ideal gas, must be calculated as follows (suggested error is < 0.2% in range of (-10 to 50) °C):

$$\rho_{HA} = \frac{P_d}{R_d T} + \frac{P_v}{R_v T} = \frac{P_d M_d + P_v M_v}{RT}$$

Where:

ρ_{HA} is Density of the humid air [kg/m³]

P_d is Partial pressure of dry air [Pa]

R_d is Specific gas constant for dry air, 287.058 [J/(kg·K)]

T is Temperature [K], $K = [^{\circ}\text{C}] + 273.15$

P_v is Pressure of water vapor [Pa]

GM Confidential

© Copyright 2017 General Motors Company All Rights Reserved

November 2017

Page 5 of 16



Documents

Document Sharing Hub